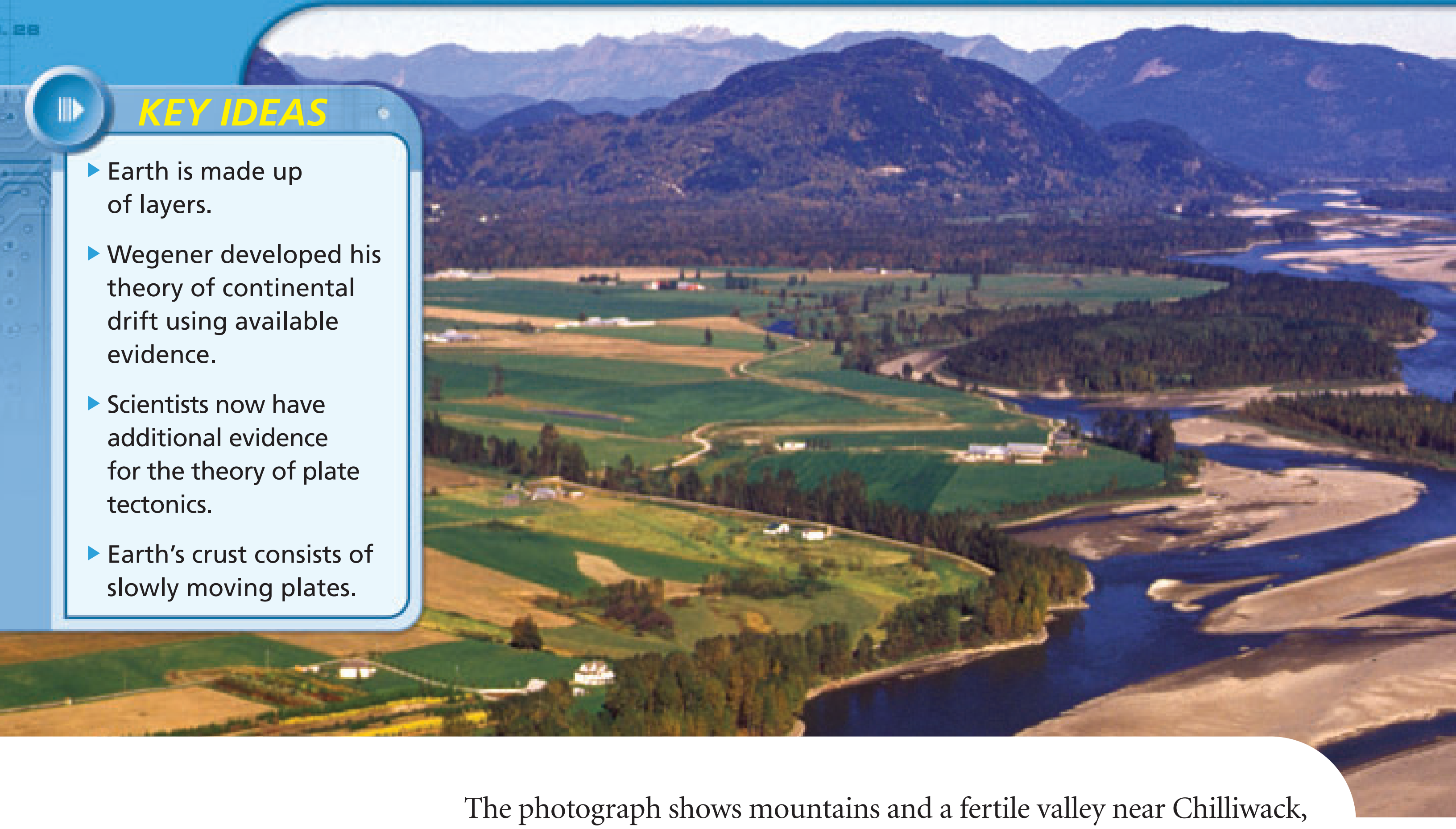
CHAPTER 8

Earth's crust is made up of moving plates.



KEY IDEAS

- Earth is made up of layers.
- Wegener developed his theory of continental drift using available evidence.
- Scientists now have additional evidence for the theory of plate tectonics.
- Earth's crust consists of slowly moving plates.

The photograph shows mountains and a fertile valley near Chilliwack, British Columbia. By looking at the photograph, what can you tell about how the mountains and valley were formed? Have these land features always been the same, or have they undergone changes? If you were hiking on one of the mountains and came across the fossil of an ocean fish, how would you explain what you found?

In Chapter 7, you learned that the surface of Earth is constantly being changed by weathering and erosion. You know that these slow processes are wearing away the mountains in the photograph. In this chapter, you will learn about the structure of Earth. You will learn about the slow, continuous processes that formed the mountains, and you will create models of Earth to show these processes. As well, you will interpret data supporting a scientific theory that was first proposed 100 years ago to explain these processes.

Earth: A Layered Planet

8.1

Imagine that you could drive a car at 100 km/h from the surface of Earth to its very centre. What would you see along the way? How long would your journey take? **Figure 1** shows what scientists think you would see.

LEARNING TIP

As you read this section, use the arrows on the diagram to help you follow this journey to the centre of Earth. Look at the thermometers on the diagram to see how the temperature changes along the way.

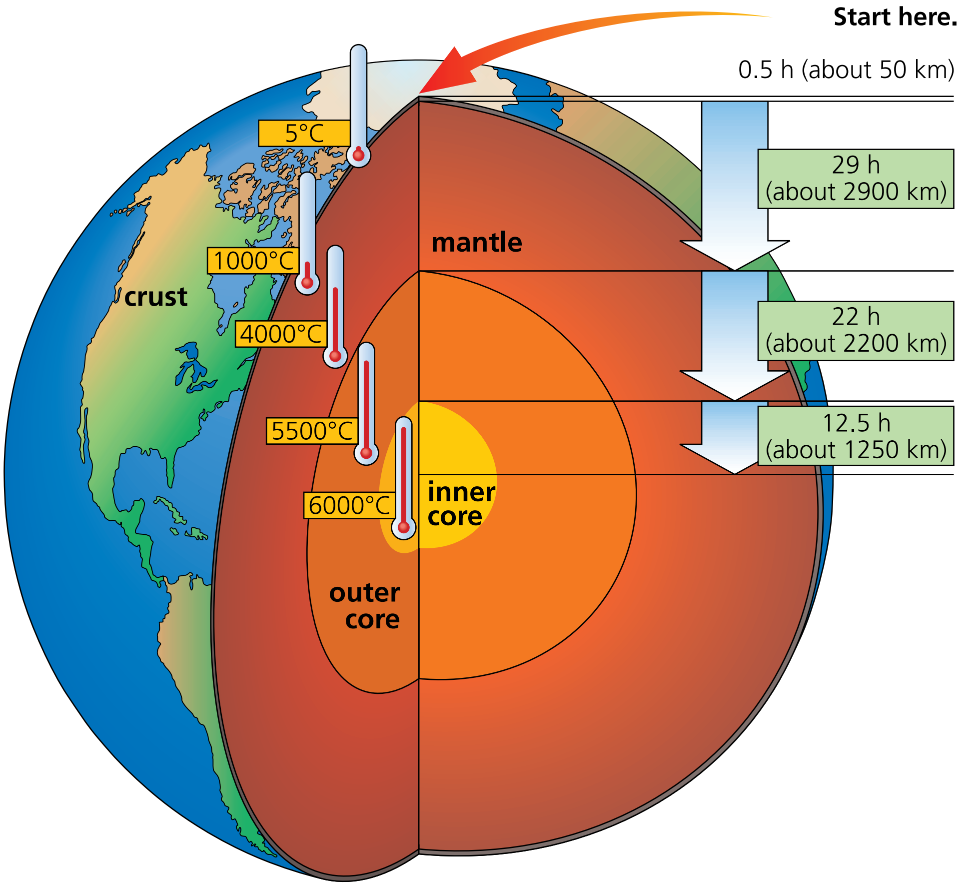


Figure 1
The layers of Earth

For the first half hour, you would pass through the crust. The **crust** is the thin layer of solid rock that makes up Earth's outermost layer. The materials in the crust tend to be lighter than the materials below. Earth's crust "floats" on the inner layers.

For the next 29 h, you would travel through the **mantle,** a hot, thick layer of solid and partly melted rock. Here you would begin to feel some pressure. The pressure would gradually increase because of all the layers above pushing down on you. The mantle moves sluggishly, like thick syrup.

Then you would travel for 22 h through the **outer core,** a dense, hot region that is made up mostly of liquid iron and some nickel. The pressure is very high. Like the mantle, the material in the outer core flows.

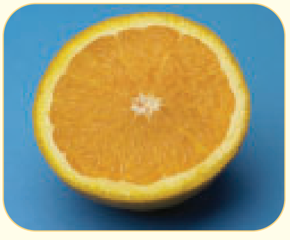
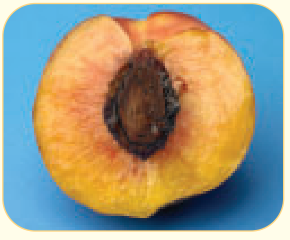
Finally, on the last part of your journey to Earth's centre, you would travel for 12.5 h through the **inner core,** a large ball of iron and nickel. Here, pressure from the weight of the other layers keeps the material solid, even though the temperature is almost as hot as the temperature on the surface of the Sun.

The idea of travelling to the centre of Earth is not new. In 1864, a French writer named Jules Verne published a novel called *Journey to the Centre of the Earth*. It describes the journey of a group of explorers as they try to reach Earth's core. In reality, the deepest hole that humans have made in Earth's crust is a mine that goes down approximately 12 km. At this depth, the temperature is already 70°C. The extreme heat and pressure at deeper levels prevent scientists from making a journey to the centre of Earth even today.

TRY THIS: MODEL A LAYERED EARTH

Skills Focus: creating models

Look at the photos of the orange, the peach, and the hard-boiled egg.


What are the strengths and weaknesses of each model of Earth? Which do you think is the best model? What layer of Earth does each part of this model represent?

CHECK YOUR UNDERSTANDING

1. Draw a diagram of a cross-section of Earth and label the four layers.
2. How are the layers different from one another?
3. Your journey to the centre of Earth took 64 h at 100 km/h. What was the total distance you travelled?
4. Why have scientists never dug a hole to the centre of Earth?

Putting Together the Pieces of a Puzzle

8.2

In December 1910, a young German scientist named Alfred Wegener [VEG-nuhr] wrote in a letter to his girlfriend, "Doesn't the east coast of South America fit exactly against the west coast of Africa, as if they had once been joined? This is an idea I'll have to pursue." Two years later, Wegener presented his hypothesis that, a very long time ago, the continents were all part of one supercontinent he called **Pangaea** [pan-JEE-uh].

LEARNING TIP

The word "Pangaea" comes from the Greek language and means "all lands."

The evidence that Wegener used to support his hypothesis came from the shapes of the continents and from fossils, landforms, and an ancient ice age. None of these observations were new. Other scientists had made these observations, but Wegener put them together and came up with a new scientific idea to explain them.

Shape of the Continents

Wegener observed that South America and Africa seemed to fit together like pieces of a jigsaw puzzle (**Figure 1**).

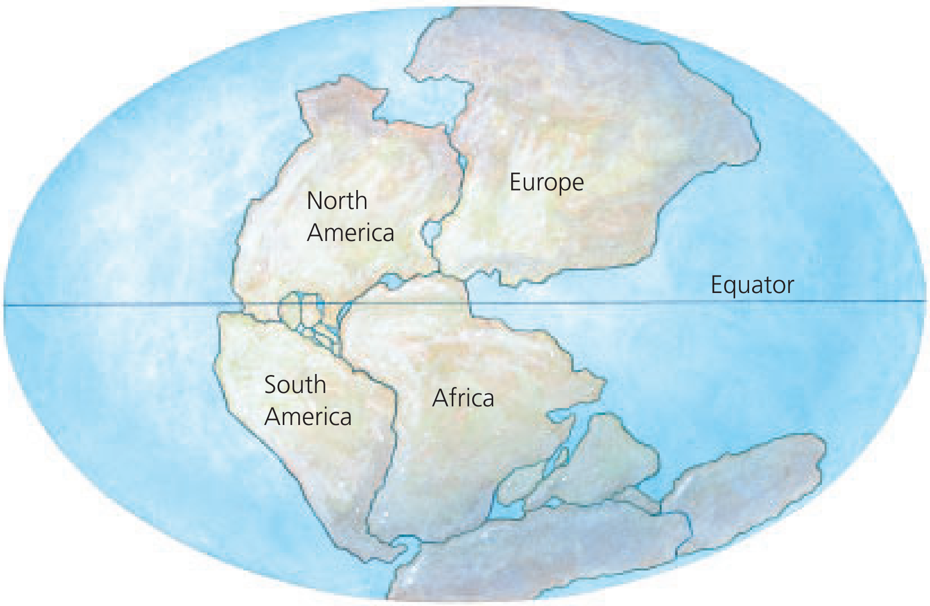


Figure 1
Were the continents once part of one giant supercontinent?

Fossil Record

Scientists had found fossils of identical plants and animals on different sides of the ocean (**Figure 2**). These plants and animals could not have travelled across the vast oceans, so they must have lived on the same continent at some time in the distant past. Scientists in Wegener's day hypothesized that there was once a land bridge between the continents, but Wegener disagreed. He thought that the continents had actually been joined.

LEARNING TIP

When reading maps, remember to check the legend to find out what the different symbols or colours on a map represent.

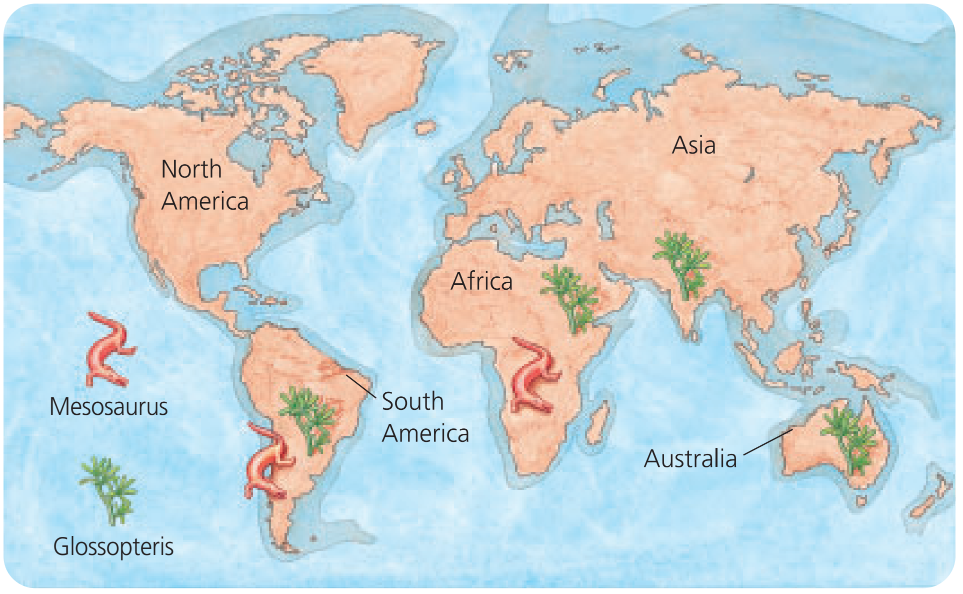
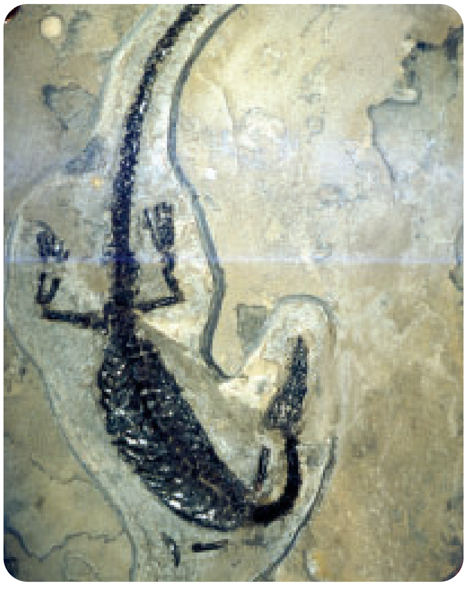


Figure 2

This map shows some of the fossil evidence Wegener used to support his hypothesis that the continents had once been joined to form Pangaea. Below are actual fossils of Mesosaurus (left) and Glossopteris (right).



Landforms

Wegener noticed that when he put together the continents in his map of Pangaea, landforms on different continents matched. For example, mountains that run east to west across South Africa lined up with mountains in Argentina. Unusual rock formations and coal deposits in South Africa were the same as rock formations and coal deposits in Brazil. The Appalachian Mountains in the eastern United States matched the highlands of Scotland (**Figure 3**).

Figure 3
This map of Pangaea shows some of the landform evidence Wegener used to support his hypothesis that the continents had once been joined.

Ancient Ice Age

Scientists had found striations caused by ancient glaciers along the coasts of both South America and South Africa. The patterns formed by these striations were the same.

Scientists had also found deposits left by glaciers during an ancient ice age. Wegener found that on his map of Pangaea, the continents where this evidence had been found—Africa, India, Australia, and Antarctica—had once fit around the South Pole, where it would have been very cold.

Wegener said that, over time, the pieces of Pangaea separated, forming separate continents. He also said that the continents were still moving, or "drifting." He called this idea the theory of continental drift.

Imagine Wegener's disappointment when no one believed him. The main objection to Wegener's idea was that he could not come up with a good explanation for how the continents "drifted." Other scientists had difficulty imagining a way that huge continents could move thousands of kilometres.

LEARNING TIP

Always try to connect new information to things you have already learned. For example, think back to what you learned about mechanical weathering by glaciers. Are striations on the rocks caused by ice or by the rocks in the ice?

CHECK YOUR UNDERSTANDING

1. What pieces of the puzzle did Wegener have? In other words, what evidence did he have to support his hypothesis that the continents had once been joined to form the supercontinent Pangaea?
2. What pieces of the puzzle did Wegener not have? In other words, what was the weakness in Wegener's theory of continental drift?

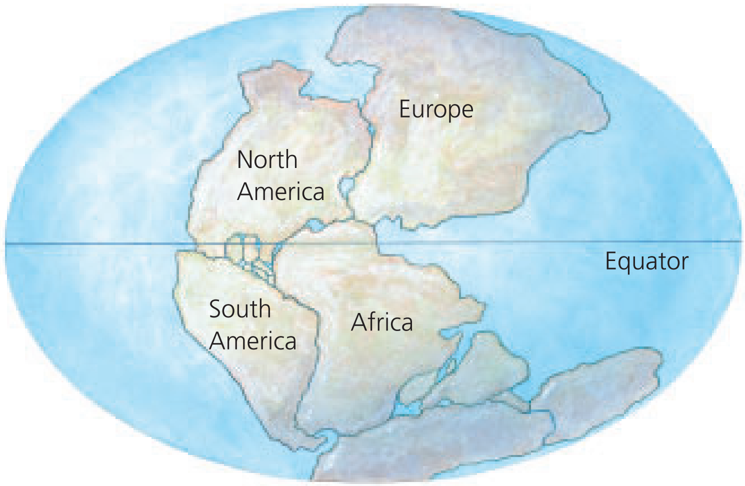
8.3 Solve a Problem

▶ **LEARNING TIP**

For a review about creating models, see the Skills Handbook section "Creating Models."

Creating a Model of Pangaea

Imagine that you are Alfred Wegener in the early 1900s. You are excited about your new hypothesis that today's separate continents were once joined together as Pangaea. You have evidence from the observations of other scientists, but the other scientists have different explanations for their observations. You are having a lot of trouble convincing them that your hypothesis about Pangaea could be correct.



Problem

You want to make a model that will summarize all the evidence for Pangaea. You do not have the luxury of modern technology. You must use very simple materials to make your model.

Task

Using only the simple materials provided, develop a model of Pangaea. Your model must show Wegener's evidence for Pangaea, including evidence from the shapes of the continents, the fossil record, landforms, and an ancient ice age.

Criteria

To be successful, your model must

- be an accurate model of Pangaea
- include Alfred Wegener's evidence for Pangaea
- be made with only the materials listed

Plan and Test

Materials

- modelling clay in various colours
- paper or thin cardboard
- coloured pencils or markers
- dinner knife

Handle the knife carefully. Always cut away from yourself and others when using a knife.

Procedure

1. Using the materials listed above, make a model that shows Wegener's evidence for Pangaea.
2. Check your model against the criteria. Does it meet all the criteria?
3. If your model does not meet all the criteria, try again.

Evaluate

1. How does your model work? Does it show all of Wegener's evidence?
2. How is your model like the real Earth? How is it different?

Communicate

3. Draw a diagram to show how your model works.
4. What other materials could you use to make a model like this? List these materials, and explain how you would use them to represent moving continents. With your teacher's permission, create a new model. Compare your new model with your modelling-clay model. Which model is better? Why?

CHECK YOUR UNDERSTANDING

1. What are some of the limitations of your models?
2. Why are models useful?
3. Where else are models used to demonstrate ideas or represent real things?

8.4 Evidence for a New Theory

After Wegener died on an expedition to Greenland in 1930, his ideas were almost forgotten. It was not until the 1960s that new evidence made scientists reconsider his ideas about Pangaea and continental drift. By then, advances in technology had given scientists new information about the ocean floor.

Mapping the Ocean Floor

The ocean floor is not flat, as was previously believed (**Figure 1**). Scientists mapping the ocean floor were surprised to find deep trenches. These long, narrow trenches usually run parallel to and near the edges of the oceans. Scientists were also surprised to find a huge mountain range that almost encircles the Earth. This ridge of mountains is about 50 000 km long and runs through the middle of the oceans. It is called a **mid-ocean ridge.**

LEARNING TIP

Check for understanding as you read. Turn each subheading into a question and answer it.

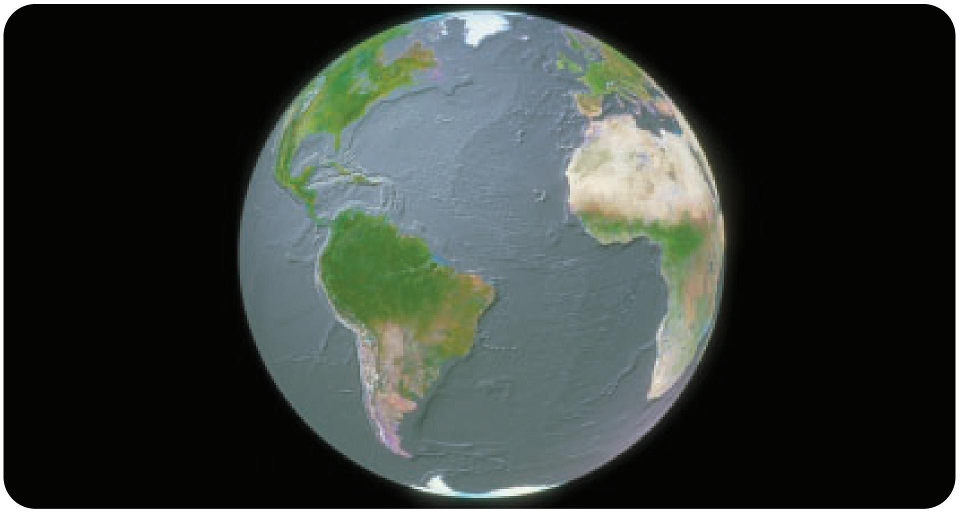


Figure 1

This map shows what the sea floor of the Atlantic Ocean would look like if all the water could be drained away. The ridge of mountains is called the mid-Atlantic ridge.

Ages of Rocks on the Ocean Floor

Scientists discovered that the layers of sediment on the ocean floor in the mid-Atlantic are quite thin. This suggested that the ocean floor is not as old as they had thought. If the ocean floor had remained unchanged for millions of years, the layers of sediment would have been thick.

As well, scientists found very young rocks at the top of mid-ocean ridges. The farther away from the ridge, the older the rocks are. Scientists concluded that the ridge is where the crust is splitting apart. Magma is rising at the ridge to form new crust. The sea floor at the mid-ocean ridge is increasing in size as new crust is formed. A scientist named Harry Hess called this process sea-floor spreading.

Hess suggested that the new ocean crust is constantly moving away from the ridge as if it is on a huge, and very slow, conveyor belt. After millions and millions of years, the crust sinks at a trench. Since Earth does not seem to be getting bigger, Hess concluded that the Atlantic Ocean is expanding and the Pacific Ocean is shrinking.

Magnetic Reversals

Scientists know that Earth's magnetic field has reversed several times over millions and millions of years. The mineral magnetite is magnetic. Grains of magnetite in molten magma line up like little magnets. The north ends of magnetite grains point to Earth's North Pole and the south ends point to Earth's South Pole. These patterns become locked into the rock as magma hardens. When Earth's magnetic field changes, this pattern reverses. Magnetite in solid rock cannot move, so only the magnetite in molten magma moves in the new direction.

The magnetic patterns locked into rock tell scientists about the direction of Earth's magnetic field at the time the rock was formed. Stripes of rock, parallel to the mid-ocean ridge, alternate between normal and reversed magnetic fields. This indicates that new rock is formed at the ridge.

TRY THIS: *CREATE A MODEL OF A MID-OCEAN RIDGE*

Skills Focus: creating models, observing, inferring

Push together two desks or tables. Take two pieces of lined paper. Hold the pieces of paper together beneath the desks, and push them slowly up through the crack as shown in **Figure 2**, about 4 cm at a time. Each time you stop, use a different colour to draw a stripe of rock on each side. Also draw arrows on each side to show the direction of magnetism. Reverse the direction of magnetism each time by reversing the direction of the arrow.

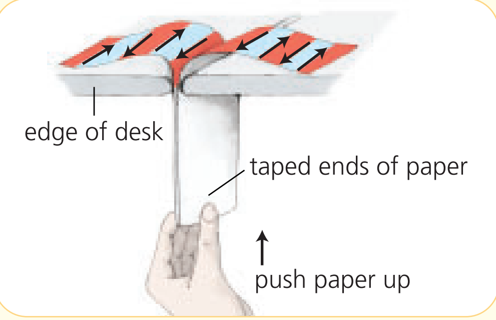


Figure 2

Locations of Earthquakes and Volcanoes

Improvements in technology allowed scientists to record earthquakes and volcanoes under the oceans as well as on land. These new observations gave scientists a clearer pattern from which to draw conclusions about the movement of the continents and about Earth's crust in general. (You will learn more about the locations of earthquakes and volcanoes in Investigation 8.5.)

> **LEARNING TIP**
>
> The term "tectonic" is used to refer to building or construction. It comes from the Greek word *tektonikos*, meaning "carpenter." So "plate tectonics" means "built or constructed of plates."

From these new observations, and the previous observations made by Wegener, the theory of **plate tectonics** [tek-TON-iks] was developed. According to this theory, the surface of Earth consists of about a dozen large plates that are continually moving (**Figure 3**).

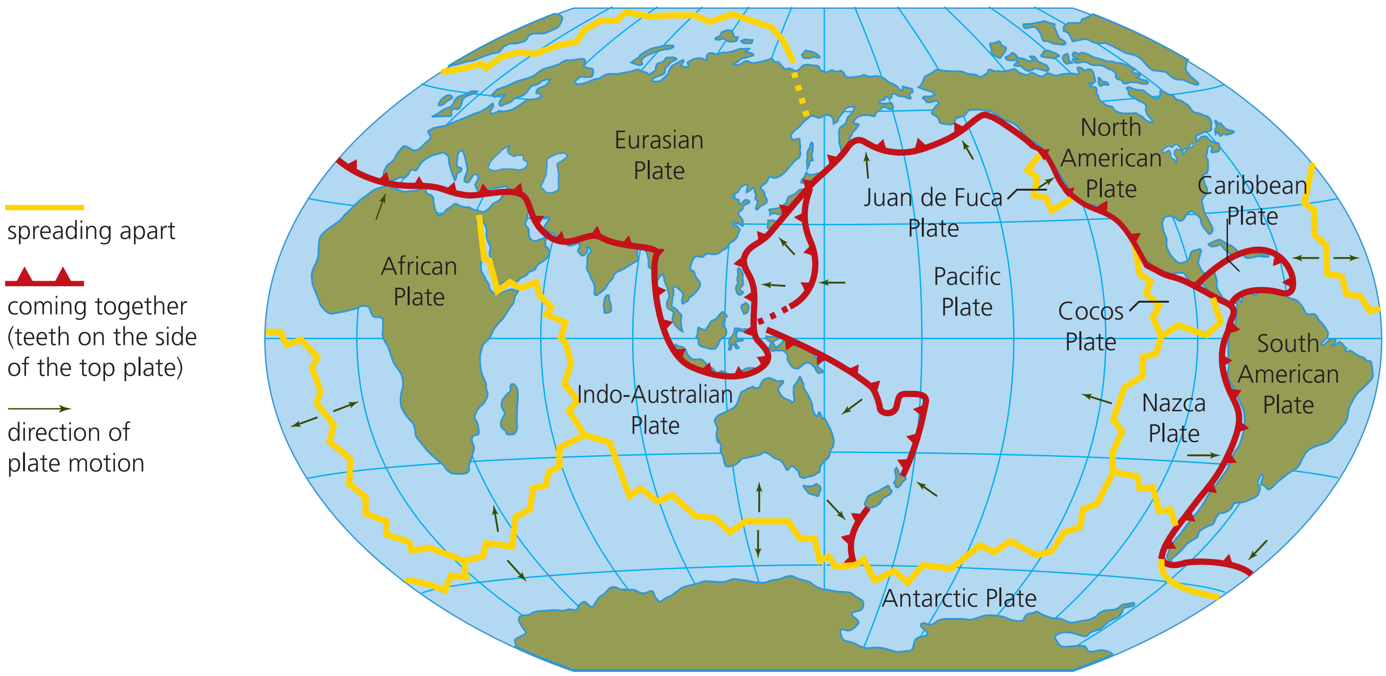


Figure 3
The major plates of Earth's crust: One small plate that is very important to British Columbia is the Juan de Fuca Plate. This plate is sandwiched between the North American Plate and the Pacific Plate.

The parts of Earth's crust that have continents on them are called **continental crust.** The parts that have only ocean floor on them are called **oceanic crust.** Plates can be made up of continental crust, oceanic crust, or both. Wegener's theory of continental drift was wrong in one way: not only the continents are moving. Both the continents and the ocean floor form plates that move.

The plates move at different rates. The fastest plate movement, about 15 cm per year, is at the East Pacific Rise near Easter Island in the South Pacific Ocean. The Australian Plate moves about 6 cm per year. The slowest plate movement, about 2.5 cm per year, is at the Arctic Ridge.

Scientists are still working on the question that was such a problem for Wegener: What makes the plates move? Scientists generally agree with Hess's theory that the slow movement of the hot mantle below the plates moves the plates. However, the details about what causes this movement are still being discussed. Hess thought that the movement commonly seen in boiling water or soup played a role. Now scientists think that the sinking of oceanic crust into trenches, which pulls the rest of the plate behind it, is an important cause of plate motion. Unfortunately, none of the current theories fully explain all the observations about plate movement.

CHECK YOUR UNDERSTANDING

1. What is the theory of plate tectonics? How is it different from Wegener's theory of continental drift?
2. What new scientific evidence was added to Wegener's evidence to develop the theory of plate tectonics?
3. Why are we not able to observe with our senses that Earth's plates are moving?
4. In section 8.1, you used an orange, a peach, and a hard-boiled egg as models of Earth. Which one could you use to show plate movement? Explain how you would do this.

8.5 Conduct an Investigation

SKILLS MENU

Questioning	Observing
Predicting	Measuring
Hypothesizing	Classifying
Designing Experiments	Inferring
Controlling Variables	Interpreting Data
Creating Models	Communicating

Finding Patterns in Geological Data

Scientists look for patterns in data to support theories. Geologists know that tremendous forces build up as tectonic plates move against each other. Is there a direct connection between plate movement and the location of mountain ranges, volcanoes, and earthquakes? If so, how would this connection support the theory of plate tectonics?

Question

Is there a pattern in the location of earthquakes, volcanoes, and mountain ranges (**Figure 1**)?

a) The 2003 earthquake in Bam, Iran, was devastating.

b) Scientists were able to warn people before Mount St. Helens, in the state of Washington, erupted in 1980.

Figure 1
Some areas of our planet seem to be more dangerous than others.

LEARNING TIP

For help in writing hypotheses, see the Skills Handbook section "Hypothesizing."

Hypothesis

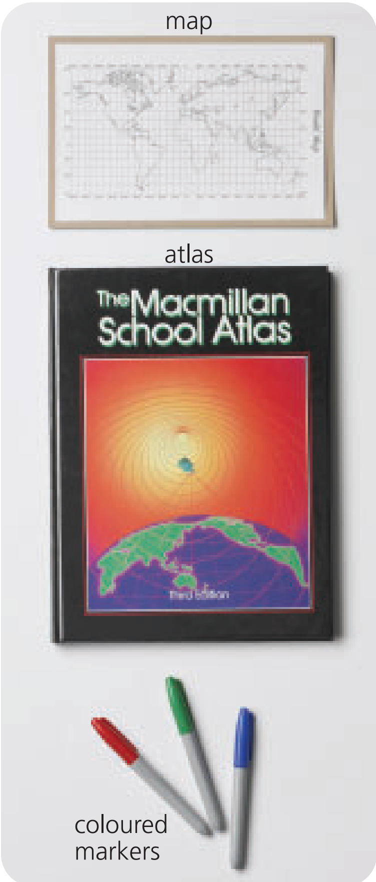
Based on your knowledge of plate tectonics, make a prediction to answer each of the following questions:

(i) Where are earthquakes most likely to occur?
(ii) Where are volcanoes most likely to occur?
(iii) Where are mountain ranges most likely to occur?

Use your predictions to develop a hypothesis.

Materials

- map of the world with lines of longitude and latitude
- atlas or globe
- coloured markers



Procedure

1 Practise finding latitude and longitude on a map.

- To find latitude, measure from 0° at the equator up to 90° north (at the North Pole) or down to 90° south (at the South Pole).
- To find longitude, measure from 0° at the prime meridian (at Greenwich, England) either east or west to 180° at the International Date Line.
- As an example, look up the longitude and latitude of your home town or city and plot it on your world map.

2 On your world map, place a small blue circle ● at the location of each earthquake listed in **Table 1**.

3 Place a small red triangle ▲ on your world map at the location of each volcano listed in **Table 2**.

4 Use a third colour ■ to mark the locations of the following mountain ranges: Rockies, Andes, Himalayas, Alps, Urals, and Appalachians. You can use an atlas or a globe to help you find these mountain ranges.

Table 1 Major Earthquakes

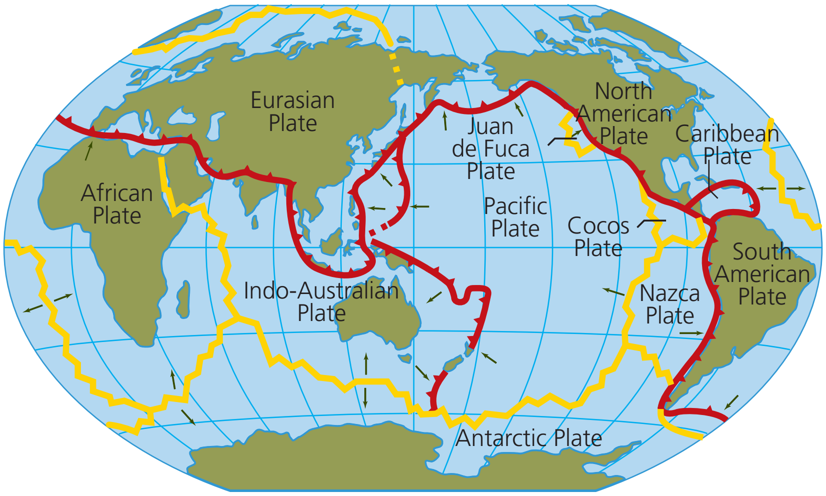
Year	Location	Coordinates
1906	San Francisco, California	38°N, 122°W
1923	Tokyo, Japan	36°N, 140°E
1935	Quetta, Pakistan	30°N, 67°E
1939	Concepcion, Chile	37°S, 73°W
1964	Anchorage, Alaska	60°N, 150°W
1970	Yungay, Peru	9°S, 72°W
1972	Managua, Nicaragua	12°N, 86°W
1976	Guatemala City, Guatemala	14°N, 91°W
1976	Tangshan, China	40°N, 119°E
1985	Mexico City, Mexico	19°N, 99°W
1988	Shirokamud, Armenia	41°N, 44°E
1989	San Francisco Bay, California	38°N, 122°W
1990	Rasht, Iran	37°N, 49°E
1991	Valla de la Estrella, Costa Rica	10°N, 84°W
1993	Maharashtra, India	23°N, 75°E
1994	Northridge, California	34°N, 119°W
1995	Kobe, Japan	34°N, 135°E
1999	Taichung, Taiwan	24°N, 120°E
1999	Izmit, Turkey	41°N, 30°E
2001	Gujarat State, India	23°N, 70°E
2002	Hindu Kush Region, Afghanistan	36°N, 69°E
2003	Bam, Iran	29°N, 58°E

Table 2 Some Active Volcanoes

Volcano and Location	Coordinates
Etna, Italy	37°N, 15°E
Tambora, Indonesia	8°S, 117°E
Krakatoa, Indonesia	6°S, 105°E
Peleé, Martinique	14°N, 61°W
Vesuvius, Italy	41°N, 14°E
Lassen, California	40°N, 121°W
Mauna Loa, Hawaii	21°N, 157°W
Paricutin, Mexico	19°N, 103°W
Surtsey, Iceland	63°N, 20°W
Kelud, Indonesia	8°S, 112°E
Arenal, Costa Rica	10°N, 84°W
Eldfell, Iceland	65°N, 23°W
Mount St. Helens, Washington	46°N, 122°W
Laki-Fogrufjoll, Iceland	64°N, 18°W
Kilauea, Hawaii	22°N, 159°W
Mount Katmai, Alaska	58°N, 155°W
Avachinsky, Russia	53°N, 159°E
El Chichon, Mexico	17°N, 93°W
Ubinas, Peru	16°S, 71°W
Villarica, Chile	39°S, 72°W
Asama, Japan	36°N, 138°E
Shikotsu, Japan	41°N, 141°E

Analyze

1. Compare your map with the plate boundaries map. Describe any patterns you see in the locations of
   - earthquakes
   - volcanoes
   - mountain ranges



2. Are volcanoes always located near mountain ranges?

Write a Conclusion

3. Go back to your hypothesis. Do the patterns you found support, partly support, or not support your hypothesis? Write a conclusion for the investigation.

Apply and Extend

4. How do the patterns you found support the theory of plate tectonics?
5. Explain, using evidence from your map, why the edge of the Pacific Ocean is often called the Ring of Fire.
6. Which area of British Columbia is most likely to experience an earthquake? Explain.

CHECK YOUR UNDERSTANDING

1. Was your hypothesis correct? If not, explain why not.
2. Maps can be important tools when looking for patterns. Think of another situation in which maps could be important for providing evidence.

Tech.CONNECT

Using Technology to Study Plate Movement

Scientists who study plate movement today have several technologies that were not available to Wegener.

Deep-Sea Submersibles

Deep-sea submersibles (**Figure 1**) allow scientists to investigate activity along mid-ocean ridges. Scientists now know that these are areas where plates are moving apart.

Alvin, used to explore the Mid-Atlantic Ridge, could operate at a depth of 4000 m. A submersible with a crew of two has reached the deepest part of the ocean, the 10 920 m Challenger Deep. Scientists do not yet have the technology to keep submersibles at that depth for the time it takes to explore the deep ocean.

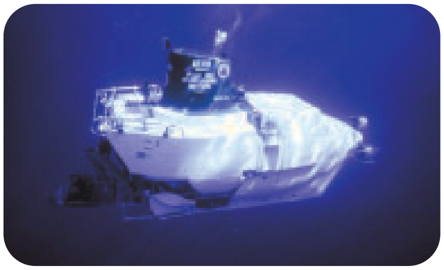


Figure 1
The deep-sea submersible *Alvin*.

Satellite Technologies

Satellites can be used to map features of Earth's surface and to measure distances between these features. The global positioning system (GPS) (**Figure 2**) allows scientists to make extremely accurate measurements. Even the creeping pace of a continent's movement is measurable by signals sent from satellites to the GPS receivers on Earth.

Figure 2
A temporary GPS receiver near the top of Mount Logan, British Columbia

Fibre-Optic Technologies

Scientists are laying 3000 km of fibre-optic sensors along the border of the Juan de Fuca Plate and the North American Plate (**Figure 3**). This project, called the Neptune Project, will allow scientists at stations in Victoria, British Columbia, and in Oregon to collect information about even the smallest movement of these plates. The movement of these plates causes earthquakes in British Columbia.

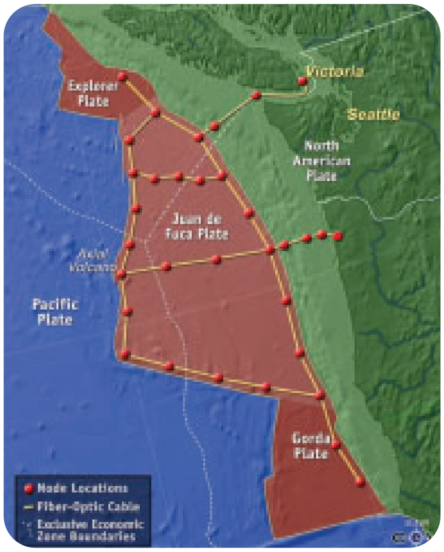


Figure 3
Thousands of kilometres of fibre-optic sensors will allow scientists to track the movement of the Juan de Fuca Plate.

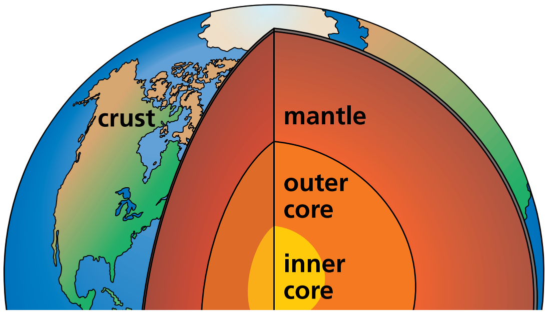
Visit the Nelson Web site to learn more about the Alvin *submersible, GPS, and the Neptune Project.*

www.science.nelson.com GO

8 Chapter Review

Earth's crust is made up of moving plates.

Key Idea: Earth is made up of four layers: the crust, the mantle, the outer core, and the inner core.



Vocabulary

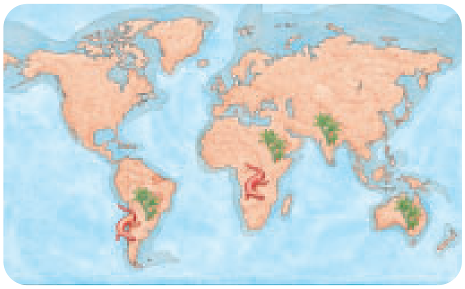
crust p. 219

mantle p. 219

outer core p. 220

inner core p. 220

Key Idea: Wegener developed his theory of continental drift using available evidence—the shapes of the continents, the fossil record, landforms, and an ancient ice age.

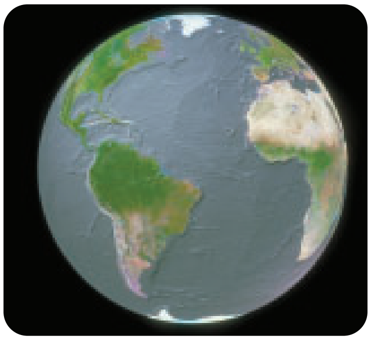


Vocabulary

Pangaea p. 221

Key Idea: Scientists now have additional evidence for the theory of plate tectonics from

- mapping of the ocean floor
- the age of the rock on the ocean floor
- magnetic reversals
- the locations of earthquakes and volcanoes



Vocabulary

mid-ocean ridge p. 226

plate tectonics p. 228

continental crust p. 228

oceanic crust p. 228

Key Idea: Earth's crust consists of slowly moving plates.

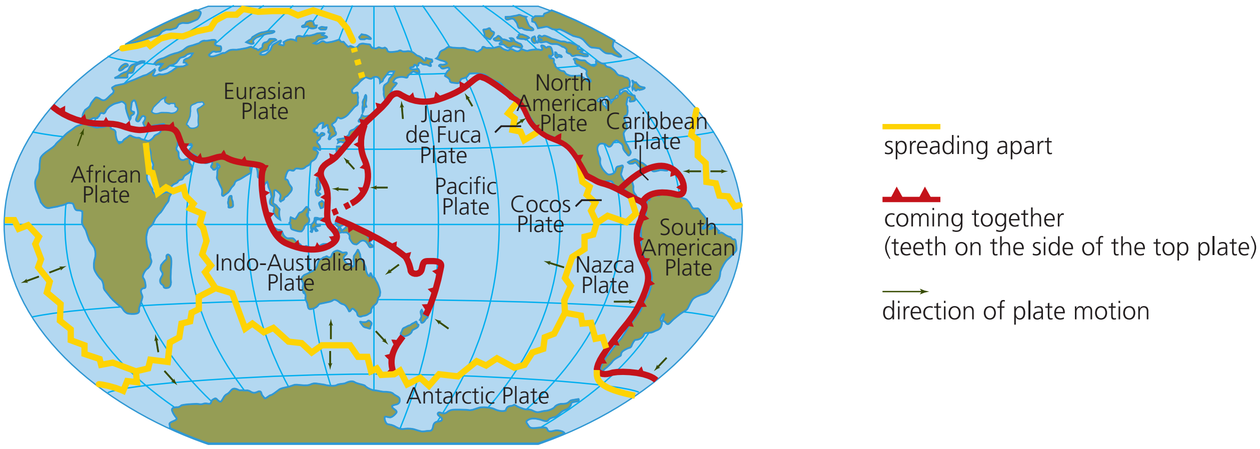
Review Key Ideas and Vocabulary

When answering the questions, remember to use vocabulary from the chapter.

1. Draw a diagram of the layers of Earth. Describe each layer in point form on your diagram.
2. Explain Alfred Wegener's theory of continental drift.
3. What evidence do scientists have to support the theory of plate tectonics?
4. How has technology helped scientists explore Earth?

Use What You've Learned

5. What is the name of your "home plate"—that is, the plate on which your home is located? Which plate or plates border on your home plate?



6. Look at the map of Earth's plates. Why do you think that many more volcanoes and earthquakes occur along the west coast of North America than along the east coast? (Refer to plates and the edges of plates in your answer.)

Think Critically

7. Why do you think it is important for scientists to learn more about Earth's plates?
8. What do you think is the most convincing piece of evidence for plate tectonics? Justify your answer.

Reflect on Your Learning

9. List two things you learned in this unit that you did not know before. What questions do you still have about the effects of plate movement?
10. Explain how learning about the theory of plate tectonics has changed the way that you think about
    (a) the area in which you live
    (b) Earth