TOPIC 4.1

What ideas, observations, and evidence led to the theory of plate tectonics?

Key Concepts

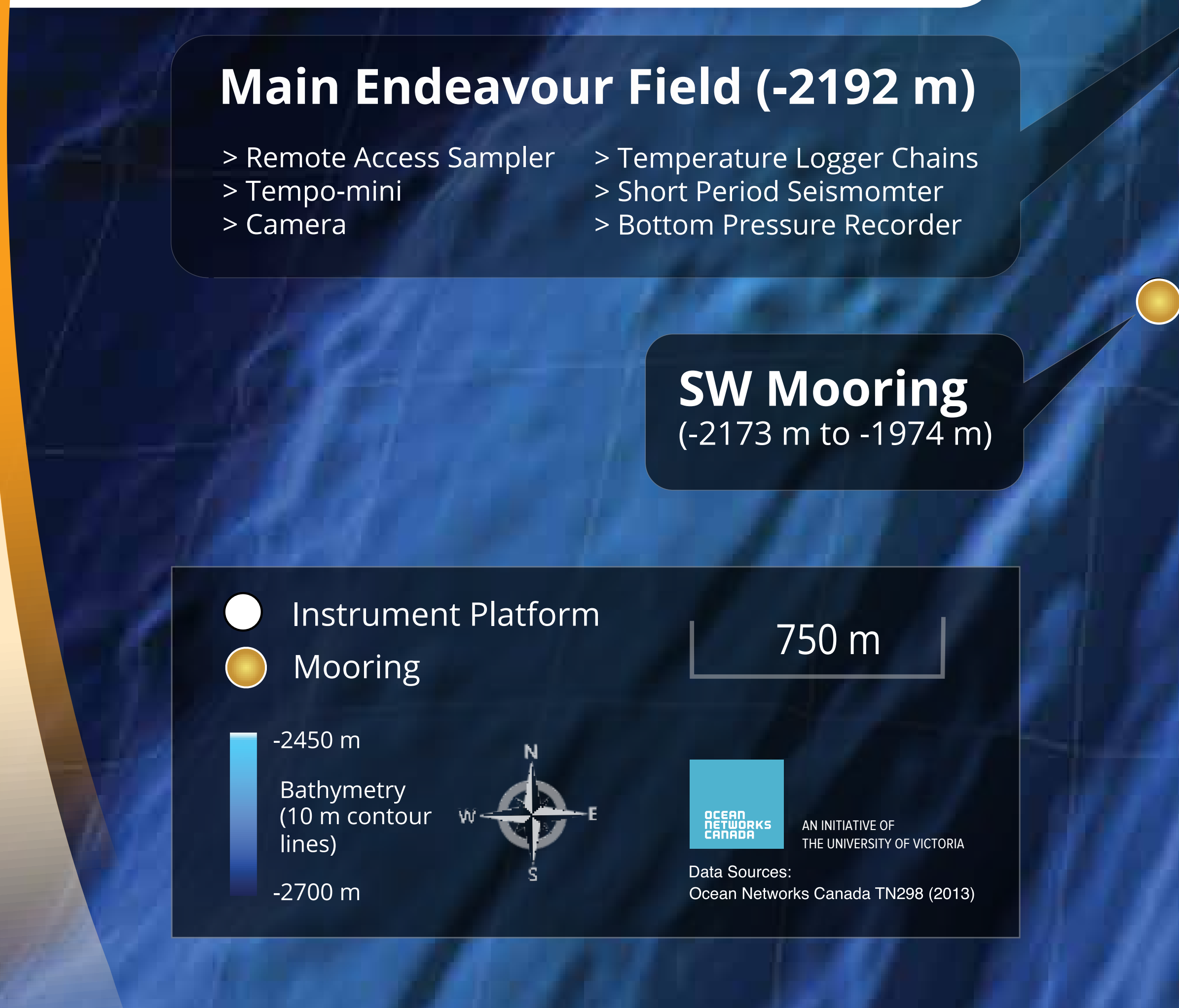
- Scientists debated how to interpret the shapes and positions of Earth's continents.
- Technology helps scientists make inferences about the different layers of Earth.
- Studies of the ocean floor revealed where new rock is made.
- The theory of plate tectonics provides a unified explanation for geological features and processes.

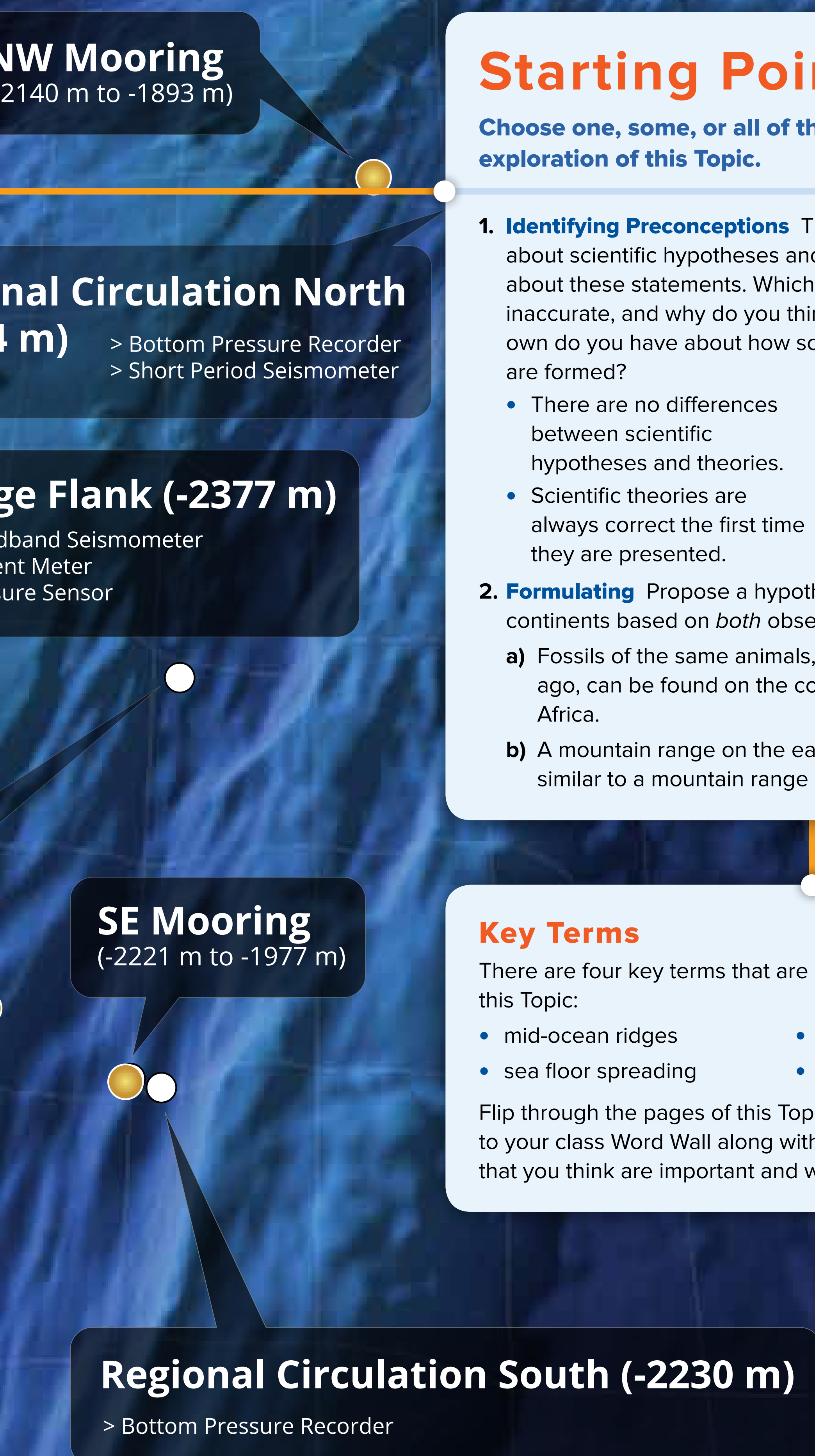
Curricular Competencies

- Seek patterns and connections in observations.
- Use scientific understanding to draw conclusions.
- Transfer and apply learning to new situations.
- Apply First Peoples perspectives and knowledge, other ways of knowing, and local knowledge as sources of information

Looking east from the Pacific coastline, you face a chain of mountains called the Coast Mountains. If you turn to face west, it's islands and water—water as far as the eye can see. But 300 km off the coast, and 2.2 km beneath the surface, lies another chain of mountains called the Juan de Fuca Ridge. Here, huge slabs of Earth's crust slowly move apart, and new ocean floor is forming. Ocean ridges like this exist elsewhere on Earth. These formations and the processes connected with them have shaped Earth's surface for millions of years, and they continue to do so today.

Scientists study areas of the ocean floor like the Juan de Fuca Ridge, shown here. They place instruments, such as seismometers, pressure sensors, and cameras, to monitor changes. The data they collect helps them to make predictions about where, and sometimes when, these geological processes may occur.





Starting Points

Choose one, some, or all of the following to start your exploration of this Topic.

1. **Identifying Preconceptions** The statements below are about scientific hypotheses and theories. Discuss your ideas about these statements. Which do you think are accurate or inaccurate, and why do you think so? What questions of your own do you have about how scientific hypotheses and theories are formed?
   - There are no differences between scientific hypotheses and theories.
   - Scientific theories are always correct the first time they are presented.
   - Scientific theories do not change if new information is discovered.
   - Scientists do not work together to develop scientific hypotheses and theories.
2. **Formulating** Propose a hypothesis about the movement of continents based on *both* observations below:
   a) Fossils of the same animals, which lived millions of years ago, can be found on the continents of South America and Africa.
   b) A mountain range on the east coast of North America is very similar to a mountain range in northern Scotland.

Key Terms

There are four key terms that are highlighted in bold type in this Topic:

- mid-ocean ridges
- sea floor spreading
- trenches
- theory of plate tectonics

Flip through the pages of this Topic to find these terms. Add them to your class Word Wall along with their meaning. Add other terms that you think are important and want to remember.

CONCEPT 1

Scientists debated how to interpret the shapes and positions of Earth's continents.

Activity

Looking at Maps

Conduct brief research on maps from different time periods in history. What does the oldest known map show? What do maps from the 16th century show? How do they differ from maps from the 19th century (**Figure 4.1**)? What observations can you make about the position and shape of continents from modern-day maps?

With the exception of events such as earthquakes, volcanic eruptions, and landslides, most of Earth's surface appears to remain relatively unchanged during the course of a human lifetime. On a geologic time scale, however, Earth's surface has changed dramatically. Some of the first people to suggest that Earth's major features might have changed were early mapmakers. In the 1500s, mapmakers noticed that the edges of continents on either side of the Atlantic Ocean seemed to fit together, like pieces of a jigsaw puzzle. The world map shown in **Figure 4.1** is one that was made in the 1800s. For hundreds of years scientists questioned how continents came to be in the configuration that they are today.

Connect to Investigation 4-A on pages 284–285

Figure 4.1 This map of the world was made in the 1800s. **Which continents look like they might have once fit together?**

Until the mid-1900s, most geologists thought that the locations of the continents and oceans were determined when Earth first formed. This idea, called *fixism*, assumes that the continents have been in the same locations since Earth first formed. However, after observing that some of the continents looked like they could fit together, some people wondered if Earth's continents were once joined together. A German scientist named Alfred Wegener also thought this and decided to investigate the possibility. He did research and collected rock, climate, and fossil information from around the world to see if he could find evidence to support the idea that the continents were once joined together. In 1912, Wegener presented his findings to the scientific community.

The Continental Drift Hypothesis

Based on the evidence he collected, Wegener proposed his *continental drift hypothesis*. Wegener created a new map of Earth by fitting the continents together. He suggested that about 200 million years ago all the continents were connected as a single supercontinent called Pangaea. In Greek *pan* means "all" and *gaea* means "world." **Figure 4.2** shows the possible shape of Pangaea. Wegener hypothesized that over time, the continents slowly moved apart until they reached their current positions.

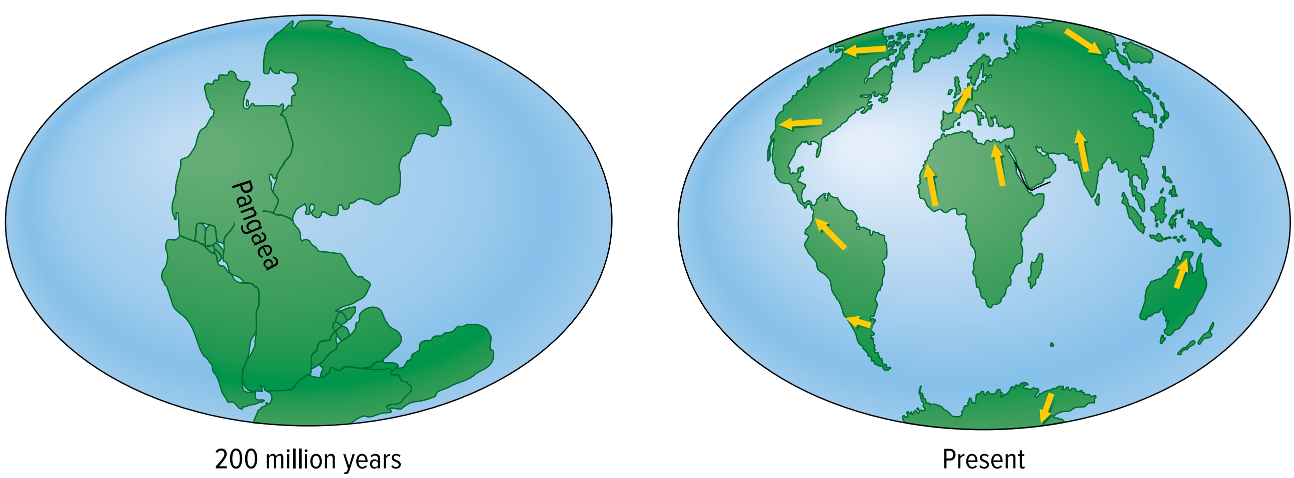


Figure 4.2 Wegener suggested that a supercontinent existed 200 million years ago. (Arrows in the right diagram indicate direction of movement.) **Draw a sketch that shows how the continents could get to their present locations from where they were 200 million years ago. Your sketch should show two or three stages of the process.**

Wegener's Hypothesis Is Rejected

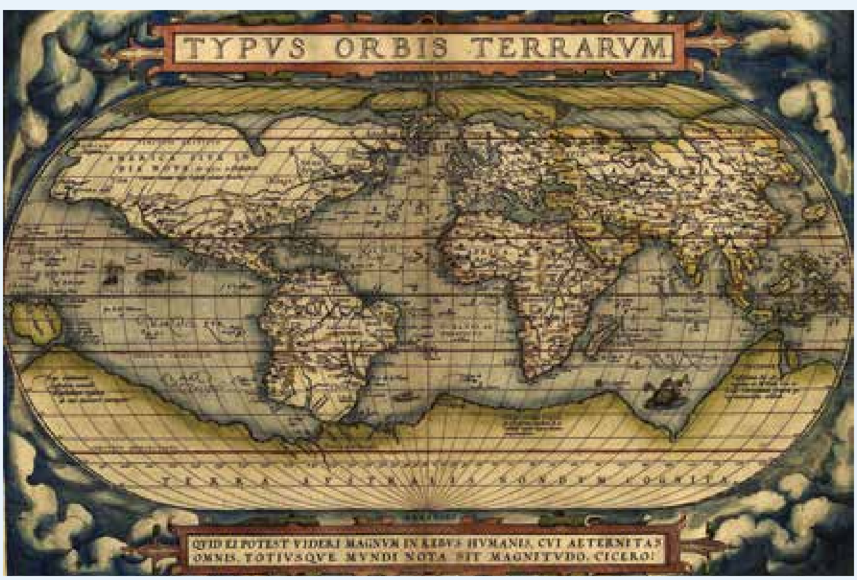
Even though Wegener's evidence supported the idea that the continents may have once been joined, most scientists strongly rejected his hypothesis. Wegener could not explain how continents could move. Also, scientists could not imagine what forces could be large enough to make a continent move.

Although Wegner's hypothesis was initially rejected, it was revisited decades later. Discoveries about the ocean floor provided information that supported the idea that continents move. His hypothesis is now seen as the start of the development of the theory of plate tectonics.

Activity

What Goes Into Making Maps?

The map below was drawn in the 1570s. Compare it with the map in Figure 4.1. Use digital and print resources to find other maps from the past. What assumptions about the world do you think map-makers have when they draw their maps? Is it possible to eliminate bias from a map? See if your class can reach a consensus on these questions.



Before you leave this page . . .

1. In your own words, describe the continental drift hypothesis.
2. How did Wegener support his hypothesis? Why do you think he chose this type of information?
3. Why was the continental drift hypothesis rejected?

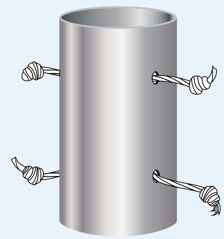
CONCEPT 2

Technology helps scientists make inferences about the different layers of Earth.

Activity

How Well Can You Describe What You Can't See?

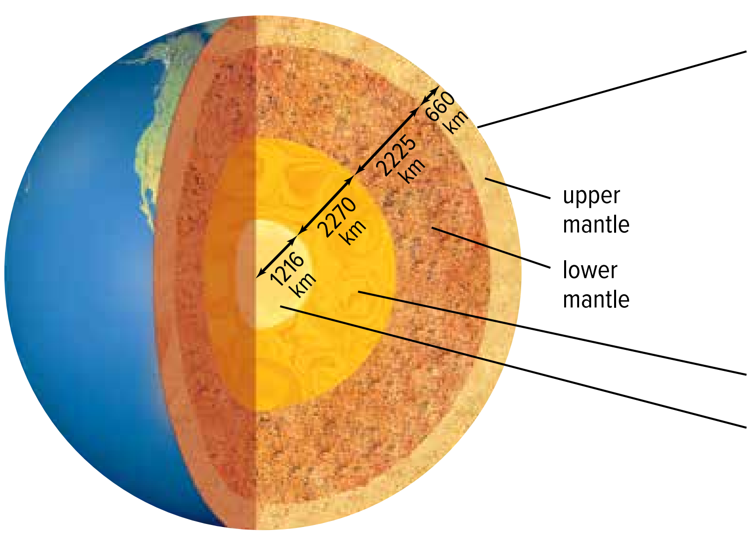
Your teacher will give your group a mystery tube like the one shown here. Your challenge is to figure out what the inside of the tube looks like—without opening the tube! Discuss, record, and try out all your ideas until you are confident in your solution.



Earth is about 12 700 km in diameter. This means there are about 6350 km between you and the centre. But no one has ever seen Earth's inner layers, and no tools can probe that deep. Since scientists cannot observe the interior directly, they use indirect evidence to model Earth's structure. One way is by studying energy waves that travel through the interior during earthquakes. The speed and behaviour of the waves are affected by the material they pass through. By studying the waves, scientists infer Earth's structure and composition (Figure 4.3).

Connect to Topic 2.4 on page 157

Figure 4.3 A model of Earth, showing its interior layers



crust: This is a thin layer of solid rock surrounding Earth. The crust is thinner under the oceans (oceanic crust) and thicker under the continents (continental crust). Oceanic crust is mostly basalt. Continental crust is mostly granite.

mantle: There is an upper and lower mantle. The top part of the upper mantle is solid. A part just below this is made of rock that is like soft taffy, so it can flow slowly. The rest of the upper mantle and the lower mantle are made of denser, more solid material.

outer core: The outer core is the only layer that is liquid.

inner core: Earth's deepest layer is also the hottest at more than 5000°C. It is solid because the very dense core material is under extreme pressure.

Before you leave this page . . .

1. In what way does the structure of Earth support the idea that continents can move?

CONCEPT 3

Studies of the ocean floor revealed where new rock is made.

mid-ocean ridges mountain ridges along the ocean floor

trenches deep valleys in the ocean floor

Mountains and Trenches of the Ocean Floor

By the 1870s, scientists had begun to study and map the ocean floor using weighted ropes and piano wire dragged by ships. When contact was made with objects below the surface, the length of the ropes and wires was recorded. In the 1920s, ropes and wires were replaced with sonar—devices that send out sound waves and record the time for the waves to bounce back. This technology helped scientists discover and detail vast mountain ranges and deep valleys. These **mid-ocean ridges** and **trenches** are shown in **Figure 4.4**.

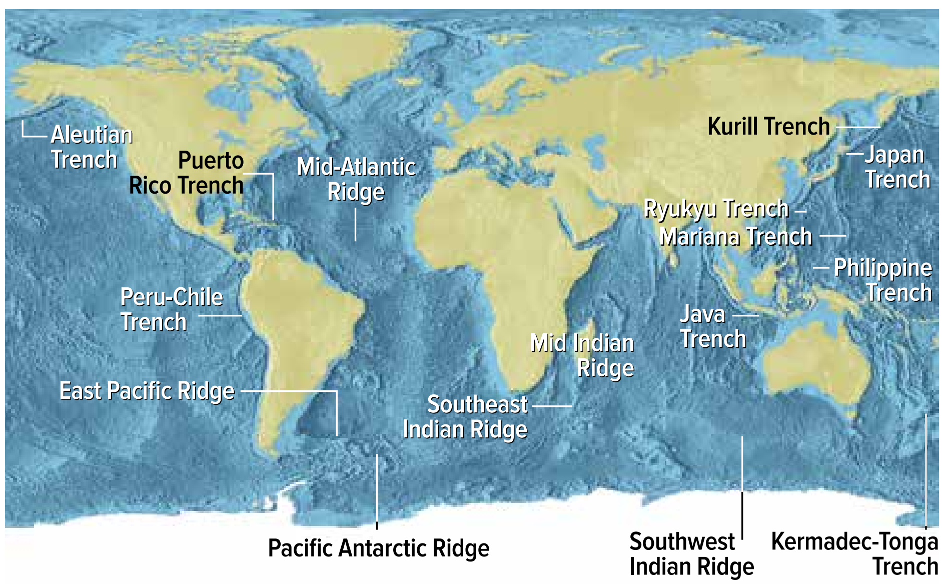


Figure 4.4 The ocean floor consists of mid-ocean ridges and deep sea trenches. **What does the presence of mountain ranges on both land and on the ocean floor tell you about how they are formed?**

Mid-ocean ridges circle Earth and are nearly 60 000 km long. Some tower as high as 3 km above the ocean floor. The mid-Atlantic ridge, at 16 000 km long, is longer than any mountain range on land. Scientists also discovered that earthquakes and volcanic eruptions are common along mid-ocean ridges.

Deep sea trenches are long, narrow depressions in the ocean floor. They can be thousands of kilometres long and many kilometres deep. The Mariana Trench is more than 11 km deep. Compare this to Mount Everest, the world's tallest mountain, which is about 9 km above sea level. **Figure 4.5** shows a few features of mid-ocean ridges and trenches that have been discovered.

Extending the Connections

Sonar Reveals Hidden Haida Gwaii Village

Archeological excavations on Haida Gwaii have demonstrated that people lived there 12 700 years ago. But oral histories of First Peoples tell of a human presence there thousands of years earlier. Two archeologists with the University of Victoria, Quentin Mackie and Daryl Fedje, agree. And now, thanks to sonar technology, there is evidence that supports First Peoples Traditional Ecological Knowledge of the region. Find out about the discoveries that have been made off the east coast of Haida Gwaii.

Making New Rock on the Ocean Floor

In general, ocean rocks are much younger than land rocks. As well, the ocean floor near mid-ocean ridges is younger than ocean floor farther away from the ridges (**Figure 4.5**).

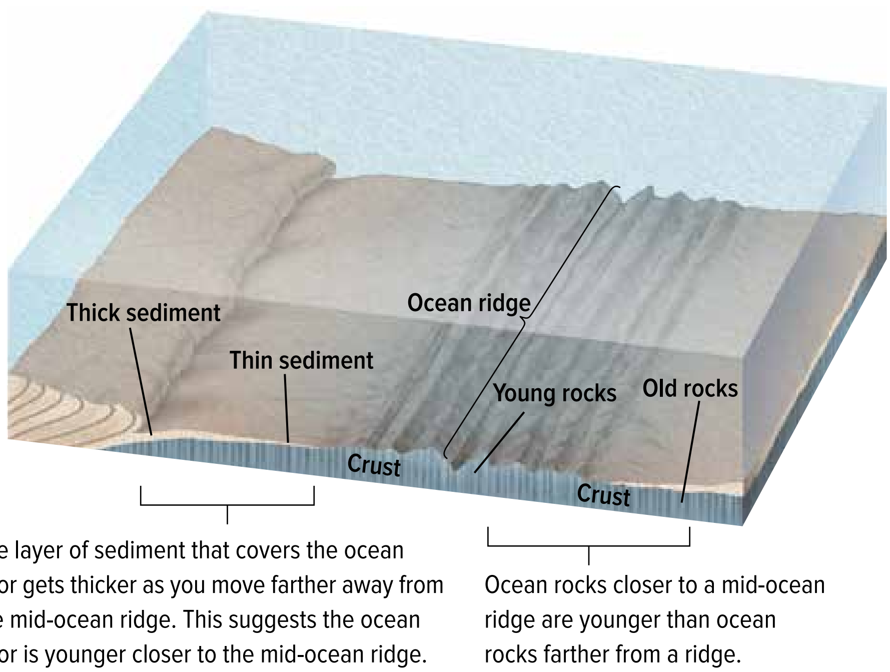


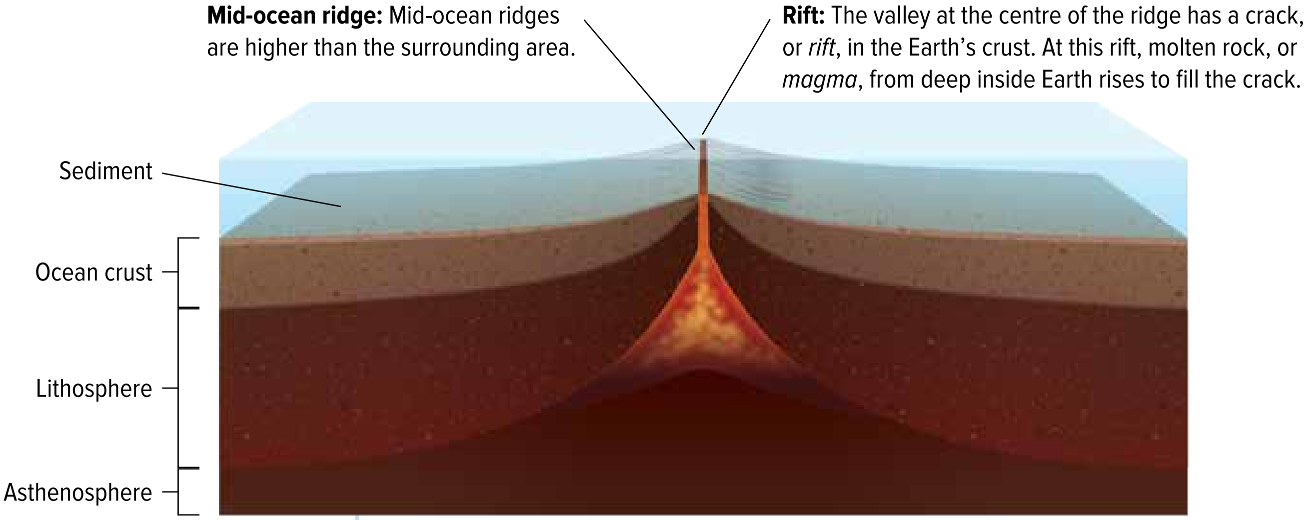
Figure 4.5 Ocean floor near mid-ocean ridges is younger than ocean floor farther away from mid-ocean ridges.

The ages of rocks at mid-ocean ridges puzzled many scientists. In 1962, a geologist named Harry Hess proposed an explanation. He suggested that new ocean crust is made at mid-ocean ridges. This process is called **sea floor spreading**, and it is described in **Figure 4.6**, on the next page.

sea floor spreading process of magma rising to the surface at mid-ocean ridges to form new ocean crust

The discovery of sea floor spreading was an important step to understanding how continents could move. Molten rock from a rift in a mid-ocean ridge cools, hardens, and continuously pushes older rock aside in the opposite direction on both sides of the ridge. Continents can be carried by the widening ocean floor in much the same way that objects are moved by a conveyer belt.

Connect to Investigation 4-B on page 286



Magma erupts on the ocean floor and creates new rock. As this process is repeated over millions of years, new rock pushes older rock away from the ridge. The result is the formation of new oceanic crust.

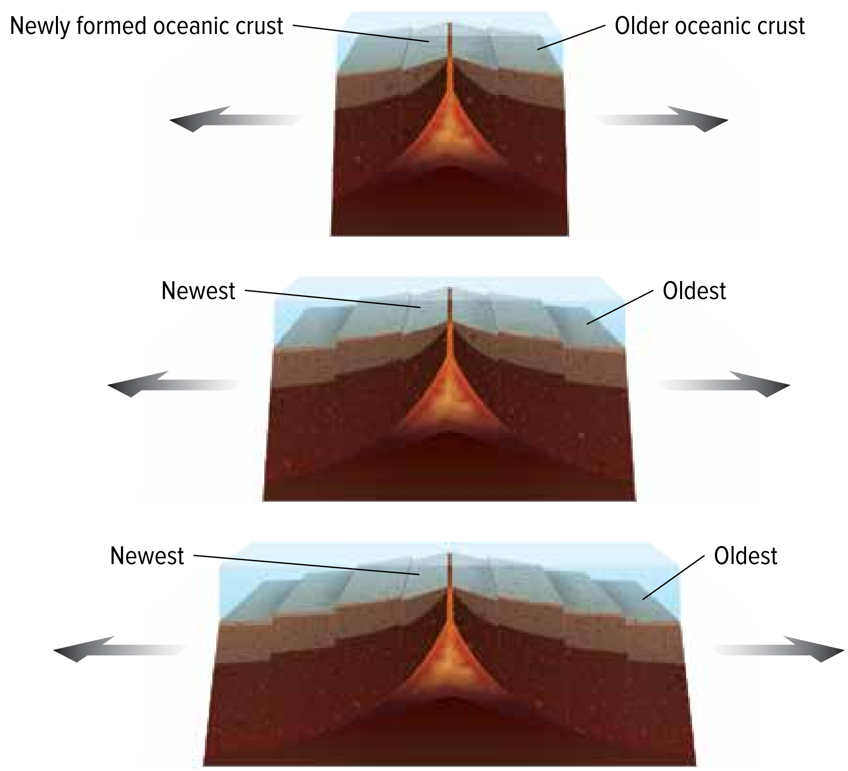


Figure 4.6 Sea floor spreading explains how new oceanic crust is made. **Describe how the formation of new oceanic crust supports the idea that continents can move.**

Before you leave this page . . .

1. In two or three sentences, describe how the discoveries of mid-ocean ridges and the ages of ocean rock support the idea that the ocean floor is spreading apart.
2. Describe the process of sea floor spreading.

CONCEPT 4

The theory of plate tectonics provides a unified explanation for geological features and processes.

By the early 1960s, despite the evidence for sea floor spreading, many scientists were still unwilling to reject ideas about geological processes they had held for so long. But in the 1970s, small research submarines called ROVs (remote operated vehicles) were taking photos of the ocean floor. Now scientists could make direct observations of mid-ocean ridges and trenches. Now, for the first time, scientists had direct evidence of sea floor spreading.

As time passed, more and more evidence suggested that Wegener's original hypothesis had merit. A key feature that it lacked—a way to explain how continents could move—was now available. Eventually, scientists came to understand that Earth's surface is made up of huge slabs of rock called *tectonic plates* floating slowly on a layer of fluid-like rock in the mantle. The names and locations of these plates are shown in **Figure 4.7**. There are 12 major plates, and many smaller ones, that all fit together. The activity at mid-ocean ridges and trenches (**Figure 4.8** on the next page) is related to how the boundaries (edges) of these plates interact. The theory that explains these and other of Earth's geological processes is called the **theory of plate tectonics**.

theory of plate tectonics the lithosphere is broken into large plates that interact and cause geologic activities

Figure 4.7 Earth's tectonic plates move very slowly—about 2.5 cm per year. This is about the same rate that your fingernails grow.

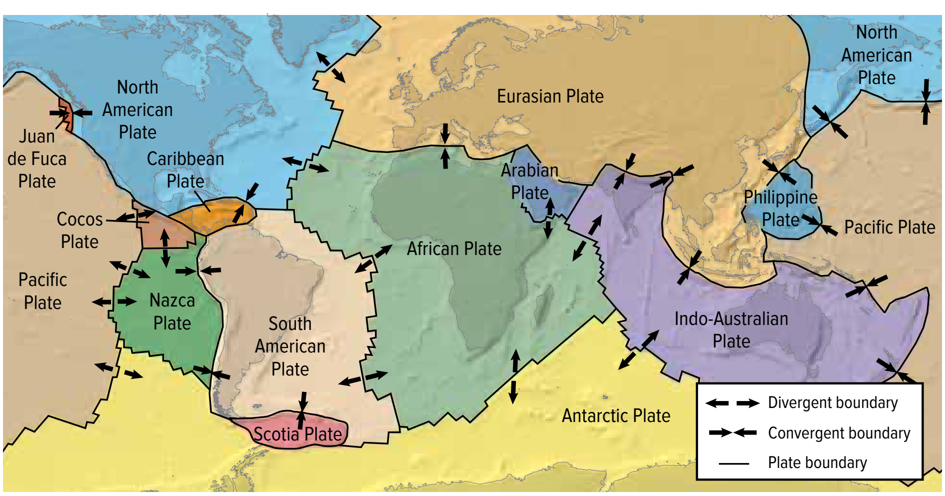
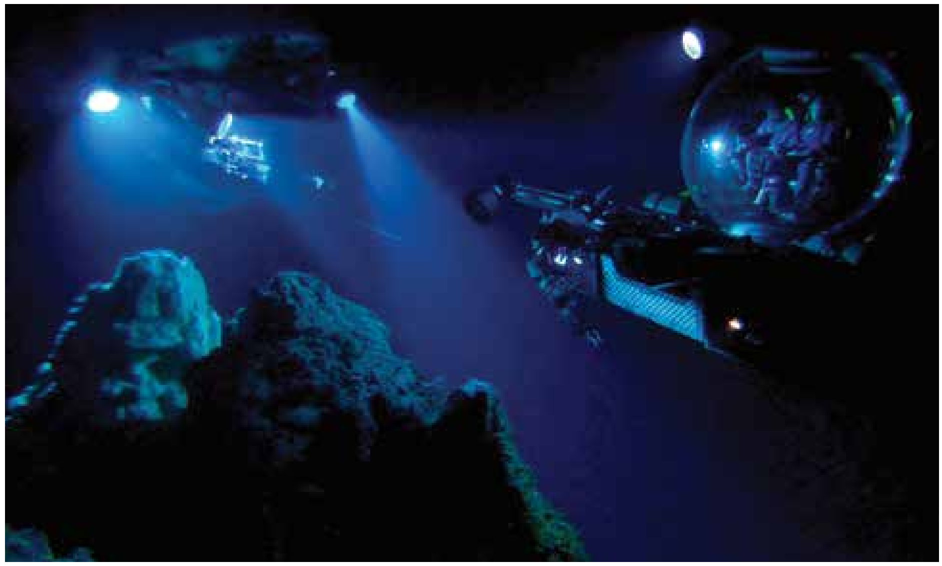
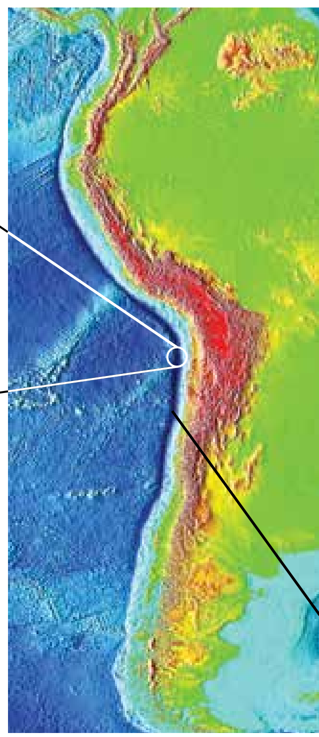


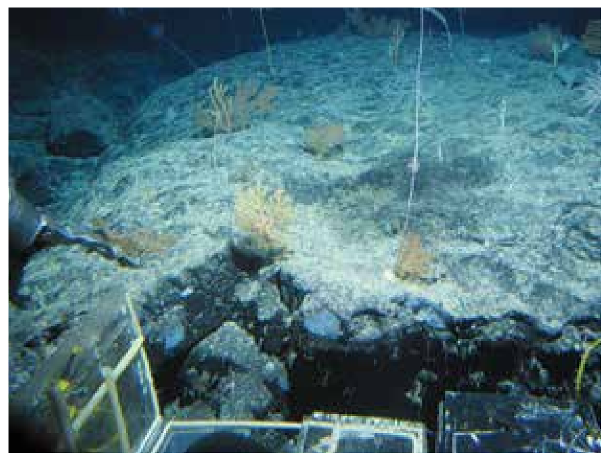
Figure 4.8 Examples of features of mid-ocean ridges and trenches



Scientists explore a mid-ocean ridge in submersible vehicles.

This snailfish, discovered in 2010 at a depth of 7000 m, is one of many unique organisms living in the Peru-Chile trench.





A coral and sponge garden grows on the Kelvin Seamount, part of the New England Seamount Chain in the Atlantic Ocean.

The Peru-Chile trench is 8000 m deep and 6000 km long. It formed when the Nazca plate was subducted under the South American plate.

Plate Tectonics—A Unifying Theory

The theory of plate tectonics explains many of the features and events that take place at and below Earth's surface. It explains how and why the continents move; how and why sea floor spreading occurs; and how, why, and where earthquakes, volcanoes, and the formation of mountains occur. It is a unifying theory, because it elegantly brings together (unifies) ideas and explanations from a wide array of scientific and other ways of knowing.

Connect to Investigation 4-C on page 287

Check Your Understanding of Topic 4.1

QP Questioning and Predicting   PC Planning and Conducting   PA Processing and Analyzing   E Evaluating
AI Applying and Innovating   C Communicating

Understanding Key Ideas

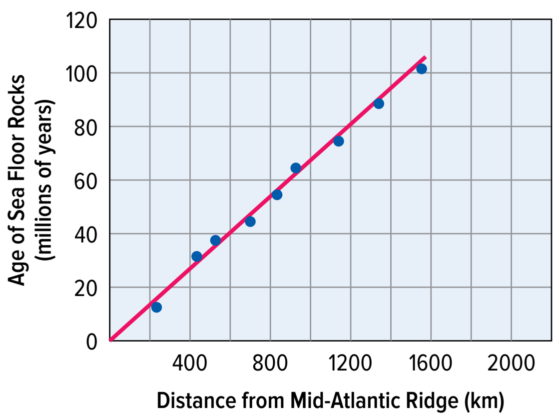
1. Describe the role that Pangaea played in Alfred Wegener's hypothesis. PA

2. Why did the ages of rocks at mid-ocean ridges puzzle scientists? PA

3. How do the theories of plate tectonics and continental drift differ? PA C

4. Use a diagram or graphic organizer to compare three key facts about Earth's layers. PA E C

5. The graph shows ages and locations of rock samples taken at the bottom of the mid-ocean ridge in the Atlantic Ocean. Each dot represents a sample of rock. PA E AI



   a) What is the age of the oldest rock and the youngest rock?
   b) How far would you have to travel east or west from the mid-ocean ridge before you found rocks that were 60 million years old?
   c) Describe the relationship between the age of rocks in the Atlantic Ocean and the distance they are from the mid-ocean ridge.
   d) What conclusion could you draw from this graph?

6. Why was there so little information about the oceans during the time that Wegener was collecting evidence for his theory? Why was it possible to learn much more about the oceans during and after the 1940s? E C

Connecting Ideas

7. Many scientists who contributed to the theory of plate tectonics were taught in school that the fixed-continent hypothesis was fact. Now the theory of plate tectonics is used to describe the movement of Earth's surface.
   a) Look up the meaning of the word "fact." How can facts change? What does this tell you about science and scientific discoveries?
   b) Think of a fact that you recently learned. What discovery may make you question whether it is a fact or not?
   E AI

8. Compose a letter to the editor of a newspaper from a scientist in the early 1900s arguing against the continental drift hypothesis. C PA

Making New Connections

9. If continents continue to move, is it possible that a new supercontinent will form? Which continents might be next to each other 200 million years from now? AI QP

INVESTIGATION
4-A

STRUCTURED INQUIRY

Skills and Strategies

- Processing and Analyzing
- Evaluating
- Applying and Innovating

What You Need

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

Wegener's Evidence for Piecing Together Pangaea

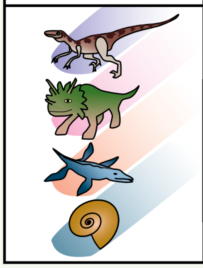
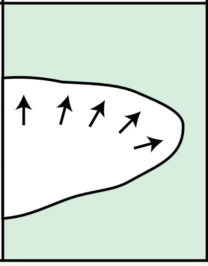
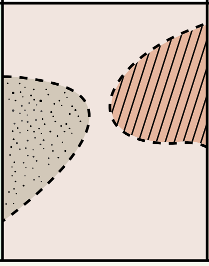
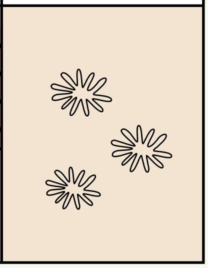
Alfred Wegener (1880–1930) was one of many people who noticed that the shapes of some continents looked like they were once joined together. Wegener collected evidence and analyzed data in hopes of showing that this was more than just chance. In this investigation, you will use some of the evidence Wegener collected to assemble a paper model of the supercontinent Pangaea that he hypothesized.

Question

How does geological and biological evidence support the existence of Pangaea?

Procedure

1. Obtain a sheet of paper with the outlines of the continents. Cut out each continent, with its continental shelf. The dotted lines represent the edges of the continental shelves.
2. The key below represents different types of evidence that Wegener collected. The symbols in the key are drawn on the continent shapes you cut out.

Fossils	Glacial Deposits	Matching Mountain Ranges	Coal Deposits
			

3. Piece together the continents using the shapes of continents and the evidence as a guide.
4. Some of Wegener's evidence is summarized in the table on the opposite page. Check your assembled supercontinent against the evidence described in the table. Modify your representation if needed.

5. Have your teacher check your assembled Pangaea. Then, glue the pieces onto the larger piece of paper.

Process and Analyze

1. Summarize the process you used to assemble the supercontinent.
2. Why did the pieces you fit together include the continental shelf?
3. Why was using several pieces of evidence, instead of just one, important?

Evaluate, Apply, and Communicate

4. Was the supercontinent you assembled just like the Pangaea supercontinent that Wegener proposed? If not, explain how it is different and why.
5. To discredit Wegener's ideas, some scientists suggested that land bridges once existed between continents. For example, they argued that a land bridge between South America and Africa would have allowed animals to pass between these continents, and that is why fossils of these animals are found on both continents. It was suggested that these land bridges later sank into the ocean. Do you think this is a possible scenario? Explain your answer.

Wegener's Evidence (for Procedure Step 4)	On Your Map?
Grooves in rock once formed by large, moving glaciers are found in southern Africa, South America, Australia, and India. When these places are fitted together, the grooves expand outward in all directions. This supports the idea that an ice cap was once centred over Antarctica and South Africa and the ice moved outwards from there.	
When the continents are pieced together, there is a continuous band of fossils of the reptile *Mesosaurus* through southern Africa and the eastern coast of South America.	
When the continents are pieced together, there is a continuous band of fossils of the plant *Glossopteris* through Africa, South America, Australia, Antarctica, Madagascar, and India.	
When the continents are pieced together, there is a continuous band of fossils of *Lystrosaurus* through east Africa, India, and Antarctica.	
When the continents are pieced together, there is a continuous mountain range on the east coast of North America, North Africa, and Europe.	
Coal deposits have been found in Antarctica. The coal is thought to form from plants that grew in warm weather. Therefore, Antarctica was likely in a much warmer climate than it is now.	

INVESTIGATION

4-B

GUIDED INQUIRY

Skills and Strategies

- Questioning and Predicting
- Planning and Conducting
- Processing and Analyzing
- Evaluating
- Applying and Innovating
- Communicating

What You Need

Possible materials include:

- large sheets of paper
- coloured pencils or markers
- craft materials, such as foam blocks, glue, and coloured clay

Modelling Sea Floor Spreading

Sea floor spreading is a process that describes how new oceanic crust forms at mid-ocean ridges. In this investigation, you will work with your classmates to develop a model that shows how sea floor spreading occurs.

Question

How can a model show sea floor spreading?

Procedure

1. Decide how you will use a model to represent sea floor spreading. Your goal is to design and build the model to show what happens during sea floor spreading.
2. Use the following questions to guide your decisions.
   - What important features and processes do you need to show? Remember that your model must be consistent with the evidence collected at mid-ocean ridges.
   - What materials do you need to safely build the model? Are these available from your teacher?
   - What is the procedure to make the model?
3. Have your teacher approve your idea for your model.
4. Build your model and demonstrate it to the class.

Analyze and Interpret

1. Draw a design of your model. Make a list of the features that are represented. Were you able to represent all the features? Why or why not?
2. Describe which feature was most difficult to represent.

Conclude and Communicate

3. Assess how well your model worked. How could you improve it?
4. As a class, compare your models. Make a list of the strengths and weaknesses of the models.

INVESTIGATION
4-C

OPEN INQUIRY

Using Maps

Skills and Strategies

- Questioning and Predicting
- Planning and Conducting
- Processing and Analyzing
- Evaluating
- Applying and Innovating
- Communicating

What You Need

- map of tectonic plates

Maps are common ways of representing information about locations of features and processes on Earth. In this investigation, you will use maps to answer a question you have about tectonic plates, earthquakes, and volcanic activity.

Procedure

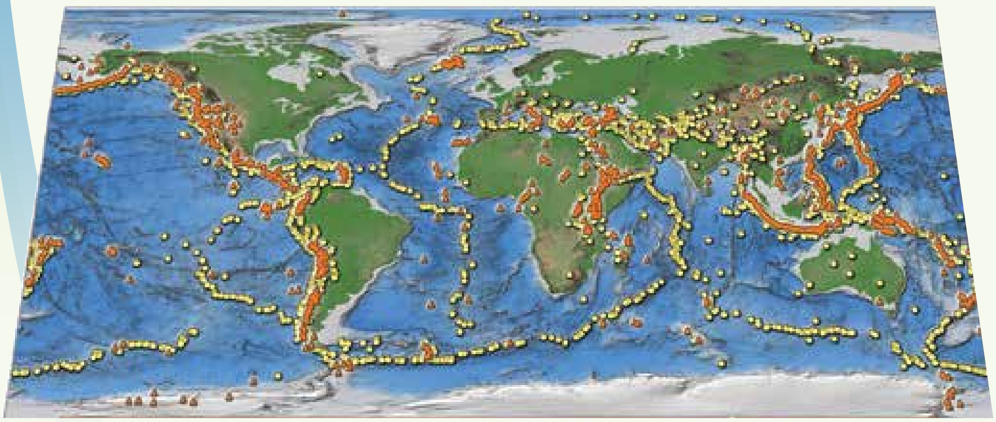
1. Write out any questions you have about the relationship between tectonic plate boundaries and locations of earthquakes and volcanoes.
2. Decide which question you will investigate using the information in the maps, and determine how you will use the maps. Carry out your plan.

Process and Analyze

1. Did you determine the answer to your question? If so, what is it? If not, why were you not able to? What other information would you need to answer your question?

Evaluate and Communicate

2. Create an infographic for people who live in areas where earthquakes and volcanoes are common. Include a description of the theory of plate tectonics and how it explains why those areas experience these geologic activities. It will be for people of different ages and backgrounds, who live in different countries. How can you develop the notice for the largest audience?



Yellow circles show where earthquakes happened. Orange triangles show volcanic eruptions.