

EARTHQUAKES, VOLCANOES, AND PLATE TECTONICS

Earthquake Activity

Place	Magnitude
Kobe, Japan	7.2
Anchorage, Alaska	9.2
San Francisco, California	7.7
Southern Chile	9.5
Los Angeles, California	6.7
Western Iran	7.7
Mexico City	8.1
Tokyo-Yokohama, Japan	8.2
Guatemala	7.5
Peru	7.9

Volcano Activity

Name	Place
Arenal	Costa Rica
Krakatoa	Java, Indonesia
Mount Pele	Martinique
Mount Pinatubo	Philippines
Mount Ruapehu	New Zealand
Mount St. Helens	Washington, United States
Mount Tambora	Sumbawa, Indonesia
Mount Vesuvius	Naples, Italy
Paricutin	Paricutin, Mexico
Surtsey Island	Iceland

The Question

Where in the world do earthquakes occur? Where in the world do volcanoes occur? Is there a pattern?

The Hypothesis

Develop a hypothesis based on the earthquake and volcano data given on this page.

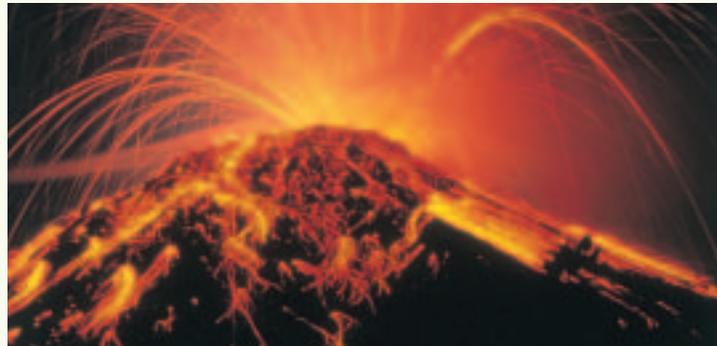


Figure 3.4 Arenal Volcano, Costa Rica

Procedure

- 1 Mark on a world map the location of the volcanoes and earthquakes listed in the charts to the left.
- 2 Review subsection 1.2, Sudden Earth Events.
- 3 Note any patterns you observe on your map.
- 4 Indicate on your map the principal mountain ranges in the world.

Analyzing and Interpreting

- 5 Work with a partner or small group and brainstorm possible reasons for your observations. Choose one of the reasons that you think best explains your observations. Does your reason fit your hypothesis? Do you need to revise your hypothesis?

Forming Conclusions

- 6 Write a brief report that supports your hypothesis.

Applying and Connecting

Compare your report with others in the class. What similarities do you find? What differences do you find? If necessary, revise your hypothesis to reflect what you have learned from the other reports.

Extending

Research other volcanic and earthquake activity and mark their locations on your map. Are these new locations in the same regions as the other volcanoes and earthquakes?

INTERPRETING THE PATTERNS

Scientists noticed that volcanoes and earthquakes tended to occur in the same areas around the world. They also noticed distinctive deep valleys under the oceans, usually near the edges of continents. These valleys are called **trenches**. And they noticed long underwater mountain ranges called **ridges**.

The mountain range in the middle of the Atlantic Ocean was an important piece of evidence in the development of the new theory to explain Earth's surface structures. This mountain range is called the Mid-Atlantic Ridge. The rock at its top was younger than the rock on the surrounding ocean floor and the edges of the continents.

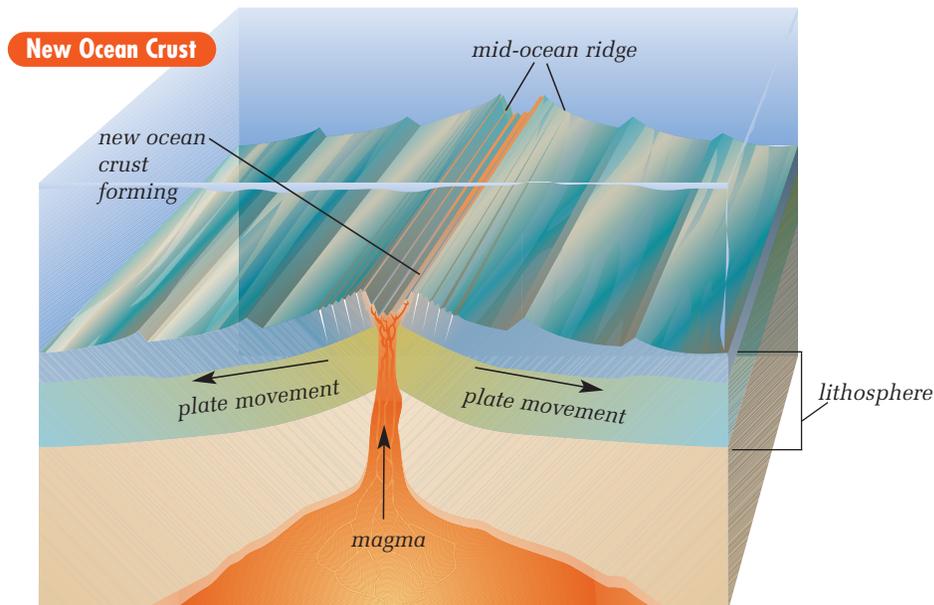


Figure 3.5 Deep under the water, new crust is forming continuously from lava at mid-ocean ridges.

Figure 3.5 shows what is occurring at the Mid-Atlantic Ridge. Magma rises from deep within Earth and flows out at the ridge. On either side of the ridge, scientists found that the farther rock is away from the top of the ridge, the older the rock is. This means that the rock must be moving away from the ridge and toward the continents.

Evidence showed that this sea floor spreading was taking place in other areas as well. Did this mean that the planet was increasing in size? No, it isn't because, in other areas, the sea floor is moving down into the deep ocean trenches. Scientists now had strong evidence for their new theory.

- Most earthquakes and volcanoes are concentrated in specific areas.
- There are large areas on Earth where few or no earthquakes and volcanoes occur.



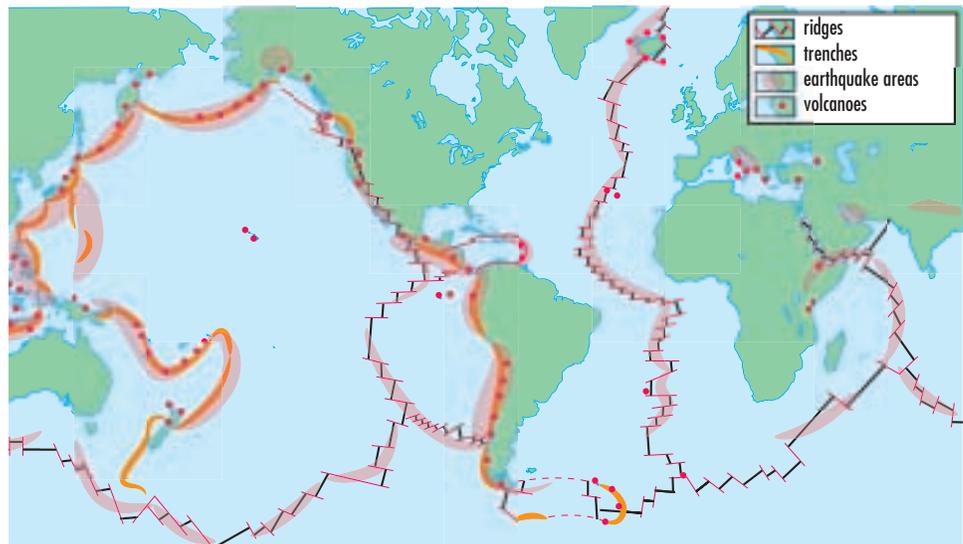
Figure 3.6 Water within the crust layer is superheated by hot magma just a few kilometres below the surface. This is called **geothermal activity**. When water returns to the surface, hot springs like this one are the result.

- The ocean floor is spreading away from mid-ocean ridges.
- The ocean floor is moving down into deep trenches on or near the edges of continents.

THE THEORY OF PLATE TECTONICS

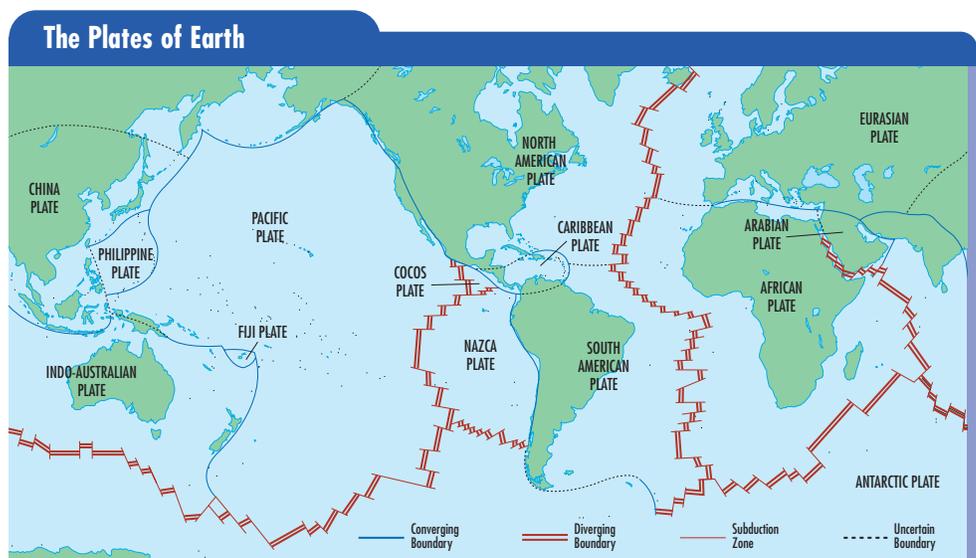
When all this evidence was pieced together, scientists suggested the **Theory of Plate Tectonics**. According to this theory, the lithosphere is broken up into large areas much like a cracked eggshell. These areas are called **plates**. The plates usually carry both continental and oceanic crust. All these plates are moving very slowly on a semi-solid layer of crust.

Figure 3.7 This map shows the major features scientists discovered when they surveyed the ocean floors. They found deep valleys called **trenches** and mountain chains called **ridges**.



The following illustrations show what happens at the different types of plate boundaries around the world. A **boundary** is the edge where plates meet. Look at the map of The Plates of Earth (Figure 3.8) while you read these descriptions so you can see where they are.

Figure 3.8 Earth's lithosphere is broken up into many large and small plates. The plates are all solid rock, but they “float” on the partly melted layer of the mantle below the lithosphere.



Diverging Boundaries

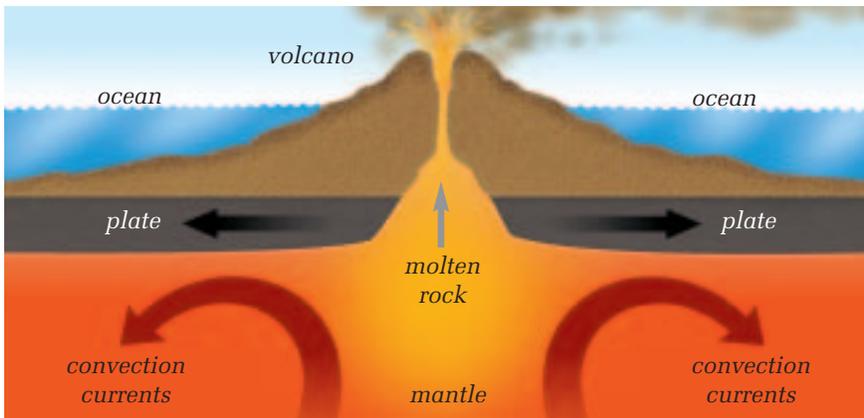


Figure 3.9 A diverging boundary

A **diverging boundary** is one where two of Earth's plates are moving apart. The Mid-Atlantic Ridge on the floor of the Atlantic Ocean is an example of a diverging plate boundary. At this type of boundary, lava flows from the ridge to form new oceanic crust. Sometimes, volcanoes grow high enough that they are visible above the ocean's surface, like those that form Iceland.

Converging Boundaries

At **converging boundaries**, plates are moving toward each other. Although plates move very slowly, they are so huge that we experience the effects of their collision. We can feel the earthquakes and see the mountains, including volcanoes, that grow up at or near these boundaries. There are two kinds of converging boundaries.

One kind of converging boundary happens where a trench forms. One plate carries *oceanic crust*, and the other one carries *continental crust*. When the plates push together, the heavier, thinner oceanic crust is forced down below the lighter, thicker continental crust (see Figure 3.11). This process is called **subduction**. As one plate grinds down past the other, earthquakes rumble, and the continental crust wrinkles to form mountains. The oceanic crust moves lower and gets hotter and melts. This molten rock rises in some places to form volcanoes.

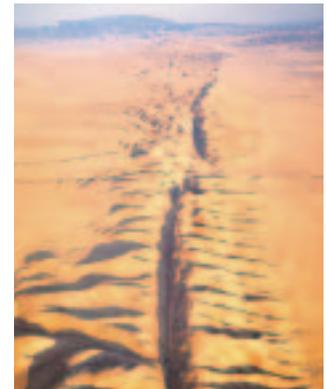


Figure 3.10 The San Andreas fault is a crack in Earth's crust that runs along part of the west coast of the United States.

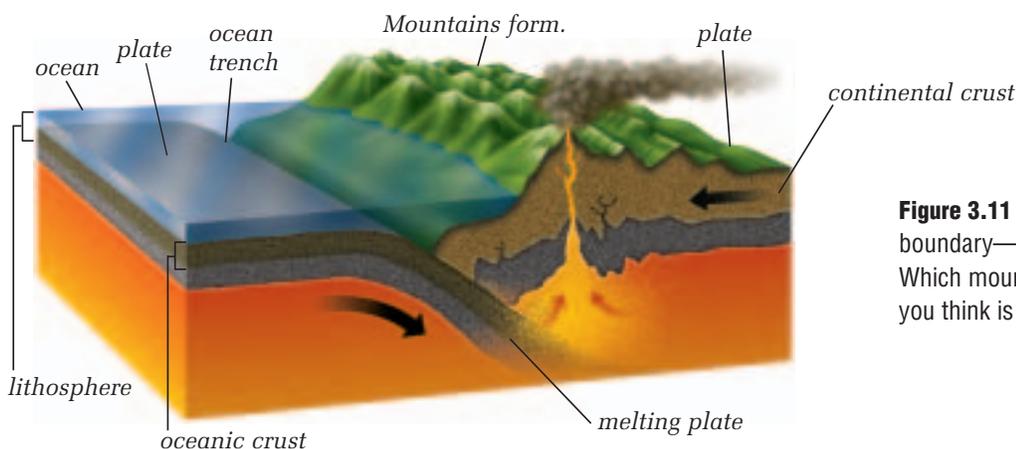


Figure 3.11 Converging boundary—at an ocean trench. Which mountain range in Canada do you think is formed by this process?

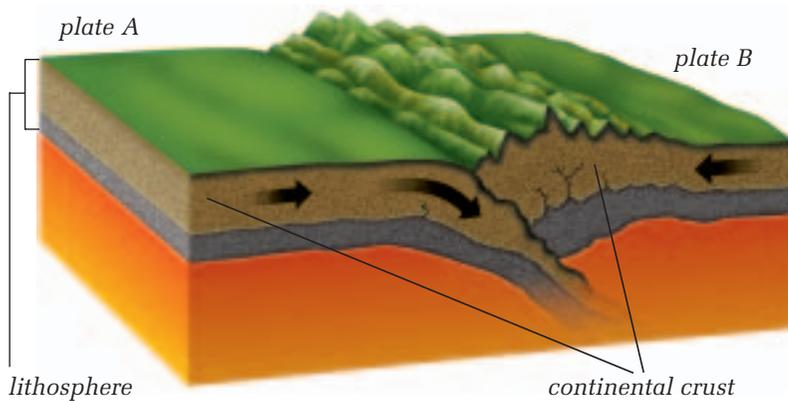


Figure 3.12 Converging boundary—when two continental plates collide

The second kind of converging boundary happens where two plates with continental crust move up against each other. They crush together to form huge mountain ranges. Which high mountain range in Asia is being formed by this process?

RESEARCH

Hawaiian Islands

J. Tuzo Wilson proposed an interesting theory of why the Hawaiian islands formed.

- Find out how these islands formed.
- Find out more about J. Tuzo Wilson and his work as a scientist.

Transform Boundaries

The third type of boundary is called a **transform boundary** (Figure 3.13). Here, plates slide sideways past each other. But this sliding doesn't take place smoothly. The rocks bind and catch on each other, causing earthquakes. You can find a transform boundary along the west coast of the United States at the San Andreas fault (Figure 3.10).

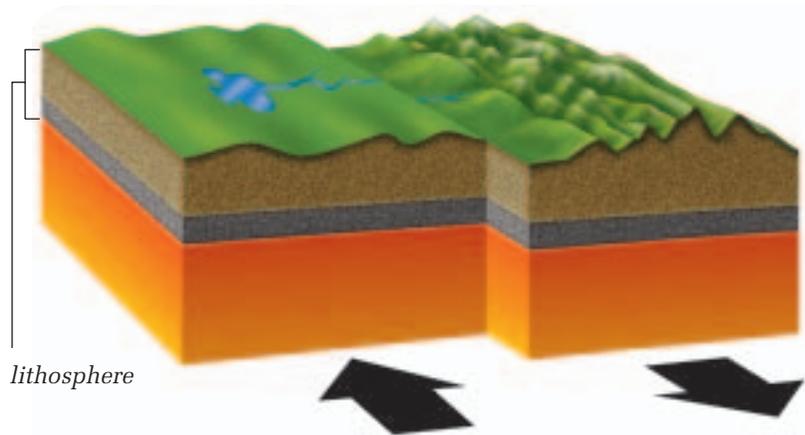


Figure 3.13 Transform boundary—when two plates slide

CHECK AND REFLECT

1. Explain three pieces of evidence to support the belief that Earth's crust is slowly moving.
2. List the three types of plate boundaries.
3. Look at the map of The Plates of Earth (Figure 3.8). Do you think South America is moving closer to or farther away from Africa?
4. If the South American and African Plates are diverging at a rate of 2 cm/year, calculate how much wider the Atlantic Ocean will be when you are 50 years old.

Experiment

ON YOUR OWN

PREDICTING CONTINENTAL DRIFT

Before You Start ...

As you can see from your studies, scientists think that the continents once formed one large land mass called Pangaea. They believe that the continents have been slowly drifting apart at the rate of about 10 cm a year. Figure 3.14 shows the possible positions over the last 200 million years.

Continental Drift

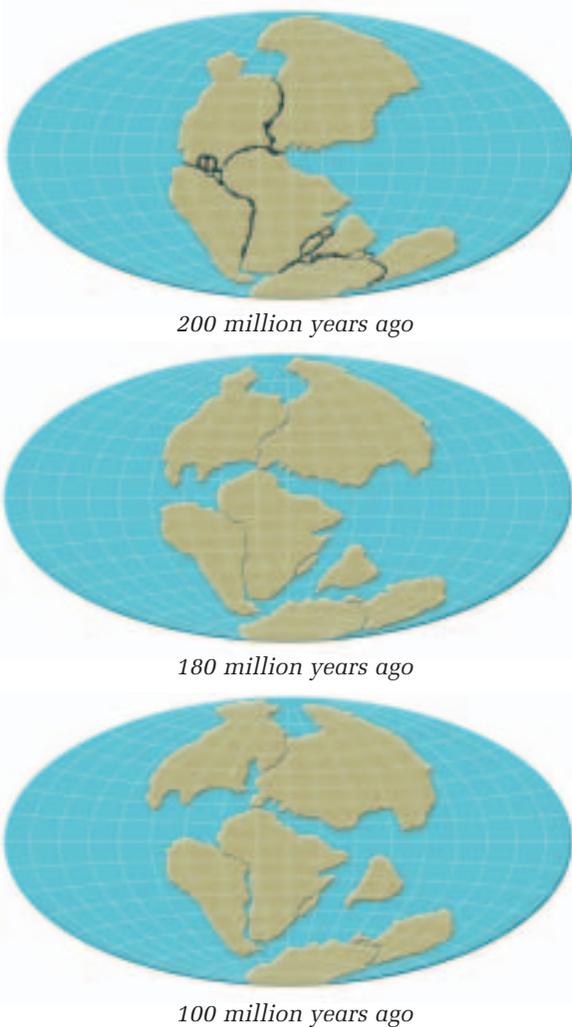


Figure 3.14 The changing positions of the continents over the last 200 million years

The Question

What will a map of the globe look like 100 million years from now, assuming the continents move apart at the current rate? (See Toolbox 2 to review The Inquiry Process of Science.)

Design and Make Your Model

- 1 The map below shows the continental plates and the direction they are moving.

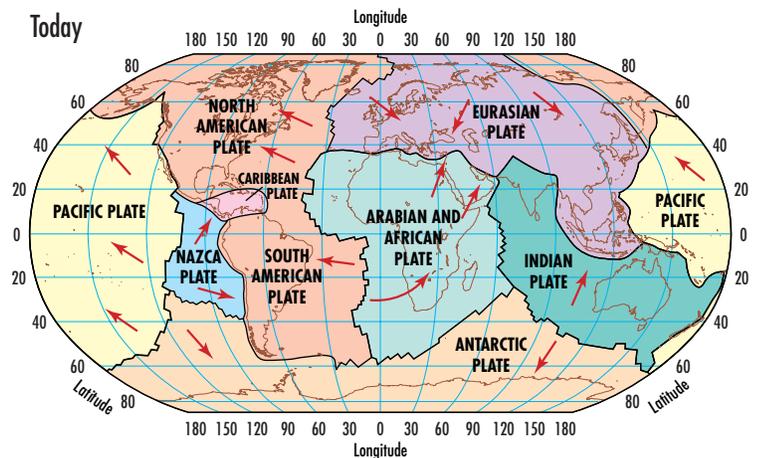


Figure 3.15 Direction of continental drift today

- 2 Create a plan of how you will use the map information to build a model map of the planet. List the materials and equipment you will need. Show your plan to your teacher for approval.
- 3 Make your model. Be prepared to explain and defend your model and how you developed it to your class.
- 4 Compare your model with others in the class. How successful were the other models? Were many models similar to yours?

3.3 Mountain Building

Think about Alberta's landscape. There is a tremendous diversity of mountains, plateaus, valleys, and rolling hills. Now think of the landscape where you live. What are some of the dominant features on it? What's the highest point of land in your area? Would you call it a mountain? Why or why not? Have you ever visited the Rocky Mountains? Describe in words or a drawing your impression of mountains.

WHAT IS MOUNTAIN BUILDING?

A **mountain** is part of Earth's surface that is much higher than the land around it. A **mountain range** is a series of mountains. The Rocky Mountains extend from the north in the Yukon territory, through the United States and into southern Mexico, making it one of the longest mountain ranges in the world. In Alberta, the Rocky Mountains straddle the border with British Columbia. These mountains are the result of several processes that geologists call **mountain building**.

In subsection 3.2, you learned that Earth's crust is not one smooth piece of rock. It is made of several plates that fit together like a giant jigsaw puzzle, and that are in constant motion.

Figure 3.16 The Canadian Rockies near Pincher Creek, Alberta



Mountain Trivia Quiz

- What is the highest mountain in the world?
- What is the highest mountain in Canada?
- What is the highest mountain in Alberta?

Answers:
 Mt. Everest 8850 m
 Mt. Logan 5920 m
 Mt. Columbia 3747 m

You also have learned that mountains form in places where these plates collide. For example, the land mass we call India is currently pressing into southern Asia. We have evidence of this as there are many earthquakes in this region in places like Turkey, Azerbaijan, Armenia, and other countries that border northern India. Evidence of this movement is also seen from the ever-growing Himalayas. (Mt. Everest, in the Himalayas, is about 50 cm higher than it was 40 years ago—and it’s still growing!) Alberta’s Rocky Mountains formed in much the same way over 200 million years ago, but the building stopped after about 140 million years.

BUILDING THE MOUNTAINS: AN ALBERTA STORY

Nearly 500 million years ago, Alberta had a much different climate than it does now. It was tropical. The border that is now shared with British Columbia was on the coast of a warm, shallow sea.

The shallow sea was constantly being filled with sediments. They flowed over the land and carried all sorts of debris, depositing it in layers on the coast. Over time, these layers of sediment created a pile that was 10–15 km thick. Rivers and streams that drained into that ancient sea carried with them a great deal of sand, mud, and gravel. These sediments were deposited in thick layers on the sea floor, reaching depths of up to 15 km.

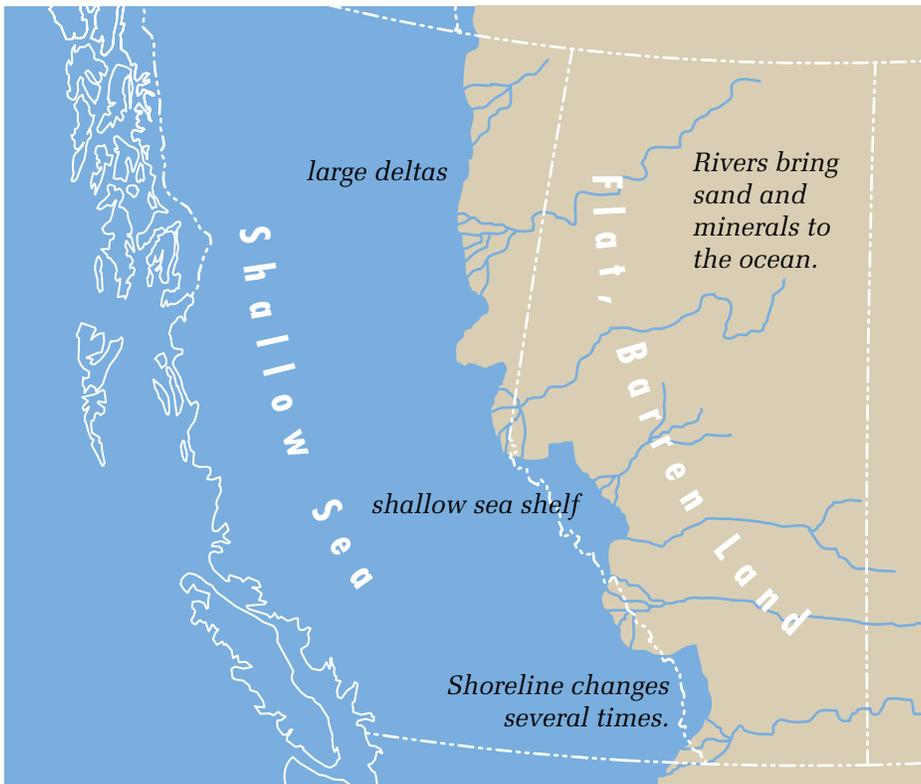
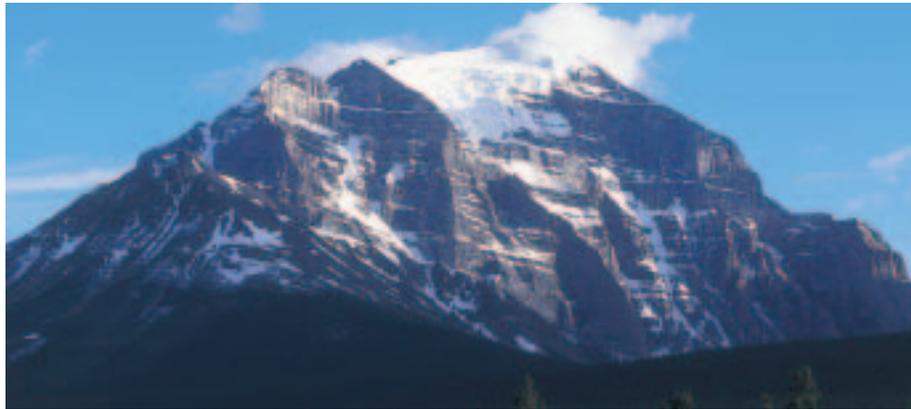


Figure 3.17 Five hundred million years ago, Alberta had no mountains, just flat land at the edge of a warm shallow sea.

Figure 3.18 Mt. Temple was formed at the leading edge of the collision between the North American Plate and the Pacific Plate. It was here that sedimentary rocks were first stacked on top of each other like a wedding cake.



After more than a billion years of sediment deposition, the collision of two plates occurred. The North American Plate, carrying what is now Alberta, collided with the edge of the Pacific Plate. The force of this collision had two major effects. It forced the denser oceanic crust of the Pacific Plate downward below the lighter continental crust of the North American Plate, as you can see in Figure 3.19.

At the same time, the pressure of the two plates ramming against each other forced the sediments on the edge of the North American Plate to fold and break. Some of these sediment layers were pushed so hard that they separated and slid over top of each other. The continuing pressure moved them more than 250 km east of where they were originally deposited. Mount Rundle in Banff was formed in this way. This folding, breaking, sliding, and piling created the Rocky Mountains.

The oceanic plate, which is thinner and heavier, slides under the continental plate.

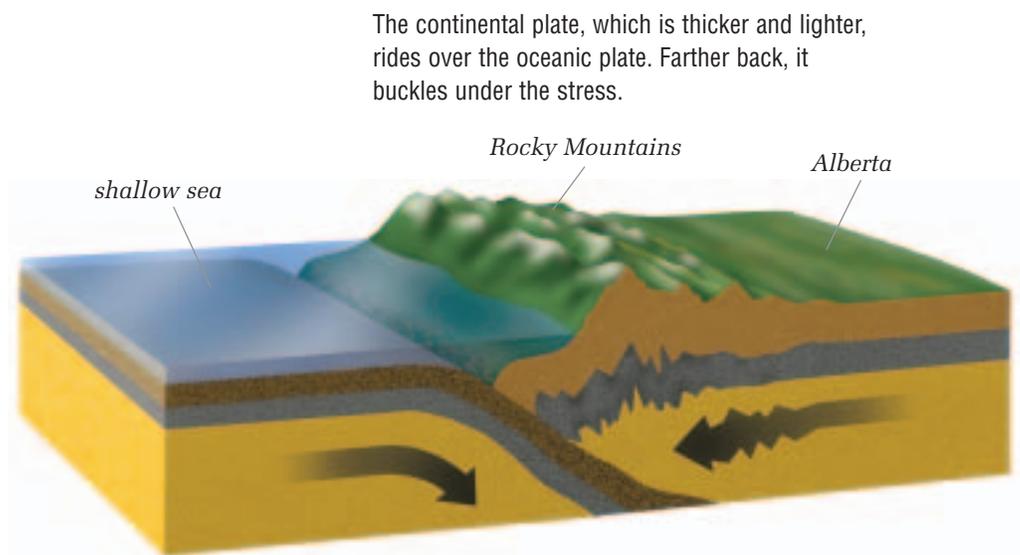


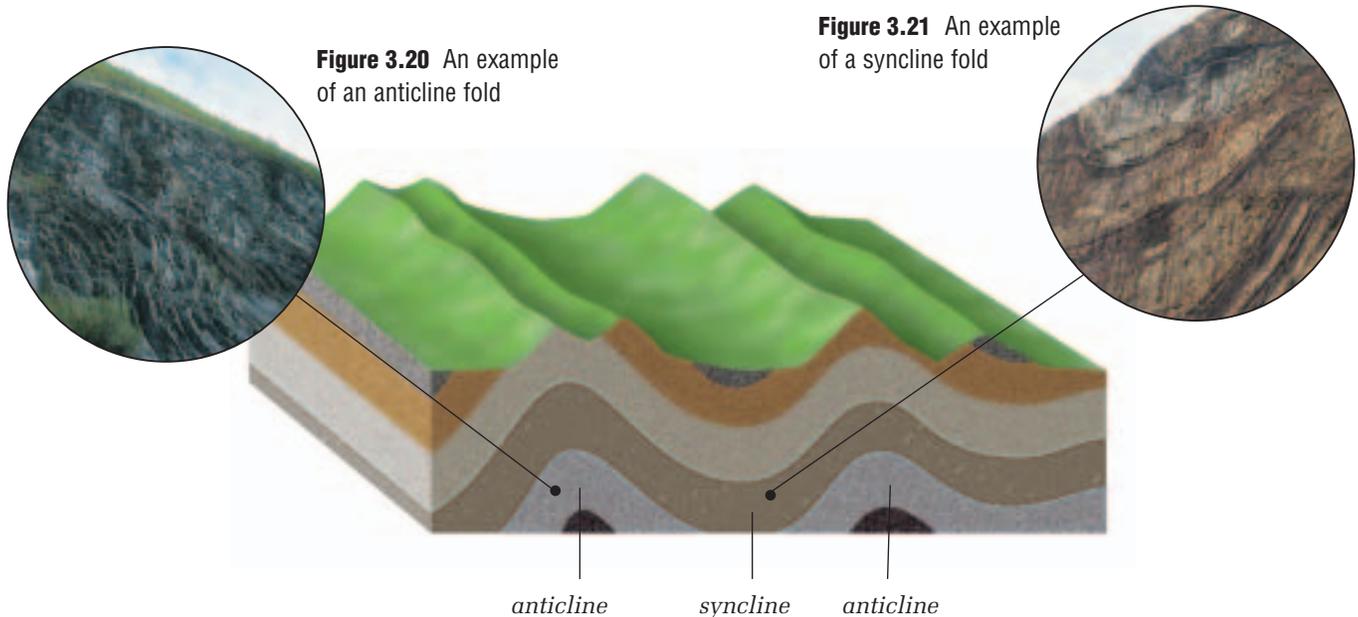
Figure 3.19 How the Rocky Mountains were formed

THE STRUCTURE AND DEVELOPMENT OF FOLD AND FAULT MOUNTAINS

Have you ever seen interesting shapes or landforms when you drive in a car? Many Canadian roads travel through some amazing places that can leave you wondering: “How did it get to look like that?”

When mountains are built, they undergo several processes that result in the final formations that we see today. For example, as a result of the collision between plates, all of the sedimentary rocks in the present Rocky Mountains felt compression forces. These forces caused the sedimentary rocks to bend and break. Folding and faulting are the results. The bends in these rock beds are called **folds**. Large cracks in the rock beds also formed. **Faults** occurred wherever the rocks on either side of a crack moved. Most mountains were created by a combination of folding and faulting. There are two kinds of folds found in rocks:

- an *anticline* or an upfold in the rock
- a *syncline* or a downfold in the rock

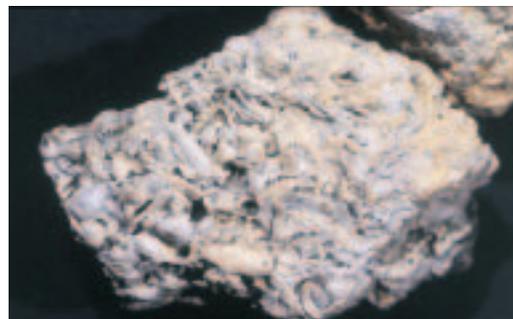


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An Ancient Limestone Reef

Deep below the surface of southern Alberta are fossil remains of sea animals that lived millions of years ago. These ancient limestone reefs contain oil and gas.

This piece of limestone shows the fossilized remains of ancient sea animals.



FORMING FOLDED MOUNTAINS

Materials & Equipment

- 5 rectangular strips of modelling clay, each a different colour but the same size
- 2 pieces of wood, each 10 cm × 8 cm × 8 cm
- bar clamp, longer than 50 cm

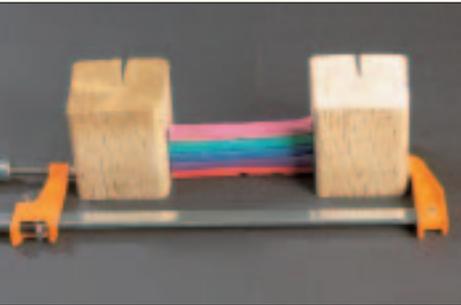


Figure 3.22 Step 2

The Question

How can mountains form by folding?

The Hypothesis

Form or develop a hypothesis that you think best predicts what will happen.

Procedure

- 1 Place one piece of modelling clay on your desk. Lay the other pieces one by one on top of each other to form a pile.
- 2 Put a block of wood at each end. Place the clamp so that the modelling clay and the blocks of wood are between the clamps.
- 3 One person holds both ends of the clamp as another person slowly closes the clamp.
- 4 Stop when the clamp is half closed.
- 5 Clean up after you have completed the activity, and wash your hands.



Figure 3.23 Step 3

Collecting Data

- 6 As you slowly close the clamp, stop from time to time to record your observations in words and diagrams.

Analyzing and Interpreting

- 7 Is the clay folded into an anticline or a syncline? or both?
- 8 What does the clamp represent in this model?
- 9 What does the modelling clay represent in this model?
- 10 What happens to the modelling clay as you close the clamp?
- 11 Why doesn't the clay break from the pressure of the clamp?

Forming Conclusions

- 12 Write a summary statement that answers the question: "How do mountains fold?" Include a diagram with your answer.

Applying and Connecting

Look through the photographs on pages 392 to 405 and identify examples of anticline and syncline folding.

Extending

Find other pictures in magazines that show these two types of folding. Use these pictures to create a poster describing and explaining this folding.

WHERE DOES THE FOLDING HAPPEN?

The clay you used in the previous activity may seem much too soft to be a good model for layered rocks. Rocks are hard. How can they fold? Rocks can only fold after they have been softened by heat and pressure within Earth's crust. This heat and pressure allows the rocks to bend without breaking. These conditions are most likely to happen where powerful forces are at work in the crust.

Think about the Theory of Plate Tectonics that you studied earlier in this section. Colliding plates provide the heat and pressure needed to soften the rock. As the plates push against each other, the rock "wrinkles" into folds and is forced upward.

Look back at the map of The Plates of Earth (Figure 3.8). What two plates are colliding to form the Himalayas? If the Himalayas keep rising at 1 cm per year, how much taller will they be in 1 000 000 years?



Figure 3.24 The Himalayas are still rising at a rate of 1 cm each year.



Figure 3.25 This fence was one straight piece when it was built. Why do you think it now has this gap?

reSEARCH

Researching the Rockies

Use library resources and the Internet to research what major fault (or faults) is in North America.



The Rocky Mountains—were these mountains built by a fault?

MOUNTAINS WITH FAULTS

Another powerful Earth process that can build mountains is faulting. Earlier in this unit, you learned that earthquakes can sometimes happen at faults far from plate boundaries. Faults can be so deep in the crust that we can't see them. However, some faults are visible on Earth's surface. Have you ever noticed a fault? How could you tell it was a fault?



Figure 3.26 One place where faults are easy to find is in layered rock. Where is the fault in this picture? What evidence do you see of movement along the fault?

CHECK AND REFLECT

1. Describe how the Rocky Mountains were formed.
2. How does the Theory of Plate Tectonics explain why ancient plant fossils found in Alberta rock represent a climate very different from today?
3. You have been asked to join a scientific expedition to investigate a remote mountain region in the Antarctic. Your team wants to discover how these mountains formed. Describe the evidence you will look for.



Assess Your Learning

1. Describe the three types of plate boundaries.
2. Coal deposits have been found beneath the ice of Antarctica, but coal only forms in warm swamps. Use Wegener's theory to explain how coal could be found so near the South Pole.
3. Explain why the rock of the Mid-Atlantic Ridge is younger than the rock found on the edge of the continents.
4. It has been suggested that we should dispose of our dangerous waste materials near a converging plate boundary. What do you think of this idea?
5. What would you expect to see when divergent boundaries occur on land? Draw a diagram of the result.
6. a) Describe the difference between a fold and a fault.
b) Why do you think folded mountains contain faults?
7. During the building of the Rocky Mountains, the fault activity resulted in very thick layers of rocks to be pushed on top of one another. What do you think this additional weight did to Earth's crust? (Hint: Imagine what would happen if weights were piled onto a floating raft.)
8. Using what you know about the formation of faults, explain how mountain building can be compared with shovelling a sidewalk after a snowstorm.

Focus On

THE NATURE OF SCIENCE

The goal of scientists is to try to explain and interpret their observations. These interpretations are recorded in the form of scientific theories and models.

1. What theories did you learn about in this section?
2. What do you think are the differences between a scientific theory and a model?
3. What should scientists do if they discover that a theory or model doesn't explain all their observations?

4.0

The fossil record provides evidence of Earth's changes over time.

Key Concepts

In this section, you will learn about the following key concepts:

- tracing evidence of geologic change using fossils
- methods used to interpret fossils
- geologic time
- understanding fossil evidence

Learning Outcomes

When you have completed this section, you will be able to:

- describe the nature and formation of different kinds of fossils
- explain and apply methods used to interpret fossils
- describe different life forms based on fossil records
- identify uncertainties in interpreting fossil records



Dinosaur Provincial Park—These paleontologists are carefully digging out the skull of *Albertosaurus*, a dinosaur that lived 75 million years ago.

Geologists can have a difficult time studying Earth's history and the events that occurred. Fortunately, they have “time capsules” that they can use to give them a picture of life long ago. These time capsules are called fossils. They are found in the sedimentary rocks and can tell us a great deal about Earth's past.

Perhaps you've been to a museum or gallery that has different kinds of fossils on display. Was the fossil you saw an animal or a plant? Could you tell what the organism could have looked like when it was alive? Have you ever found a fossil in the field? What would you do if you found a fossil? Describe with words and a diagram your experiences with or knowledge of fossils.