

Deforming the Earth's Crust

Have you ever tried to bend something, only to have it break? Take long, uncooked pieces of spaghetti, and bend them very slowly but only a little. Now, bend them again, but this time, bend them much farther and faster. What happened?

How can a material bend at one time and break at another time? The answer is that the stress you put on the material was different each time. *Stress* is the amount of force per unit area on a given material. The same principle applies to the rocks in the Earth's crust. Different things happen to rock when different types of stress are applied.

Deformation

The process by which the shape of a rock changes because of stress is called *deformation*. In the example above, the spaghetti deformed in two different ways—by bending and by breaking. **Figure 1** illustrates this concept. The same thing happens in rock layers. Rock layers bend when stress is placed on them. But when enough stress is placed on rocks, they can reach their elastic limit and break.

Compression and Tension

The type of stress that occurs when an object is squeezed, such as when two tectonic plates collide, is called **compression**. When compression occurs at a convergent boundary, large mountain ranges can form.

Another form of stress is *tension*. **Tension** is stress that occurs when forces act to stretch an object. As you might guess, tension occurs at divergent plate boundaries, such as mid-ocean ridges, when two tectonic plates pull away from each other.

✓ Reading Check How do the forces of plate tectonics cause rock to deform? (See the Appendix for answers to Reading Checks.)

What You Will Learn

- Describe two types of stress that deform rocks.
- Describe three major types of folds.
- Explain the differences between the three major types of faults.
- Identify the most common types of mountains.
- Explain the difference between uplift and subsidence.

Vocabulary

compression	fault
tension	uplift
folding	subsidence

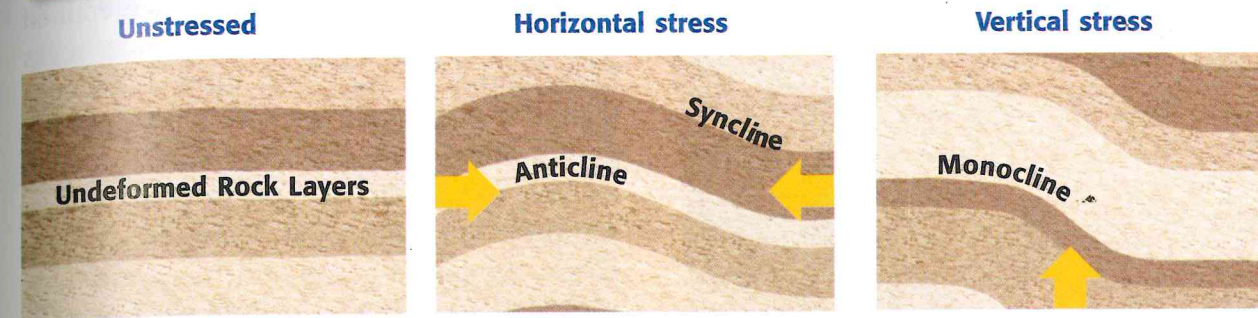
READING STRATEGY

Discussion Read this section silently. Write down questions that you have about this section. Discuss your questions in a small group.

Figure 1 When a small amount of stress is placed on uncooked spaghetti, the spaghetti bends. Additional stress causes the spaghetti to break.



Figure 2 Folding: When Rock Layers Bend Because of Stress



Folding

The bending of rock layers because of stress in the Earth's crust is called **folding**. Scientists assume that all rock layers started as horizontal layers. So, when scientists see a fold, they know that deformation has taken place.

Types of Folds

Depending on how the rock layers deform, different types of folds are made. **Figure 2** shows the two most common types of folds—*anticlines*, or upward-arching folds, and *synclines*, downward, troughlike folds. Another type of fold is a *monocline*. In a monocline, rock layers are folded so that both ends of the fold are horizontal. Imagine taking a stack of paper and laying it on a table. Think of the sheets of paper as different rock layers. Now put a book under one end of the stack. You can see that both ends of the sheets are horizontal, but all of the sheets are bent in the middle.

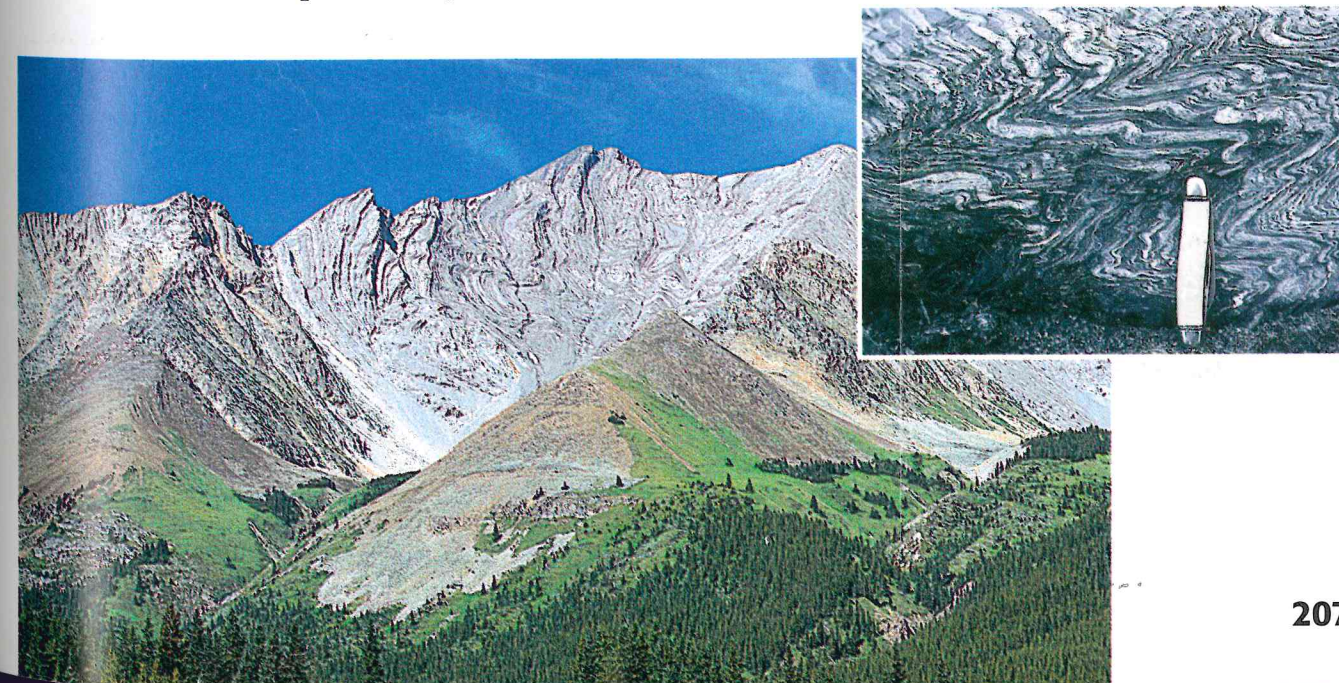
Folds can be large or small. The largest folds are measured in kilometers. Other folds are also obvious but are much smaller. These small folds can be measured in centimeters. **Figure 3** shows examples of large and small folds.

compression stress that occurs when forces act to squeeze an object

tension stress that occurs when forces act to stretch an object

folding the bending of rock layers due to stress

Figure 3 The large photo shows mountain-sized folds in the Rocky Mountains. The small photo shows a rock that has folds smaller than a penknife.



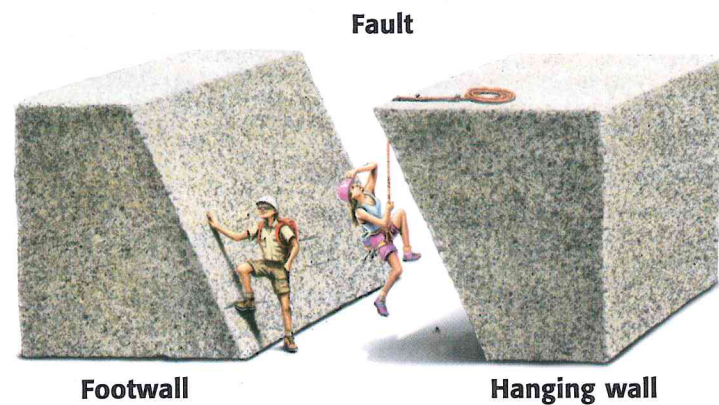


Figure 4 The position of a fault block determines whether it is a hanging wall or a footwall.

Faulting

Some rock layers break when stress is applied to them. The surface along which rocks break and slide past each other is called a **fault**. The blocks of crust on each side of the fault are called *fault blocks*.

When a fault is not vertical, understanding the difference between its two sides—the *hanging wall* and the *footwall*—is useful. **Figure 4** shows the difference between a hanging wall and a footwall. Two main types of faults can form. The type of fault that forms depends on how the hanging wall and footwall move in relationship to each other.

Normal Faults

A *normal fault* is shown in **Figure 5**. When a normal fault moves, it causes the hanging wall to move down relative to the footwall. Normal faults usually occur when tectonic forces cause tension that pulls rocks apart.

Reverse Faults

A *reverse fault* is shown in **Figure 5**. When a reverse fault moves, it causes the hanging wall to move up relative to the footwall. This movement is the reverse of a normal fault. Reverse faults usually happen when tectonic forces cause compression that pushes rocks together.

✓ Reading Check How does the hanging wall in a normal fault move in relation to a reverse fault?

Figure 5 Normal and Reverse Faults

Normal Fault When rocks are pulled apart because of tension, normal faults often form.



Reverse Fault When rocks are pushed together by compression, reverse faults often form.

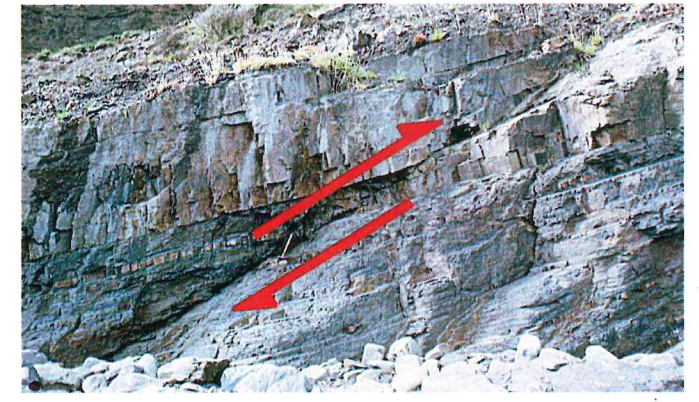


Figure 6 The photo at left is a normal fault. The photo at right is a reverse fault.

Telling the Difference Between Faults

It's easy to tell the difference between a normal fault and a reverse fault in drawings with arrows. But what types of faults are shown in **Figure 6**? You can certainly see the faults, but which one is a normal fault, and which one is a reverse fault? In the top left photo in **Figure 6**, one side has obviously moved relative to the other side. You can tell this fault is a normal fault by looking at the order of sedimentary rock layers. If you compare the two dark layers near the surface, you can see that the hanging wall has moved down relative to the footwall.

Strike-Slip Faults

A third major type of fault is called a *strike-slip fault*. An illustration of a strike-slip fault is shown in **Figure 7**. *Strike-slip faults* form when opposing forces cause rock to break and move horizontally. If you were standing on one side of a strike-slip fault looking across the fault when it moved, the ground on the other side would appear to move to your left or right. The San Andreas Fault in California is a spectacular example of a strike-slip fault.

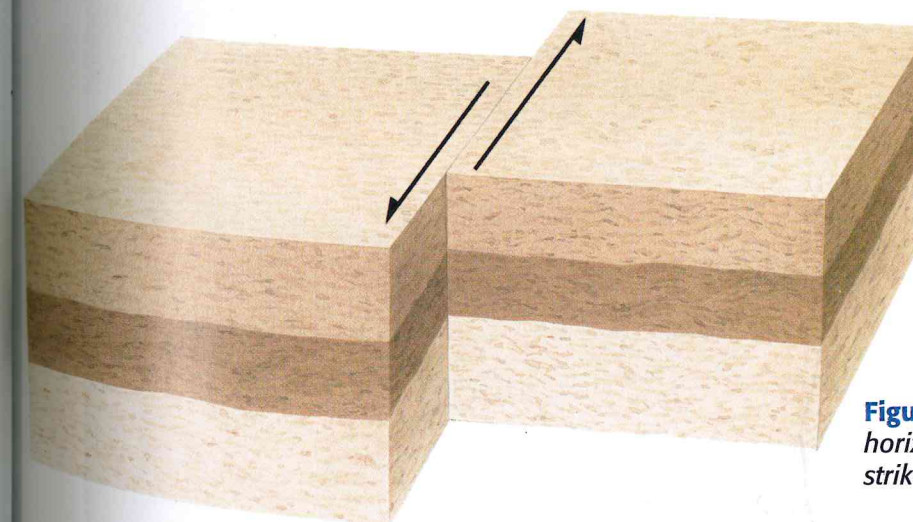


Figure 7 When rocks are moved horizontally by opposing forces, strike-slip faults often form.

Quick Lab

Modeling Strike-Slip Faults

1. Use **modeling clay** to construct a box that is 6 in. × 6 in. × 4 in. Use different colors of clay to represent different horizontal layers.
2. Using **scissors**, cut the box down the middle. Place **two 4 in. × 6 in. index cards** inside the cut so that the two sides of the box slide freely.
3. Using gentle pressure, slide the two sides horizontally past one another.
4. How does this model illustrate the motion that occurs along a strike-slip fault?



Figure 8 The Andes Mountains formed on the edge of the South American plate where it converges with the Nazca plate.

Plate Tectonics and Mountain Building

You have just learned about several ways the Earth's crust changes because of the forces of plate tectonics. When tectonic plates collide, land features that start as folds and faults can eventually become large mountain ranges. Mountains exist because tectonic plates are continually moving around and colliding with one another. As shown in **Figure 8**, the Andes Mountains formed above the subduction zone where two tectonic plates converge.

When tectonic plates undergo compression or tension, they can form mountains in several ways. Take a look at three of the most common types of mountains—folded mountains, fault-block mountains, and volcanic mountains.

Folded Mountains

The highest mountain ranges in the world are made up of folded mountains. These ranges form at convergent boundaries where continents have collided. *Folded mountains* form when rock layers are squeezed together and pushed upward. If you place a pile of paper on a table and push on opposite edges of the pile, you will see how folded mountains form.

An example of a folded mountain range that formed at a convergent boundary is shown in **Figure 9**. About 390 million years ago, the Appalachian Mountains formed when the landmasses that are now North America and Africa collided. Other examples of mountain ranges that consist of very large and complex folds are the Alps in central Europe, the Ural Mountains in Russia, and the Himalayas in Asia.

✓ Reading Check Explain how folded mountains form.

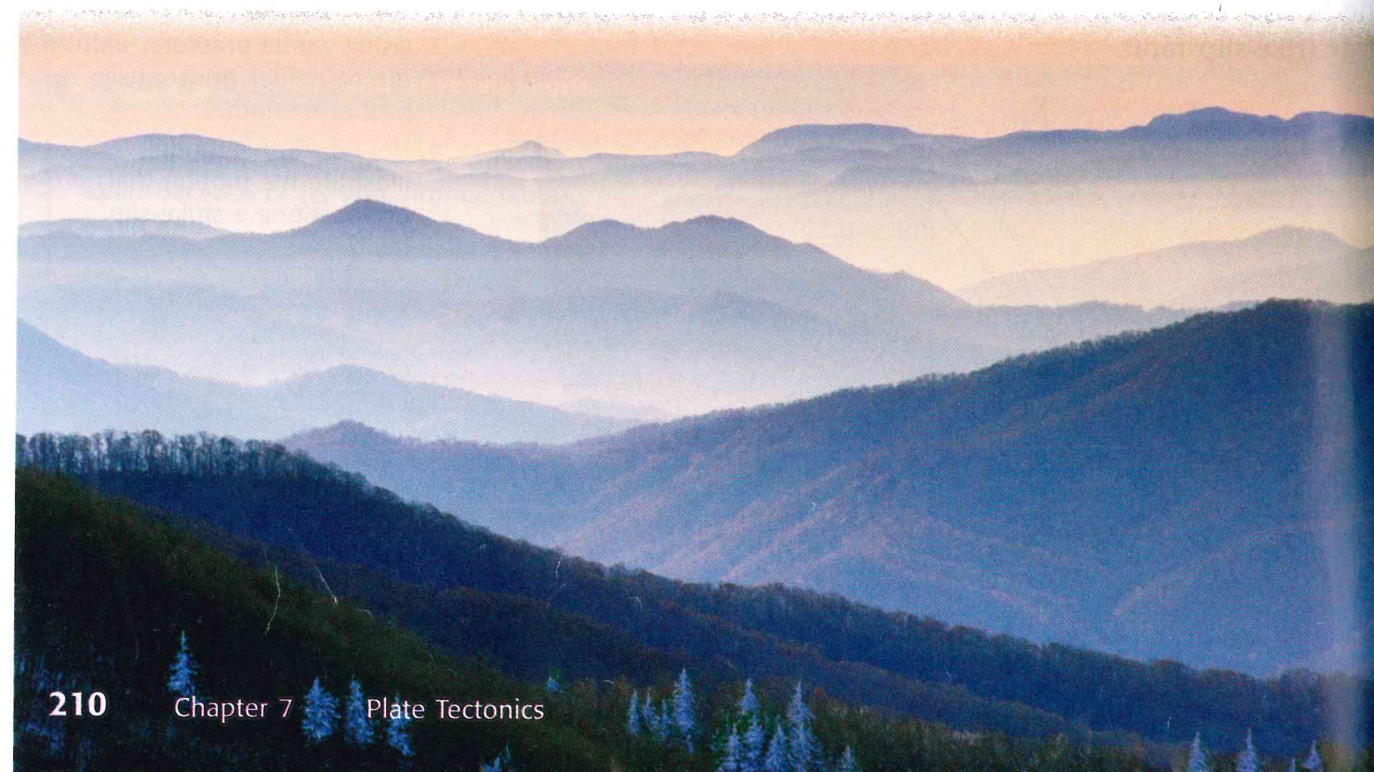


Figure 9 The Appalachian Mountains were once as tall as the Himalaya Mountains but have been worn down by hundreds of millions of years of weathering and erosion.

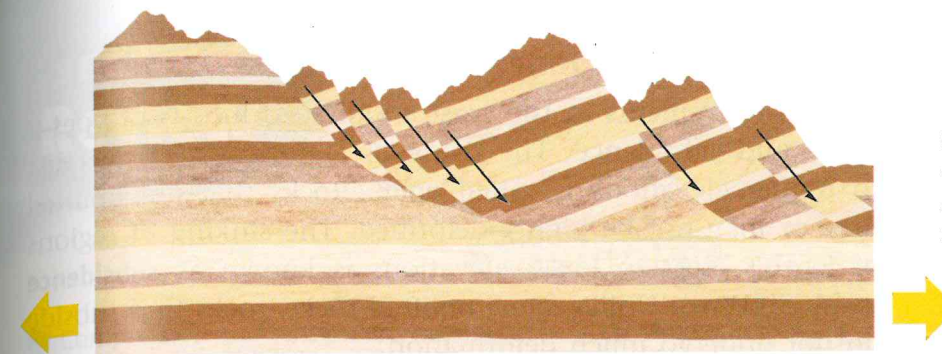


Figure 10 When the crust is subjected to tension, the rock can break along a series of normal faults, which creates fault-block mountains.

Fault-Block Mountains

When tectonic forces put enough tension on the Earth's crust, a large number of normal faults can result. *Fault-block mountains* form when this tension causes large blocks of the Earth's crust to drop down relative to other blocks. **Figure 10** shows one way that fault-block mountains form.

When sedimentary rock layers are tilted up by faulting, they can produce mountains that have sharp, jagged peaks. As shown in **Figure 11**, the Tetons in western Wyoming are a spectacular example of fault-block mountains.

Volcanic Mountains

Most of the world's major volcanic mountains are located at convergent boundaries where oceanic crust sinks into the asthenosphere at subduction zones. The rock that is melted in subduction zones forms magma, which rises to the Earth's surface and erupts to form *volcanic mountains*. Volcanic mountains can also form under the sea. Sometimes these mountains can rise above the ocean surface to become islands. The majority of tectonically active volcanic mountains on the Earth have formed around the tectonically active rim of the Pacific Ocean. The rim has become known as the *Ring of Fire*.



Figure 11 The Tetons formed as a result of tectonic forces that stretched the Earth's crust and caused it to break in a series of normal faults.

CONNECTION TO Social Studies

WRITING SKILL The Naming of the Appalachian Mountains

How did the Appalachian Mountains get their name? It is believed that the Appalachian Mountains were named by Spanish explorers in North America during the 16th century. It is thought that the name was taken from a Native American tribe called *Appalachee*, who lived in northern Florida. Research other geological features in the United States, including mountains and rivers, whose names are of Native American origin. Write the results of your research in a short essay.

INTERNET ACTIVITY

For another activity related to this chapter, go to go.hrw.com and type in the keyword **HZ5TECW**.

uplift the rising of regions of the Earth's crust to higher elevations

subsidence the sinking of regions of the Earth's crust to lower elevations

Uplift and Subsidence

Vertical movements in the crust are divided into two types—uplift and subsidence. The rising of regions of Earth's crust to higher elevations is called **uplift**. Rocks that are uplifted may or may not be highly deformed. The sinking of regions of Earth's crust to lower elevations is known as **subsidence** (suhb SIED'ns). Unlike some uplifted rocks, rocks that subside do not undergo much deformation.

Uplifting of Depressed Rocks

The formation of mountains is one type of uplift. Uplift can also occur when large areas of land rise without deforming. One way areas rise without deforming is a process known as *rebound*. When the crust rebounds, it slowly springs back to its previous elevation. Uplift often happens when a weight is removed from the crust.

Subsidence of Cooler Rocks

Rocks that are hot take up more space than cooler rocks. For example, the lithosphere is relatively hot at mid-ocean ridges. The farther the lithosphere is from the ridge, the cooler and denser the lithosphere becomes. Because the oceanic lithosphere now takes up less volume, the ocean floor subsides.

Tectonic Letdown

Subsidence can also occur when the lithosphere becomes stretched in rift zones. A *rift zone* is a set of deep cracks that forms between two tectonic plates that are pulling away from each other. As tectonic plates pull apart, stress between the plates causes a series of faults to form along the rift zone. As shown in **Figure 12**, the blocks of crust in the center of the rift zone subside.

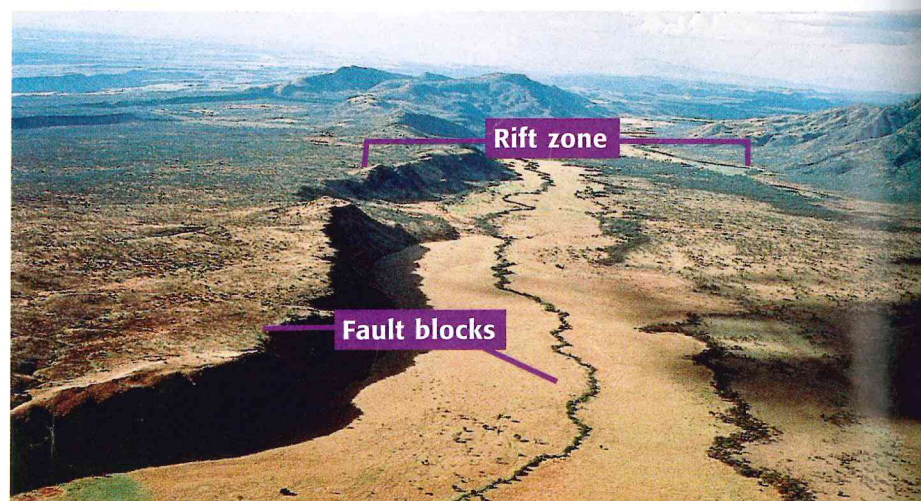


Figure 12 The East African Rift, from Ethiopia to Kenya, is part of a divergent boundary, but you can see how the crust has subsided relative to the blocks at the edge of the rift zone.

SECTION Review

Summary

- Compression and tension are two forces of plate tectonics that can cause rock to deform.
- Folding occurs when rock layers bend because of stress.
- Faulting occurs when rock layers break because of stress and then move on either side of the break.
- Mountains are classified as either folded, fault-block, or volcanic depending on how they form.
- Mountain building is caused by the movement of tectonic plates. Folded mountains and volcanic mountains form at convergent boundaries. Fault-block mountains form at divergent boundaries.
- Uplift and subsidence are the two types of vertical movement in the Earth's crust. Uplift occurs when regions of the crust rise to higher elevations. Subsidence occurs when regions of the crust sink to lower elevations.

Using Key Terms

For each pair of key terms, explain how the meanings of the terms differ.

1. *compression* and *tension*
2. *uplift* and *subsidence*

Understanding Key Ideas

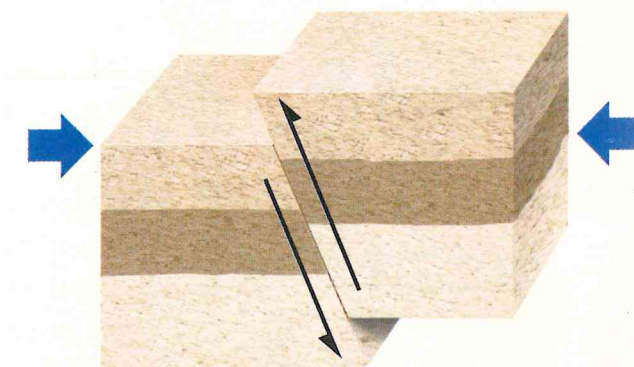
3. The type of fault in which the hanging wall moves up relative to the footwall is called a
 - a. strike-slip fault.
 - b. fault-block fault.
 - c. normal fault.
 - d. reverse fault.
4. Describe three types of folds.
5. Describe three types of faults.
6. Identify the most common types of mountains.
7. What is rebound?
8. What are rift zones, and how do they form?

Critical Thinking

9. **Predicting Consequences** If a fault occurs in an area where rock layers have been folded, which type of fault is it likely to be? Why?
10. **Identifying Relationships** Would you expect to see a folded mountain range at a mid-ocean ridge? Explain your answer.

Interpreting Graphics

Use the diagram below to answer the questions that follow.



11. What type of fault is shown in the diagram?
12. At what kind of tectonic boundary would you most likely find this fault?

SciLINKS
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Topic: Faults; Mountain Building
SciLinks code: HSM0566; HSM0999





Chapter Review

USING KEY TERMS

- 1 Use the following terms in the same sentence: *crust*, *mantle*, and *core*.

Complete each of the following sentences by choosing the correct term from the word bank.

asthenosphere uplift
tension continental drift

- 2 The hypothesis that continents can drift apart and have done so in the past is known as ____.
- 3 The ____ is the soft layer of the mantle on which the tectonic plates move.
- 4 ____ is stress that occurs when forces act to stretch an object.
- 5 The rising of regions of the Earth's crust to higher elevations is called ____.

UNDERSTANDING KEY IDEAS

Multiple Choice

- 6 The strong, lower part of the mantle is a physical layer called the
 - a. lithosphere.
 - b. mesosphere.
 - c. asthenosphere.
 - d. outer core.
- 7 The type of tectonic plate boundary that forms from a collision between two tectonic plates is a
 - a. divergent plate boundary.
 - b. transform plate boundary.
 - c. convergent plate boundary.
 - d. normal plate boundary.
- 8 The bending of rock layers due to stress in the Earth's crust is known as
 - a. uplift.
 - b. folding.
 - c. faulting.
 - d. subsidence.
- 9 The type of fault in which the hanging wall moves up relative to the footwall is called a
 - a. strike-slip fault.
 - b. fault-block fault.
 - c. normal fault.
 - d. reverse fault.
- 10 The type of mountain that forms when rock layers are squeezed together and pushed upward is the
 - a. folded mountain.
 - b. fault-block mountain.
 - c. volcanic mountain.
 - d. strike-slip mountain.
- 11 Scientists' knowledge of the Earth's interior has come primarily from
 - a. studying magnetic reversals in oceanic crust.
 - b. using a system of satellites called the *global positioning system*.
 - c. studying seismic waves generated by earthquakes.
 - d. studying the pattern of fossils on different continents.

Short Answer

- 12 Explain how scientists use seismic waves to map the Earth's interior.
- 13 How do magnetic reversals provide evidence of sea-floor spreading?

- 14 Explain how sea-floor spreading provides a way for continents to move.
- 15 Describe two types of stress that deform rock.
- 16 What is the global positioning system (GPS), and how does GPS allow scientists to measure the rate of motion of tectonic plates?

CRITICAL THINKING

- 17 **Concept Mapping** Use the following terms to create a concept map: *sea-floor spreading*, *convergent boundary*, *divergent boundary*, *subduction zone*, *transform boundary*, and *tectonic plates*.
- 18 **Applying Concepts** Why does oceanic lithosphere sink at subduction zones but not at mid-ocean ridges?
- 19 **Identifying Relationships** New tectonic material continually forms at divergent boundaries. Tectonic plate material is also continually destroyed in subduction zones at convergent boundaries. Do you think that the total amount of lithosphere formed on the Earth is about equal to the amount destroyed? Why?
- 20 **Applying Concepts** Folded mountains usually form at the edge of a tectonic plate. How can you explain folded mountain ranges located in the middle of a tectonic plate?

INTERPRETING GRAPHICS

Imagine that you could travel to the center of the Earth. Use the diagram below to answer the questions that follow.

Composition	Structure
Crust (50 km)	Lithosphere (150 km)
Mantle (2,900 km)	Asthenosphere (250 km)
	Mesosphere (2,550 km)
Core (3,430 km)	Outer core (2,200 km)
	Inner core (1,228 km)

- 21 How far beneath the Earth's surface would you have to go before you were no longer passing through rock that had the composition of granite?
- 22 How far beneath the Earth's surface would you have to go to find liquid material in the Earth's core?
- 23 At what depth would you find mantle material but still be within the lithosphere?
- 24 How far beneath the Earth's surface would you have to go to find solid iron and nickel in the Earth's core?

