Tracking Tectonic Plate Motion

Just how fast do tectonic plates move? The answer to this question depends on many factors, such as the type of tectonic plate, the shape of the tectonic plate, and the way it interacts with the tectonic plates that surround it. Tectonic movements are generally so slow and gradual that you can't see or feel them—they are measured in centimeters per year.

One exception to this rule is the San Andreas Fault, in California. The Pacific plate and the North American plate do not slide past each other smoothly nor continuously. Instead, this movement happens in jerks and jolts. Sections of the fault remain stationary for years and then suddenly shift several meters, causing an earthquake. Large shifts that occur at the San Andreas fault can be measured right on the surface. Unfortunately for scientists, however, most movements of tectonic plates are very difficult to measure. So how do they do it?

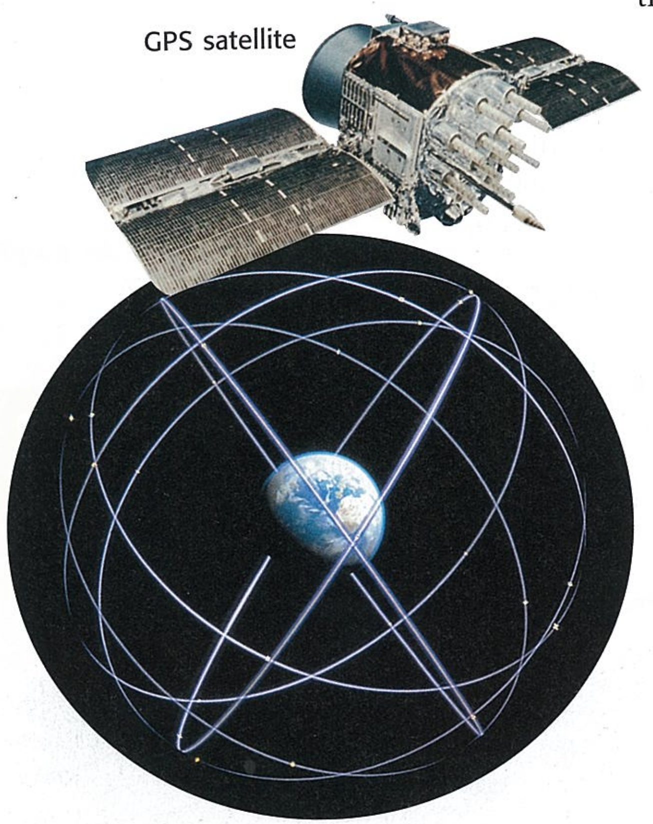

Figure 15 *The image above shows the orbits of the GPS satellites.*

The Global Positioning System Scientists use a network of satellites called the *Global Positioning System* (GPS), shown in **Figure 15,** to measure the rate of tectonic plate movement. Radio signals are continuously beamed from satellites to GPS ground stations, which record the exact distance between the satellites and the ground station. Over time, these distances change slightly. By recording the time it takes for the GPS ground stations to move a given distance, scientists can measure the rate of motion of each tectonic plate.

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REVIEW

1. List and describe three possible driving forces of tectonic plate motion.
2. How do the three types of convergent boundaries differ from one another?
3. Explain how scientists measure the rate at which tectonic plates move.
4. **Identifying Relationships** When convection takes place in the mantle, why does cooler material sink, while warmer material rises?

Section 4

Deforming the Earth's Crust

Terms to Learn

stress	fault
compression	normal fault
tension	reverse fault
folding	strike-slip fault

What You'll Do

- Describe major types of folds.
- Explain how the three major types of faults differ.
- Name and describe the most common types of mountains.
- Explain how various types of mountains form.

Have you ever tried to bend something, only to have it break? Try this: take a long, uncooked piece of spaghetti, and bend it very slowly, and only a little. Now bend it again, but this time much farther and faster. What happened to it the second time? How can the same material bend at one time and break at another? The answer is that the *stress* you put on it was different. **Stress** is the amount of force per unit area that is put on a given material. The same principle works on the rocks in the Earth's crust. The conditions under which a rock is stressed determine its behavior.

Rocks Get Stressed

When rock changes its shape due to stress, this reaction is called *deformation.* In the example above, you saw the spaghetti deform in two different ways—by bending and by breaking. **Figure 16** illustrates this concept. The same thing happens in rock layers. Rock layers can bend when stress is placed on them. But when more stress is placed on them, they can break. Rocks can deform due to the forces of plate tectonics.

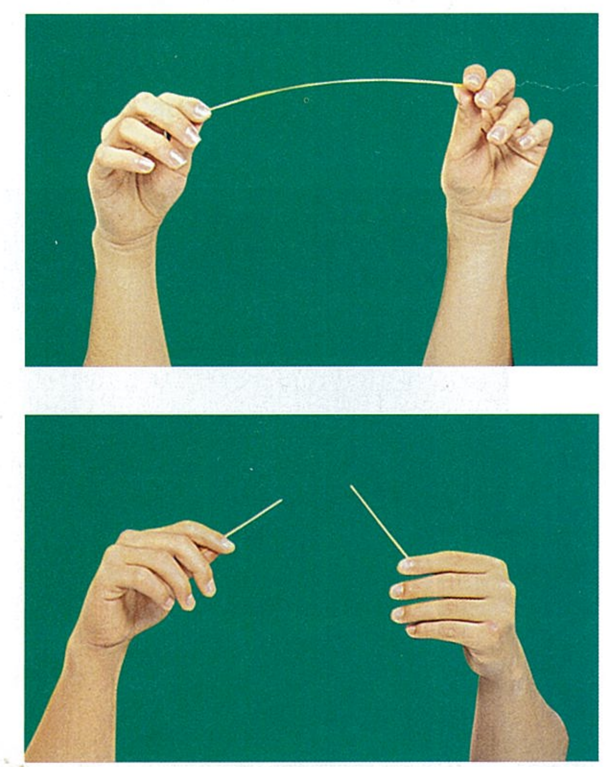


Figure 16 *With a small amount of stress, uncooked spaghetti bends. Additional stress causes it to break.*

The type of stress that occurs when an object is squeezed, as when two tectonic plates collide, is called **compression.** Compression can have some spectacular results. The Rocky Mountains and the Cascade Range are two examples of compression at a convergent plate boundary.

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, when two tectonic plates pull away from each other. In the following pages you will learn how these two tectonic forces—compression and tension—bend and break rock to form some of the common landforms you already know.

Folding

Folding occurs when rock layers bend due to stress in the Earth's crust. We assume that all sedimentary rock layers started out as horizontal layers. So when you see a fold, you know that deformation has taken place. Depending on how the rock layers deform, different types of folds are made. **Figure 17** shows the two most common types—*anticlines* and *synclines*.

Another type of fold is a *monocline*. In a monocline, rock layers are folded so that both ends of the fold are still horizontal. Imagine taking a stack of paper and laying it on a table top. Think of all 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 still horizontal, but all the sheets are bent in the middle.

Folds can be large or small. Take a look at **Figure 18.** The largest folds are measured in kilometers. They can make up the entire side of a mountain. Other folds are still obvious but much smaller. Note the size of the pocket knife in the smaller photo. Now look at the smallest folds. You would measure these folds in centimeters.

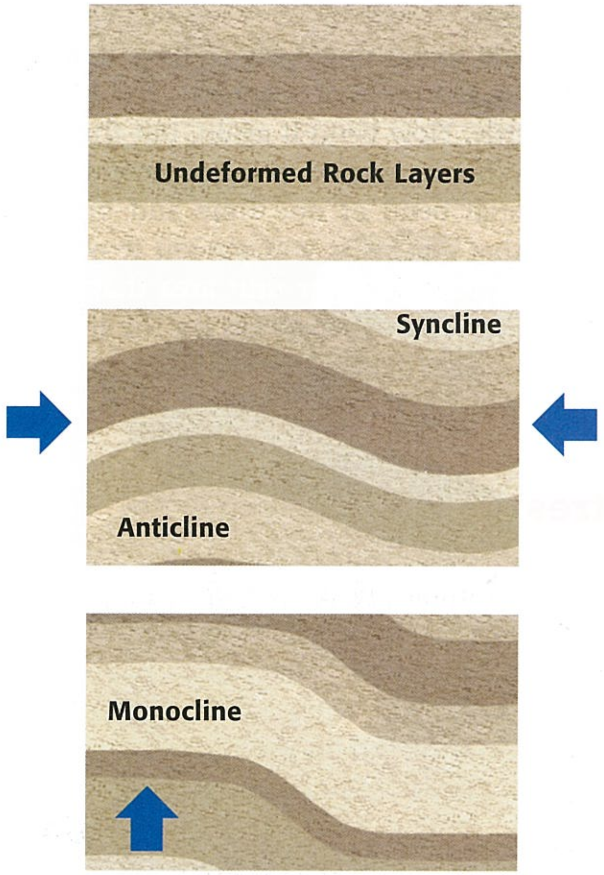


Figure 17 *When tectonic forces put stress on rock layers, they can cause the layers to bend and fold.* Anticlines *and* synclines *form when horizontal stress acts on rock.* Monoclines *form when vertical stress acts on rock.*

Figure 18 *The larger photo at right shows mountain-sized folds in the Rocky Mountains. The smaller photo shows a rock with much smaller folds.*

Faulting

While some rock layers bend and fold when stress is applied, other rock layers break. 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*.

If a fault is not vertical, it is useful to distinguish between its two sides—the *hanging wall* and the *footwall*. **Figure 19** shows the difference between a hanging wall and a footwall. Depending on how the hanging wall and footwall move relative to each other, one of two main types of faults can form.

Normal Faults A *normal fault* is shown in **Figure 20.** The movement of a **normal fault** 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 21.** The movement of a **reverse fault** causes the hanging wall to move up relative to the footwall—the "reverse" of a normal fault. Reverse faults usually happen when tectonic forces cause compression that pushes rocks together.

Self-Check

How is folding different from faulting? *(See page 726 to check your answer.)*

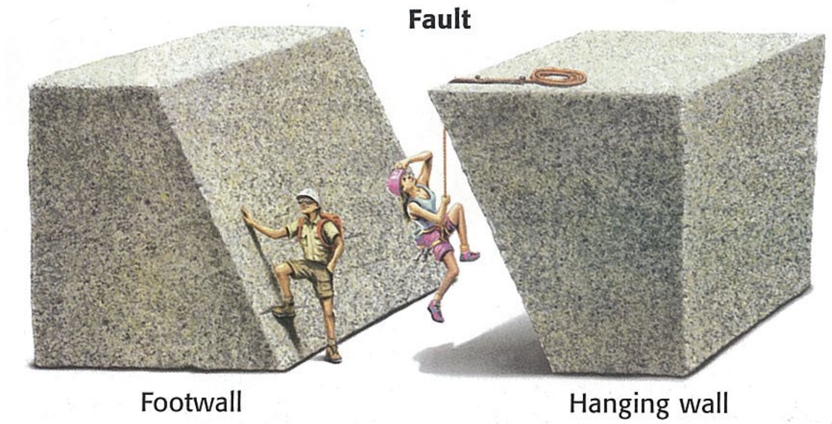


Figure 19 *The position of a fault block determines whether it is a hanging wall or a footwall.*

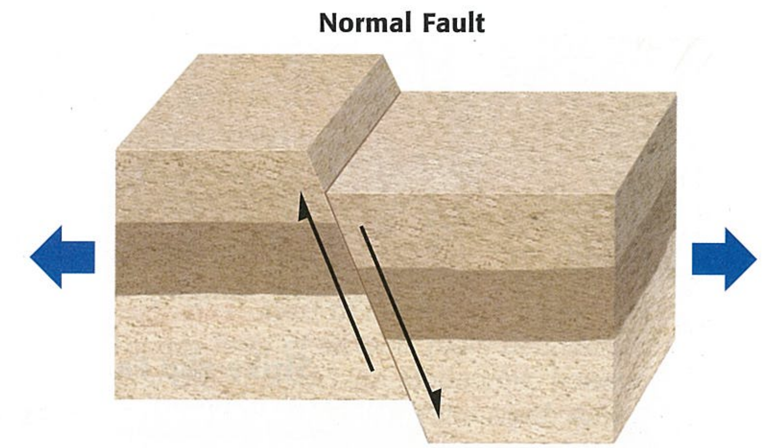


Figure 20 *When rocks are pulled apart due to tension, normal faults often result.*

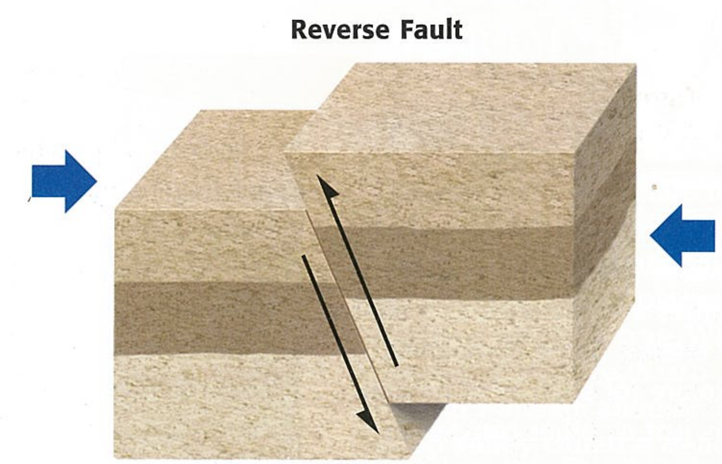


Figure 21 *When rocks are pushed together by compression, reverse faults often result.*

Figure 22 *The photo at left is a normal fault. The photo at right is a reverse fault.*

Telling the Difference It's easy to tell the difference between a normal fault and a reverse fault in diagrams with arrows. But what about the faults in **Figure 22?** 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, one side has obviously moved relative to the other. You can tell this is a normal fault by looking at the sequence of sedimentary rock layers. You can see by the relative positions of the two dark layers 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.* **Strike-slip faults** occur 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.

APPLY

Tectonics and Natural Gas

Natural gas is used in many homes and factories as a source of energy. Some companies explore for sources of natural gas just as other companies explore for oil and coal. Like oil, natural gas travels upward through rock layers until it hits a layer through which it cannot travel and becomes trapped. Imagine that you are searching for pockets of trapped natural gas. Would you expect to find these pockets associated with anticlines, synclines, or faults? Explain your answer in your ScienceLog. Include drawings to help in your explanation.

Plate Tectonics and Mountain Building

You have just learned about several ways the Earth's crust changes due to the forces of plate tectonics. When tectonic plates collide, land features that start out as small folds and faults can eventually become great mountain ranges. The reason mountains exist is that tectonic plates are continually moving around and bumping into one another. As you can see in **Figure 23,** most major mountain ranges form at the edges of tectonic plates.

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

Figure 23 *Most of the world's major mountain ranges form at tectonic plate boundaries. Notice that the Appalachian Mountains, however, are located in the middle of the North American plate.*

Folded Mountains *Folded mountains* form when rock layers are squeezed together and pushed upward. If you take a pile of paper on a table top and push on opposite edges of the pile, you will see how a folded mountain forms. You saw how these layers crunched together in Figure 17. **Figure 24** shows an example of a folded mountain range that formed at a convergent boundary.

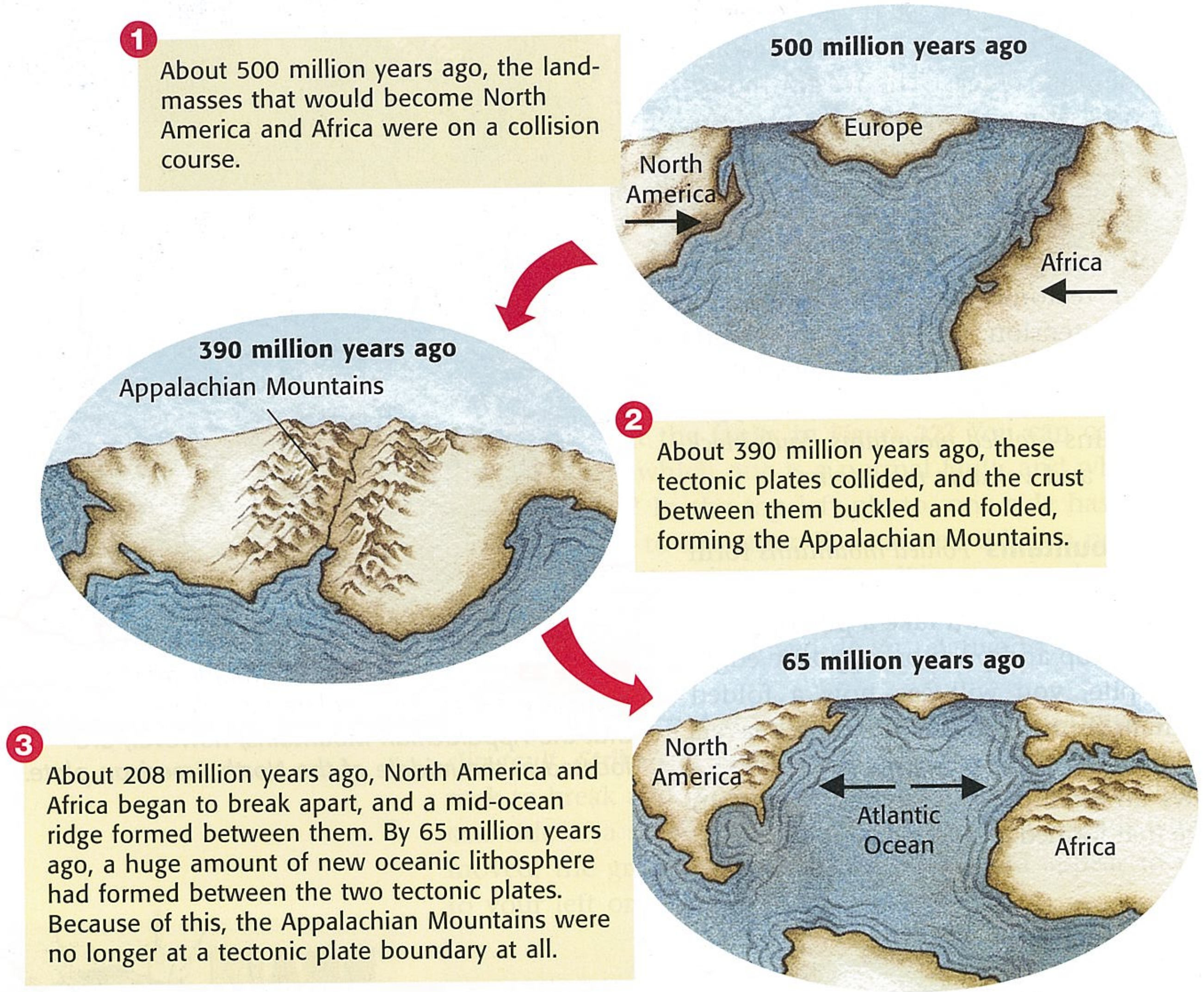
Figure 24 *Once as mighty as the Himalayas, the Appalachians have been worn down by hundreds of millions of years of weathering and erosion.*

BRAIN FOOD

Did you know that plate tectonics is responsible for creating not only mountains but some of the lowest places on Earth as well? It's true. When one tectonic plate is subducted beneath another, a deep valley called a *trench* forms at the boundary. The Mariana Trench is the deepest point in the oceans—11,033 m below sea level!

Formation of the Appalachian Mountains

Look back at Figure 23. The Appalachians are in the middle of the North American plate. How can this be? Shouldn't they be at the edge of a tectonic plate? Follow along in this diagram to find the answer.



1. About 500 million years ago, the landmasses that would become North America and Africa were on a collision course.

2. About 390 million years ago, these tectonic plates collided, and the crust between them buckled and folded, forming the Appalachian Mountains.

3. About 208 million years ago, North America and Africa began to break apart, and a mid-ocean ridge formed between them. By 65 million years ago, a huge amount of new oceanic lithosphere had formed between the two tectonic plates. Because of this, the Appalachian Mountains were no longer at a tectonic plate boundary at all.

Figure 25 *When the crust is subjected to tension, the rock can break along a series of normal faults, resulting in fault-block mountains.*

Fault-block Mountains Where tectonic forces put enough tension on the Earth's crust, a large number of normal faults can result. *Fault-block mountains* form when this faulting causes large blocks of the Earth's crust to drop down relative to other blocks. **Figure 25** shows one way this can happen.

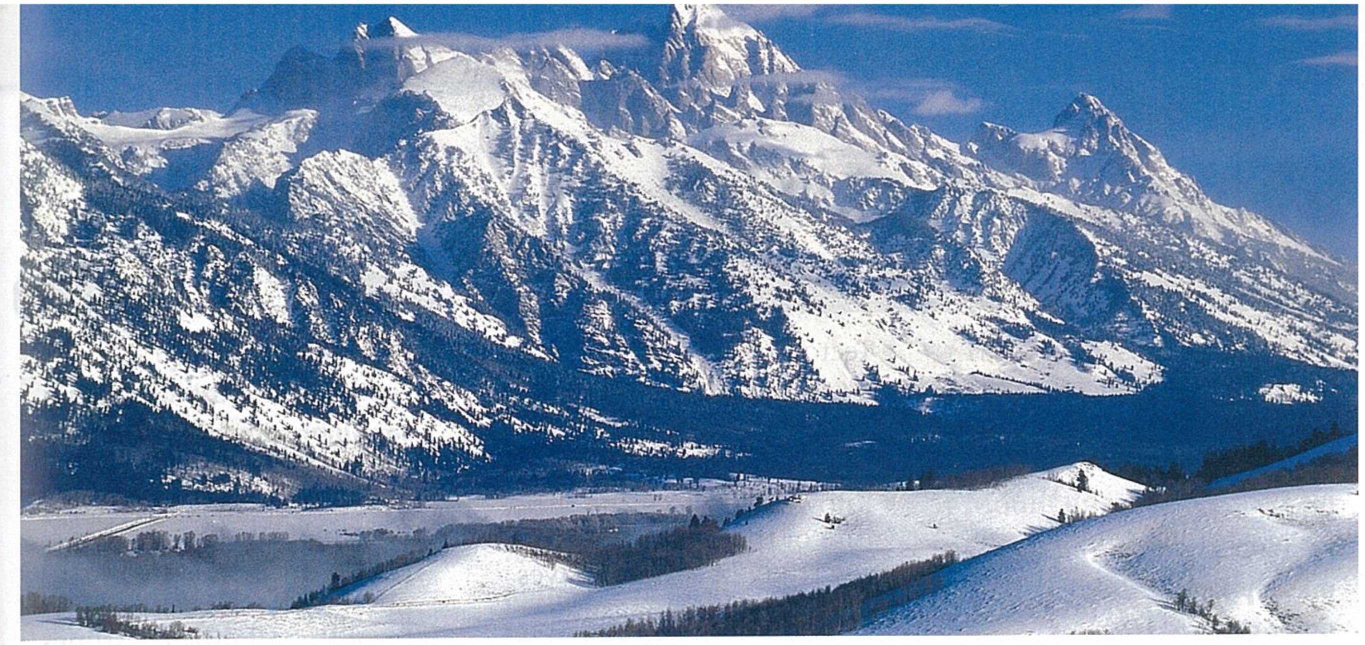


Figure 26 *The Tetons formed as a result of tectonic forces that stretched the Earth's crust, causing it to break in a series of normal faults. Compare this photo with the illustration in Figure 25.*

When sedimentary rock layers are tilted up by faulting, they can produce mountains with sharp, jagged peaks. As you can see in **Figure 26,** the Tetons, in western Wyoming, are a spectacular example of this type of mountain.

Volcanic Mountains Most of the world's major volcanic mountains are located at convergent boundaries. *Volcanic mountains* form when molten rock erupts onto the Earth's surface. Unlike folded and fault-block mountains, volcanic mountains form from new material being added to the Earth's surface. Most volcanic mountains tend to form over the type of convergent boundaries that include subduction zones. There are so many volcanic mountains around the rim of the Pacific Ocean that early explorers named it the *Ring of Fire.*

REVIEW

1. What is the difference between an anticline and a syncline?
2. What is the difference between a normal fault and a reverse fault?
3. Name and describe the type of tectonic stress that forms folded mountains.
4. Name and describe the type of tectonic stress that forms fault-block mountains.
5. **Making Predictions** If a fault occurs in an area where rock layers have been folded, which type of fault is it likely to be? Why?

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Section 1

Terms to Learn

seismology
fault
deformation
elastic rebound
seismic waves
P waves
S waves

What You'll Do

- Determine where earthquakes come from and what causes them.
- Identify different types of earthquakes.
- Describe how earthquakes travel through the Earth.

What Are Earthquakes?

The word *earthquake* defines itself fairly well. But there is more to an earthquake than just ground shaking. In fact, there is a branch of Earth science devoted to earthquakes called seismology (siez MAHL uh jee). **Seismology** is the study of earthquakes. Earthquakes are complex, and they present many questions for *seismologists,* the scientists who study earthquakes.

Where Do Earthquakes Occur?

Most earthquakes take place near the edges of tectonic plates. *Tectonic plates* are giant masses of solid rock that make up the outermost part of the Earth. **Figure 1** shows the Earth's tectonic plates and the locations of recent major earthquakes recorded by scientists.

Tectonic plates move in different directions and at different speeds. Two plates can push toward each other or pull away from each other. They can also slip past each other like slow-moving trains traveling in opposite directions.

As a result of these movements, numerous features called faults exist in the Earth's crust. A **fault** is a break in the Earth's crust along which blocks of the crust slide relative to one another. Earthquakes occur along faults due to this sliding.

Faults occur in many places, but they are especially common near the edges of tectonic plates where they form the boundaries along which the plates move. This is why earthquakes are so common near tectonic plate boundaries.

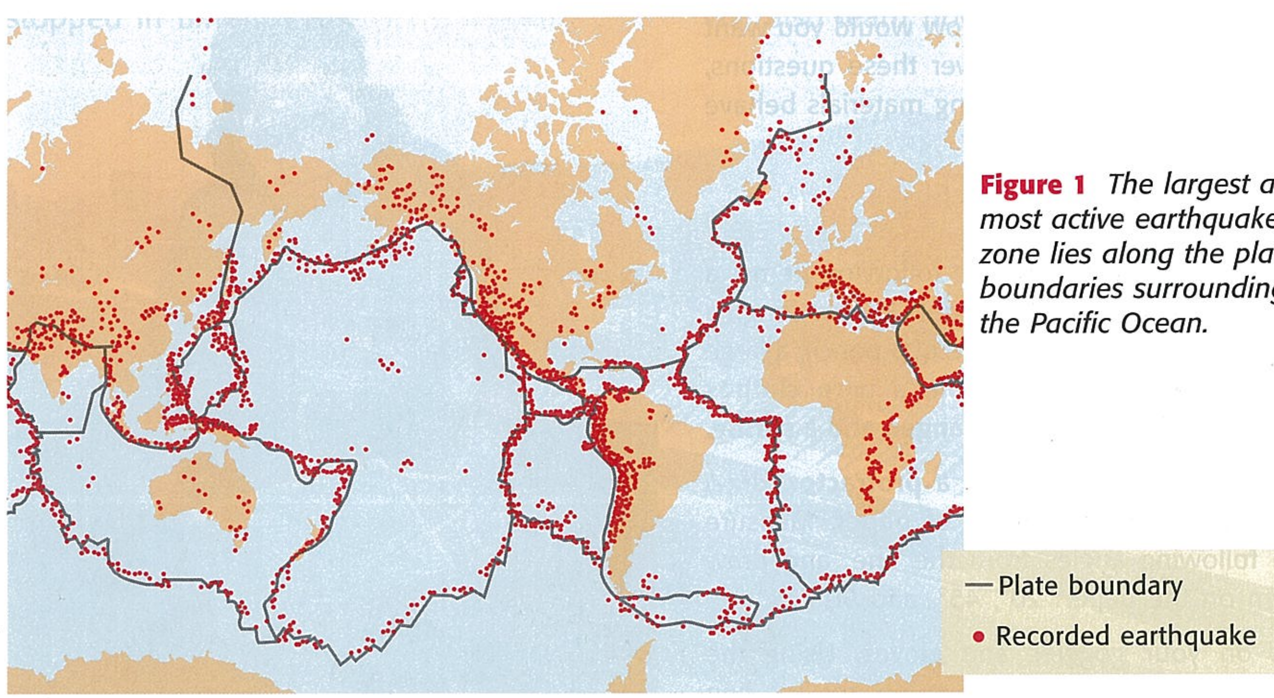


Figure 1 *The largest and most active earthquake zone lies along the plate boundaries surrounding the Pacific Ocean.*

What Causes Earthquakes?

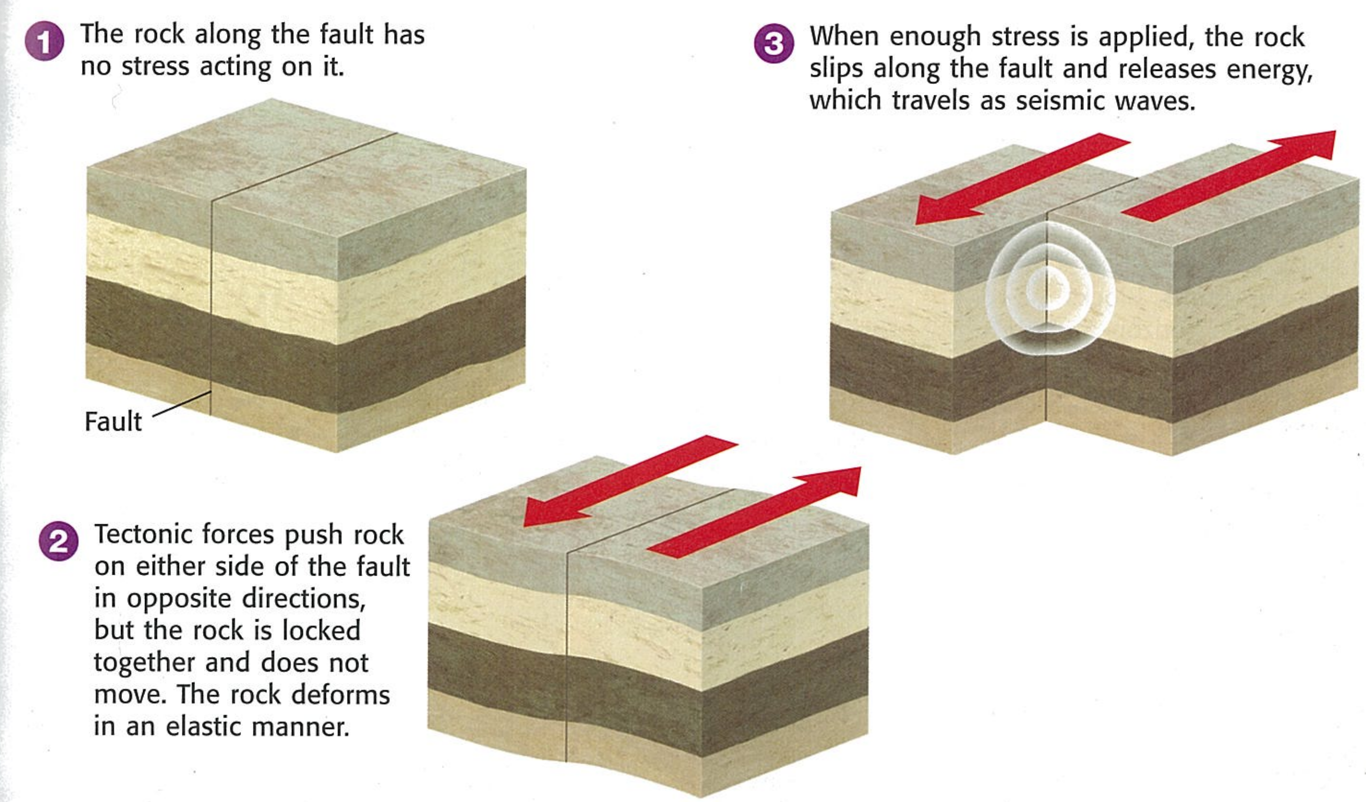
As tectonic plates push, pull, or scrape against each other, stress builds up along faults near the plates' edges. In response to this stress, rock in the plates deforms. **Deformation** is the change in the shape of rock in response to stress. Rock along a fault deforms in mainly two ways—in a plastic manner, like a piece of molded clay, or in an elastic manner, like a rubber band. *Plastic deformation,* which is shown in **Figure 2,** does not lead to earthquakes.

Elastic deformation, however, does lead to earthquakes. While rock can stretch farther than steel without breaking, it will break at some point. Think of elastically deformed rock as a stretched rubber band. You can stretch a rubber band only so far before it breaks. When the rubber band breaks, it releases energy, and the broken pieces return to their unstretched shape.

Like the return of the broken rubber-band pieces to their unstretched shape, **elastic rebound** is the sudden return of elastically deformed rock to its original shape. Elastic rebound occurs when more stress is applied to rock than the rock can withstand. During elastic rebound, rock releases energy that causes an earthquake, as shown in **Figure 3.**

Figure 2 *This photograph, taken in Hollister, California, shows how plastic deformation along the Calaveras Fault permanently bent a wall.*

Figure 3 Elastic Rebound and Earthquakes



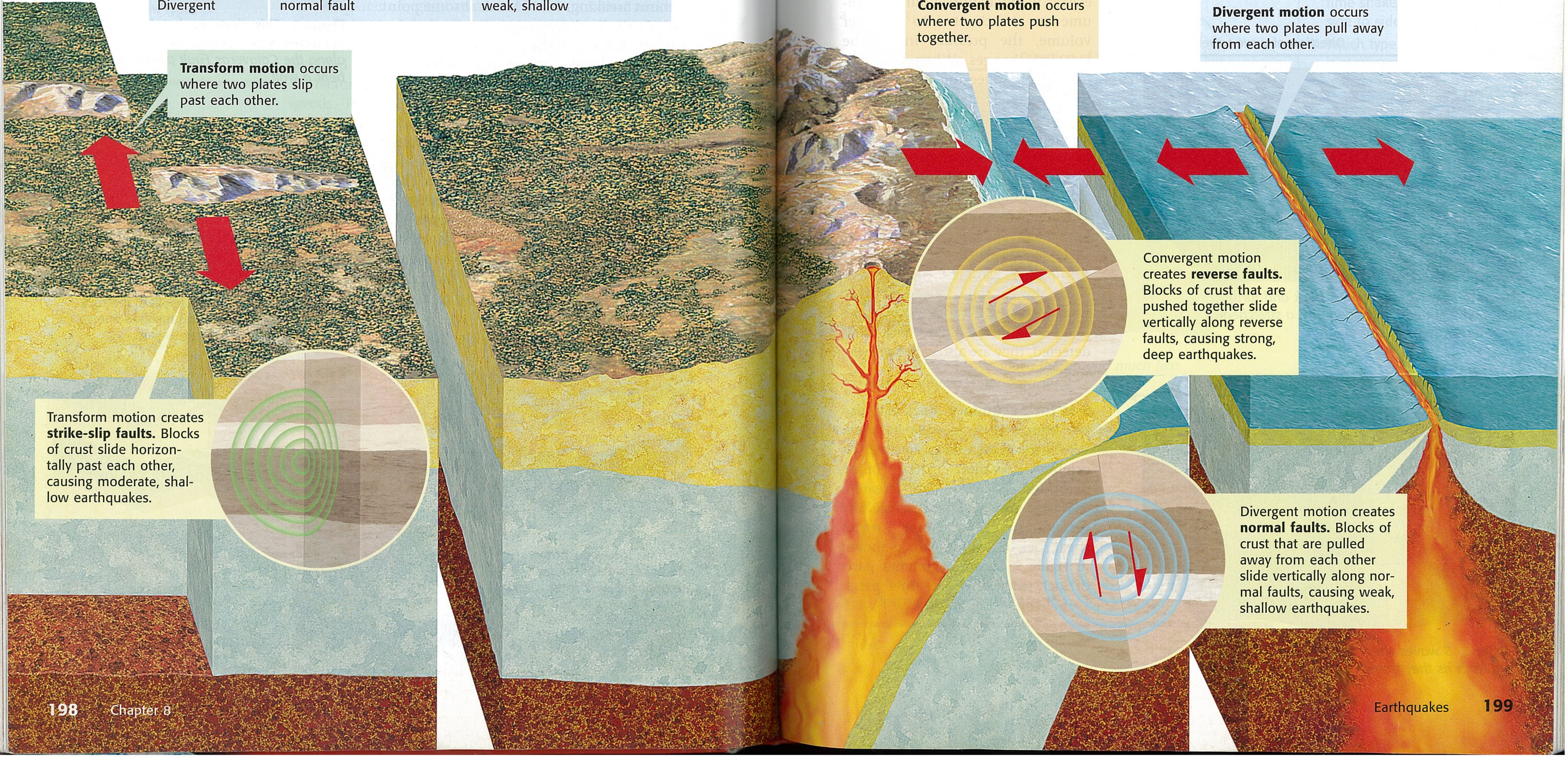
Are All Earthquakes the Same?

Earthquakes differ in strength and in the depth at which they begin. These differences depend on the type of tectonic plate motion that produces the earthquake. Examine the chart and the diagram below to learn how earthquakes differ.

Plate motion	Prominent fault type	Earthquake characteristics
Transform	strike-slip fault	moderate, shallow
Convergent	reverse fault	strong, deep
Divergent	normal fault	weak, shallow

Self-Check

Name two differences between the results of convergent motion and the results of divergent motion. *(See page 726 to check your answer.)*



How Do Earthquakes Travel?

Remember that rock releases energy when it springs back after being deformed. This energy travels in the form of seismic waves. **Seismic waves** are waves of energy that travel through the Earth. Seismic waves that travel through the Earth's interior are called *body waves*. There are two types of body waves: P waves and S waves. Seismic waves that travel along the Earth's surface are called *surface waves*. Different types of seismic waves travel at different speeds and move the materials that they travel through differently.

Physics CONNECTION

All types of waves share basic features. Understanding one type, such as seismic waves, can help you understand many other types. Other types of waves include light waves, sound waves, and water waves.

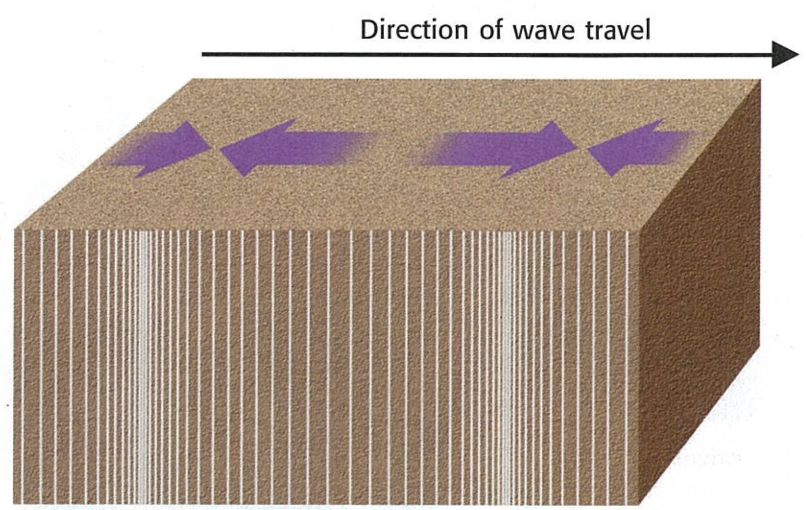


Figure 4 *P waves move rock back and forth between a squeezed position and a stretched position as they travel through it.*

P Is for Primary If you squeeze an elastic material into a smaller volume or stretch it into a larger volume, the pressure inside the material changes. When you suddenly stop squeezing or stretching the material, it springs briefly back and forth before returning to its original shape. This is how P waves (pressure waves) affect rock, as shown in **Figure 4.** **P waves,** which travel through solids, liquids, and gases, are the fastest seismic waves. Because they are the fastest seismic waves and because they can move through all parts of the Earth, P waves always travel ahead of other seismic waves. Because P waves are always the first seismic waves to be detected, they are also called *primary* waves.

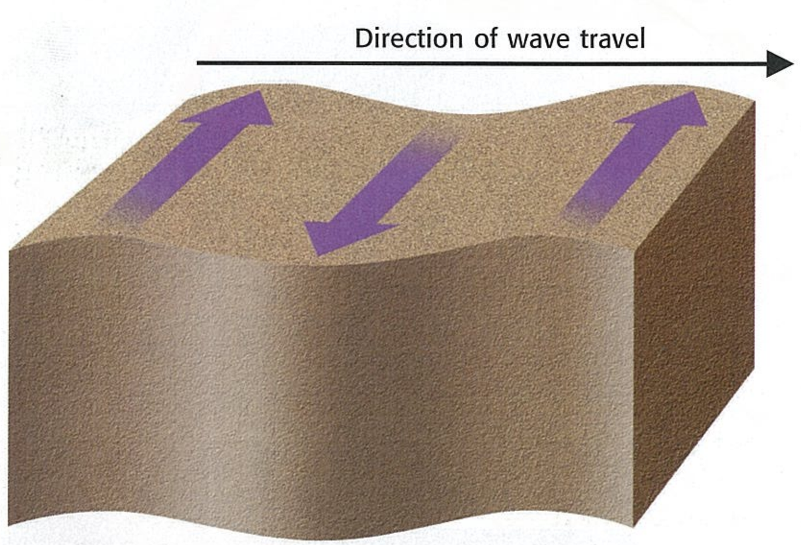


Figure 5 *S waves shear rock back and forth as they travel through it.*

S Is for Secondary Rock can also be deformed from side to side. When the rock springs back to its original position after being deformed, S waves are created. **S waves,** or shear waves, are the second-fastest seismic wave. S waves shear rock back and forth, as shown in **Figure 5.** *Shearing* stretches parts of rock sideways from other parts.

Unlike P waves, S waves cannot travel through parts of the Earth that are completely liquid. Also, S waves are slower than P waves and always arrive second; thus, they are also called *secondary* waves.

Surface Waves Surface waves move the ground up and down in circles as the waves travel along the surface. This is shown in **Figure 6.** Many people have reported feeling like they were on a roller coaster during an earthquake. This feeling comes from surface waves passing along the Earth's surface. Surface waves travel more slowly than body waves but are more destructive. Most damage during an earthquake comes from surface waves, which can literally shake the ground out from under a building.

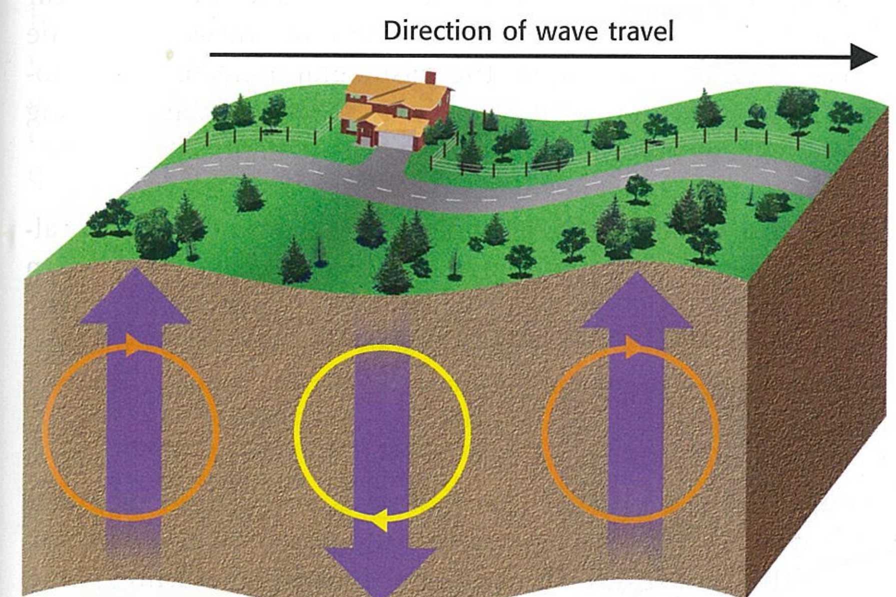


Figure 6 *Surface waves move the ground much like ocean waves move water particles.*

QuickLab

Modeling Seismic Waves

1. Stretch a **spring toy** lengthwise on a **table.**
2. Hold one end of the spring while a partner holds the other end. Push your end toward your partner's end, and observe what happens.
3. Repeat step 2, but this time shake the spring from side to side.
4. Which type of seismic wave is represented in step 2? in step 3?

TRY at HOME

REVIEW

1. Where do earthquakes occur?
2. What directly causes earthquakes?
3. Arrange the types of earthquakes caused by the three plate-motion types from weakest to strongest.
4. **Analyzing Relationships** Why are surface waves more destructive to buildings than P waves or S waves?

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