**BEFORE YOU READ**

After you read this section, you should be able to answer these questions:

- Where do most earthquakes happen?
- What makes an earthquake happen?
- What are seismic waves?

---

**What Is an Earthquake?**

Have you ever been in an earthquake? An earthquake is a movement or shaking of the ground. Earthquakes happen when huge pieces of Earth’s crust move suddenly and give off energy. This energy travels through the ground and makes it move. **Seismology** is the study of earthquakes. Scientists who study earthquakes are called **seismologists**.

**Where Do Most Earthquakes Happen?**

Most earthquakes happen at places where two tectonic plates touch. Tectonic plates are always moving. In some places, they move away from each other. In some places, they move toward each other. And in some places, they grind past each other.

The movements of the plates cause Earth’s rocky crust to break. A place where the crust is broken is called a **fault**. Earthquakes happen when rock breaks and slides along a fault.

**Earthquakes and Plate Boundaries**

- Recorded earthquakes

---

**STUDY TIP**

**Learn New Words**

As you read this section, circle words that you don’t understand. When you learn what they mean, write the words and their definitions in your notebook.

---

**READING CHECK**

1. Define What is a fault?

---

**TAKE A LOOK**

2. Infer Use the earthquake locations to help you figure out where the tectonic plate boundaries are. Use a colored pen or marker to draw plate boundaries on the map.
**Why Do Earthquakes Happen?**

When tectonic plates move, pressure builds up on the rock near the edges of the plates. When rock is put under pressure, it changes shape, or deforms. This is called **deformation**.

Some rock can bend and fold like clay. When the pressure is taken away, the rock stays folded. When rock stays folded after the pressure is gone, the change is called **plastic deformation**.

In some cases, rock acts more like a rubber band. It changes shape under pressure, but then it goes back to its original size and shape when the pressure goes away. This change is called **elastic deformation**.

Earthquakes happen when rock breaks under pressure. When the rock breaks, it snaps back to its original shape. This snap back is called **elastic rebound**. When the rock breaks and rebounds, it gives off energy. This energy creates faults and causes the ground to shake.

1. Forces push rock in opposite directions. The rock deforms elastically. It does not break.
2. If enough force is placed on the rock, it breaks. The rock slips along the fault. Energy is released.

**TAKE A LOOK**

3. Explain How do you know that the rock layers in the figure were once under a lot of pressure?

**STANDARDS CHECK**

**ES 1b** Lithospheric plates on the scales of continents and oceans constantly move at rates of centimeters per year in response to movements in the mantle. Major geological events, such as earthquakes, volcanic eruptions, and mountain building result from these plate motions.

Word Help: **response**
an action brought on by another action; a reaction

Word Help: **major**
of great importance or large scale

4. Explain How does the movement of tectonic plates cause earthquakes?
How Do Earthquakes Happen at Divergent Boundaries?

A **divergent boundary** is a place where two tectonic plates are moving away from each other. As the plates pull apart, the crust stretches. The crust breaks along faults.

Most of the crust at divergent boundaries is thin and weak. Most earthquakes at divergent boundaries are small because only a little bit of pressure builds up before the rock breaks.

How Do Earthquakes Happen at Convergent Boundaries?

A **convergent boundary** is a place where two tectonic plates collide. When two plates come together, the rock is put under a lot of pressure. The pressure grows and grows until the rock breaks.

The earthquakes that happen at convergent boundaries can be very strong because there is so much pressure. The strongest earthquakes ever recorded have all happened at convergent boundaries.

**READING CHECK**

5. Define What is a divergent boundary?

6. Identify Label the faults on the figure. Put a star where an earthquake is likely to happen.

7. Explain Why are many earthquakes at convergent boundaries very strong?

8. Identify Draw arrows on the figure to show the directions that the two tectonic plates are moving.
SECTION 1 What Are Earthquakes? continued

How Do Earthquakes Happen at Transform Boundaries?

A transform boundary is a place where two tectonic plates slide past each other. As the plates move, pressure builds up on the rock. Eventually, the rock breaks and the plates slide past each other along a fault.

What Is an Earthquake Zone?

A place where there are a lot of faults is called an earthquake zone. The San Andreas Fault Zone in California is an example of an earthquake zone. Most earthquake zones are near plate boundaries, but some are in the middle of tectonic plates.

How Does Earthquake Energy Travel?

When an earthquake occurs, a lot of energy is given off. This energy travels through the Earth in the form of waves called seismic waves.

There are two kinds of seismic waves. Body waves are seismic waves that travel through the inside of Earth to the surface. Surface waves are seismic waves that travel through the top part of Earth’s crust.

BODY WAVES

There are two kinds of body waves: P waves and S waves. P waves are also called pressure waves. They are the fastest kind of seismic wave.

P waves can move through solids, liquids, and gases. When a P wave travels through a rock, it squeezes and stretches the rock. P waves make the ground move back and forth.

S waves are also called shear waves. S waves move rock from side to side. They can travel only through solids. S waves travel more slowly than P waves.
SURFACE WAVES

Surface waves travel along the top of Earth’s crust. Only the very top part of the crust moves when a surface wave passes.

Surface waves travel much more slowly than body waves. When an earthquake happens, surface waves are the last waves to be felt. Surface waves cause a lot more damage to buildings and landforms than body waves do.

P waves are body waves that squeeze and stretch rock.

S waves are body waves that can move rock from side to side.

Surface waves can move the ground up and down in a circular motion.

---

READING CHECK

12. Compare Which kind of seismic wave travels the most slowly?

TAKE A LOOK

13. Compare How are the motions of P waves and S waves different?

Critical Thinking

14. Infer What do you think is the reason surface waves usually cause the most damage?
Section 1 Review

SECTION VOCABULARY

defformation the bending, tilting, and breaking of the Earth's crust; the change in the shape of rock in response to stress
elastic rebound the sudden return of elastically deformed rock to its undeformed shape
P wave a seismic wave that causes particles of rock to move in a back-and-forth direction
S wave a seismic wave that causes particles of rock to move in a side-to-side direction
seismic wave a wave of energy that travels through the Earth, away from an earthquake in all directions
seismology the study of earthquakes

1. Compare  What is the difference between an earthquake and a fault?

2. Identify  Where do most earthquakes happen?

3. Describe  What causes earthquakes?

4. Compare  What is the main difference between body waves and surface waves?

5. Apply Concepts  Why are some earthquakes stronger than others?

6. Infer  Why do few earthquakes happen in Earth's mantle?
How Do Scientists Study Earthquakes?

Scientists who study earthquakes use an important tool called a seismograph. A seismograph records vibrations that are caused by seismic waves. When the waves from an earthquake reach a seismograph, it records them as lines on a chart called a seismogram.

Remember that earthquakes happen when rock in Earth’s crust breaks. The rock might break in one small area, but the earthquake can be felt many miles away.

The place inside the Earth where the rock first breaks is called the earthquake’s focus. The place on Earth’s surface that is right above the focus is called the epicenter. Seismologists can use seismograms to find the epicenter of an earthquake.

STUDY TIP

Ask Questions  Read this section quietly to yourself. As you read, write down questions that you have. Discuss your questions in a small group.

READING CHECK

1. Explain  What is the difference between the epicenter and the focus of an earthquake?

TAKE A LOOK

2. Identify  On the figure, mark the epicenter of the earthquake with a star.
How Do Seismologists Know When and Where an Earthquake Happened?

Seismograms help us learn when an earthquake happened. They can also help seismologists find the epicenter of an earthquake. The easiest way to do this is to use the S-P time method. This is how the S-P time method works:

1. The seismologist uses seismograms of the earthquake made at three different places.

2. The seismologist lines up the P waves and S waves on each seismogram with the curves on a graph of time versus distance. The curves on the graph were made using information from earthquakes that happened in the past.

3. Then, the seismologist uses the graph to figure out the difference in arrival times of the P and S waves at each location. The seismologist can use the difference in arrival times to figure out when the earthquake happened. The seismologist can also determine how far away each station is from the epicenter of the earthquake.

4. On a map, a circle is drawn around a seismograph station. The radius of the circle equals the distance from the seismograph to the epicenter. (This distance is taken from the time-distance graph.)

5. When a second circle is drawn around another seismograph station, the circle overlaps the first circle in two spots. One of these spots is the earthquake’s epicenter.

6. When a circle is drawn around the third seismograph station, all three circles meet in one spot—the earthquake’s epicenter.

Math Focus

3. Read a Graph Look at the middle seismogram in step 3. What is the difference between the time the P waves arrived and the time the S waves arrived?

4. Read a Graph Look at step 3. How far away from the epicenter is the farthest seismograph station?

TAKE A LOOK

5. Identify On the map in step 6, draw a star at the earthquake’s epicenter.
What Is the Magnitude of an Earthquake?

Scientists study seismograms to find out how much the ground moved during an earthquake. They can use the seismograms to figure out how strong the earthquake was.

Have you ever heard someone say that an earthquake was 6.8 or 7.4 “on the Richter scale”? The Richter scale is used to describe the strength, or magnitude, of an earthquake. The higher the number, the stronger the earthquake.

<table>
<thead>
<tr>
<th>Richter magnitude</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.0</td>
<td>can be detected only by a seismograph</td>
</tr>
<tr>
<td>3.0</td>
<td>can be felt at the epicenter</td>
</tr>
<tr>
<td>4.0</td>
<td>can be felt by most people in the area</td>
</tr>
<tr>
<td>5.0</td>
<td>causes damage at the epicenter</td>
</tr>
<tr>
<td>6.0</td>
<td>can cause widespread damage</td>
</tr>
<tr>
<td>7.0</td>
<td>can cause great, widespread damage</td>
</tr>
</tbody>
</table>

The Richter scale can be used to compare the magnitudes of different earthquakes. When the Richter magnitude of an earthquake goes up by one unit, the amount of ground shaking caused by the earthquake goes up 10 times. For example, an earthquake with a magnitude of 5.0 is 10 times stronger than an earthquake with a magnitude of 4.0.

What Is the Intensity of an Earthquake?

The intensity of an earthquake describes how much damage the earthquake caused and how much it was felt by people. Seismologists in the United States use the Modified Mercalli Intensity Scale to compare the intensity of different earthquakes.

The effects of an earthquake can be very different from place to place. An earthquake can have many different intensity numbers, even though it has only one magnitude.

<table>
<thead>
<tr>
<th>Mercalli intensity (from I to XII)</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>shaking felt by only a few people</td>
</tr>
<tr>
<td>IV</td>
<td>shaking felt indoors by many, no damage</td>
</tr>
<tr>
<td>VIII</td>
<td>damage to some buildings</td>
</tr>
<tr>
<td>XII</td>
<td>total damage</td>
</tr>
</tbody>
</table>
Section 2 Review

SECTION VOCABULARY

| **epicenter** | the point on Earth’s surface directly above an earthquake’s starting point, or focus |
| **focus**     | the point along a fault at which the first motion of an earthquake occurs   |
| **seismogram**| a tracing of earthquake motion that is created by a seismograph             |
| **seismograph**| an instrument that records vibrations in the ground and determines the location and strength of an earthquake |

1. **Compare** What is the difference between a seismograph and a seismogram?

2. **Apply Concepts** Which city would more likely be the epicenter of an earthquake: San Francisco, California, or St. Paul, Minnesota? Explain your answer.

3. **Explain** How does a seismologist use the graph of time versus distance for seismic waves to find the location of an earthquake’s epicenter?

4. **Analyze Methods** What can you learn from only one seismogram? What can’t you learn?

5. **Infer** How can an earthquake with a moderate magnitude have a high intensity?
Earthquakes and Society

BEFORE YOU READ

After you read this section, you should be able to answer these questions:

- Can scientists predict when earthquakes will happen?
- Why do some buildings survive earthquakes better than others?
- How can you prepare for an earthquake?

What Is Earthquake Hazard?

Earthquake hazard tells how likely it is that a place will have a damaging earthquake in the future. Scientists look to the past to figure out earthquake-hazard levels. A place that has had a lot of strong earthquakes in the past has a high earthquake-hazard level. A place that has had few or no earthquakes has a much lower level.

Earthquake Hazard Map of the Continental United States

Look at the map above. Notice that California has the highest earthquake-hazard level in the country. The San Andreas Fault Zone runs through most of California, and a lot of earthquakes happen there. Minnesota has a very low earthquake-hazard level. Very few strong earthquakes have been recorded in Minnesota.

TAKE A LOOK

1. Identify On the map, find the place where you live. What is its earthquake-hazard level?
Can Scientists Predict Earthquakes?

You know that earthquakes have different magnitudes. You can probably guess that earthquakes don’t happen on a set schedule. But what you may not know is that the strength of earthquakes is related to how often they happen.

Scientists can’t predict earthquakes. However, by looking at how often earthquakes have happened in the past, they can estimate where and when an earthquake is likely to happen.

Look at the table below. It shows the number of earthquakes of different sizes that happen every year. There are many more weak earthquakes than strong earthquakes every year.

<table>
<thead>
<tr>
<th>Description</th>
<th>Magnitude on the Richter scale</th>
<th>Average number per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Great</td>
<td>8.0 and higher</td>
<td>1</td>
</tr>
<tr>
<td>Major</td>
<td>7.0 to 7.9</td>
<td>18</td>
</tr>
<tr>
<td>Strong</td>
<td>6.0 to 6.9</td>
<td>120</td>
</tr>
<tr>
<td>Moderate</td>
<td>5.0 to 5.9</td>
<td>800</td>
</tr>
<tr>
<td>Light</td>
<td>4.0 to 4.9</td>
<td>6,200</td>
</tr>
<tr>
<td>Minor</td>
<td>3.0 to 3.9</td>
<td>49,000</td>
</tr>
<tr>
<td>Very minor</td>
<td>2.0 to 2.9</td>
<td>365,000</td>
</tr>
</tbody>
</table>

Scientists can guess when an earthquake will happen by looking at how many have happened in the past. For example, if only a few strong earthquakes have happened recently in an earthquake zone, scientists can guess that a strong earthquake will happen there soon.

What Is the Gap Hypothesis?

Some faults are very active. They have a lot of earthquakes every year. These faults sometimes have very strong earthquakes. A part of an active fault that hasn’t had a strong earthquake in a long time is called a seismic gap.

The gap hypothesis says that if an active fault hasn’t had a strong earthquake in a long time, it is likely to have one soon. In other words, it says that strong earthquakes are more likely to happen in seismic gaps.
**How Do Earthquakes Affect Buildings?**

Have you ever seen pictures of a city after a strong earthquake has hit? You may have noticed that some buildings don’t have very much damage. Other buildings, however, are totally destroyed. Engineers can study the damage to learn how to make buildings that are stronger and safer.

---

**Critical Thinking**

4. **List** Give three factors that can affect how much a building will be damaged by an earthquake.

---

**TAKE A LOOK**

5. **Compare** How is a mass damper different from an active tendon system?
How Can You Prepare for an Earthquake?

If you live in a place where earthquakes happen often, you and your family should have an earthquake plan. You should practice your plan so you will be prepared if an earthquake happens.

How Can You Make an Earthquake Plan?

There are several things to include in your earthquake plan.

SAFE HOME

Put heavy things near the floor so that they do not fall during an earthquake. Make sure things that can burn are kept away from electric wires and other things that can start a fire.

SAFE PLACES IN YOUR HOME

Make sure you know a safe place in each room in your home. Safe places are areas far from windows or heavy objects that could fall or break.

PLAN TO MEET OTHERS

Talk to your family, friends, or neighbors and set up a place where you all will meet after an earthquake. If you all know where to meet one another, it will be easy to make sure that everyone is safe.

EARTHQUAKE KIT

Your earthquake kit should have things that you might need after an earthquake. Remember that you may not have electricity or running water after an earthquake.

<table>
<thead>
<tr>
<th>What Should Be in an Earthquake Kit</th>
</tr>
</thead>
<tbody>
<tr>
<td>• water</td>
</tr>
<tr>
<td>• a fire extinguisher</td>
</tr>
<tr>
<td>• a small radio that runs on batteries</td>
</tr>
<tr>
<td>• medicines</td>
</tr>
<tr>
<td>• food that won’t go bad</td>
</tr>
<tr>
<td>• a flashlight with batteries</td>
</tr>
<tr>
<td>• extra batteries for the radio and flashlight</td>
</tr>
<tr>
<td>• a first-aid kit</td>
</tr>
</tbody>
</table>
What Should You Do During an Earthquake?

If you are inside when an earthquake happens, crouch or lie facedown under a table or a desk. Make sure you are far away from windows or heavy objects that might fall. Cover your head with your hands.

If you are outside during an earthquake, lie face down on the ground. Make sure you are far from buildings, power lines, and trees. Cover your head with your hands.

If you are in a car or bus, you should ask the driver to stop. Everyone should stay inside the car or bus until the earthquake is over.

What Should You Do After an Earthquake?

Being in an earthquake can be scary. After an earthquake happens, people are often confused about what happened. They may not know what to do or where to go.

After an earthquake, try to stay calm. Look around you. If you are near something dangerous, like a power line or broken glass, get away as quickly as you can. Never go into a building after an earthquake until your parent, a teacher, a police officer, or a firefighter tells you it is safe.

Always remember that there could be aftershocks. Aftershocks are weaker earthquakes that can happen after a large earthquake. Even though they are weaker than the main earthquake, aftershocks can still be very strong and damaging.

Stick to your earthquake plan. Stay together with your family or friends so that they know you are safe.
Section 3 Review

SECTION VOCABULARY

<table>
<thead>
<tr>
<th>gap hypothesis</th>
<th>seismic gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>a hypothesis that is based on the idea that a major earthquake is more likely to occur along the part of an active fault where no earthquakes have occurred for a certain period of time</td>
<td>an area along a fault where relatively few earthquakes have occurred recently but where strong earthquakes have occurred in the past</td>
</tr>
</tbody>
</table>

1. Identify  Why are seismologists interested in seismic gaps?

2. Describe  Fill in the chart below to show what you should do during an earthquake.

<table>
<thead>
<tr>
<th>If you are...</th>
<th>Then you should...</th>
</tr>
</thead>
<tbody>
<tr>
<td>...inside a building</td>
<td>...lie face down on the ground with your hands on your head, far from power lines or fire hazards.</td>
</tr>
<tr>
<td>...in a car or bus</td>
<td></td>
</tr>
</tbody>
</table>

3. Identify  What do engineers do to learn how to make a building more likely to survive an earthquake?

4. Identify Relationships  What is the relationship between the strength of an earthquake and how often it occurs?

5. Infer  In most cases, you should stay inside a car or a bus in an earthquake. When might it be best to leave a car or a bus during an earthquake?