Section 1

Forces in Earth's Crust

Reading Preview

Key Concepts

- How does stress in the crust change Earth's surface?
- Where are faults usually found, and why do they form?
- What land features result from the forces of plate movement?

Key Terms

- stress • tension
- compression • shearing
- normal fault • hanging wall
- footwall • reverse fault
- strike-slip fault • anticline
- syncline • plateau

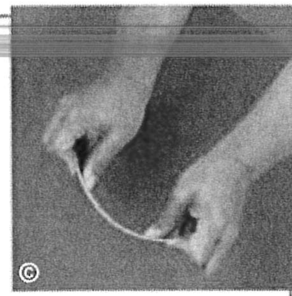
Target Reading Skill

Building Vocabulary

A definition states the meaning of a word or phrase. As you read, write a definition of each Key Term in your own words.

Lab zone Discover Activity

How Does Stress Affect Earth's Crust?



1. Put on your goggles.
2. Holding a popsicle stick at both ends, slowly bend it into an arch.
3. Release the pressure on the popsicle stick and observe what happens.
4. Repeat Steps 1 and 2. This time, however, keep bending the ends of the popsicle stick toward each other. What happens to the wood?

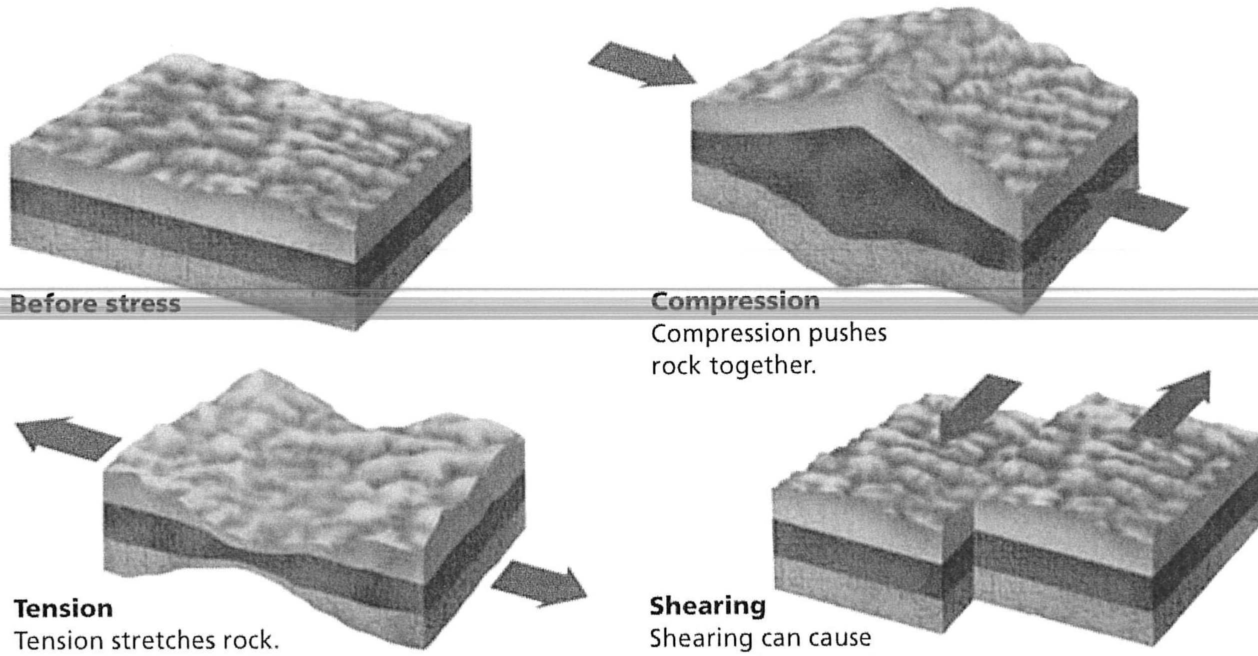
Think It Over

Predicting Think of the popsicle stick as a model for part of Earth's crust. What do you think might eventually happen as the forces of plate movement bend the crust?

The movement of Earth's plates creates enormous forces that squeeze or pull the rock in the crust as if it were a candy bar. These forces are examples of **stress,** a force that acts on rock to change its shape or volume. (A rock's volume is the amount of space the rock takes up.) Because stress is a force, it adds energy to the rock. The energy is stored in the rock until the rock changes shape or breaks.

If you try to break a caramel candy bar in two, it may only bend and stretch at first. Like a candy bar, many types of rock can bend or fold. But beyond a certain limit, even these rocks will break.

FIGURE 1
Effects of Stress
Powerful forces in Earth's crust caused the ground beneath this athletic field in Taiwan to change its shape.



Types of Stress

Three different kinds of stress can occur in the crust—tension, compression, and shearing. **Tension, compression, and shearing work over millions of years to change the shape and volume of rock.** These forces cause some rocks to become brittle and snap. Other rocks bend slowly, like road tar softened by the sun. Figure 2 shows how stress affects the crust.

Most changes in the crust occur so slowly that they cannot be observed directly. But if you could speed up time so a billion years passed by in minutes, you could see the crust bend, stretch, break, tilt, fold, and slide. The slow shift of Earth's plates causes these changes.

Tension The stress force called **tension** pulls on the crust, stretching rock so that it becomes thinner in the middle. The effect of tension on rock is somewhat like pulling apart a piece of warm bubble gum. Tension occurs where two plates are moving apart.

Compression The stress force called **compression** squeezes rock until it folds or breaks. One plate pushing against another can compress rock like a giant trash compactor.

Shearing Stress that pushes a mass of rock in two opposite directions is called **shearing.** Shearing can cause rock to break and slip apart or to change its shape.

Reading Checkpoint **How does shearing affect rock in Earth's crust?**

FIGURE 2
Stress in Earth's Crust
Stress forces push, pull, or twist the rocks in Earth's crust.
Relating Cause and Effect *Which type of stress tends to shorten part of the crust?*

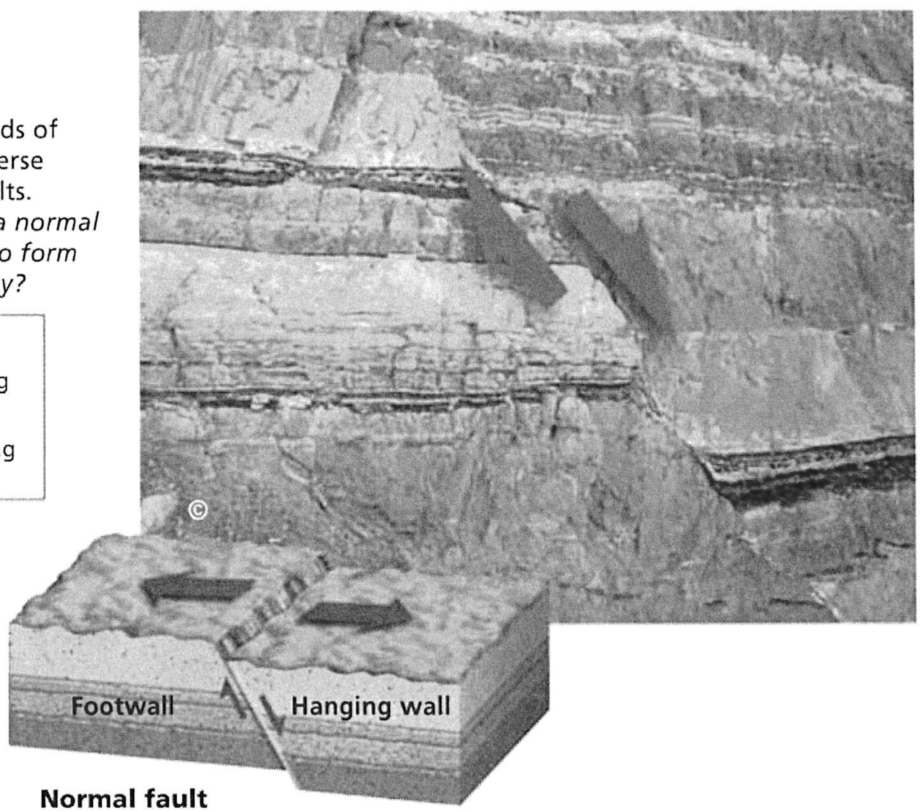
Kinds of Faults

When enough stress builds up in rock, the rock breaks, creating a fault. Recall that a fault is a break in the rock of the crust where rock surfaces slip past each other. The rocks on both sides of a fault can move up or down or sideways. **Most faults occur along plate boundaries, where the forces of plate motion push or pull the crust so much that the crust breaks. There are three main types of faults: normal faults, reverse faults, and strike-slip faults.**

Normal Faults Tension in Earth's crust pulls rock apart, causing **normal faults.** In a normal fault, the fault is at an angle, so one block of rock lies above the fault while the other block lies below the fault. The block of rock that lies above is called the **hanging wall.** The rock that lies below is called the **footwall.** Look at Figure 3 to see how the hanging wall lies above the footwall. When movement occurs along a normal fault, the hanging wall slips downward. Normal faults occur where plates diverge, or pull apart. For example, normal faults are found along the Rio Grande rift valley in New Mexico, where two pieces of Earth's crust are under tension.

FIGURE 3
Kinds of Faults
There are three main kinds of faults: normal faults, reverse faults, and strike-slip faults.
Inferring *Which half of a normal fault would you expect to form the floor of a valley? Why?*

Key
- Force deforming the crust
- Movement along the fault



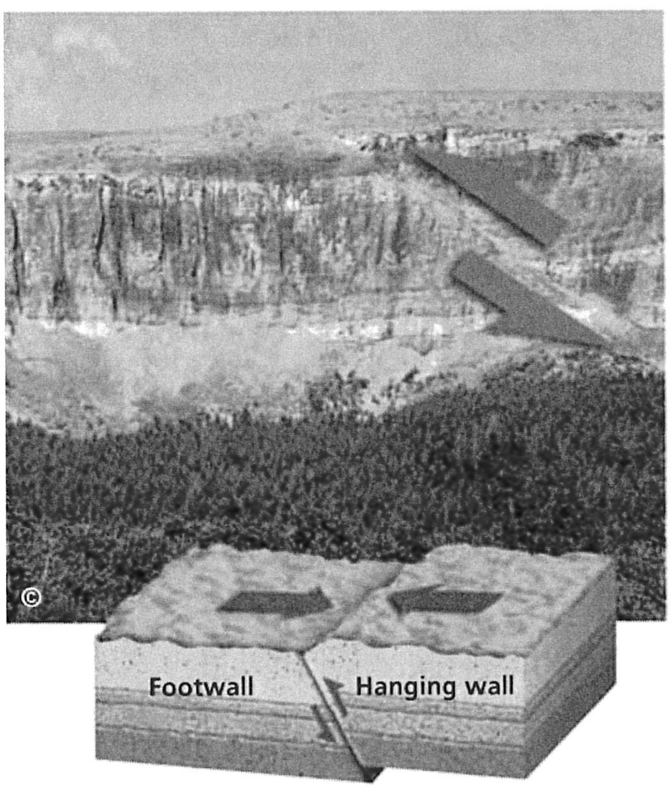
Normal fault
In a normal fault, the hanging wall slips down relative to the footwall.

Reverse Faults In places where the rock of the crust is pushed together, compression causes reverse faults to form. A **reverse fault** has the same structure as a normal fault, but the blocks move in the opposite direction. Look at Figure 3 to see how the rocks along a reverse fault move. As in a normal fault, one side of a reverse fault lies at an angle above the other side. The rock forming the hanging wall of a reverse fault slides up and over the footwall. Movement along reverse faults produced part of the northern Rocky Mountains in the western United States and Canada.

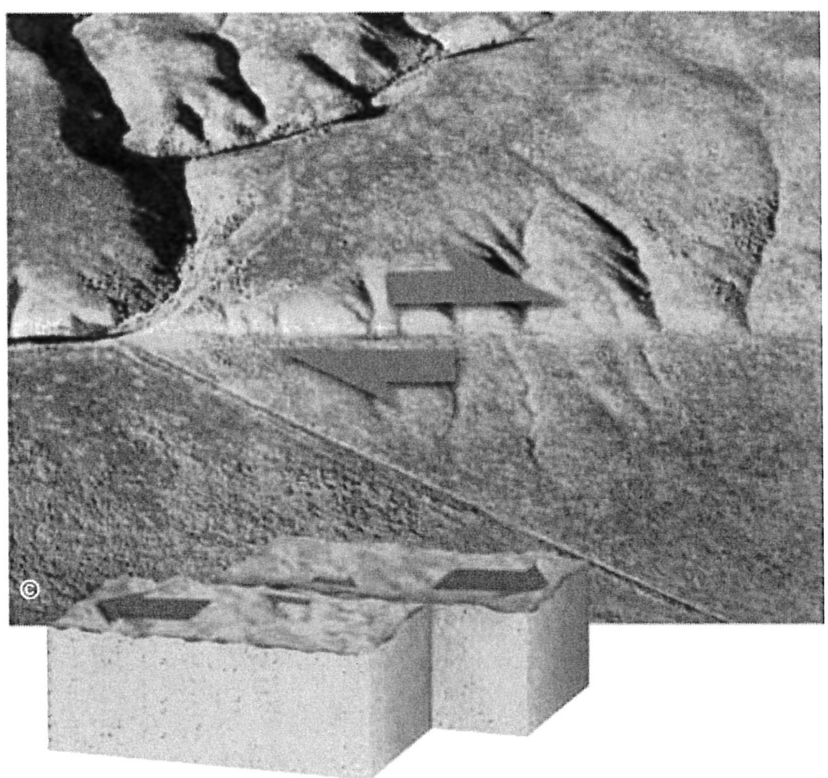
Strike-Slip Faults In places where plates move past each other, shearing creates strike-slip faults. In a **strike-slip fault**, the rocks on either side of the fault slip past each other sideways, with little up or down motion. A strike-slip fault that forms the boundary between two plates is called a transform boundary. The San Andreas fault in California is an example of a strike-slip fault that is a transform boundary.

Reading Checkpoint **What is the difference between a hanging wall and a footwall?**

Go Online
SCILINKS NSTA
For: Links on faults
Visit: www.SciLinks.org
Web Code: scn-1021

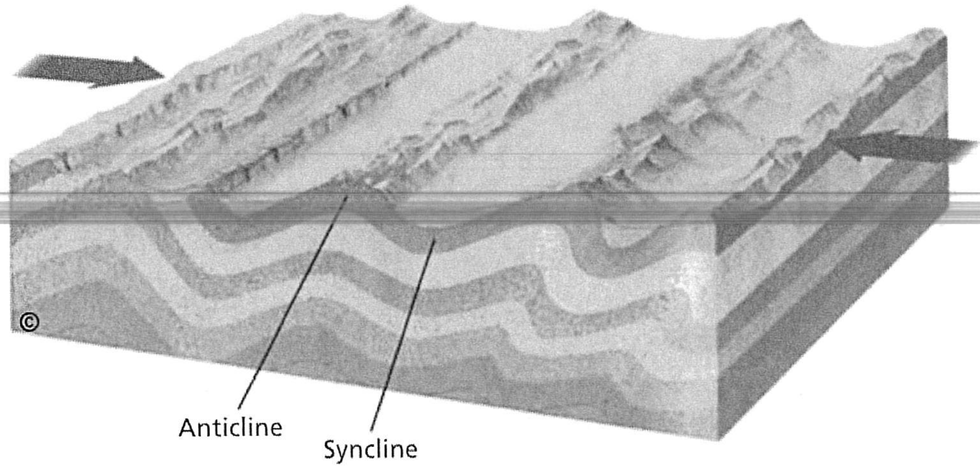


Reverse fault
In a reverse fault, the hanging wall moves up relative to the footwall.



Strike-slip fault
Rocks on either side of a strike-slip fault slip past each other.

FIGURE 4
Effects of Folding
Compression and folding of the crust produce anticlines, which arch upward, and synclines, which dip downward. Over millions of years, folding can push up high mountain ranges.
Predicting *If the folding in the diagram continued, what kind of fault might form?*



Changing Earth's Surface

The forces produced by the movement of Earth's plates can fold, stretch, and uplift the crust. **Over millions of years, the forces of plate movement can change a flat plain into landforms such as anticlines and synclines, folded mountains, fault-block mountains, and plateaus.**

Folding Earth's Crust Sometimes plate movement causes the crust to fold. Have you ever skidded on a rug that wrinkled up as your feet pushed it across the floor? Much as the rug wrinkles, rock stressed by compression may bend without breaking. Folds are bends in rock that form when compression shortens and thickens part of Earth's crust. A fold can be only a few centimeters across or hundreds of kilometers wide. You can often see small folds in the rock exposed where a highway has been cut through a hillside.

Geologists use the terms anticline and syncline to describe upward and downward folds in rock. A fold in rock that bends upward into an arch is an **anticline**, shown in Figure 4. A fold in rock that bends downward to form a valley is a **syncline**. Anticlines and synclines are found in many places where compression forces have folded the crust. The central Appalachian Mountains in Pennsylvania are folded mountains made up of anticlines and synclines.

The collision of two plates can cause compression and folding of the crust over a wide area. Folding produced some of the world's largest mountain ranges. The Himalayas in Asia and the Alps in Europe formed when pieces of the crust folded during the collision of two plates.

Lab zone **Try This Activity**

Modeling Stress

You can model the stresses that create faults.

1. Knead a piece of plastic putty until it is soft.
2. Push the ends of the putty toward the middle.
3. Pull the ends apart.
4. Push half of the putty one way and the other half in the opposite direction.

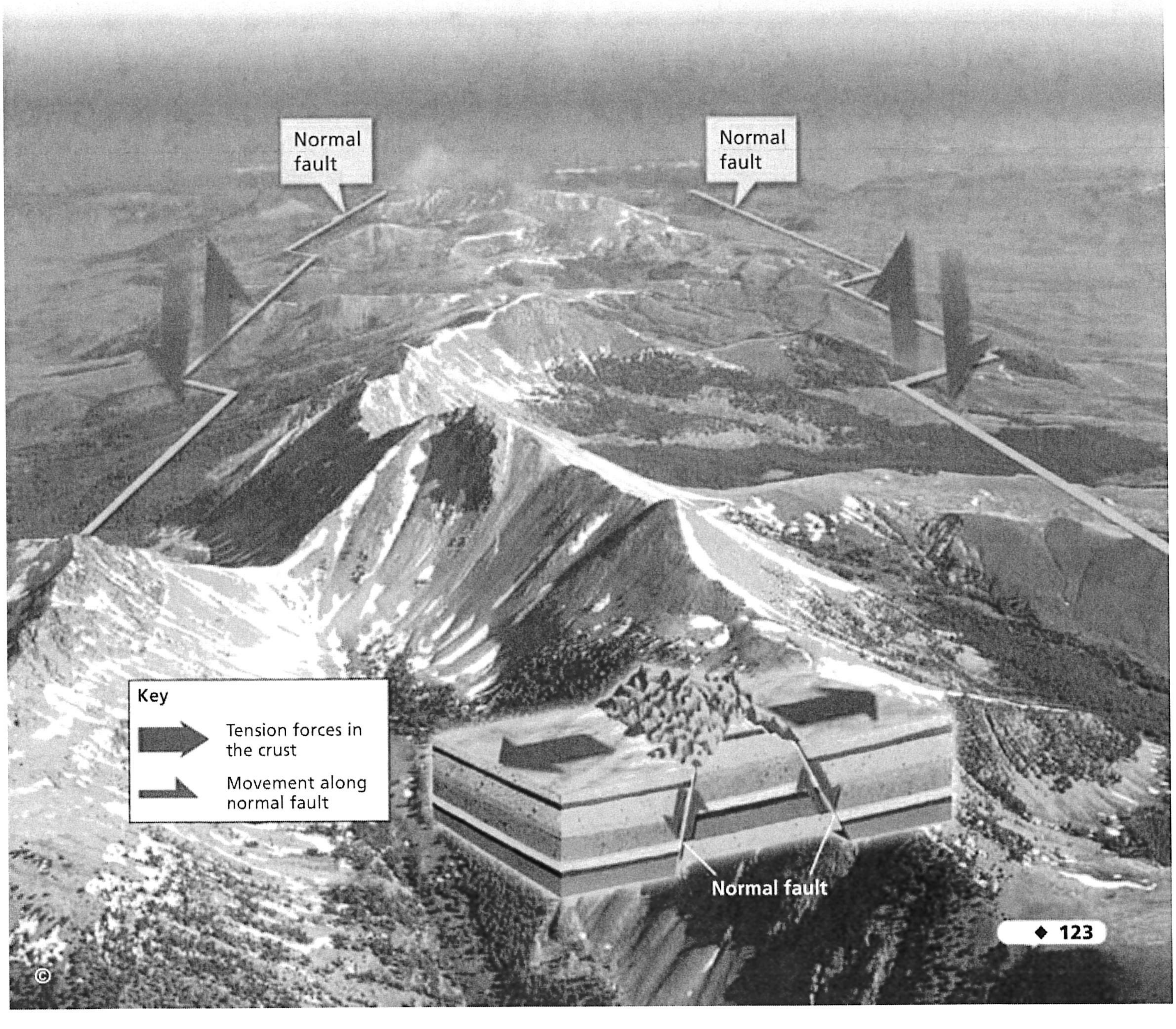
Classifying Which step in this activity models the type of stress that would produce anticlines and synclines?

Stretching Earth's Crust When two normal faults cut through a block of rock, a fault-block mountain forms. You can see a diagram of this process in Figure 5. How does this process begin? Where two plates move away from each other, tension forces create many normal faults. When two of these normal faults form parallel to each other, a block of rock is left lying between them. As the hanging wall of each normal fault slips downward, the block in between moves upward, forming a fault-block mountain.

If you traveled by car from Salt Lake City to Los Angeles, you would cross the Great Basin. This region contains many ranges of fault-block mountains separated by broad valleys, or basins.

Reading Checkpoint **What type of plate movement causes fault-block mountains to form?**

FIGURE 5
Fault-Block Mountains
As tension forces pull the crust apart, two parallel normal faults can form a range of fault-block mountains, like this mountain range in Idaho.



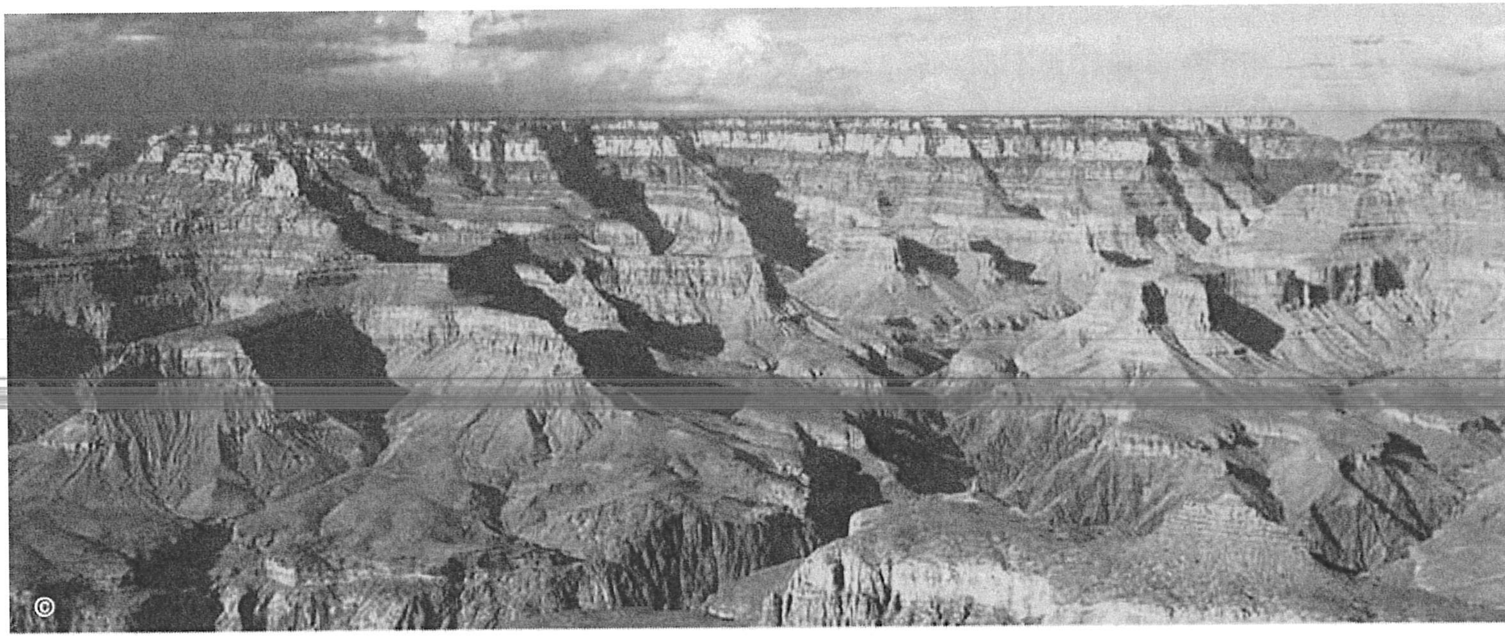


FIGURE 6
The Kaibab Plateau
The flat land on the horizon is the Kaibab Plateau, which forms the North Rim of the Grand Canyon in Arizona. The Kaibab Plateau is part of the Colorado Plateau.

Uplifting Earth's Crust The forces that raise mountains can also uplift, or raise, plateaus. A **plateau** is a large area of flat land elevated high above sea level. Some plateaus form when forces in Earth's crust push up a large, flat block of rock. Like a fancy sandwich, a plateau consists of many different flat layers, and is wider than it is tall.

Forces deforming the crust uplifted the Colorado Plateau in the "Four Corners" region of Arizona, Utah, Colorado, and New Mexico. Much of the Colorado Plateau lies more than 1,500 meters above sea level. Figure 6 shows one part of that plateau in northern Arizona.

Section 1 Assessment

Vocabulary Skill Identify Multiple Meanings
What does *stress* mean to a geologist? What is another meaning for *stress*.

Reviewing Key Concepts

HINT 1. a. Reviewing What are the three main types of stress in rock?
HINT b. Relating Cause and Effect How does tension change the shape of Earth's crust?
HINT c. Comparing and Contrasting Compare the way that compression affects the crust to the way that tension affects the crust.
HINT 2. a. Describing What is a fault?
HINT b. Explaining Why do faults often occur along plate boundaries?
HINT c. Relating Cause and Effect What type of fault is formed when plates diverge, or pull apart? What type of fault is formed when plates are pushed together?

3. a. Listing Name five kinds of landforms caused by plate movement. HINT
b. Relating Cause and Effect What are three landforms produced by compression in the crust? What landform is produced by tension? HINT

Lab zone At-Home Activity

Modeling Faults To model Earth's crust, roll modeling clay into layers and then press the layers together to form a rectangular block. Use a plastic knife to slice through the block at an angle, forming a fault. Explain which parts of your model represent the land surface, the hanging wall, and the footwall. Then show the three ways in which the sides of the fault can move.

Section 2

Earthquakes and Seismic Waves

Reading Preview

Key Concepts

- How does the energy of an earthquake travel through Earth?
- What are the scales used to measure the strength of an earthquake?
- How do scientists locate the epicenter of an earthquake?

Key Terms

- earthquake • focus
- epicenter • P wave
- S wave • surface wave
- Mercalli scale • magnitude
- Richter scale • seismograph
- moment magnitude scale

Target Reading Skill

Identifying Main Ideas As you read Types of Seismic Waves, write the main idea in a graphic organizer like the one below. Then write three supporting details. The supporting details further explain the main idea.

Main Idea

Seismic waves carry the energy of an earthquake.

Detail	Detail	Detail

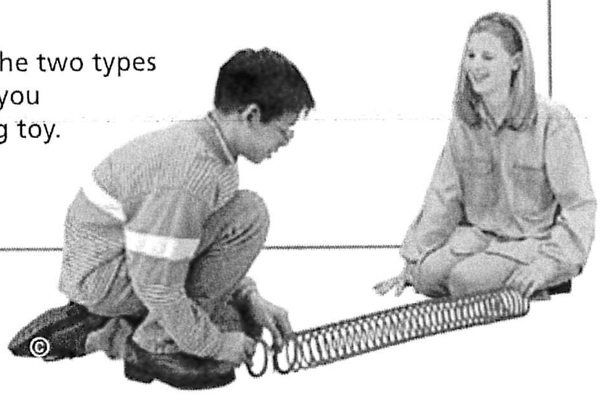
Lab zone Discover Activity

How Do Seismic Waves Travel Through Earth?

1. Stretch a spring toy across the floor while a classmate holds the other end. Do not overstretch the toy.
2. Gather together about four coils of the spring toy and release them. In what direction do the coils move?
3. Once the spring toy has stopped moving, jerk one end of the toy from side to side once. Be certain your classmate has a secure grip on the other end. In what direction do the coils move?

Think It Over

Observing Describe the two types of wave motion that you observed in the spring toy.



Earth is never still. Every day, worldwide, there are several thousand earthquakes. An **earthquake** is the shaking and trembling that results from the movement of rock beneath Earth's surface. Most earthquakes are too small to notice. But a large earthquake can produce dramatic changes in Earth's surface and cause great damage.

The forces of plate movement cause earthquakes. Plate movements produce stress in Earth's crust, adding energy to rock and forming faults. Stress increases along a fault until the rock breaks. An earthquake begins. In seconds, the earthquake releases an enormous amount of stored energy.

Most earthquakes begin in the lithosphere within about 100 kilometers of Earth's surface. The **focus** (FOH kus) is the area beneath Earth's surface where rock that is under stress breaks, triggering an earthquake. The point on the surface directly above the focus is called the **epicenter** (EP uh sen tur).

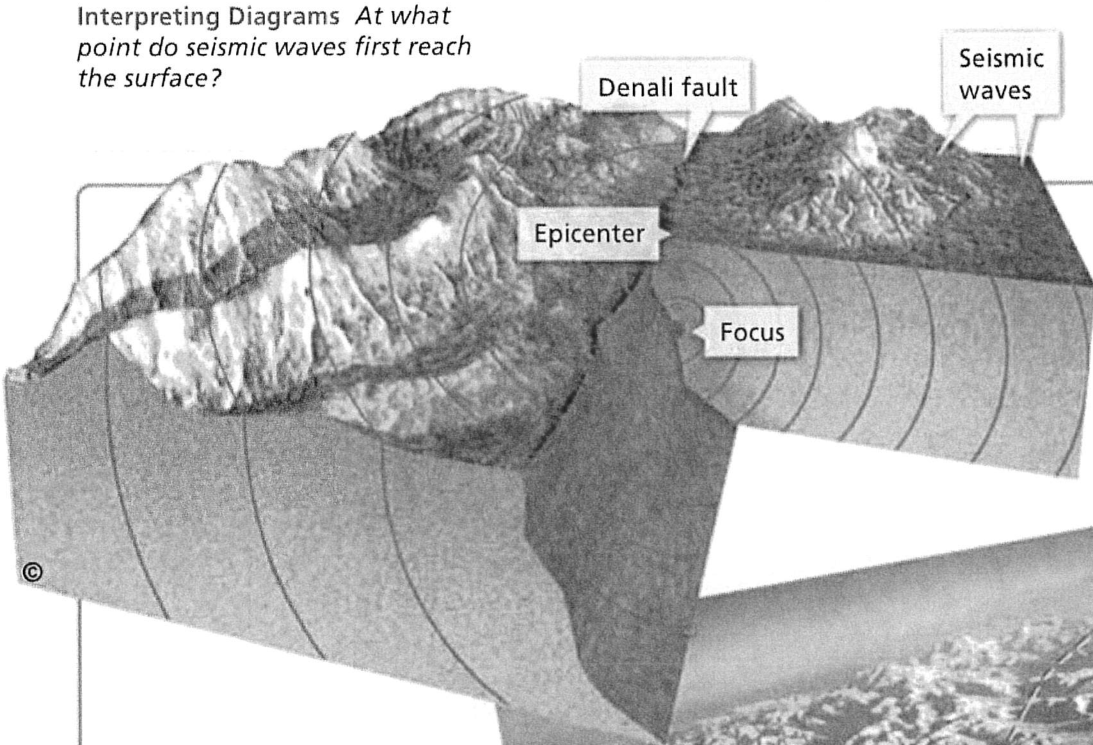
Types of Seismic Waves

Like a pebble thrown into a pond, an earthquake produces vibrations called waves. These waves carry energy as they travel outward. During an earthquake, seismic waves race out from the focus in all directions. Seismic waves are vibrations that travel through Earth carrying the energy released during an earthquake. The seismic waves move like ripples in a pond. **Seismic waves carry energy from an earthquake away from the focus, through Earth's interior, and across the surface.** That's what happened in 2002, when a powerful earthquake ruptured the Denali fault in Alaska, shown in Figure 7.

There are three main categories of seismic waves: P waves, S waves, and surface waves. An earthquake sends out two types of waves from its focus: P waves and S waves. When these waves reach Earth's surface at the epicenter, surface waves develop.

FIGURE 7
Seismic Waves

This diagram shows an earthquake along the Denali fault. An earthquake occurs when rocks fracture deep in the crust. The seismic waves move out in all directions from the focus.
Interpreting Diagrams *At what point do seismic waves first reach the surface?*



The Denali fault lies about 150 km south of Fairbanks, Alaska.▶

P Waves The first waves to arrive are primary waves, or P waves. **P waves** are seismic waves that compress and expand the ground like an accordion. Like the other types of seismic waves, P waves can damage buildings. Look at Figure 7 to see how P waves move.

S Waves After P waves come secondary waves, or S waves. **S waves** are seismic waves that vibrate from side to side as well as up and down. They shake the ground back and forth. When S waves reach the surface, they shake structures violently. Unlike P waves, which travel through both solids and liquids, S waves cannot move through liquids.

Surface Waves When P waves and S waves reach the surface, some of them become surface waves. **Surface waves** move more slowly than P waves and S waves, but they can produce severe ground movements. Some surface waves make the ground roll like ocean waves. Other surface waves shake buildings from side to side.

Reading Checkpoint Which type of seismic wave causes the ground to roll like ocean waves?

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For: Seismic Waves activity
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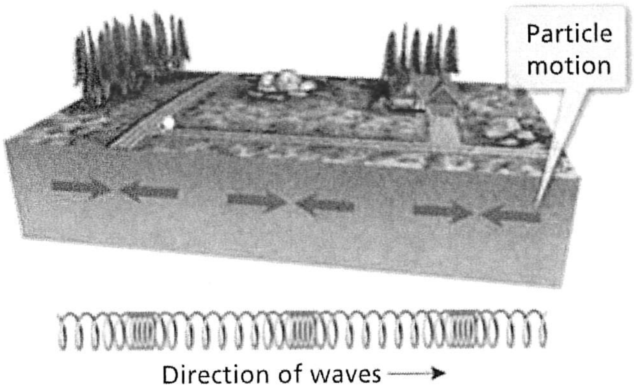
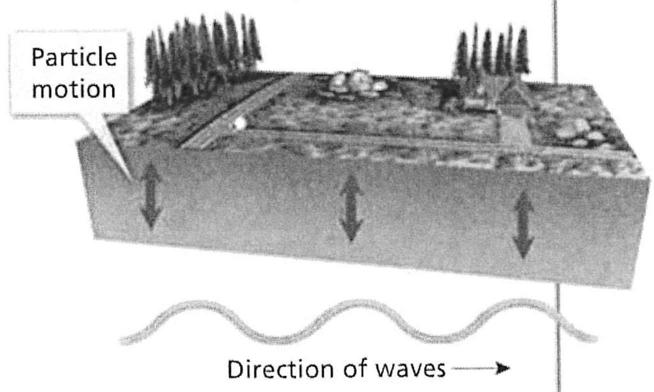
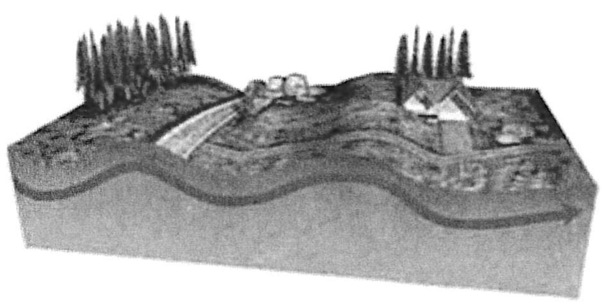
Web Code: cfp-1022

P waves
The crust vibrates forward and back along the path of the wave.



S waves
The crust vibrates from side to side and up and down.





Surface waves
The ground surface rolls with a wavelike motion.

Discovery Channel School

Earthquakes

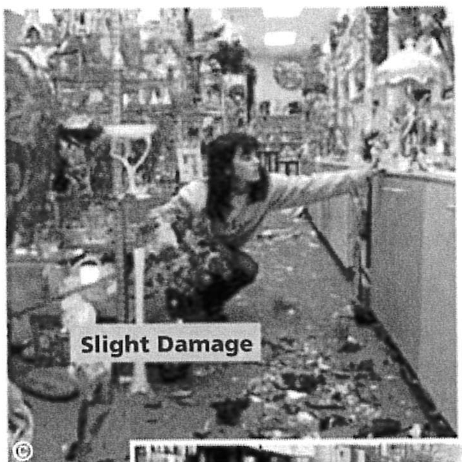
- Video Preview
- ▶ Video Field Trip
- Video Assessment

Measuring Earthquakes

When an earthquake occurs, people want to know "How big was the quake?" and "Where was it centered?" When geologists want to know the size of an earthquake, they must consider many factors. As a result, there are at least 20 different measures for rating earthquakes, each with its strengths and shortcomings. **Three commonly used methods of measuring earthquakes are the Mercalli scale, the Richter scale, and the moment magnitude scale.**

The Mercalli Scale The **Mercalli scale** was developed to rate earthquakes according to the level of damage at a given place. The 12 steps of the Mercalli scale, shown in Figure 9, describe an earthquake's effects. The same earthquake can have different Mercalli ratings because it causes different amounts of ground motion at different locations.

The Richter Scale An earthquake's **magnitude** is a number that geologists assign to an earthquake based on the earthquake's size. Geologists determine magnitude by measuring the seismic waves and fault movement that occur during an earthquake. The **Richter scale** is a rating of an earthquake's magnitude based on the size of the earthquake's seismic waves. The seismic waves are measured by a **seismograph.** A seismograph is an instrument that records and measures seismic waves. The Richter scale provides accurate measurements for small, nearby earthquakes. But it does not work well for large or distant earthquakes.



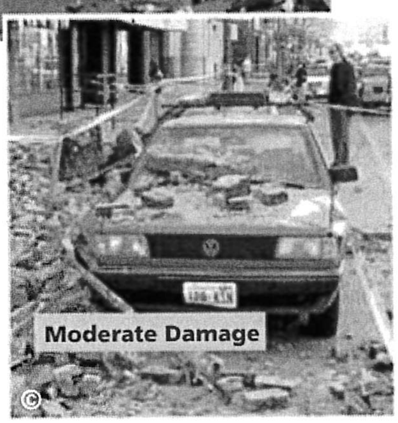


FIGURE 8
Levels of Earthquake Damage
The level of damage caused by an earthquake varies depending on the magnitude of the earthquake and the distance from the epicenter.

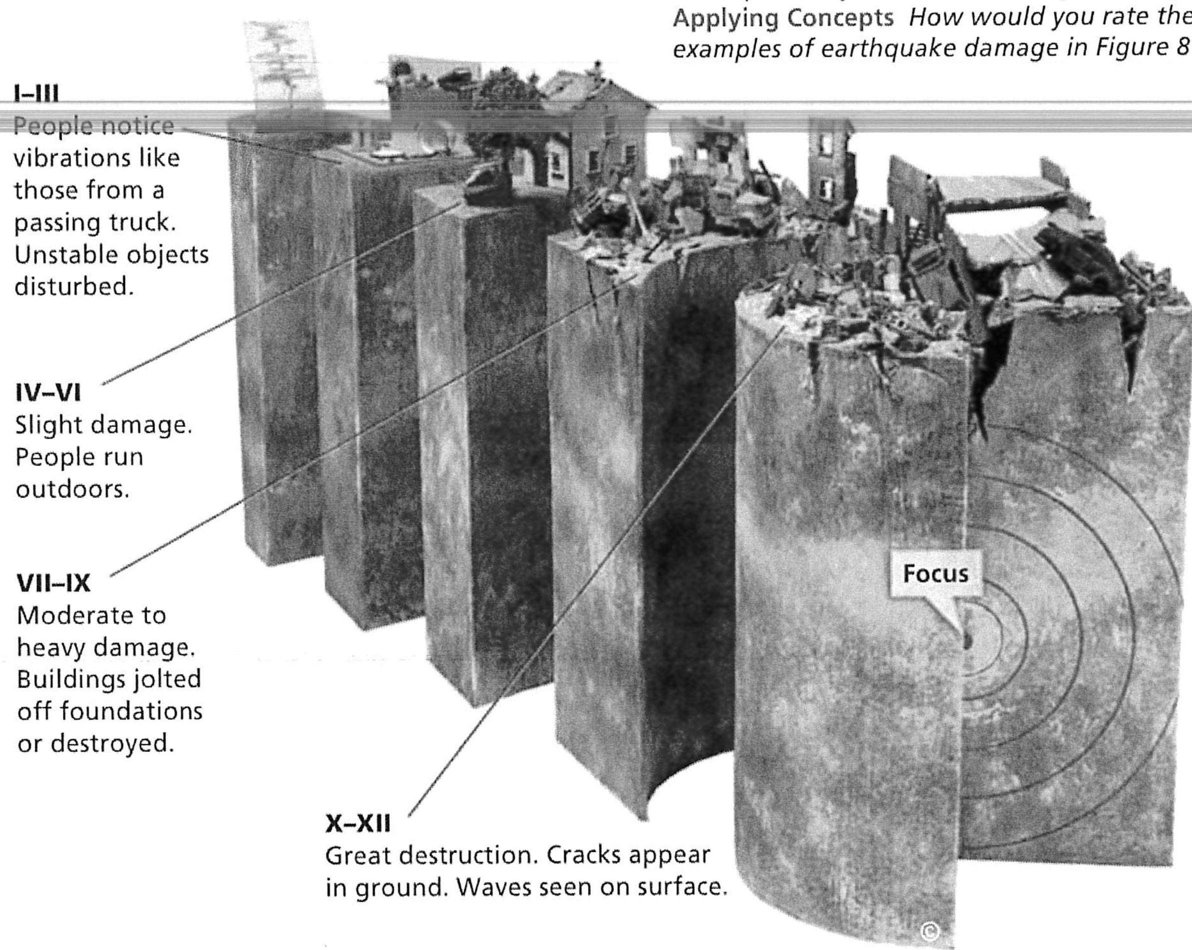


FIGURE 9
The Mercalli Scale
The Mercalli scale uses Roman numerals to rank earthquakes by how much damage they cause.
Applying Concepts *How would you rate the three examples of earthquake damage in Figure 8?*

The Moment Magnitude Scale Geologists today often use the **moment magnitude scale,** a rating system that estimates the total energy released by an earthquake. The moment magnitude scale can be used to rate earthquakes of all sizes, near or far. You may hear news reports that mention the Richter scale. But the number they quote is almost always the moment magnitude for that earthquake.

To rate an earthquake on the moment magnitude scale, geologists first study data from seismographs. The data show what kinds of seismic waves the earthquake produced and how strong they were. The data also help geologists infer how much movement occurred along the fault and the strength of the rocks that broke when the fault slipped. Geologists use all this information to rate the quake on the moment magnitude scale.

Reading Checkpoint **What evidence do geologists use to rate an earthquake on the moment magnitude scale?**

Lab zone **Skills Activity**

Classifying

Classify the earthquake damage at these locations using the Mercalli scale.

1. Many buildings are destroyed; cracks form in the ground.
2. Several old brick buildings and a bridge collapse.
3. Canned goods fall off shelves; walls crack; people go outside to see what's happening.

FIGURE 10
Collecting Seismic Data
This geologist is checking data collected after an earthquake. These data can be used to pinpoint the epicenter of an earthquake.

Comparing Magnitudes An earthquake's magnitude tells geologists how much energy was released by the earthquake. Each one-point increase in magnitude represents the release of roughly 32 times more energy. For example, a magnitude 6 quake releases 32 times as much energy as a magnitude 5 quake, and about 1,000 times as much as a magnitude 4 quake.

The effects of an earthquake increase with magnitude. People scarcely notice earthquakes with magnitudes below 3. Earthquakes with a magnitude below 5 are small and cause little damage. Those with a magnitude between 5 and 6 can cause moderate damage. Earthquakes with a magnitude above 6 can cause great damage. Fortunately, the most powerful earthquakes, with a magnitude of 8 or above, are rare. During the twentieth century, only two earthquakes measured above 9 on the moment magnitude scale. These earthquakes occurred in Chile in 1960 and in Alaska in 1964.

Locating the Epicenter

Geologists use seismic waves to locate an earthquake's epicenter. Seismic waves travel at different speeds. P waves arrive at a seismograph first, with S waves following close behind. To tell how far the epicenter is from the seismograph, scientists measure the difference between the arrival times of the P waves and S waves. The farther away an earthquake is, the greater the time between the arrival of the P waves and the S waves.

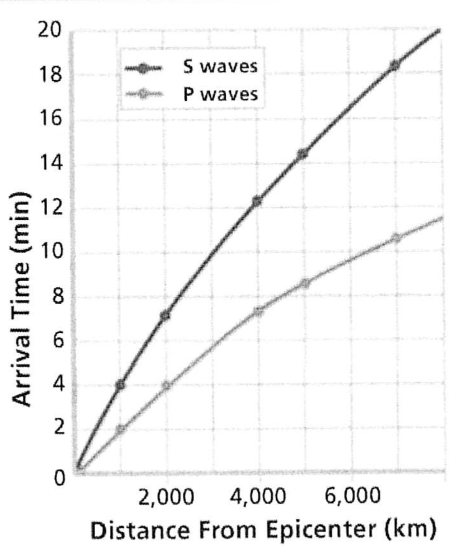
Math Analyzing Data

Seismic Wave Speeds

Seismographs at five observation stations recorded the arrival times of the P and S waves produced by an earthquake. These data are shown in the graph.

1. Reading Graphs What variable is shown on the *x*-axis of the graph? The *y*-axis?
2. Reading Graphs How long did it take the S waves to travel 2,000 km?
3. Estimating How long did it take the P waves to travel 2,000 km?
4. Calculating What is the difference in the arrival times of the P waves and the S waves at 2,000 km? At 4,000 km?

P and S Waves



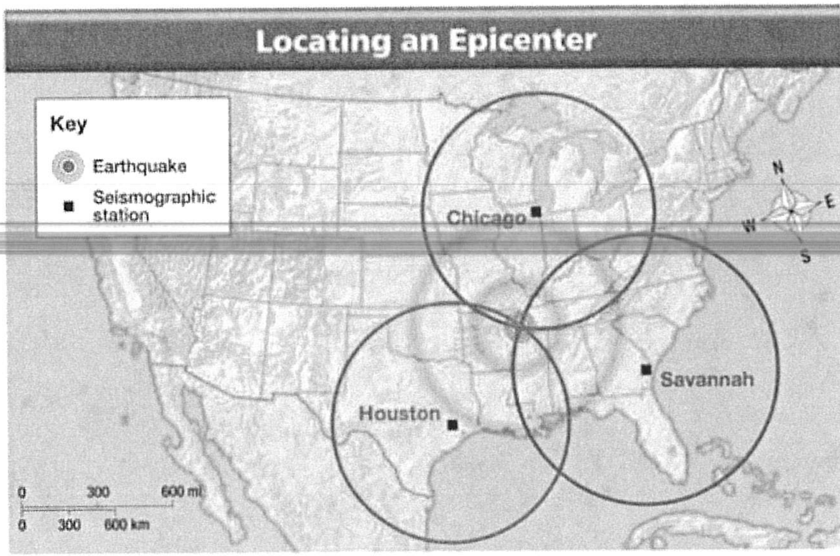


FIGURE 11
The map shows how to find the epicenter of an earthquake using data from three seismographic stations. Measuring *Use the map scale to determine the distances from Savannah and Houston to the epicenter. Which is closer?*

Geologists then draw at least three circles using data from different seismographs set up at stations all over the world. The center of each circle is a particular seismograph's location. The radius of each circle is the distance from that seismograph to the epicenter. As you can see in Figure 11, the point where the three circles intersect is the location of the epicenter.

Reading Checkpoint **What do geologists measure to determine the distance from a seismograph to an epicenter?**

Section 2 Assessment

Target Reading Skill

Identifying Main Ideas Use your graphic organizer to help you answer Question 1 below.

Reviewing Key Concepts

HINT 1. a. **Reviewing** How does energy from an earthquake reach Earth's surface?

HINT b. **Describing** What kind of movement is produced by each of the three types of seismic waves?

HINT c. **Sequencing** When do P waves arrive at the surface in relation to S waves and surface waves?

HINT 2. a. **Defining** What is an earthquake's magnitude?

HINT b. **Describing** How is magnitude measured using the Richter scale?

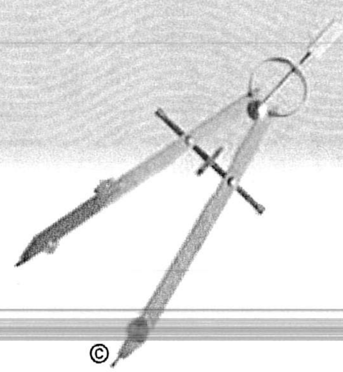
HINT c. **Applying Concepts** What are the advantages of using the moment magnitude scale to measure an earthquake?

3. a. **Explaining** What type of data do geologists use to locate an earthquake's epicenter? HINT

b. **Interpreting Maps** Study the map in Figure 11 above. Then describe the method that scientists use to determine the epicenter of an earthquake. HINT

Writing in Science

News Report As a television news reporter, you are covering an earthquake rated between IV and V on the Mercalli scale. Write a short news story describing the earthquake's effects. Your lead paragraph should tell *who, what, where, when,* and *how.* (*Hint:* Refer to Figure 9 for examples of earthquake damage.)



Finding the Epicenter

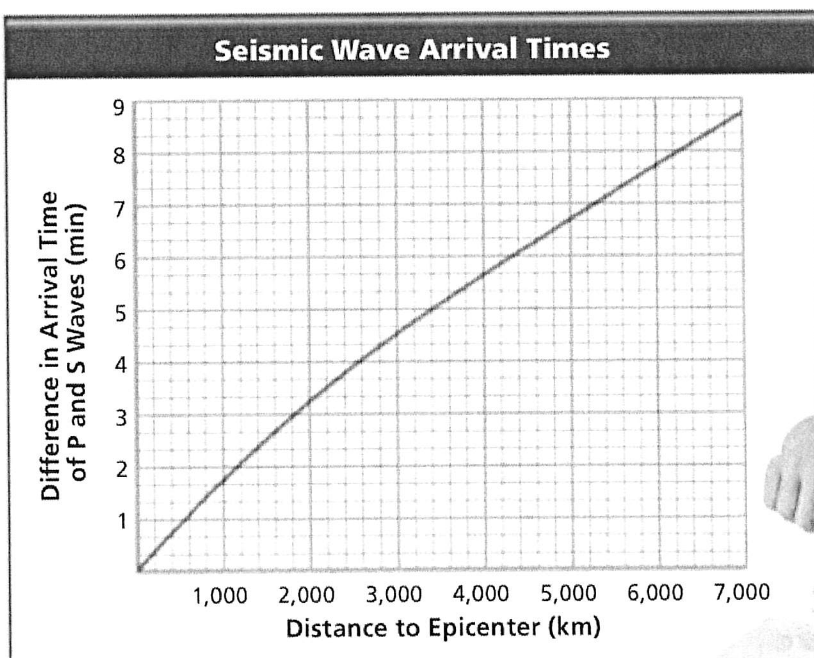
Problem
How can you locate an earthquake's epicenter?

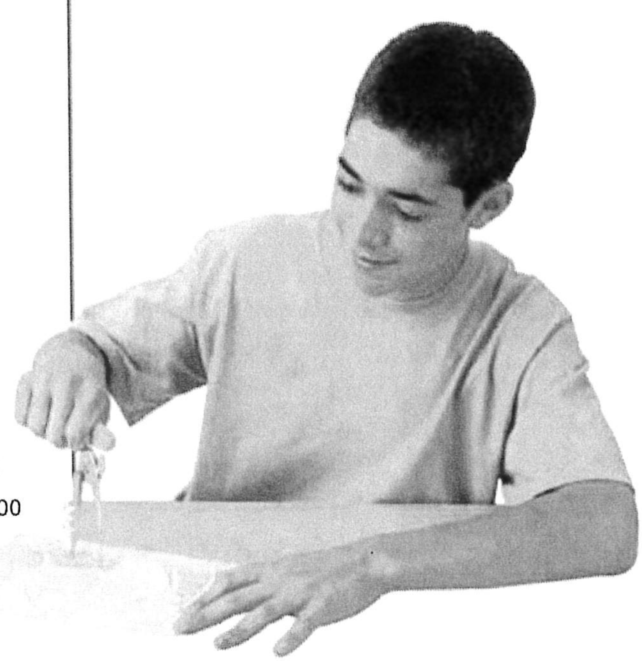
Skills Focus
interpreting data, drawing conclusions

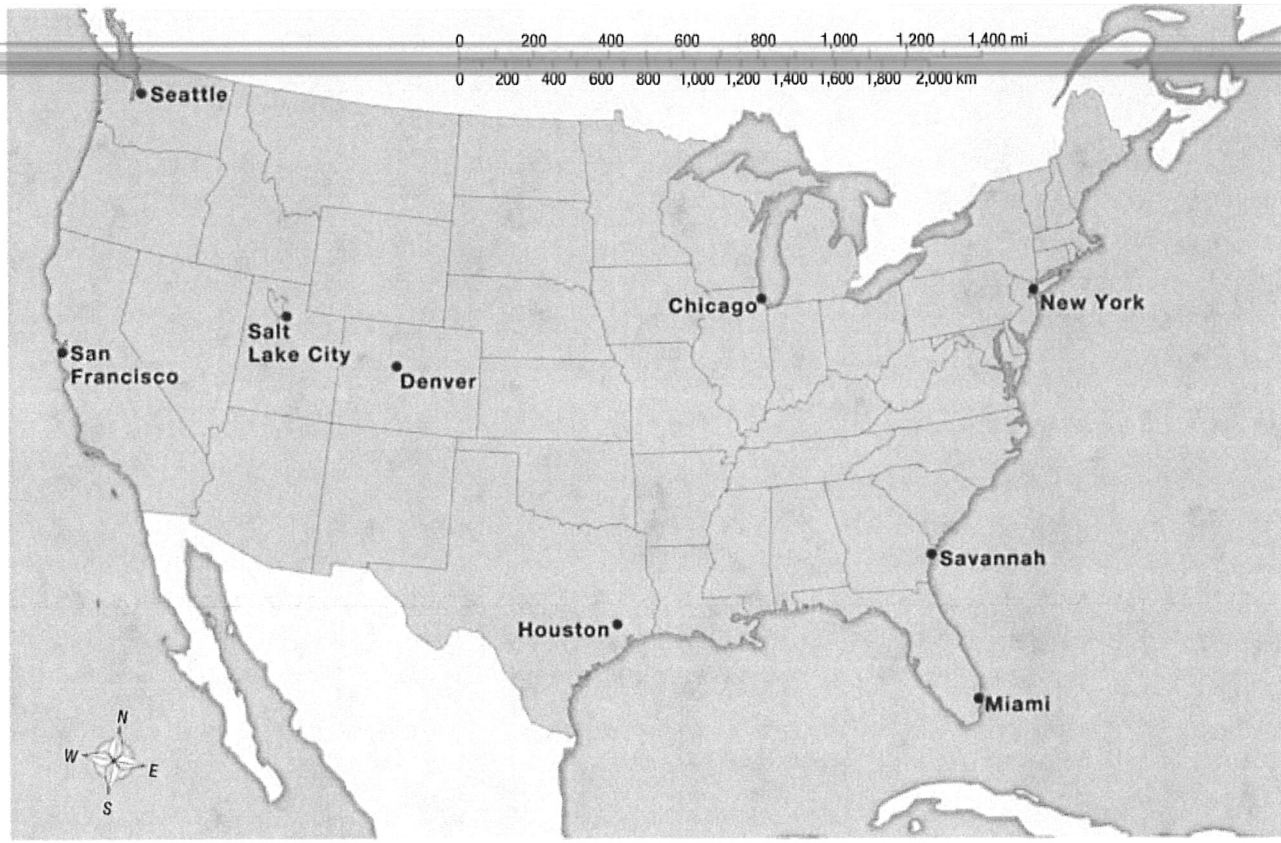
Materials
- drawing compass with pencil
- outline map of the United States

Data Table		
City	Difference in P and S Wave Arrival Times	Distance to Epicenter
Denver, Colorado	2 min 40 s	
Houston, Texas	1 min 50 s	
Chicago, Illinois	1 min 10 s	

Procedure
1. Make a copy of the data table showing differences in earthquake arrival times.
2. The graph shows how the difference in arrival time between P waves and S waves depends on the distance from the epicenter of the earthquake. Find the difference in arrival time for Denver on the *y*-axis of the graph. Follow this line across to the point at which it crosses the curve. To find the distance to the epicenter, read down from this point to the *x*-axis of the graph. Enter this distance in the data table.
3. Repeat Step 2 for Houston and Chicago.
4. Set your compass at a radius equal to the distance from Denver to the earthquake epicenter that you previously recorded in your data table.
5. Draw a circle with the radius determined in Step 4, using Denver as the center. Draw the circle on your copy of the map. (*Hint:* Draw your circles carefully. You may need to draw some parts of the circles off the map.)
6. Repeat Steps 4 and 5 for Houston and Chicago.







Analyze and Conclude

1. Drawing Conclusions Observe the three circles you have drawn. Where is the earthquake's epicenter?
2. Measuring Which city on the map is closest to the earthquake epicenter? How far, in kilometers, is this city from the epicenter?
3. Inferring In which of the three cities listed in the data table would seismographs detect the earthquake first? Last?
4. Estimating About how far from San Francisco is the epicenter that you found? What would be the difference in arrival times of the P waves and S waves for a recording station in San Francisco?
5. Interpreting Data What happens to the difference in arrival times between P waves and S waves as the distance from the earthquake increases?
6. Communicating Review the procedure you followed in this lab and then answer the following question. When you are trying to locate an epicenter, why is it necessary to know the distance from the epicenter for at least three recording stations?

More to Explore

You have just located an earthquake's epicenter. Find this earthquake's location on the map of Earthquake Risk in the United States (Figure 18). What is the risk of earthquakes in the area of this quake?

Now look at the map of Earth's Lithospheric Plates (Figure 22 in the chapter "Plate Tectonics"). What conclusions can you draw from this map about the cause of earthquakes in this area?

Section 3

· Tech & Design ·

Monitoring Earthquakes

Reading Preview

Key Concepts

- How do seismographs work?
- What are some causes of earthquake damage?

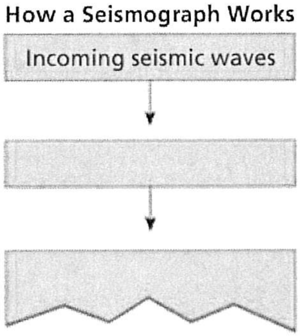
Key Terms

- seismogram
- liquefaction
- aftershock
- tsunami

Target Reading Skill

Sequencing As you read, make a flowchart like the one below that shows how a seismograph produces a seismogram. Write each step of the process in a separate box in the order in which it occurs.

How a Seismograph Works



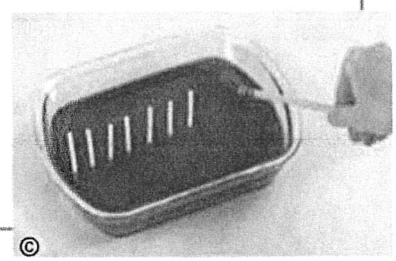
Lab zone Discover Activity

How Can Seismic Waves Be Detected?

1. Using scissors, cut 4 plastic stirrers in half. Each piece should be about 5 cm long.
2. Your teacher will give you a pan containing gelatin. Gently insert the 8 stirrer pieces into the gelatin, spacing them about 2–3 cm apart in a row. The pieces should stand upright, but not touch the bottom of the pan.
3. At the opposite end of the pan from the stirrers, gently tap the surface of the gelatin once with the eraser end of a pencil. Observe the results.

Think It Over

Inferring What happened to the stirrer pieces when you tapped the gelatin? What was responsible for this effect?



Look at the beautiful vase in the photo. You might be surprised to learn that the vase is actually a scientific instrument. Can you guess what it was designed to do? Zhang Heng, an astronomer, designed and built this earthquake detection device in China nearly 2,000 years ago. It is said to have detected an earthquake centered several hundred kilometers away.

Earthquakes are dangerous, so people want to monitor them. To *monitor* means to "watch closely." Like the ancient Chinese, many societies have used technology to determine when and where earthquakes have occurred. During the late 1800s, scientists developed seismographs that were much more sensitive and accurate than any earlier devices.

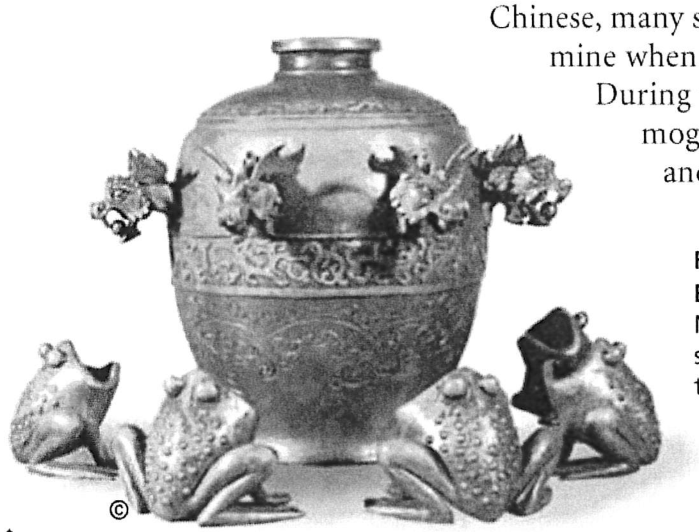


FIGURE 12
Earthquake Detector
Nearly 2,000 years ago, a Chinese scientist invented this instrument to detect earthquakes.

The Seismograph

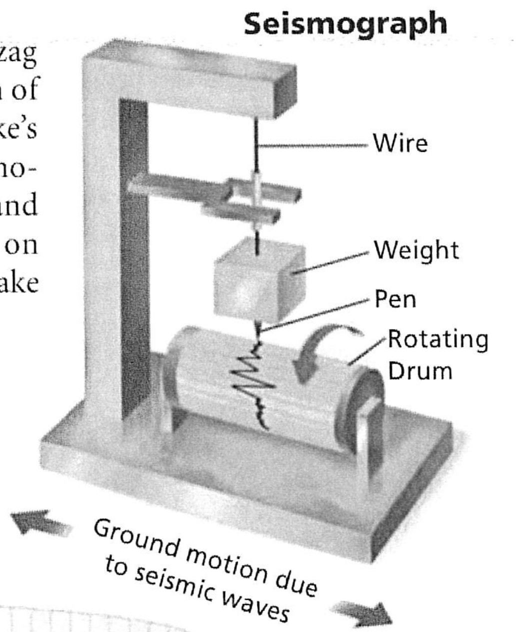
A simple seismograph can consist of a heavy weight attached to a frame by a spring or wire. A pen connected to the weight rests its point on a drum that can rotate. As the drum rotates slowly, the pen draws a straight line on paper wrapped tightly around the drum. **Seismic waves cause the seismograph's drum to vibrate. But the suspended weight with the pen attached moves very little. Therefore, the pen stays in place and records the drum's vibrations.**

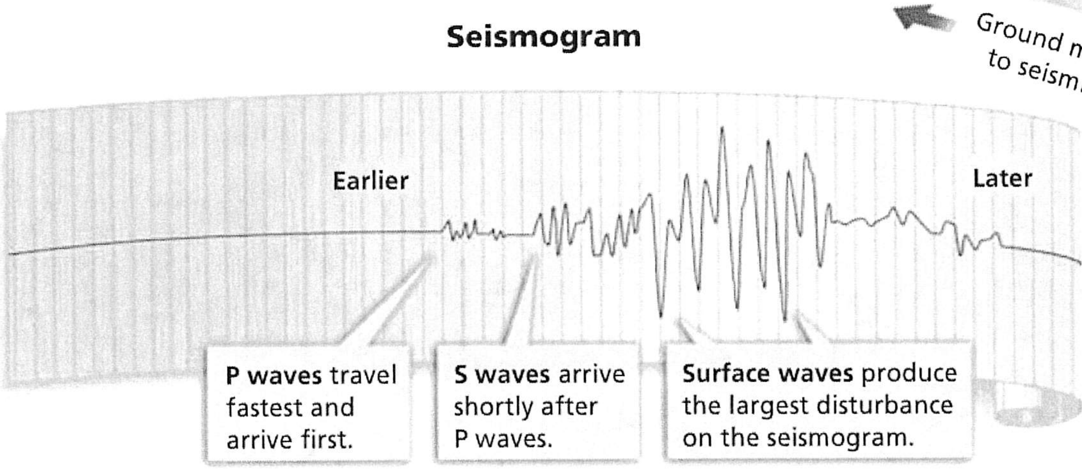
Measuring Seismic Waves When you write a sentence, the paper stays in one place while your hand moves the pen. But in a seismograph, it's the pen that remains stationary while the paper moves. Why is this? All seismographs make use of a basic principle of physics: Whether it is moving or at rest, every object resists any change to its motion. A seismograph's heavy weight resists motion during a quake. But the rest of the seismograph is anchored to the ground and vibrates when seismic waves arrive.

Reading a Seismogram You have probably seen a zigzag pattern of lines used to represent an earthquake. The pattern of lines, called a **seismogram,** is the record of an earthquake's seismic waves produced by a seismograph. Study the seismogram in Figure 13 and notice when the P waves, S waves, and surface waves arrive. The height of the jagged lines drawn on the seismograph's drum is greater for a more severe earthquake or for an earthquake close to the seismograph.

Reading Checkpoint: **What is a seismogram?**

FIGURE 13
Recording Seismic Waves
A seismograph records seismic waves, producing a seismogram. Today, electronic seismographs contain sensors instead of pens.
Interpreting Diagrams *What is the function of the weight in the seismograph?*





Lab zone **Try This Activity**

Stable or Unstable?

1. Make a model of a fault by placing two small, folded towels side by side on a flat surface.
2. Pile a stack of books on the fault by placing the light books on the bottom and the heaviest ones on top.
3. Gently pull the towels in opposite directions until the pile topples.
4. Repeat the process, but this time with the heavier books on the bottom.

Relating Cause and Effect Which one of your structures was more stable than the other? Why?

How Earthquakes Cause Damage

When a major earthquake strikes, it can cause great damage. **Causes of earthquake damage include shaking, liquefaction, aftershocks, and tsunamis.**

Shaking The shaking produced by seismic waves can trigger landslides or avalanches. Shaking can also damage or destroy buildings and bridges, topple utility poles, and fracture gas and water mains. S waves and surface waves, with their side-to-side and up-and-down movement, can cause severe damage near the epicenter. As the seismic waves sweep through the ground, they can put enough stress on buildings to tear them apart.

The types of rock and soil determine where and how much the ground shakes. The most violent shaking may occur kilometers away from the epicenter. Loose soil shakes more violently than solid rock. This means a house built on sandy soil will shake more than a house built on solid rock.

Liquefaction In 1964, when a powerful earthquake roared through Anchorage, Alaska, cracks opened in the ground. Some of the cracks were 9 meters wide. The cracks were created by liquefaction. **Liquefaction** (lik wih FAK shun) occurs when an earthquake's violent shaking suddenly turns loose, soft soil into liquid mud. Liquefaction is likely where the soil is full of moisture. As the ground gives way, buildings sink and pull apart.

Aftershocks Sometimes, buildings weakened by an earthquake collapse during an aftershock. An **aftershock** is an earthquake that occurs after a larger earthquake in the same area. Aftershocks may strike hours, days, or even months later.

FIGURE 14
Liquefaction Damage
An earthquake caused the soil beneath this building to liquefy. Liquefaction can change soil to liquid mud.
Posing Questions *What are some questions people might ask before building in a quake-prone area?*

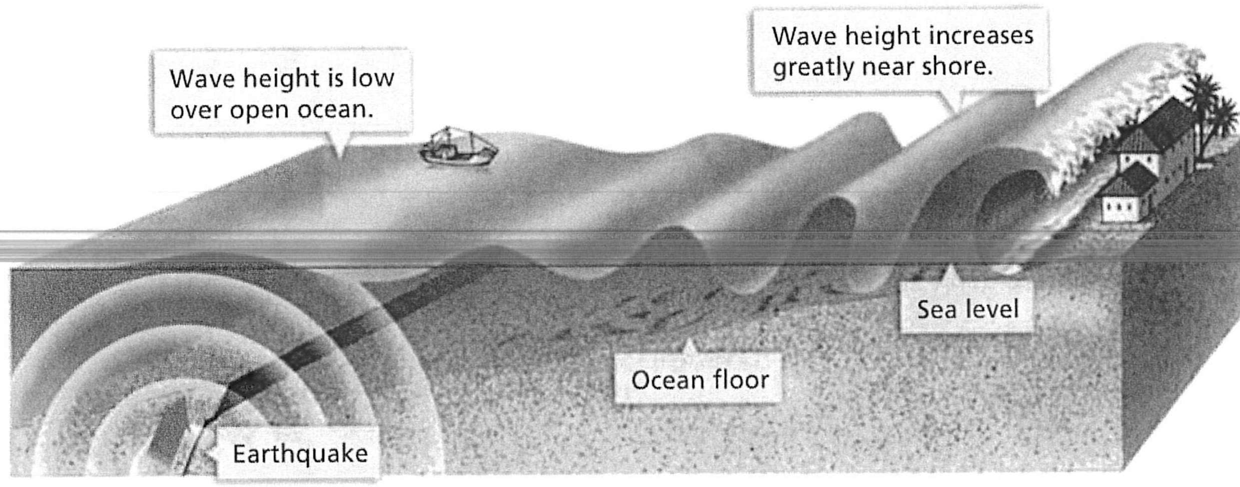


Figure 15
How a Tsunami Forms
A tsunami begins as a low wave, but turns into a huge wave as it nears the shore.

Tsunamis When an earthquake jolts the ocean floor, plate movement causes the ocean floor to rise slightly and push water out of its way. The water displaced by the earthquake may form a large wave called a **tsunami** (tsoo NAH mee), shown in Figure 15. A tsunami spreads out from an earthquake's epicenter and speeds across the ocean. In the open ocean, the height of the wave is low. As a tsunami approaches shallow water, the wave grows into a mountain of water.

In 2004, a powerful earthquake in the Indian Ocean triggered several tsunamis. The tsunamis caused great loss of life and destruction to coastal areas around the Indian Ocean.

Reading Checkpoint **What causes tsunamis?**

Section 3 Assessment

Target Reading Skill Sequencing Refer to your flowchart about seismographs as you answer Question 1.

Reviewing Key Concepts

HINT
1. a. Defining What is a seismograph?

HINT
b. Explaining How does a seismograph record seismic waves?

HINT
c. Predicting A seismograph records a strong earthquake and a weak earthquake. How would the seismograms for the two earthquakes compare?

HINT
2. a. Listing What are four ways that earthquakes cause damage?

HINT
b. Describing How does liquefaction cause damage during an earthquake?

c. Inferring How might heavy rain before an earthquake affect the danger of liquefaction?

HINT

Writing in Science

Patent Application You are an inventor who has created a simple device that can detect an earthquake. To protect your rights to the invention, you apply for a patent. In your patent application, describe your device and how it will indicate the direction and strength of an earthquake. You may include a sketch.

Lab zone **Technology Lab**

• Tech & Design •

Design a Seismograph

Problem

Can you design and build a seismograph that can record the movements of simulated earthquakes?

Skills Focus

designing, evaluating, troubleshooting

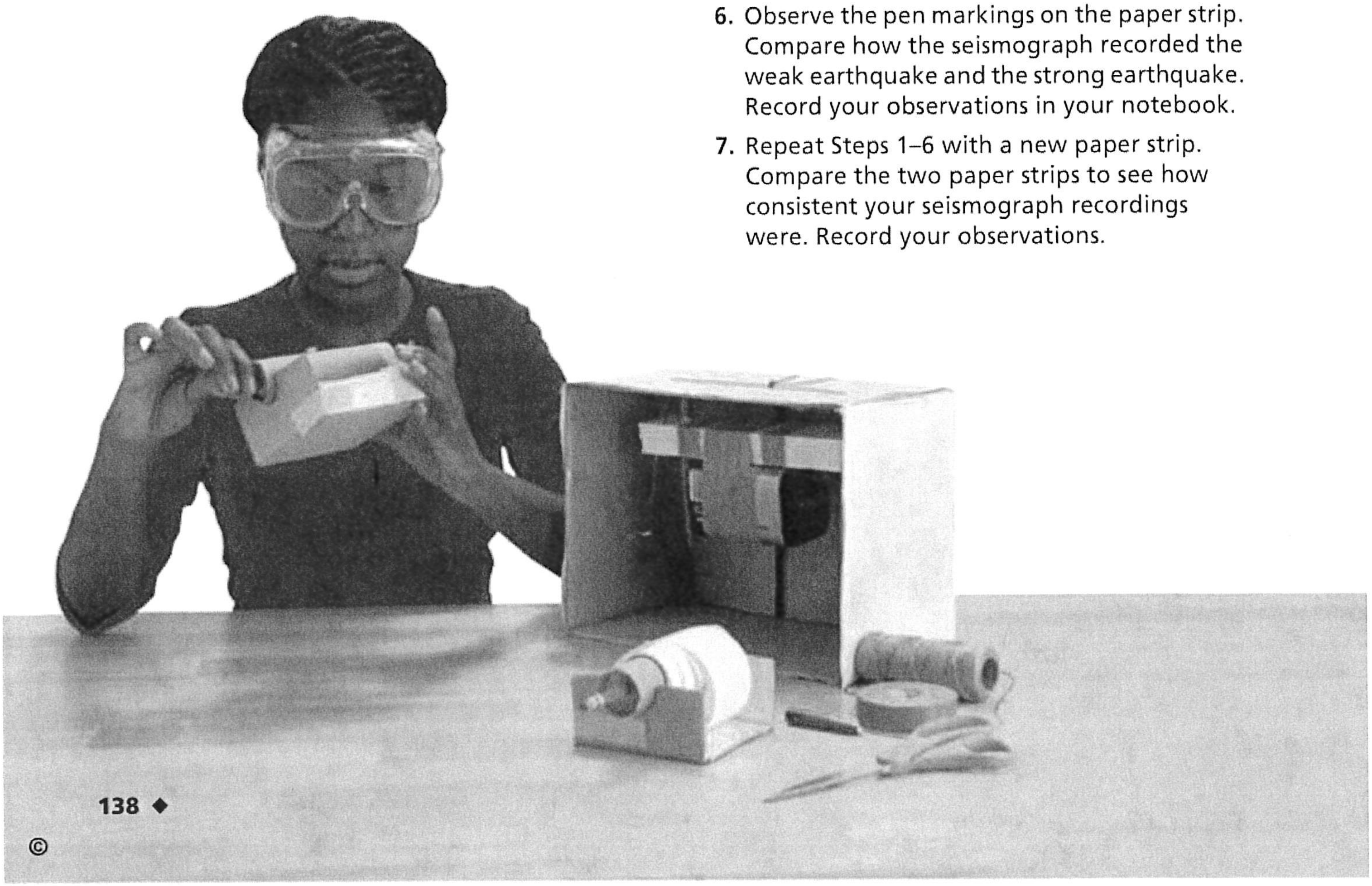
Materials

- large book
- pencil
- pen
- 2 strips of paper
- optional materials provided by your teacher

Procedure

PART 1 Research and Investigate

1. With two lab partners, create a model of a seismograph. Begin by placing a large book on a table.
2. Wind a strip of paper about one meter long around a pencil.
3. Hold the pencil with the paper wound around it in one hand. In your other hand, hold a pen against the paper.
4. As you hold the pen steady, have one lab partner slowly pull on the paper so that it slides across the book.
5. After a few seconds, the other lab partner should jiggle the book gently for 10 seconds to model a weak earthquake, and then for 10 seconds to model a strong earthquake.
6. Observe the pen markings on the paper strip. Compare how the seismograph recorded the weak earthquake and the strong earthquake. Record your observations in your notebook.
7. Repeat Steps 1–6 with a new paper strip. Compare the two paper strips to see how consistent your seismograph recordings were. Record your observations.



PART 2 Design and Build

8. Using what you learned from the seismograph model in Part 1, develop your own design for a seismograph. Your seismograph should be able to
   - record vibrations continuously for 30 seconds
   - produce a seismogram that can distinguish between gentle and strong earthquakes
   - record seismic readings consistently from trial to trial
9. Sketch your design on a sheet of paper. Then make a list of the materials you will need. Materials might include a heavy weight, a roll of paper, a pen, wood blocks, wood dowels, and duct tape.
10. Obtain your teacher's approval for your design. Then construct your seismograph.

PART 3 Evaluate and Redesign

11. Test your seismograph in a series of simulated earthquakes of different strengths. Evaluate how well your seismograph functions. Does it meet the criteria outlined in Step 8? Make note of any problems.
12. Based on your tests, decide how you could improve the design of your seismograph. Then make any necessary changes to your seismograph and test how it functions.

Analyze and Conclude

1. **Evaluating** What problems or shortcomings did you encounter with the seismograph you tested in Part 1? Why do you think these problems occurred?
2. **Designing a Solution** How did you incorporate what you learned in Part 1 into your seismograph design in Part 2? For example, what changes did you make to improve consistency from trial to trial?
3. **Troubleshooting** As you designed, built, and tested your seismograph, what problems did you encounter? How did you solve these problems?
4. **Working With Design Constraints** What limitations did factors such as gravity, materials, costs, time, or other factors place on the design and function of your seismograph? Describe how you adapted your design to work within these limitations.
5. **Evaluating the Impact on Society** Why is it important for scientists around the world to have access to accurate and durable seismographs?

Communicate

Write an advertisement trying to "sell" your seismograph. In your ad, explain how your design and evaluation process helped you improve your seismograph. Include a labeled sketch of your design.

Chapter 4 Study Guide

The BIG Idea

Composition and structure of Earth Plate motions produce stress in Earth's crust that leads to faults, mountain building, and earthquakes.

1 Forces in Earth's Crust

Key Concepts

Tension, compression, and shearing work over millions of years to change the shape and volume of rock.

Faults usually occur along plate boundaries, where the forces of plate motion push or pull the crust so much that the crust breaks. There are three main types of faults: normal faults, reverse faults, and strike-slip faults.

Over millions of years, the forces of plate movement can change a flat plain into landforms such as anticlines and synclines, folded mountains, fault-block mountains, and plateaus.

Key Terms

stress
tension
compression
shearing
normal fault
hanging wall
footwall
reverse fault
strike-slip fault
anticline
syncline
plateau

2 Earthquakes and Seismic Waves

Key Concepts

Seismic waves carry energy from an earthquake away from the focus, through Earth's interior, and across the surface.

Three commonly used ways of measuring earthquakes are the Mercalli scale, the Richter scale, and the moment magnitude scale.

Geologists use seismic waves to locate an earthquake's epicenter.

Key Terms

earthquake
focus
epicenter
P wave
S wave
surface wave
Mercalli scale
magnitude
Richter scale
seismograph
moment magnitude scale

3 Monitoring Earthquakes

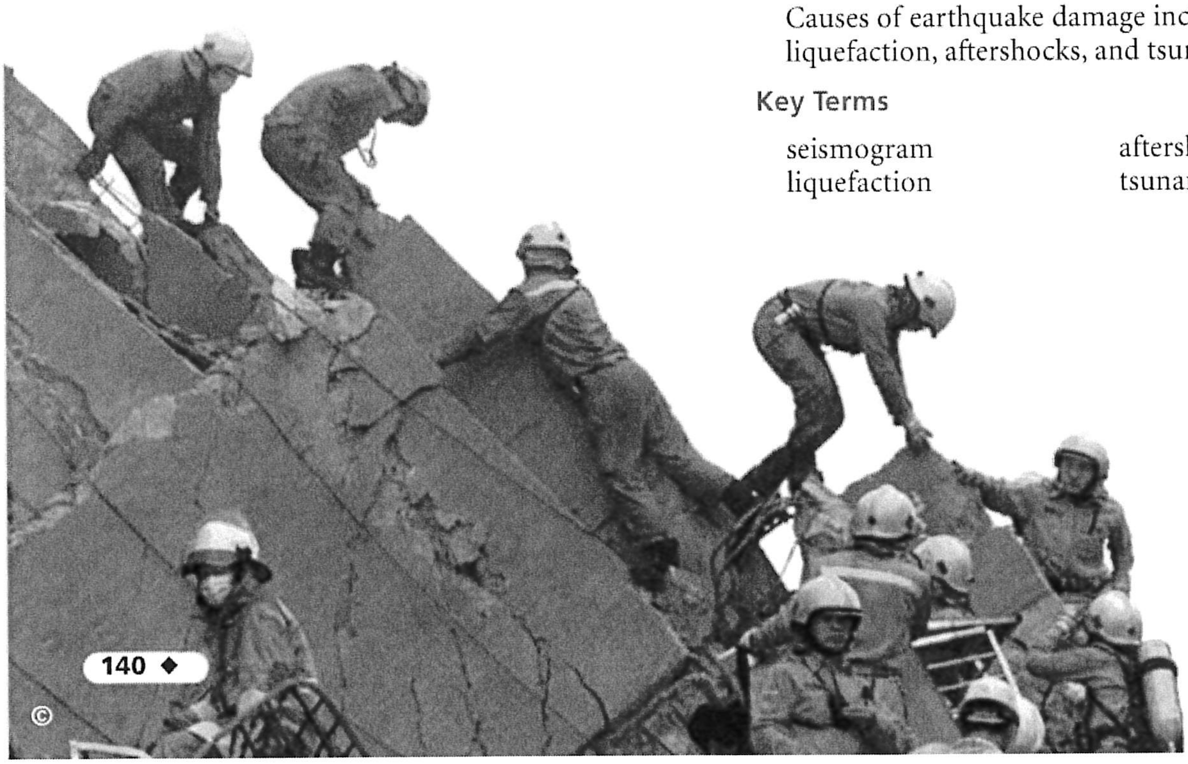
Key Concepts

During an earthquake, seismic waves cause the seismograph's drum to vibrate. But the suspended weight with the pen attached moves very little. Therefore, the pen stays in place and records the drum's vibrations.

Causes of earthquake damage include shaking, liquefaction, aftershocks, and tsunamis.

Key Terms

seismogram
liquefaction
aftershock
tsunami



Review and Assessment

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Organizing Information

Relating Cause and Effect Fill in the cause-and-effect graphic organizer to show how different stress forces produce different kinds of faults.

Cause of Fault		Effect
Compression produces	→	___?___ fault
___?___ produces	→	Normal fault
___?___ produces	→	___?___ fault

Reviewing Key Terms

Choose the letter of the best answer.

HINT
1. The force that causes part of the crust to become shorter and thicker is
   a. tension.
   b. compression.
   c. shearing.
   d. normal force.

HINT
2. When the hanging wall of a fault slips down with respect to the footwall, the result is a
   a. reverse fault.
   b. syncline.
   c. normal fault.
   d. strike-slip fault.

HINT
3. Which of the following is a rating of earthquake damage at a particular location?
   a. moment magnitude scale
   b. focus scale
   c. Mercalli scale
   d. Richter scale

HINT
4. The largest waves on a seismogram are
   a. P waves.
   b. S waves.
   c. surface waves.
   d. tsunamis.

HINT
5. In the hours after an earthquake, people should not go inside a building, even if it appears undamaged, because of
   a. aftershocks.
   b. liquefaction.
   c. tsunamis.
   d. deformation.

If the statement is true, write *true*. If it is false, change the underlined word or words to make the statement true.

6. Liquefaction forces squeeze or pull the rock in Earth's crust. HINT
7. Rock uplifted by normal faults creates fault-block mountains. HINT
8. An earthquake's epicenter is located deep underground. HINT
9. As S waves move through the ground, they cause it to compress and then expand. HINT
10. Tsunamis are triggered by earthquakes originating beneath the ocean floor. HINT

Writing in Science

Cause-and-Effect Paragraph Now that you have learned about the awesome power of earthquakes, write a paragraph about how earthquakes cause damage. Discuss both the natural and human-made factors that contribute to an earthquake's destructive power.

Discovery Channel School

Earthquakes
Video Preview
Video Field Trip
▶ Video Assessment

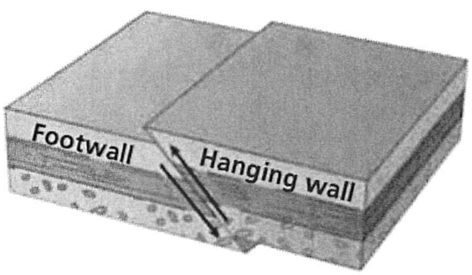
Review and Assessment

Checking Concepts

11. What process causes stress in Earth's crust?
12. Explain how a fault-block mountain forms.
13. What type of stress in the crust results in the formation of folded mountains? Explain.
14. What are plateaus and how do they form?
15. Describe what happens along a fault beneath Earth's surface when an earthquake occurs.
16. How is the amount of energy released by an earthquake related to its magnitude?
17. What does the height of the jagged lines on a seismogram indicate?
18. Explain why the most violent shaking from an earthquake may occur some distance from its epicenter.

Thinking Critically

19. **Classifying** Look at the diagram of a fault below. Describe how the hanging wall moves in relation to the footwall. What kind of fault is this?

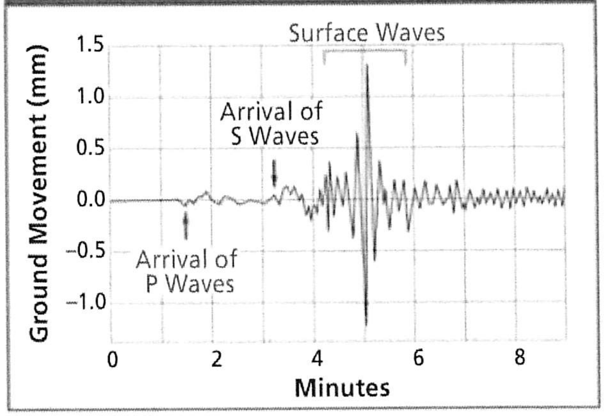


20. **Analyzing Data** A geologist has data about an earthquake from two seismographic stations. Is this enough information to determine the location of the epicenter? Why or why not?
21. **Predicting** A community has just built a street across a strike-slip fault that has frequent earthquakes. How will movement along the fault affect the street?
22. **Making Generalizations** How can filled land and loose, soft soil affect the amount of damage caused by an earthquake? Explain.

Applying Skills

Use the graph to answer Questions 23–26.

Arrival Times of P and S Waves



23. **Interpreting Diagrams** In what order did the seismic waves arrive at the seismograph station?
24. **Interpreting Diagrams** Which type of seismic wave produced the largest ground movement?
25. **Analyzing Data** What was the difference in arrival times for the P waves and S waves?
26. **Predicting** What would the seismogram look like several hours after this earthquake? How would it change if an aftershock occurred?

Lab zone Chapter Project

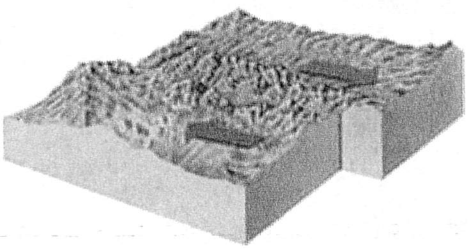
Performance Assessment Before testing how your model withstands an earthquake, explain to your classmates how and why you changed your model. When your model is tested, observe how it withstands the earthquake. How would a real earthquake compare with the method used to test your model? If it were a real building, could your structure withstand an earthquake? How could you improve your model?

Preparing for the CRCT

Test-Taking Tip

When answering questions about diagrams, read all parts of the diagram carefully, including title, captions, and labels. Make sure that you understand the meaning of arrows and other symbols. Determine exactly what the question asks. Then eliminate those answer choices that are not supported by the diagram. Practice answering this question.

Stress in the Crust



Sample Question

The diagram shows how stress affects a mass of rock in a process called

A compression.
B tension.
C squeezing.
D shearing.

Answer

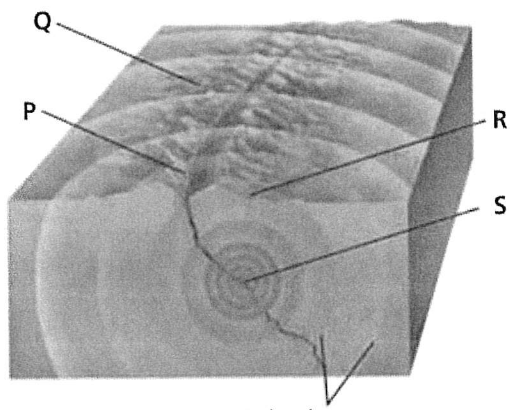
The correct answer is **D** because the arrows show forces pulling the rock in opposite directions.

Choose the letter that best answers the question or completes the statement.

1. Stress will build until an earthquake occurs if friction along a fault is
   A decreasing.
   B high.
   C low.
   D changed to heat. S6E5.d

2. To estimate the total energy released by an earthquake, a geologist should use the
   A Mercalli scale.
   B Richter scale.
   C epicenter scale.
   D moment magnitude scale. S6E5.d

Use the information below and your knowledge of science to answer Questions 3 through 5.



3. In the diagram, the epicenter is located at point
   A Q.
   B P.
   C R.
   D S. S6E5.d

4. When an earthquake occurs, seismic waves travel
   A from P in all directions.
   B from R to S.
   C from S in all directions.
   D from Q to P. S6E5.d

5. At point R, seismic waves from an earthquake would be
   A weaker than at P.
   B likely to cause little damage.
   C weaker than at Q.
   D likely to cause the most damage. S6E5.d

Constructed Response

6. Explain the process that forms a strike-slip fault and leads to an earthquake along the fault. In your answer, discuss the force that causes stress in Earth's crust, the type of stress that produces a strike-slip fault, the characteristics of a strike-slip fault, and what happens before and during the earthquake. S6E5.e