Section 19.3

Objectives

- **Compare and contrast** earthquake magnitude and intensity and the scales used to measure each.
- **Explain** why data from at least three seismic stations are needed to locate an earthquake's epicenter.
- **Describe** Earth's seismic belts.

Review Vocabulary

plot: to mark or note on a map or chart

New Vocabulary

Richter scale
magnitude
amplitude
moment magnitude scale
modified Mercalli scale

Measuring and Locating Earthquakes

MAIN Idea Scientists measure the strength and chart the location of earthquakes using seismic waves.

Real-World Reading Link When someone speaks to you from nearby, you can hear them clearly. However, the sound gets fainter as they get farther away. Similarly, the energy of seismic waves gets weaker the farther away you are from the source of an earthquake.

Earthquake Magnitude and Intensity

More than 1 million earthquakes are felt each year, but news accounts report on only the largest ones. Scientists have developed several methods for describing the size of an earthquake.

Richter scale The **Richter scale,** devised by a geologist named Charles Richter, is a numerical rating system that measures the energy of the largest seismic waves, called the **magnitude,** that are produced during an earthquake. The numbers in the Richter scale are determined by the height, called the **amplitude,** of the largest seismic wave. Each successive number represents an increase in amplitude of a factor of 10. For example, the seismic waves of a magnitude-8 earthquake on the Richter scale are ten times larger than those of a magnitude-7 earthquake. The differences in the amounts of energy released by earthquakes are even greater than the differences between the amplitudes of their waves. Each increase in magnitude corresponds to about a 32-fold increase in seismic energy. Thus, an earthquake of magnitude-8 releases about 32 times the energy of a magnitude-7 earthquake. The damage shown in **Figure 19.13** was caused by an earthquake measuring 7.6 on the Richter scale.

Figure 19.13 The damage shown here was caused by a magnitude-7.6 earthquake that struck Pakistan in December 2005.

■ **Figure 19.14** The modified Mercalli scale measures damage done by an earthquake. An earthquake strong enough to knock groceries off the store's shelves would probably be rated V using the modified Mercalli scale.

Moment magnitude scale While the Richter scale is often used to describe the magnitude of an earthquake, most earthquake scientists, called seismologists, use a scale called the moment magnitude scale. The **moment magnitude scale** is a rating scale that measures the energy released by an earthquake, taking into account the size of the fault rupture, the amount of movement along the fault, and the rocks' stiffness. Most often, when you hear about an earthquake on the news, the number given is from the moment magnitude scale.

Modified Mercalli scale Another way to describe earthquakes is with respect to the amount of damage they cause. This measure, called the intensity of an earthquake, is determined using the **modified Mercalli scale,** which rates the types of damage and other effects of an earthquake as noted by observers during and after its occurrence. This scale uses the Roman numerals I to XII to designate the degree of intensity. Specific effects or damage correspond to specific numerals; the worse the damage, the higher the numeral. A simplified version of the modified Mercalli scale is shown in **Table 19.2.** You can use the information given in this scale to rate the intensity of the earthquakes such as the one that caused the damage shown in **Figure 19.14.**

Concepts In Motion

Interactive Table To explore more about the modified Mercalli scale, visit glencoe.com.

Table 19.2 Modified Mercalli Scale

I	Not felt except under unusual conditions
II	Felt only by a few persons; suspended objects might swing.
III	Quite noticeable indoors; vibrations are like the passing of a truck.
IV	Felt indoors by many, outdoors by few; dishes and windows rattle; standing cars rock noticeably.
V	Felt by nearly everyone; some dishes and windows break and some plaster cracks.
VI	Felt by all; furniture moves; some plaster falls and some chimneys are damaged.
VII	Everybody runs outdoors; some chimneys break; damage is slight in well-built structures but considerable in weak structures.
VIII	Chimneys, smokestacks, and walls fall; heavy furniture is overturned; partial collapse of ordinary buildings occurs.
IX	Great general damage occurs; buildings shift off foundations; ground cracks; underground pipes break.
X	Most ordinary structures are destroyed; rails are bent; landslides are common.
XI	Few structures remain standing; bridges are destroyed; railroad ties are greatly bent; broad fissures form in the ground.
XII	Damage is total; objects are thrown upward into the air.

Earthquake intensity The intensity of an earthquake depends primarily on the amplitude of the surface waves generated. Like body waves, surface waves gradually decrease in size with increasing distance from the focus of an earthquake. Because of this, the intensity also decreases as the distance from a earthquake's epicenter increases. Maximum intensity values are observed in the region near the epicenter; Mercalli values decrease to I at distances far from the epicenter.

In the MiniLab, you will use the modified Mercalli scale values to make a seismic-intensity map. These maps are a visual demonstration of an earthquake's intensity. Contour lines join points that experienced the same intensity. They demonstrate how the maximum intensity is usually found near the earthquake's epicenter.

Depth of focus As you learned earlier in this section, earthquake intensity and magnitude reflect the size of the seismic waves generated by the earthquake. Another factor that determines the intensity of an earthquake is the depth of its focus. As shown in **Figure 19.15,** earthquakes can be classified as shallow, intermediate, or deep, depending on the location of the focus. Catastrophic earthquakes with high intensity values are almost always shallow-focus events.

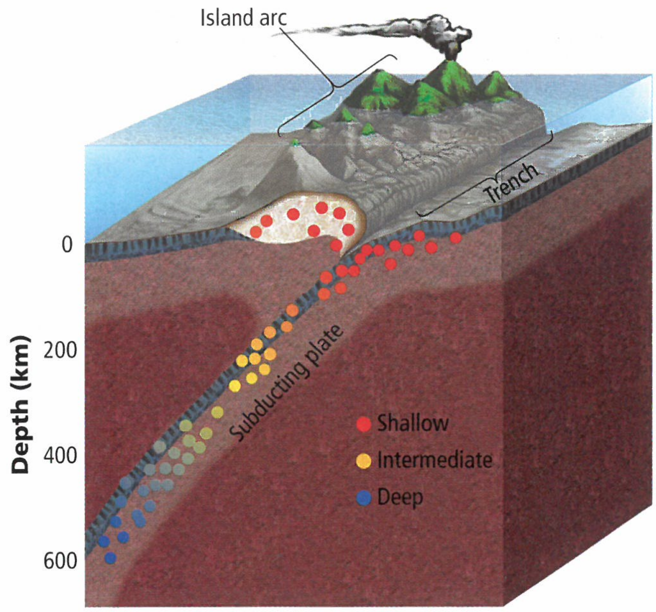


Figure 19.15 Earthquakes are classified as shallow, intermediate, or deep, depending on the location of the focus. Shallow-focus earthquakes are the most damaging.

MiniLab

Make a Map

How is a seismic-intensity map made? Seismic-intensity data plotted on contour maps give scientists a visual picture of an epicenter's location and the earthquake's intensity.

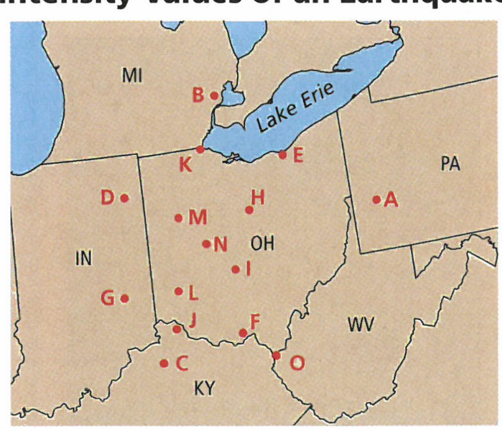
Procedure

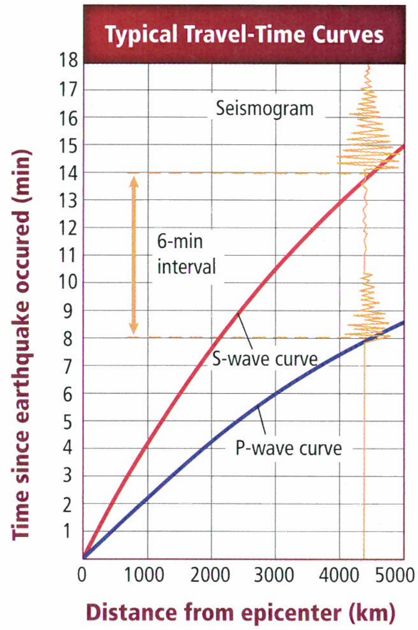
1. Read and complete the lab safety form.
2. Trace the map onto **paper.** Mark the locations indicated by the letters on the map.
3. Plot these Mercalli intensity values on the map next to the correct letter: A, I; B, III; C, II; D, III; E, IV; F, IV; G, IV; H, V; I, V; J, V; K, VI; L, VIII; M, VII; N, VIII; O, III.
4. Draw contours on the map to connect the intensity values.

Analysis

1. **Determine** the maximum intensity value.
2. **Find** the location of the maximum intensity value.
3. **Estimate** the earthquake's epicenter.

Intensity Values of an Earthquake





■ **Figure 19.16** This travel-time curve also shows seismographic data for an earthquake event.

Deep-focus earthquakes generally produce smaller vibrations at the epicenter than those produced by shallow-focus earthquakes. For example, a shallow-focus, moderate earthquake that measures a magnitude-6 on the Richter scale can generate a greater maximum intensity than a deep-focus earthquake of magnitude-8. Because the modified Mercalli scale is based on intensity rather than magnitude, it is a better measure of an earthquake's effect on people.

Locating an Earthquake

The location of an earthquake's epicenter and the time of the earthquake's occurrence are usually not known at first. However, the epicenter's location, as well as the time of occurrence, can be determined using seismograms and travel-time curves.

Distance to an earthquake Just as a person riding a bike will travel faster than a person who is walking, P-waves reach a seismograph station before the S-waves. Consider the effect of the distance traveled on the time it takes for both waves to arrive. Like the bicyclist and the walker, the gap in their arrival times will be greater when the distance traveled is longer. **Figure 19.16** shows the same travel-time curve graph shown in **Figure 19.9** of Section 19.2, but this time it is joined with the seismogram from a specific earthquake. The seismometer recorded the time that elapsed between the arrival of the first P-waves and first S-waves. Seismologists determine the distance to an earthquake's epicenter by measuring the separation on any seismogram and identifying that same separation time on the travel-time graph. The separation time for the earthquake shown in **Figure 19.16** is 6 min. Based on travel times of seismic waves, the distance between the earthquake's epicenter and the seismic station that recorded the waves can only be 4500 km. This is because the known travel time over that distance is 8 min for P-waves and 14 min for S-waves. Farther from the epicenter, the gap between the travel times for both waves increases.

Reading Check **Apply** If the gap between P- and S-waves is 2 min, what can you infer about the distance from the epicenter to the seismometer?

■ **Figure 19.17** To locate the epicenter of an earthquake, scientists identify the seismic stations on a map, and draw a circle with the radius of distance to the epicenter from each station. The point where all the circles intersect is the epicenter.
Identify *the epicenter of this earthquake.*

Seismologists analyze data from many seismograms to locate the epicenter. Calculating the distance between an earthquake's epicenter and a seismic station provides enough information to determine that the epicenter was a certain distance in any direction from the seismic station. This can be represented by a circle around the seismic station with a radius equal to the distance to the epicenter. Consider the effect of adding data from a second seismic station. The two circles will overlap at two points. When data from a third seismic station is added, the rings will overlap only at one point—the epicenter, as shown in **Figure 19.17.**

Time of an earthquake The gap in the arrival times of different seismic waves on a seismogram provides information about the distance to the epicenter. Seismologists can also use the seismogram to gain information about the exact time that the earthquake occurred at the focus. The time can be determined by using a table similar to the travel-time graph shown in **Figure 19.9.** The exact arrival times of the P-waves and S-waves at a seismic station are recorded on the seismogram. Seismologists read the travel time of either wave to the epicenter from that station using graphs similar to the one shown in **Figure 19.9.** For example, consider a seimogram that registered the arrival of P-waves at exactly 10:00 A.M. If the P-waves traveled 4500 km, and took 8 min according to the appropriate travel-time curve, then it can be determined that the earthquake occurred at the focus at 9:52 A.M.

Reading Check **List** the information contained in a seismogram.

Seismic Belts

Over the years, seismologists have collected and plotted the locations of numerous earthquake epicenters. The global distribution of these epicenters reveals a noteworthy pattern. Earthquake locations are not randomly distributed. The majority of the world's earthquakes occur along narrow seismic belts that separate large regions with little or no seismic activity.

DATA ANALYSIS LAB

Based on Real Data*

Interpret the Data

How can you find an earthquake's epicenter? To pinpoint the epicenter, analyze the P-wave and S-wave data recorded at seismic stations.

Analysis

1. Obtain a map of the western hemisphere from your teacher and mark the seismic stations listed in the table.
2. For each station, calculate and record the arrival time differences by subtracting the P-wave arrival time from the S-wave arrival times.
3. Use the arrival time differences and the travel-time curve **(Figure 19.9)** to find the distance between the epicenter and each seismic station. Record the distances.
4. Draw a circle around each station. Use the distance from the epicenter as the radius for each circle. Repeat for each seismic station.
5. Identify the epicenter of the earthquake.

Data and Observations

Seismic Station	P-wave Arrival Time (PST)	S-wave Arrival Time (PST)	Arrival Time Difference (min)	Distance from Epicenter (km)
Newcomb, NY	8:39:02	8:44:02		
Idaho Springs, CO	8:35:22	8:37:57		
Darwin, CA	8:35:38	8:38:17		

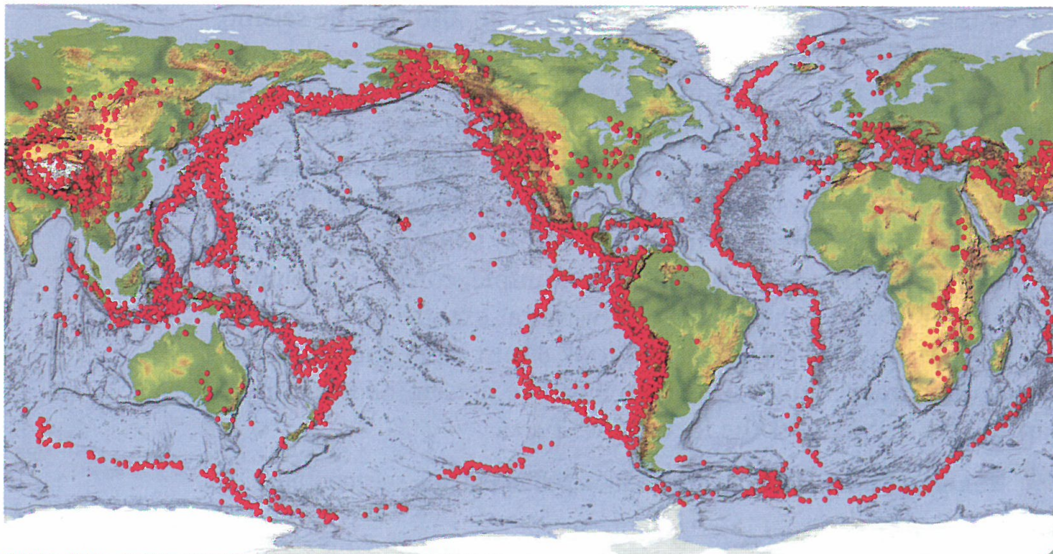
Think Critically

6. **Explain** why you need to find the difference in time of arrival between P- and S-waves for each seismic station.
7. **Identify** sources of error in determining an earthquake's epicenter.
8. **Explain** why data from more seismic stations would be useful for finding the epicenter.

*Data obtained from: Significant earthquakes of the world. 2006. *USGS Earthquake Center.*

Figure 19.18 Notice the pattern of global epicenter locations on the map.
Identify *Based on this map, do you live near an epicenter?*

Global Earthquake Epicenter Locations



As shown in **Figure 19.18,** earthquakes occur in narrow bands. The locations of most earthquakes correspond closely with tectonic plate boundaries. In fact, almost 80 percent of all earthquakes occur on the Circum-Pacific Belt and about 15 percent on the Mediterranean-Asian Belt across southern Europe and Asia. These belts are subduction zones, where tectonic plates are colliding and one plate is forced to sink beneath another. Most of the remaining earthquakes occur in narrow bands along the crests of ocean ridges, where tectonic plates are diverging.

Section 19.3 Assessment

Section Summary

- Earthquake magnitude is a measure of the energy released during an earthquake and can be measured on the Richter scale.
- Intensity is a measure of the damage caused by an earthquake and is measured with the modified Mercalli scale.
- Data from at least three seismic stations are needed to locate an earthquake's epicenter.
- Most earthquakes occur in seismic belts, which are areas associated with plate boundaries.

Understand Main Ideas

1. MAIN Idea **Summarize** the ways that scientists can use seismic waves to measure and locate earthquakes.
2. **Compare and contrast** earthquake magnitude and intensity and the scales used to measure each.
3. **Explain** why data from at least three seismic stations makes it possible to locate an earthquake's epicenter.
4. **Describe** how the boundaries between Earth's tectonic plates compare with the location of most of the earthquakes shown in the map in **Figure 19.18.**

Think Critically

5. **Formulate** a reason why a magnitude-3 earthquake can possibly cause more damage than a magnitude-6 earthquake.

MATH in Earth Science

6. Calculate how much more energy a magnitude-9 earthquake releases compared to that of a magnitude-7 earthquake.

Earth Science Online Self-Check Quiz glencoe.com