EXERCISE 8

Earthquakes and Earth's Interior

Almost all of Earth lies beneath us, yet its accessibility to direct examination is limited. Therefore, one of the most difficult problems faced by Earth scientists is determining the physical properties of Earth's interior. The branch of Earth science called **seismology** combines mathematics and physics to explain the nature of earthquakes and how they can be used to gather information about Earth beyond our view. This exercise introduces some of the techniques that are used by seismologists to determine the location of an earthquake and to investigate the structure of Earth's interior.

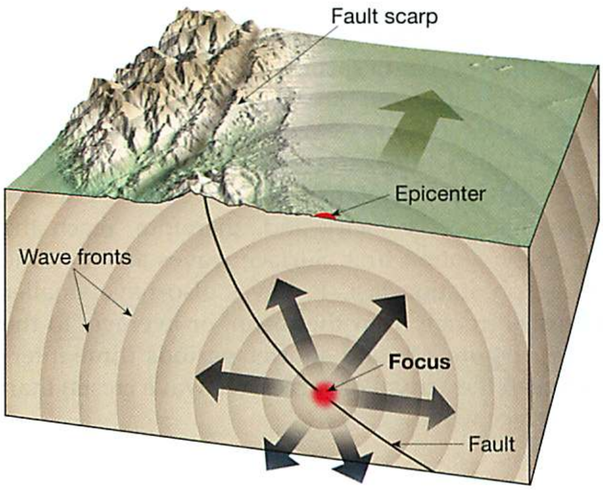

Figure 8.1 Earthquake focus and epicenter. The focus is the zone within Earth where the initial displacement occurs. The epicenter is the surface location directly above the focus.

Objectives

After you have completed this exercise, you should be able to:

1. Examine an earthquake seismogram and recognize the P waves, S waves, and surface waves.
2. Use a seismogram and travel-time graph to determine how far a seismic station is from the epicenter of an earthquake.
3. Determine the actual time that an earthquake occurred using a seismogram and travel-time graph.
4. Locate the epicenter of an earthquake by plotting seismic data from three seismic stations.
5. Explain how earthquakes are used to determine the structure of Earth's interior.
6. List the name, depth, composition, and state of matter of each of Earth's interior zones.
7. Describe the temperature gradient of the upper Earth.
8. Explain why Earth scientists think that the asthenosphere consists of partly melted, plastic material at a depth of about 100 kilometers.
9. Explain how earthquakes and Earth's temperature gradient have been used to explain the fact that large, rigid slabs of the lithosphere are descending into the mantle at various locations on Earth.

Materials

calculator
drawing compass
colored pencils
ruler

Materials Supplied by Your Instructor

atlas or wall map

Terms

seismology
lithosphere
focus
seismic wave
seismograph
seismogram
P wave
S wave
surface wave
amplitude
period
epicenter
asthenosphere
mantle
outer core
inner core
geothermal gradient

Earthquakes

Earthquakes are vibrations of Earth that occur when the rigid materials of the **lithosphere** are strained beyond their limit, yield, and "spring back" to their original shape, rapidly releasing stored energy. This energy radiates in all directions from the source of the earthquake, called the **focus**, in the form of **seismic waves**. (Figure 8.1). **Seismograph** instruments (Figure 8.2) located throughout the world amplify and record the ground motions produced by passing seismic waves on **seismograms** (Figure 8.3). The seismograms are then used to determine the time of occurrence and location of an earthquake, as well as to define the internal structure of Earth.

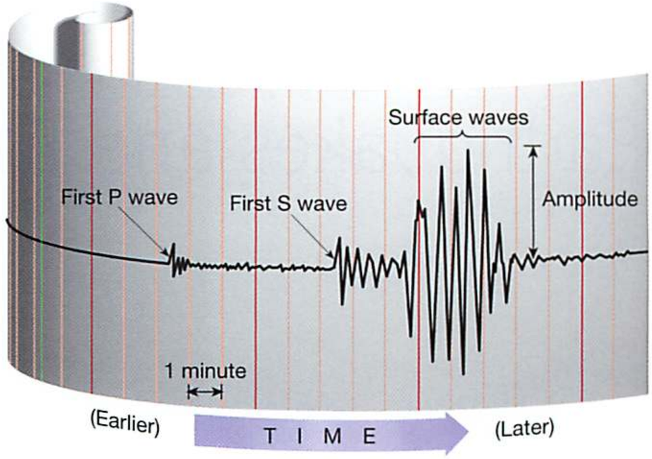

Figure 8.3 Typical earthquake seismogram.

Examining Seismograms

The three basic types of seismic waves generated by an earthquake at its focus are **P waves**, **S waves**, and **surface waves** (Figure 8.4). P and S waves travel through Earth while surface waves are transmitted along the outer layer. Of the three wave types, P waves have the greatest velocity and, therefore, reach the seismograph station first. Surface waves arrive at the seismograph station last. P waves also have smaller **amplitudes** (range from the mean, or average, to the extreme) (Figure 8.3) and shorter **periods** (time interval between the arrival of successive wave crests) than S and surface waves.

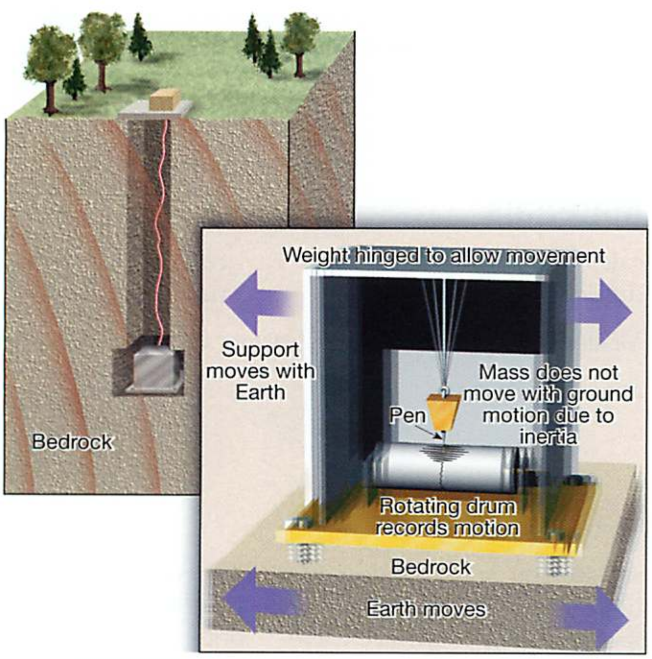

Figure 8.2 Principle of the seismograph. The inertia of the suspended mass tends to keep it motionless, while the recording drum, which is anchored to bedrock, vibrates in response to seismic waves.

On Figure 8.3, a typical earthquake recording on a seismogram, each vertical line marks a one-minute time interval. Answer questions 1–6 by referring to Figure 8.3.

1. It took approximately (5, 7, 11) minutes to record the entire earthquake from the first recording of the P waves to the end of the surface waves. Circle your answer.
2. (Five, Seven) minutes elapsed between the arrival of the first P wave and the arrival of the first S wave on the seismogram. Circle your answer.
3. (Five, Seven) minutes elapsed between the arrival of the first P wave and the first surface wave.
4. The maximum amplitude of the surface waves is approximately (5, 9) times greater than the maximum amplitude of the P waves.
5. The approximate period of the surface waves is (10, 30, 60) seconds.
6. The period of the surface waves is (greater, less) than the period for P waves.

Locating an Earthquake

The focus of an earthquake is the actual place within Earth where the earthquake originates. Earthquake foci have been recorded to depths as great as 600 km. When locating an earthquake on a map, seismologists plot the **epicenter**, the point on Earth's surface directly above the focus (Figure 8.1).

The difference in the velocities of P and S waves provides a method for locating the epicenter of an earthquake. Both P and S waves leave the earthquake focus at the same instant. Since the P wave has a greater velocity, the further away the recording instrument is from the focus, the greater will be the difference in the arrival times of the first P wave compared to the first S wave.

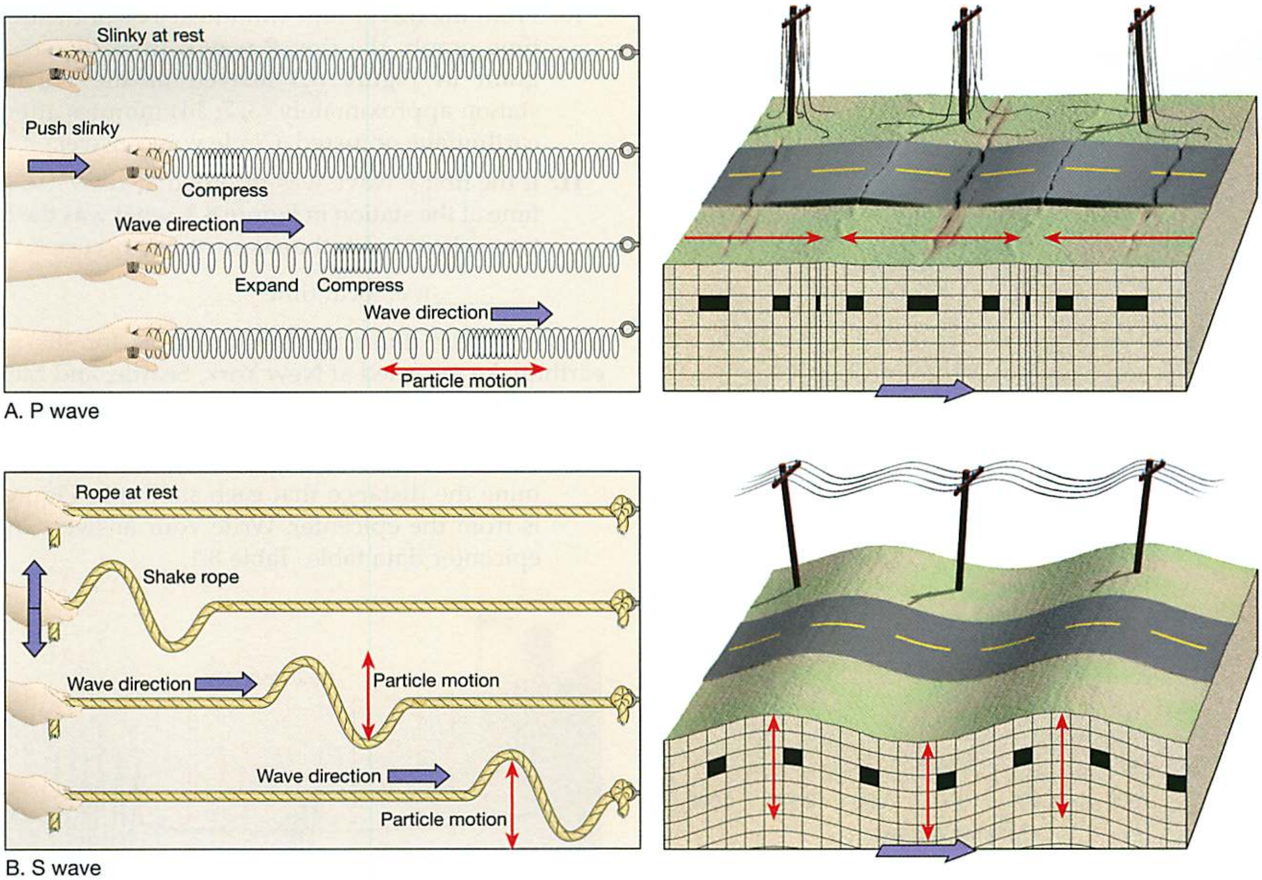

Figure 8.4 Types of seismic waves and their characteristic motion. (Note that during a strong earthquake, ground shaking consists of a combination of various kinds of seismic waves.) **A.** As illustrated by a slinky, P waves are compressional waves that alternately compress and expand the material through which they pass. The back-and-forth motion produced as compressional waves travel along the surface can cause the ground to buckle and fracture, and may cause power lines to break **B.** S waves cause material to oscillate at right angles to the direction of wave motion. Because S waves can travel in any plane, they produce up-and-down and sideways shaking of the ground.

To determine the distance between a recording station and an earthquake epicenter, find the place on the travel-time graph, Figure 8.5, where the vertical separation between the P and S curves is equal to the number of minutes difference in the arrival times between the first P and first S waves on the seismogram. From this position, a vertical line is drawn that extends to the top or bottom of the graph and the distance to the epicenter is read.

To accurately locate an earthquake epicenter, records from three different seismograph stations are needed. First, the distance that each station is from the epicenter is determined using Figure 8.5. Then, for each station, a circle centered on the station with a radius equal to the station's distance from the epicenter is drawn. The geographic point where all three circles, one for each station, intersect is the earthquake epicenter (Figure 8.6).

Answering questions 7–16 will help you understand the process used to determine an earthquake epicenter.

7. An examination of Figure 8.5 shows that the difference in the arrival times of the first P and the first S waves on a seismogram (increases, decreases), the farther a station is from the epicenter. Circle your answer.

8. Use Figure 8.5 to determine the difference in arrival times (in minutes) between the first P wave and first S wave for stations that are the following distances from an epicenter.

1,000 miles: ____________ minutes difference

2,400 km: ____________ minutes difference

3,000 miles: ____________ minutes difference

On the seismogram in Figure 8.3, you determined the difference in the arrival times between the first P and the first S waves to be five minutes.

9. Refer to the travel-time graph. What is the distance from the epicenter to the station that recorded the earthquake in Figure 8.3?

____________ miles

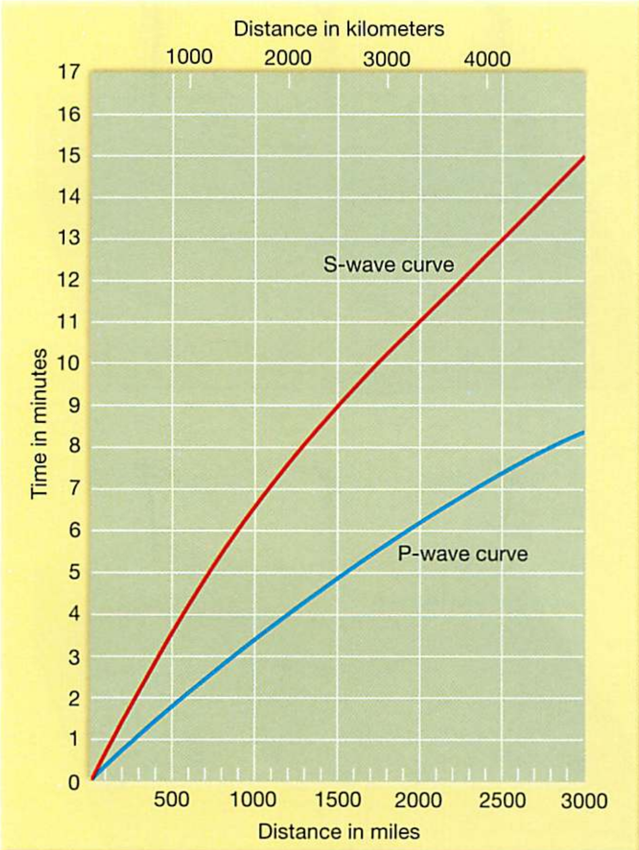

Figure 8.5 Travel-time graph used to determine distance to an earthquake epicenter.

Figure 8.6 An earthquake epicenter is located using the distances obtained from three or more seismic stations.

10. From the travel-time (minutes) axis of the travel-time graph, the first P waves from the seismogram in Figure 8.3 arrived at the recording station approximately (3, 7, 14) minutes after the earthquake occurred. Circle your answer.

11. If the first P wave was recorded at 10:39 P.M. local time at the station in Figure 8.3, what was the local time when the earthquake actually occurred?

    _______ P.M. local time

Figure 8.7 illustrates seismograms for the same earthquake recorded at New York, Seattle, and Mexico City. Use this information to answer questions 12–16.

12. Use the travel-time graph, Figure 8.5, to determine the distance that each station in Figure 8.7 is from the epicenter. Write your answers in the epicenter data table, Table 8.1.

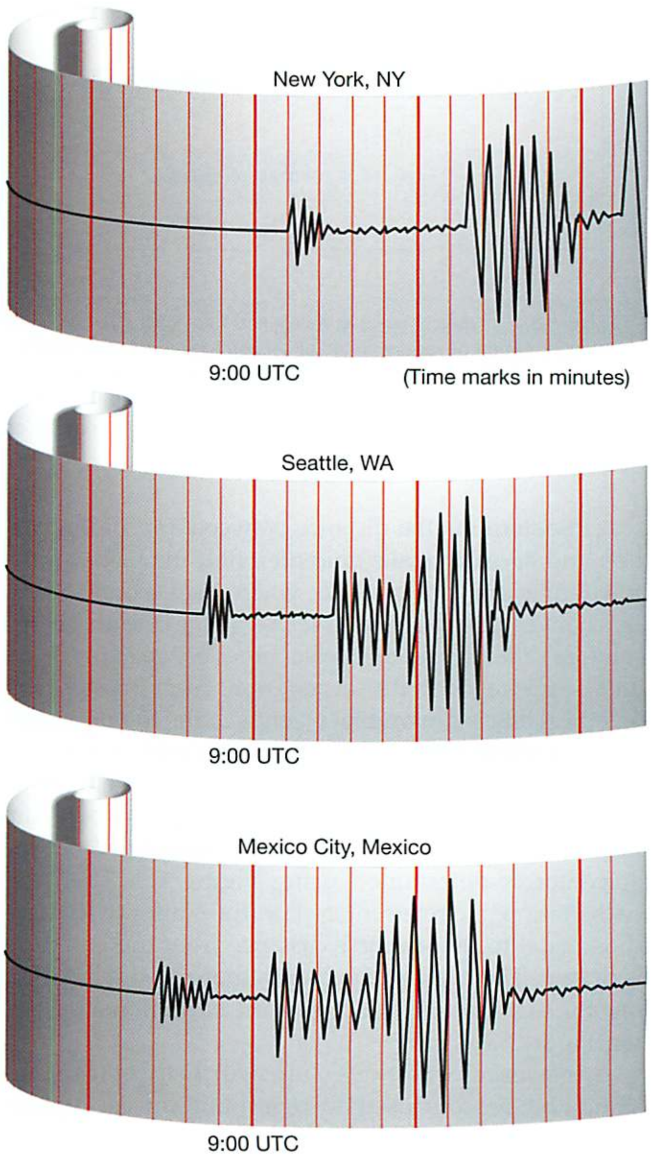

Figure 8.7 Three seismograms of the same earthquake recorded at three different locations.

Table 8.1 Epicenter Data Table

	NEW YORK	SEATTLE	MEXICO CITY
Elapsed time between first P and first S waves			
Distance from epicenter in miles			

13. After referring to an atlas or wall map, accurately place a small dot showing the location of each of the three stations on the map provided in Figure 8.8. Also label each of the three cities.

14. On Figure 8.8, use a drawing compass to draw a circle around each of the three stations with a radius, in miles, equal to its distance from the epicenter. (*Note:* Use the distance scale provided on the map to set the distance on the drawing compass for each station.)

15. What is the approximate latitude and longitude of the epicenter of the earthquake that was recorded by the three stations?

_________ latitude and _________ longitude

16. Note on the seismograms that the first P wave was recorded in New York at 9:01 Coordinated Universal Time (UTC, the international standard on which most nations base their civil time). At what time (UTC) did the earthquake actually occur?

______ UTC

Global Distribution of Earthquakes

Earth scientists have determined that the global distribution of earthquakes is not random but follows a few relatively narrow belts that wind around Earth. Figure 8.9 illustrates the world distribution of earthquakes for a period of several years. Use the figure to answer questions 17 and 18.

17. With what Earth feature is each of the following earthquake belts associated?

Western and southern Pacific Ocean basin: _____

____

Western South America: ______________________

____

Mid-Atlantic Ocean basin: ____________________

____

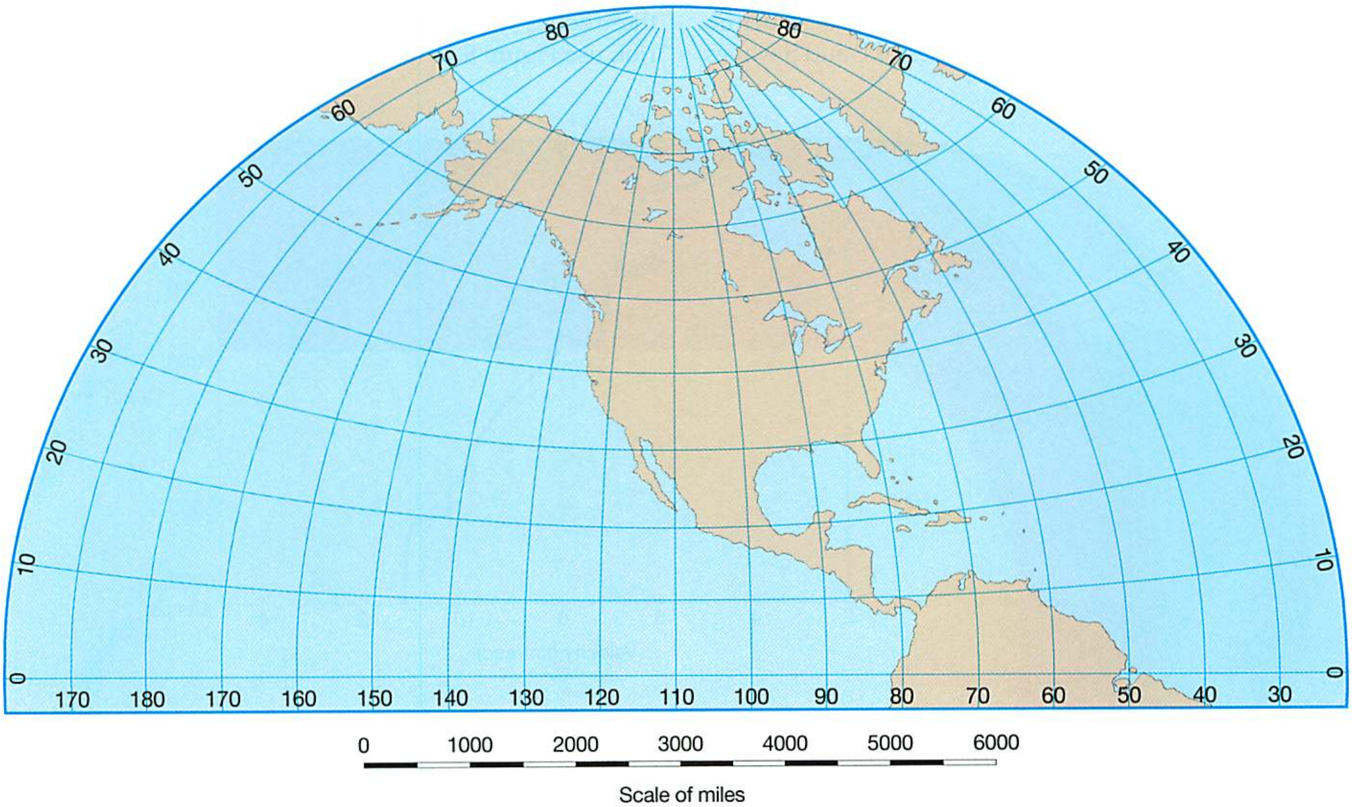

Figure 8.8 Map for locating an earthquake epicenter.

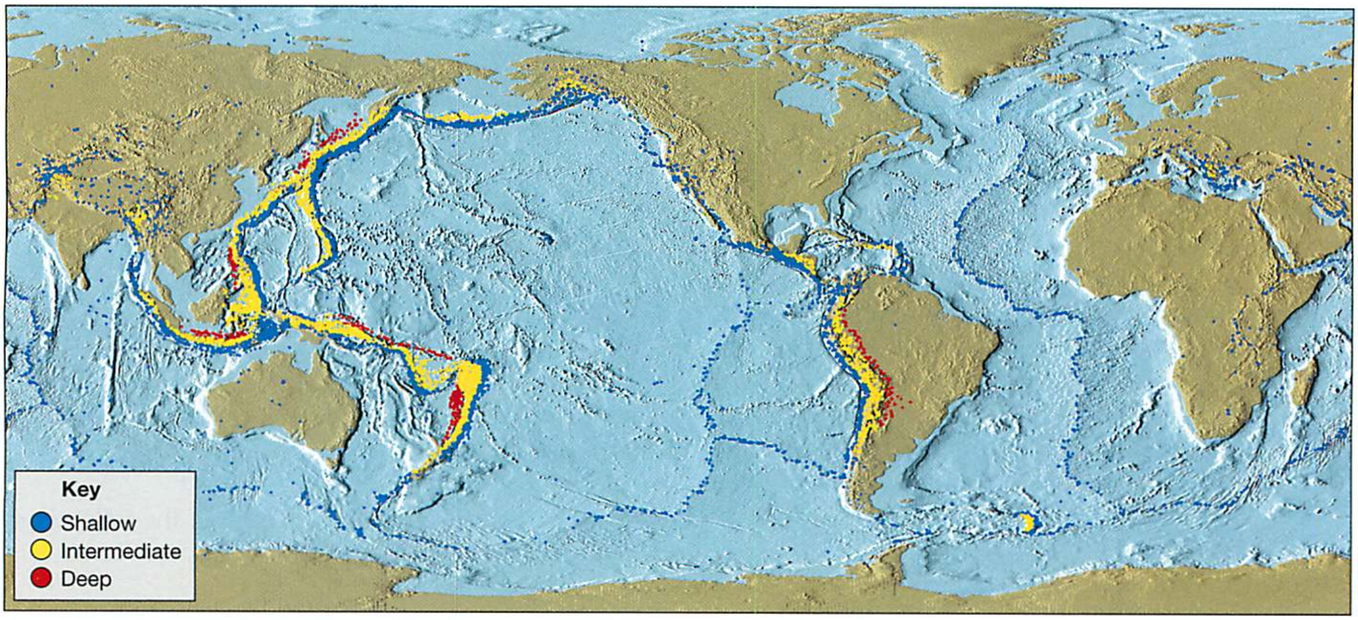

Figure 8.9 World distribution of shallow-, intermediate-, and deep-focus earthquakes. (Data from NOAA)

18. The belts of earthquake activity follow closely the boundaries of what Earth phenomenon?

____

The Earth Beyond Our View

The study of earthquakes has contributed greatly to Earth scientists' understanding of the internal structure of Earth. Variations in the travel times of P and S waves as they journey through Earth provide scientists with an indication of changes in rock properties. Also, since S waves cannot travel through fluids, the fact that they are not present in seismic waves that penetrate deep into Earth suggests a fluid zone near Earth's center.

In addition to the lithosphere, the other major zones of Earth's interior include the **asthenosphere**, **mantle**, **outer core**, and **inner core**. After you have reviewed these zones and the general structure of the Earth's interior, use Figure 8.10 to answer questions 19–24.

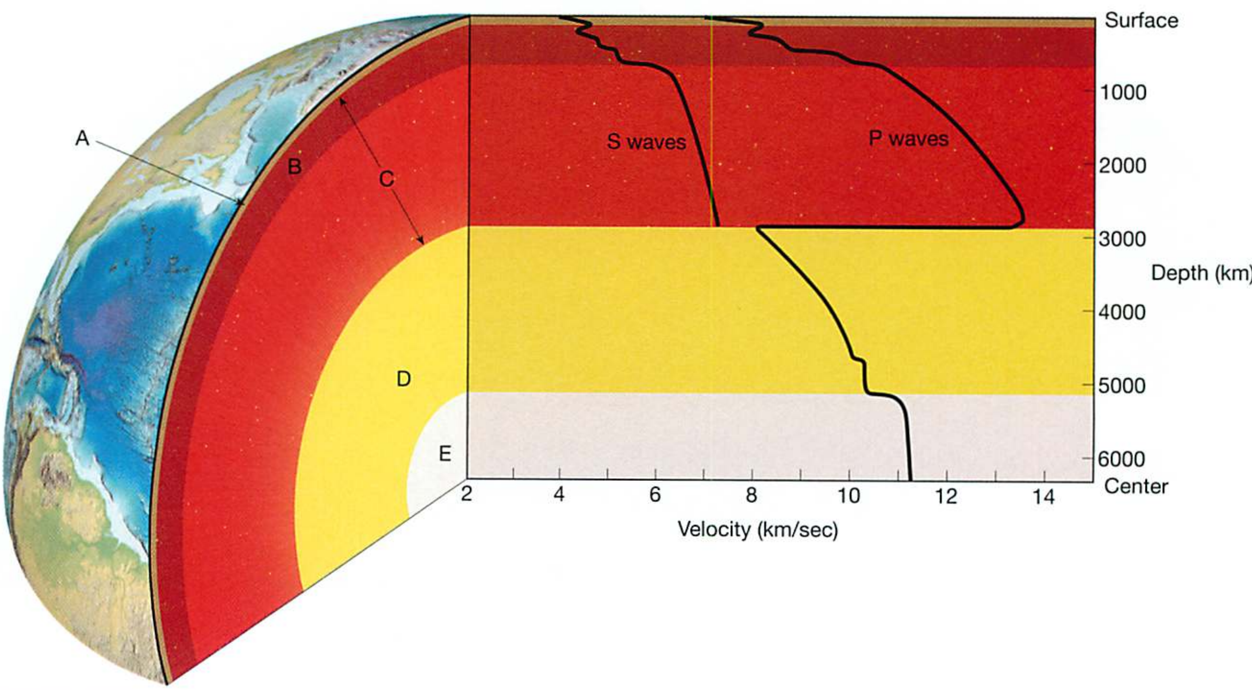

Figure 8.10 Earth's interior with variations in P and S wave velocities. (Data from Bruce A. Bolt)

19. The layer labeled A on Figure 8.10 is the solid, rigid, upper zone of Earth that extends from the surface to a depth of about (100, 500, 1,000) kilometers. Circle your answer.

a. Zone A is called the (core, mantle, lithosphere).

b. What are the approximate velocities of P and S waves in zone A?

P wave velocity: ______________ km/sec

S wave velocity: ______________ km/sec

c. The velocity of both P and S waves (increases, decreases) with increased depth in zone A. Circle your answer.

d. List the two parts of Earth's *crust* that are included in zone A and briefly describe the composition of each.

1) ________: ______________________

____

2) ________: ______________________

____

20. Zone B is the part of Earth's upper mantle that extends from the base of zone A to a depth of up to about (180, 660, 2,250) kilometers in some regions of Earth. Circle your answer.

a. Zone B is called the (crust, asthenosphere, core).

b. The velocity of P and S waves (increases, decreases) immediately below zone A in the upper part of zone B.

c. The change in velocity of the S waves in zone B indicates that it (is, is not) similar to zone A.

21. Zone C (which includes the lower part of zone A and zone B) extends to a depth of

__________ kilometers.

a. Zone C is called Earth's ______________.

b. What fact concerning S waves indicates that zone C is not liquid?

____

____

c. What is the probable composition of zone C?

____

22. Zone D extends from 2,885 km to about (5,100, 6,100) kilometers.

a. Zone D is Earth's __________ __________.

b. What happens to S waves when they reach zone D, and what does this indicate about the zone?

____

____

____

____

c. The velocity of P waves (increases, decreases) as they enter zone D. Circle your answer.

23. Zone E is Earth's __________ __________.

a. Zone E extends from a depth of _____ km to the __________ of Earth.

b. What change in velocity do P waves exhibit at the top of zone E, and what does this suggest about the zone?

____

____

____

____

c. What is the probable composition of Earth's core?

____

____

24. Label Figure 8.10 by writing the name of each interior zone at the appropriate letter.

Earth's Internal Temperature

Measurements of temperatures in wells and mines have shown that Earth's temperatures increase with depth. The rate of temperature increase is called the **geothermal gradient.** Although the geothermal gradient varies from place to place, it is possible to calculate an average. Table 8.2 shows an idealized average temperature gradient for the upper Earth compiled from many different sources. Use the information in Table 8.2 to answer questions 25–29.

Table 8.2 Idealized Internal Temperatures of Earth Compiled from Several Sources

DEPTH (KILOMETERS)	TEMPERATURE (°C)
0	20°
25	600°
50	1000°
75	1250°
100	1400°
150	1700°
200	1800°

Table 8.3 Melting Temperatures of Granite (with water) and Basalt at Various Depths within Earth

GRANITE (WITH WATER)		BASALT	
DEPTH (KM)	MELTING TEMP. (°C)	DEPTH (KM)	MELTING TEMP. (°C)
0	950°	0	1100°
5	700°	25	1160°
10	660°	50	1250°
20	625°	100	1400°
40	600°	150	1600°

25. Plot the temperature values from Table 8.2 on the graph in Figure 8.11. Then draw a single line that fits the pattern of points from the surface to 200 km. Label the line "temperature gradient."
26. Refer to the graph in Figure 8.11. The rate of increase of Earth's internal temperature (is constant, changes) with increasing depth. Circle your answer.
27. The rate of temperature increase from the surface to 100 km is (greater, less) than the rate of increase below 100 km.
28. The temperature at the base of the lithosphere, which is about 100 kilometers below the surface, is approximately (600, 1,400, 1,800) degrees Celsius.
29. Use the data and graph to calculate the average temperature gradient (temperature change per unit of depth) for the upper 100 km of Earth in °C/100 km and °C/km.

    °C/100 km: __________, °C/km: __________

Melting Temperatures of Rocks

Geologists have always been concerned with the conditions required for pockets of molten rock (magma) to form near the surface, as well as at what depth within Earth a general melting of rock may occur. The melting temperature of a rock changes as pressure increases deeper within Earth. The approximate melting points of the igneous rocks, granite and basalt, under various pressures (depths) have been determined in the laboratory and are shown in Table 8.3. Granite and basalt have been selected because they are the common materials of the upper Earth. Use the data in Table 8.3 to answer questions 30–35.

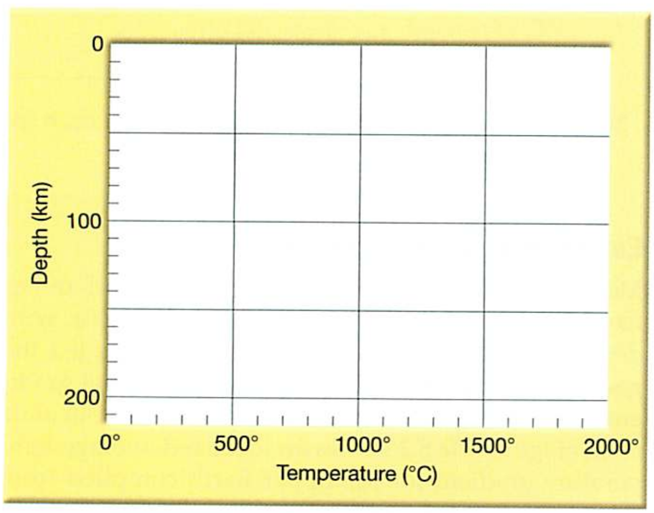

Figure 8.11 Graph for plotting temperature curves.

30. Plot the melting temperature data from Table 8.3 on the Earth's internal temperature graph you have prepared in Figure 8.11. Draw a different colored line for each set of points and label them "melting curve for wet granite" and "melting curve for basalt."

Use the graphs you have drawn in Figure 8.11 to help answer questions 31–33.

31. Assume your Earth temperature gradient is accurate. At approximately what depth within Earth would wet granite reach its melting temperature and form granitic magma?

    __________ km within Earth

32. Evidence suggests that the oceanic crust and the remaining lithosphere down to a depth of about 100 km are similar in composition to basalt. The melting curve for basalt indicates that the lithosphere above approximately 100 km (has, has not) reached the melting temperature for basalt and therefore should be (solid, molten). Circle your answers.
33. Figure 8.11 indicates that basalt reaches its melting temperature within Earth at a depth of approximately ________ km. (Solid, Partly melted) basaltic material would be expected to occur below this depth. Circle your answer.
34. Referring to Figure 8.10, what is the name of the zone within Earth that begins at a depth of about 100 km and may extend to approximately 700 km?

    ____

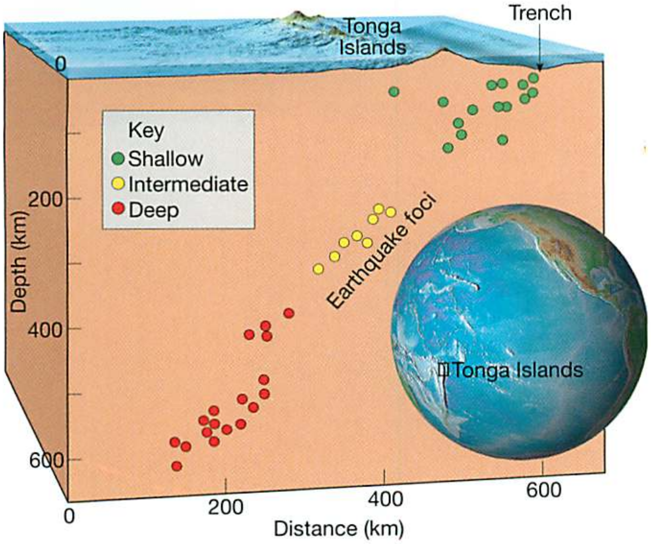

Figure 8.12 Distribution of earthquake foci in 1965 in the vicinity of the Tonga Islands. (Data from B. Isacks, J. Oliver, and L. R. Sykes)

35. Why do scientists believe that the zone in question 34 is capable of "flowing"?

____

____

Earthquakes and Earth Temperatures—A Practical Application

The study of earthquakes and Earth's internal temperature has contributed greatly to the understanding of plate tectonics. One part of the plate tectonics theory is that large, rigid slabs of the lithosphere are descending into the mantle where they generate deep focus earthquakes. Using earthquakes and Earth temperatures, Earth scientists have confirmed that this major Earth process is currently taking place near the Tonga Islands in the South Pacific and elsewhere.

Figure 8.12 illustrates the distribution of earthquake foci during a one-year period in the vicinity of the Tonga Islands. Use the figure to answer questions 36–40.

36. At approximately what depth do the deepest earthquakes occur in the area represented on Figure 8.12?

    ____________ kilometers

37. The earthquake foci in the area are distributed (in a random manner, nearly along a line). Circle your answer.
38. On the figure, outline the area of earthquakes within Earth.
39. Using previous information from this exercise, draw a line on Figure 8.12 at the proper depth that indicates the top of the *asthenosphere*—the zone of partly melted or plastic Earth material. Label the line "top of asthenosphere."
40. Recall the cause and mechanism of earthquakes. Why have Earth scientists been drawn to the conclusion of a descending slab of solid lithosphere being consumed into the mantle near Tonga?

    ____

    ____

    ____

    ____

Earthquakes on the Internet

Continue your exploration of earthquakes by completing the corresponding online activity on the *Applications & Investigations in Earth Science* website at http://prenhall.com/earthsciencelab

Notes and calculations.

Earthquakes and Earth's Interior

Date Due: ______________________

Name: ______________________

Date: ______________________

Class: ______________________

After you have finished Exercise 8, complete the following questions. You may have to refer to the exercise for assistance or to locate specific answers. Be prepared to submit this summary/report to your instructor at the designated time.

1. Use the minute marks provided below to sketch a typical seismogram where the first P wave arrives three minutes ahead of the first S wave. Label each type of wave.

   . . . .

   (minute marks)

2. How far from the earthquake epicenter is the seismic station that recorded the seismogram in question 1 of this Summary/Report page?

   __________ miles

3. Use a diagram to explain how the epicenter of an earthquake is located.

   Explanation: ______________________

   Epicenter Diagram

4. What are three Earth features associated with earthquakes?

5. The change in velocity of S waves at the top of the asthenosphere suggests that it is (similar to, different from) the lithosphere. Circle your answer.

6. Why don't S waves make it through Earth's outer core?

7. List the depths of the following interior zones of Earth.

   Crust: depth (km) from ________ to ________

   Mantle: depth (km) from ________ to ________

   Outer core: depth (km) from ________ to ________

   Inner core: depth (km) from ________ to ________

8. On the internal temperature graph you constructed in Figure 8.11, at what depth did you determine granitic magma should form?

   ________ kilometers

9. Why do Earth scientists think that rigid slabs of the lithosphere are descending into the mantle near the Tonga Islands?

   ____

   ____

10. Define the following terms:

    Earthquake focus: ____

    Earthquake epicenter: ____

    Seismogram: ____

    Asthenosphere: ____

    Geothermal gradient: ____

    Lithosphere: ____

11. Identify, label, and describe each of Earth's interior zones on Figure 8.13.

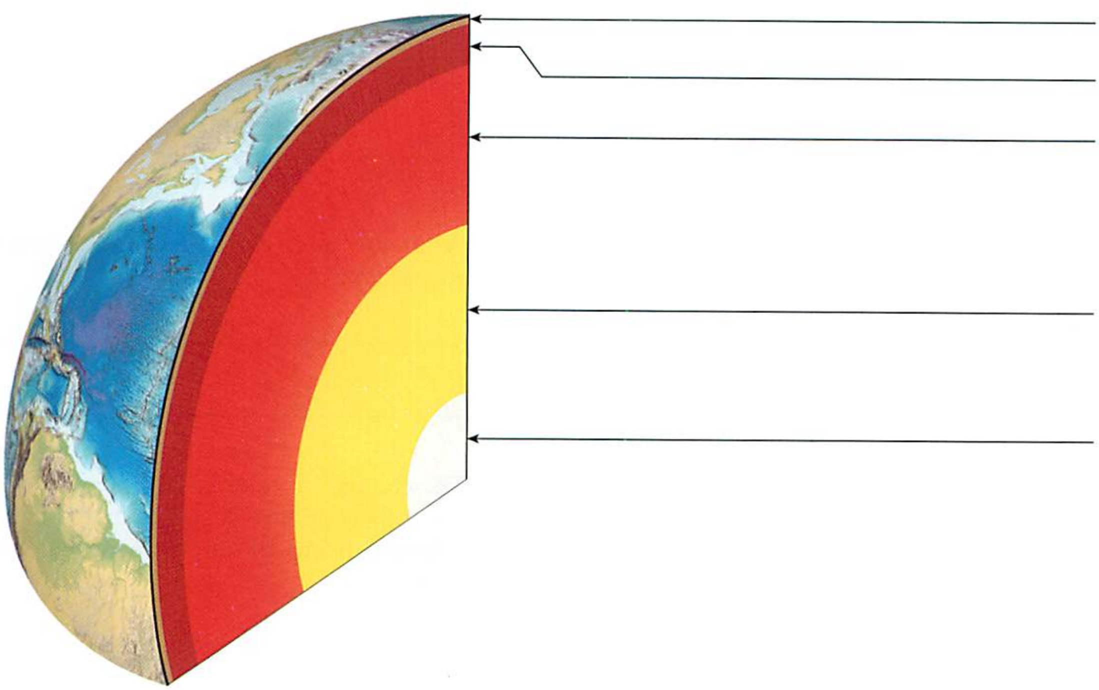

Figure 8.13 Earth's interior zones.