Objectives

- **Define** stress and strain as they apply to rocks.
- **Distinguish** among the three types of faults.
- **Contrast** three types of seismic waves.

Vocabulary

– stress
– strain
– fault
– primary wave
– secondary wave
– surface wave
– focus
– epicenter

Forces Within Earth

- Earthquakes are natural vibrations of the ground caused by movement along fractures in Earth's crust, or sometimes, by volcanic eruptions.
- In some instances a single earthquake has killed more than 100 000 people and destroyed entire cities.

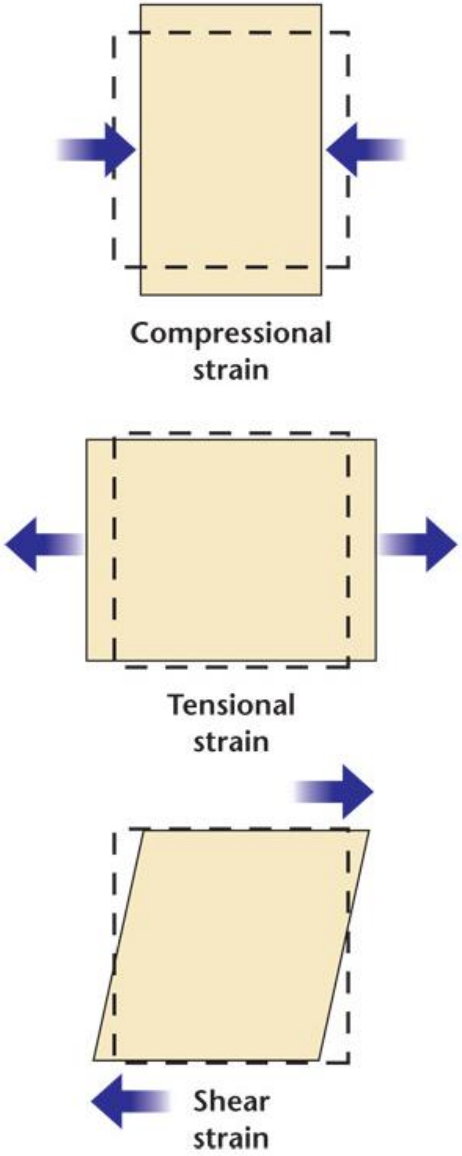
Stress and Strain

- Most earthquakes occur when rocks fracture, or break, deep within Earth.
- Fractures form when stress exceeds the strength of the rocks involved.

Stress is the forces per unit area acting on a material.

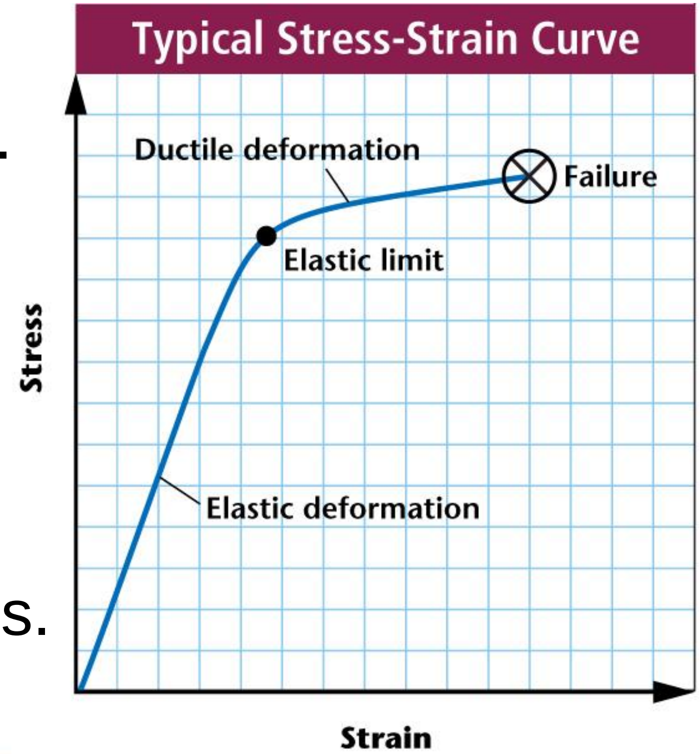
Stress and Strain

- There are three kinds of stress that act on Earth's rocks:
  - Compression is stress that decreases the volume of a material.
  - Tension is stress that pulls a material apart.
  - Shear is stress that causes a material to twist.
- **Strain** is the deformation of materials in response to stress.



Stress and Strain

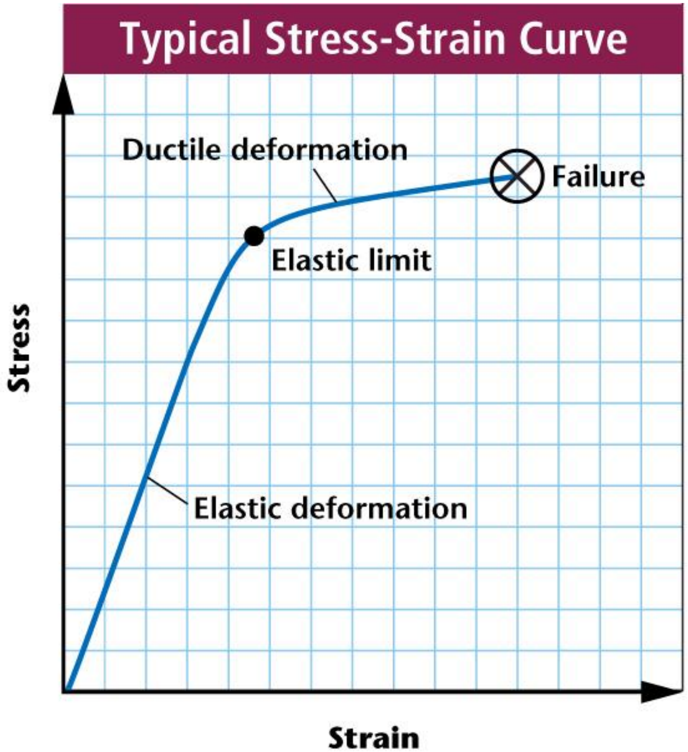
- There is a distinct relationship between stress and strain that can be plotted as a stress-strain curve.
  - A stress-strain curve usually has two segments: a straight segment and a curved segment.
  - Low stresses produce the straight segment, which represents the elastic strain of a material.
  - If the elastic strain is reduced to zero, the deformation disappears.



Stress and Strain

Ductile Deformation

- When stress exceeds a certain value, a material undergoes ductile deformation, shown by the curved segment of the graph.
- This type of strain produces permanent deformation, which means that the material stays deformed even if the stress is reduced to zero.

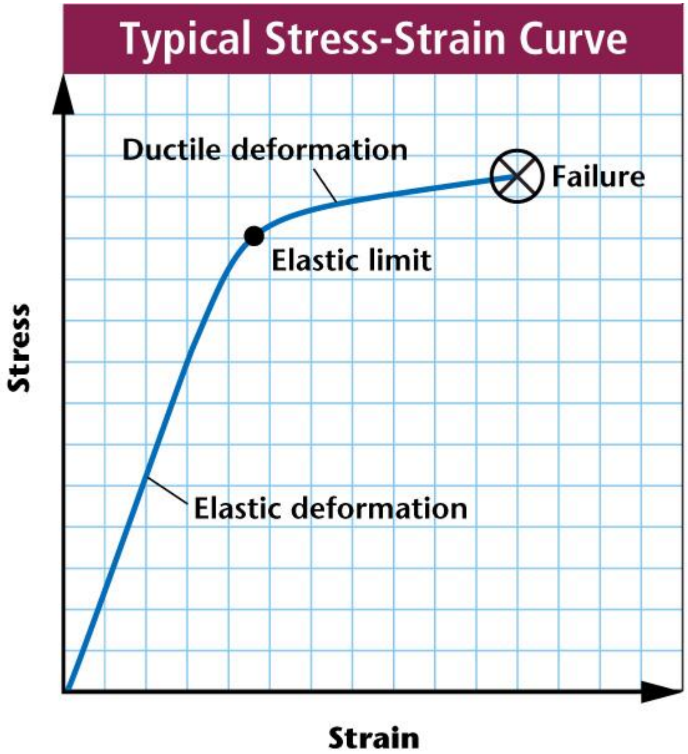


Stress and Strain

Ductile Deformation

– When stress exceeds the strength of a material, the material breaks, or fails, as designated by the X on the graph.

– Most rocks, though brittle on the surface, become ductile at the higher temperatures present at greater depths.



Faults

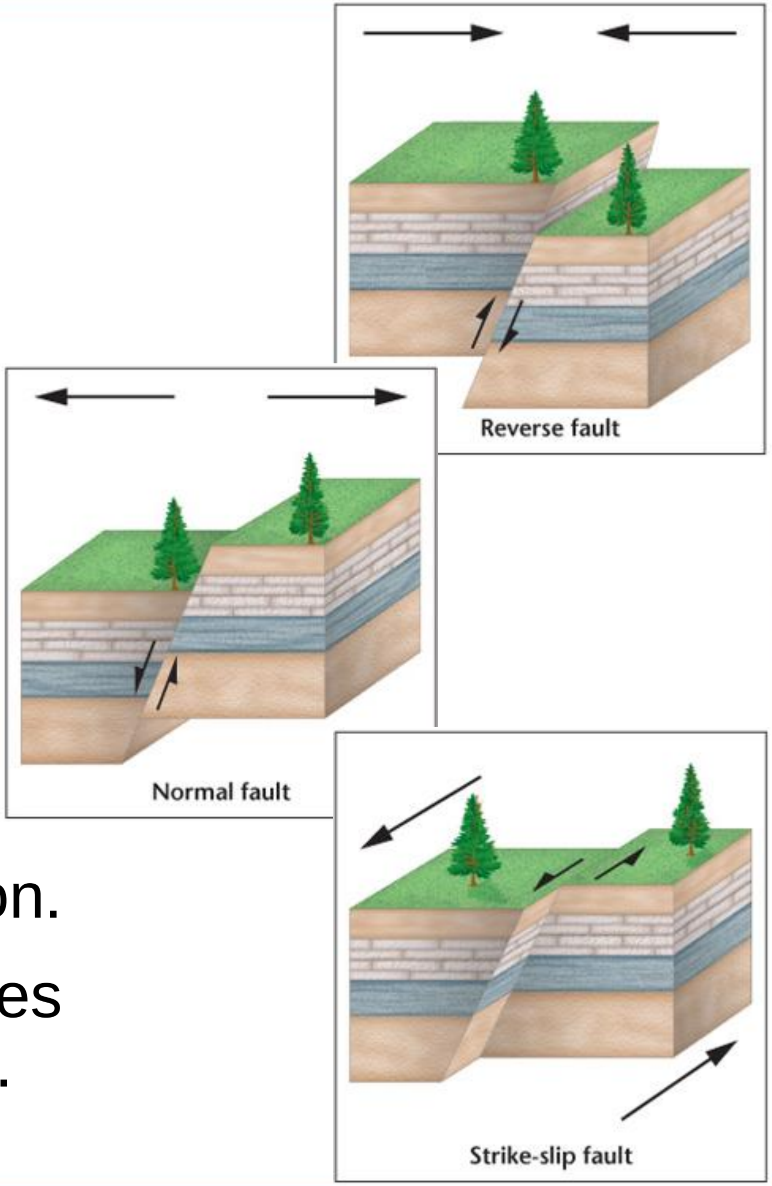
- A **fault** is the fracture or system of fractures along which movement occurs.
- The surface along which the movement takes places is called the fault plane.

Faults

Types of Faults

– There are three basic types of faults:

- Reverse faults are fractures that form as a result of horizontal compression.
- Normal faults are fractures caused by horizontal tension.
- Strike-slip faults are fractures caused by horizontal shear.



Faults

Types of Faults

Earthquake Waves

- Most earthquakes are caused by movements along faults.
- Irregular surfaces in rocks can snag and lock, causing stress to build in the rocks.
- When the rocks reach their elastic limit they break, and this produces an earthquake.

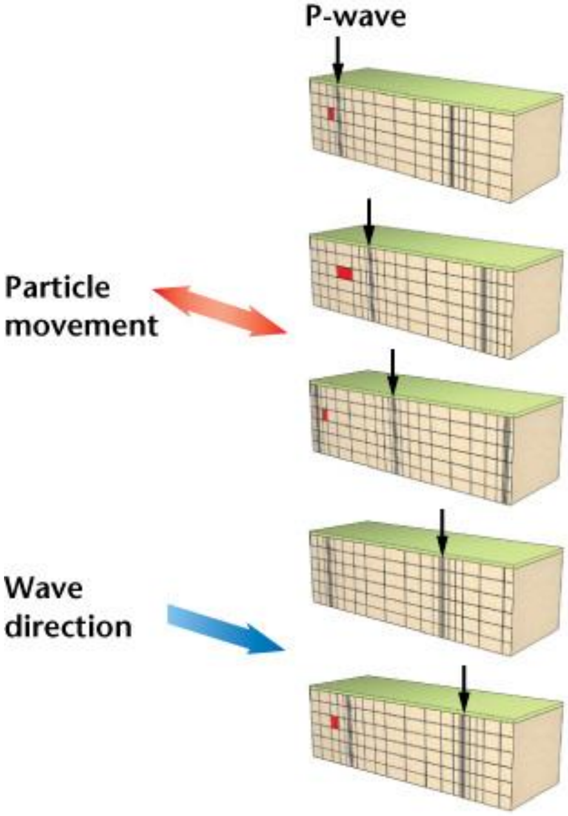
Earthquake Waves

Types of Seismic Waves

– The vibrations of the ground during an earthquake are called seismic waves.

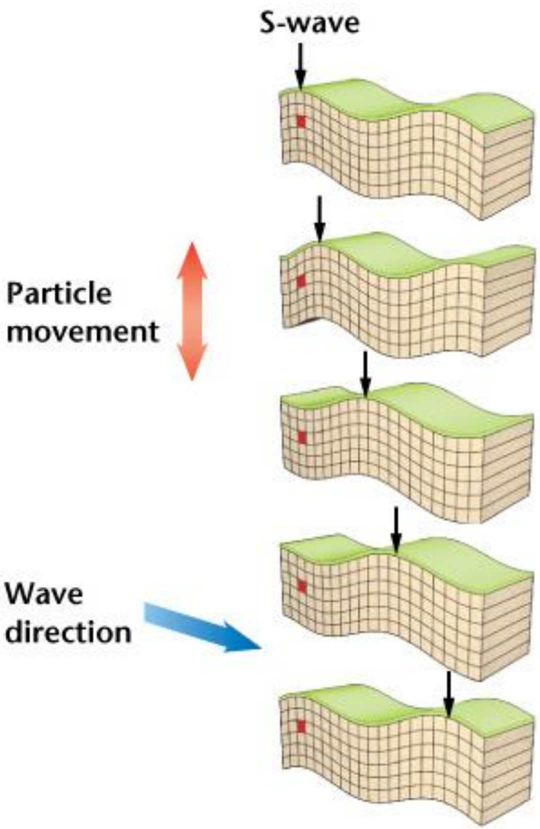
– Every earthquake generates three types of seismic waves.

- **Primary waves**, or P-waves, squeeze and pull rocks in the same direction along which the waves are traveling.

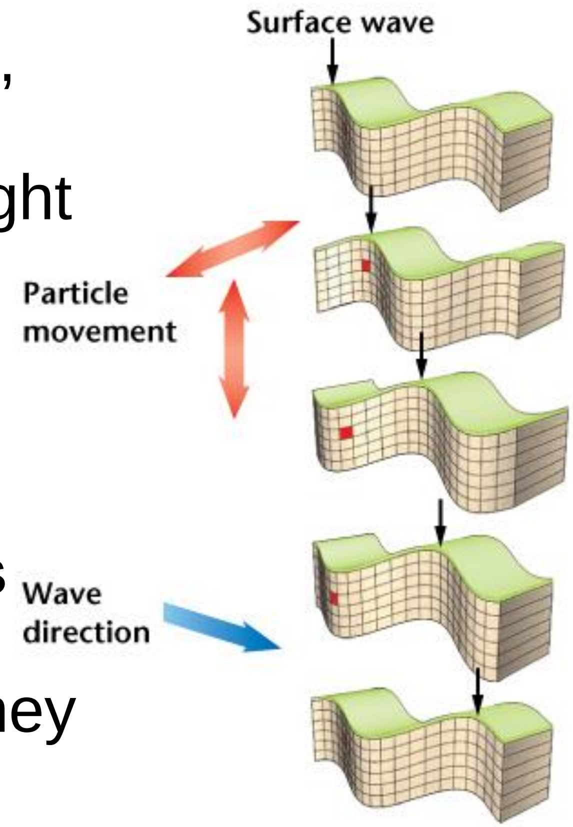


Earthquake Waves

Types of Seismic Waves



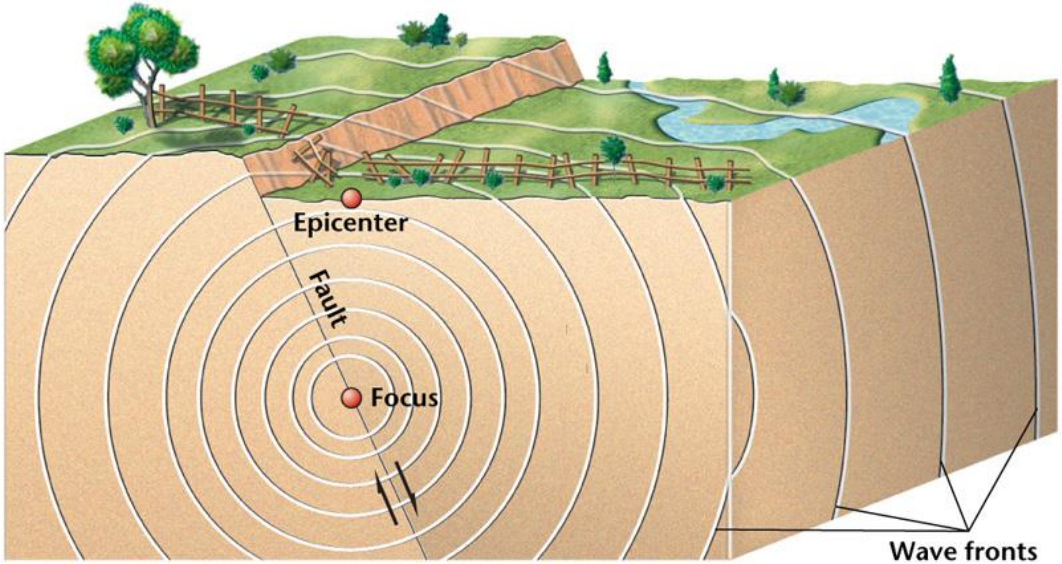
- **Secondary waves**, or S-waves, cause rocks to move at right angles in relation to the direction of the waves.
- **Surface waves** travel along Earth's surface, moving in two directions as they pass through rock.



Earthquake Waves

Types of Seismic Waves

- P-waves and S-waves, also called body waves, pass through Earth’s interior.
- The **focus** of an earthquake is the point of failure of rocks at the depth where an earthquake originates.
- The **epicenter** of an earthquake is the point on Earth’s surface directly above the focus.



Section Assessment

1. Match the following terms with their definitions.

_**E**_ stress
_**A**_ strain
_**D**_ fault
_**C**_ focus
_**B**_ epicenter

A. deformation of materials in response to forces acting upon them

B. surface point directly above an earthquake's point of origination

C. actual point where an earthquake originates

D. a fracture or system of fractures in Earth's crust along which movement occurs

E. force per unit area acting on a material

Section Assessment

2. Which type of fault best describes the San Andreas Fault? Why?

The San Andreas Fault is a strike-slip fault. The movement in this fault is primarily horizontal and is caused by two plates that are sliding past each other rather than by subduction.

Section Assessment

3. Identify whether the following statements are true or false.

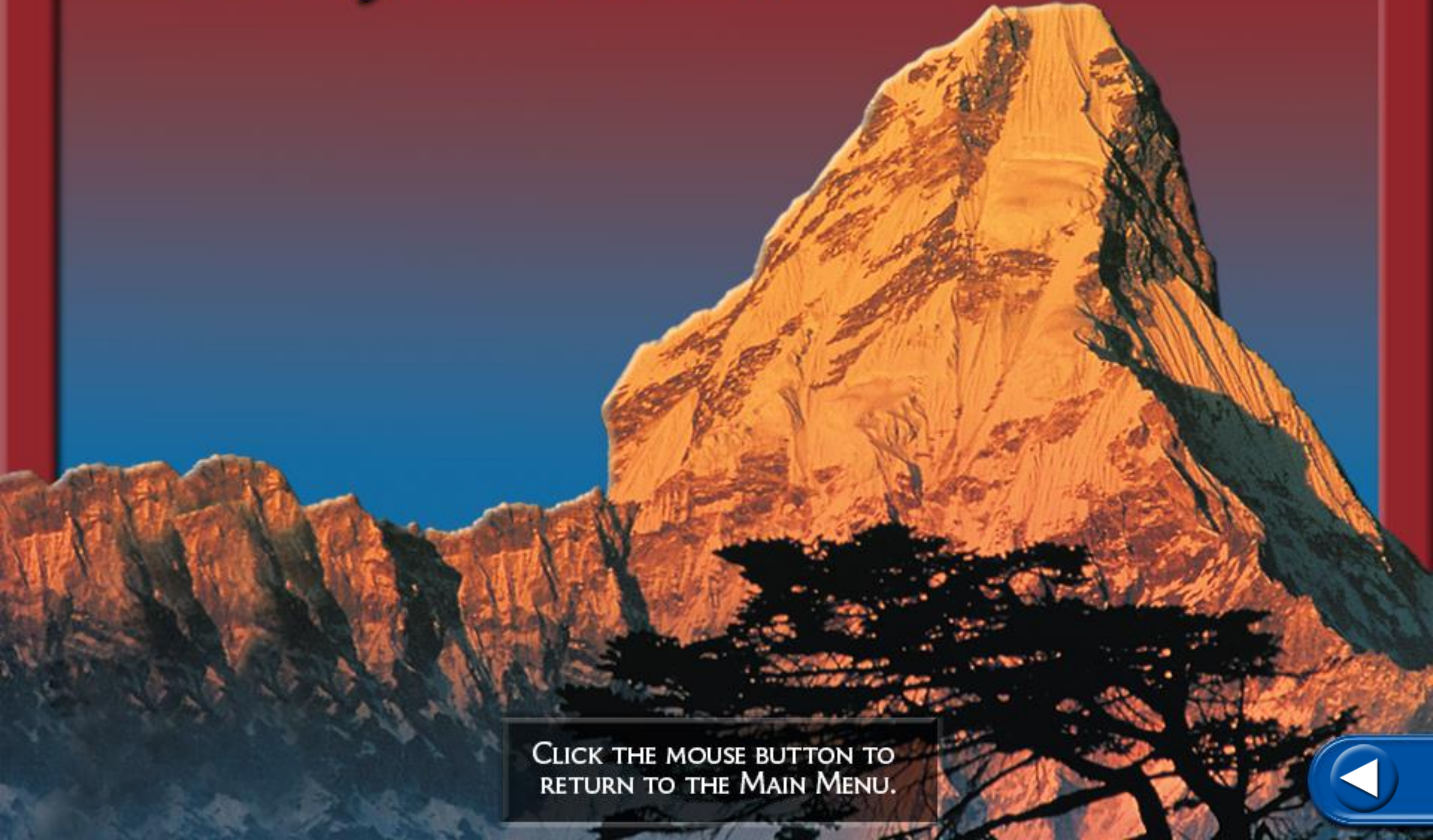
true A P-wave causes rocks to move back and forth.

true S-waves pass through Earth's interior.

false A material that undergoes ductile deformation will return to its original state if stress is reduced to zero.

true The focus of an earthquake is usually several kilometers below Earth's surface.

End of the Section



Click the mouse button to return to the Main Menu.

Objectives

- **Describe** how a seismometer works.
- **Explain** how seismic waves have been used to determine the structure and composition of Earth's interior.

Vocabulary

– seismometer

– seismogram

Seismic Wave and Earth's Interior

- Seismology is the study of earthquake waves.
- The seismic waves that shake the ground during a quake also penetrate Earth's interior.
- This has provided information that has enabled Earth scientists to construct models of Earth's internal structure.

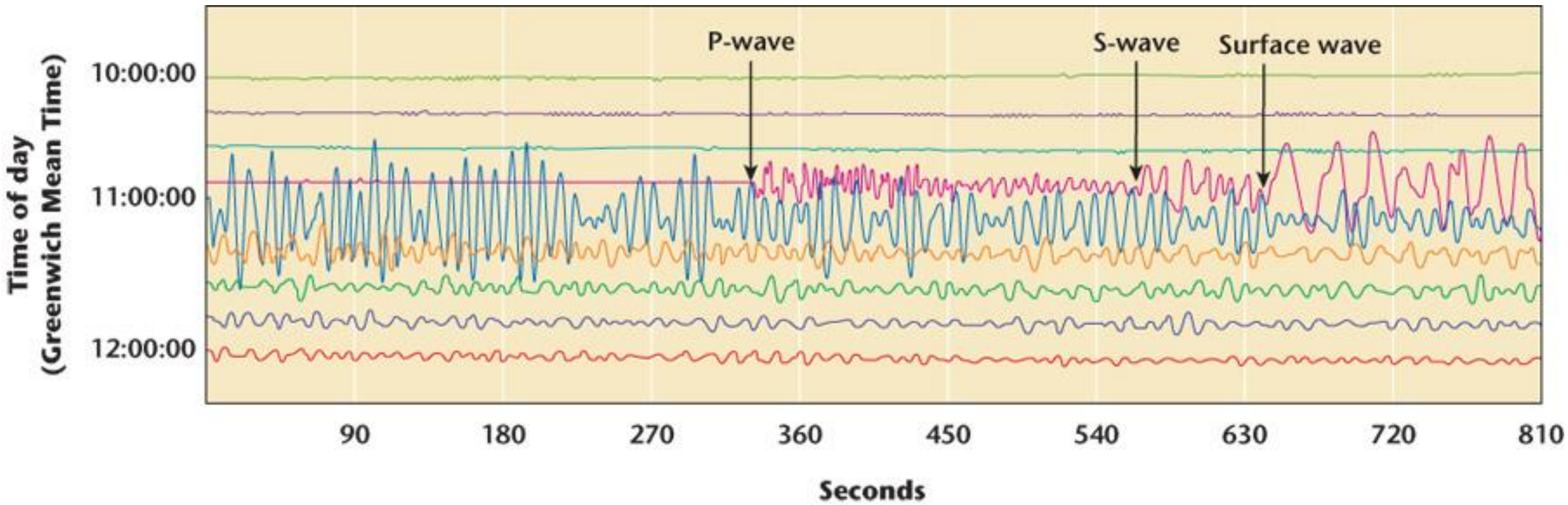
Seismometers and Seismograms

- **Seismometers**, or seismographs, are sensitive instruments that detect and record the vibrations sent out by earthquakes.
- All seismometers include a frame that is anchored to the ground and a mass that is suspended from a spring or wire.
- The relative motion of the mass in relation to the frame is recorded during an earthquake.

Seismometers and Seismograms

Seismometers and Seismograms

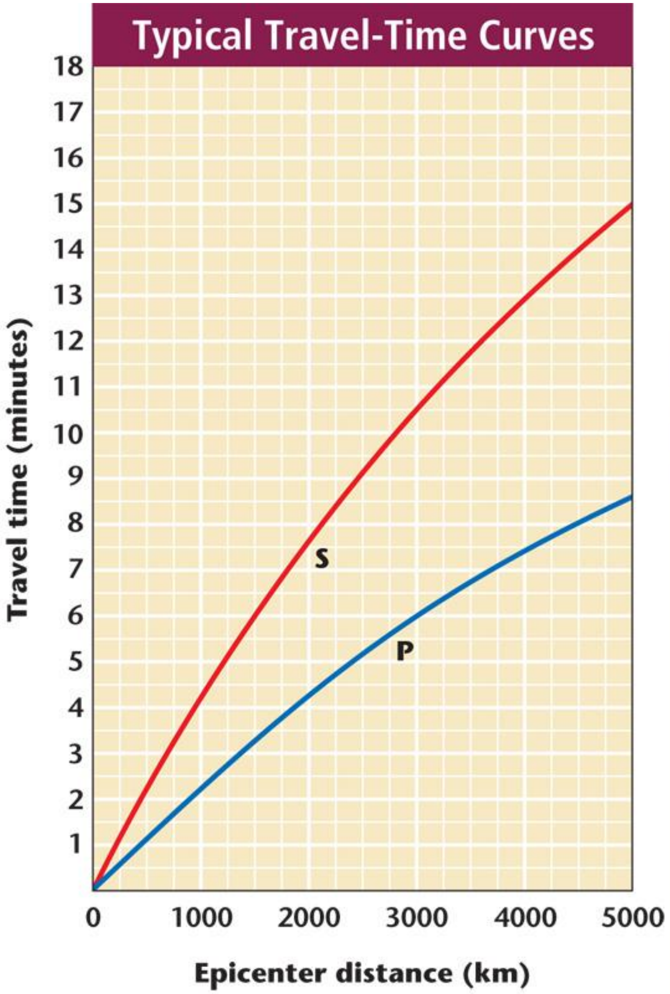
- A **seismogram** is the record produced by a seismometer.



Seismometers and Seismograms

Travel-Time Curves

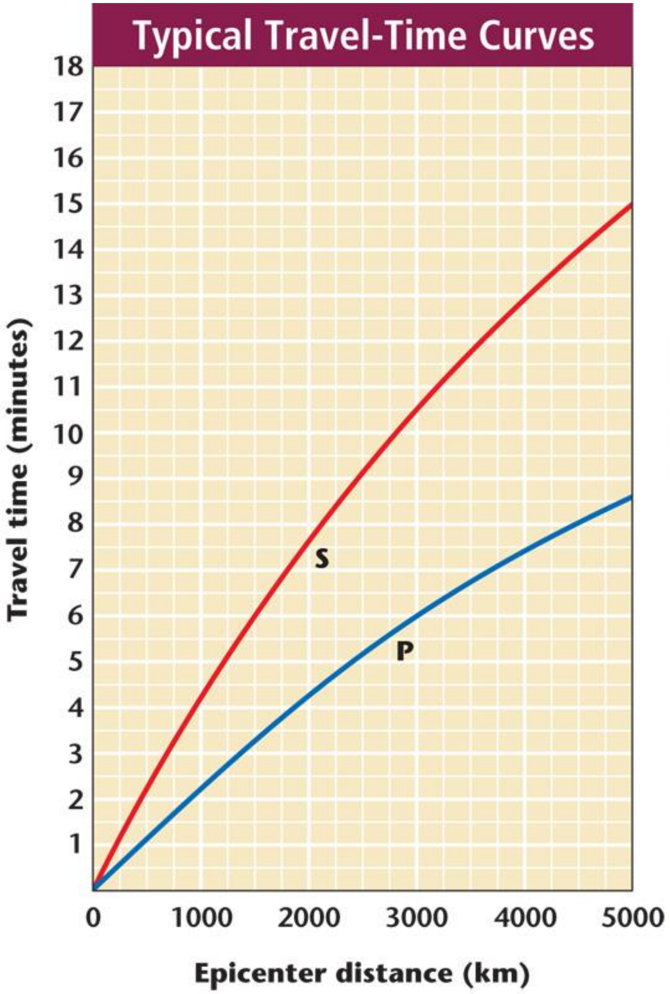
- Seismologists have been able to construct global travel-time curves for the initial P-waves and S-waves of an earthquake.
- For any distance from the epicenter, the P-waves always arrive first at a seismic facility.



Seismometers and Seismograms

Travel-Time Curves

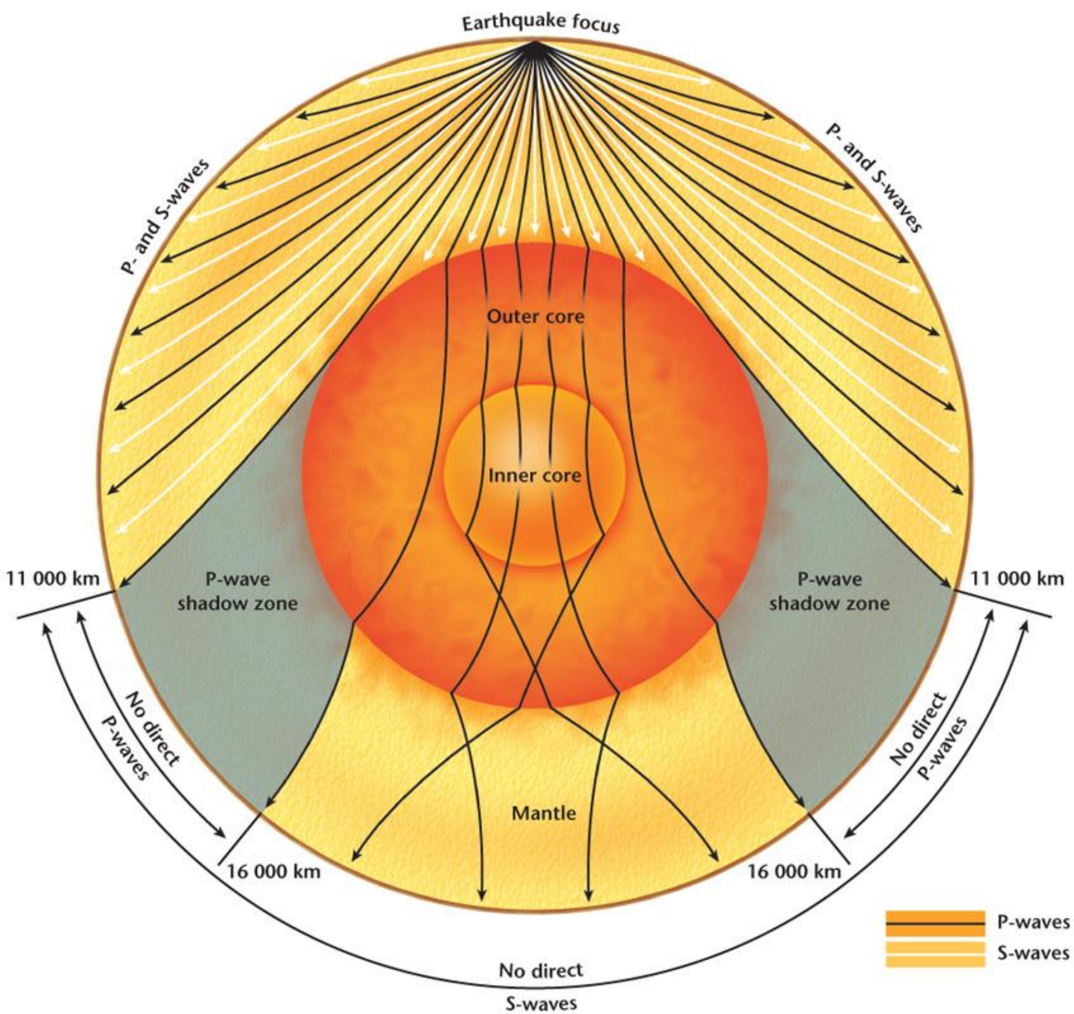
- The time separation between the curves for the P-waves and S-waves increases with travel distance.
- From this separation, the distance from the epicenter of a quake to the seismic facility that recorded the seismogram can be determined.



Clues to Earth's Interior

- Seismic waves change speed and direction when they encounter different materials in Earth's interior.
  - P-waves and S-waves traveling through the mantle follow fairly direct paths.
  - P-waves that strike the core are refracted, or bent, causing P-wave shadow zones where no direct P-waves appear on seismograms.
  - S-waves do not enter Earth's core because they cannot travel through liquids and do not reappear beyond the P-Wave shadow zone.

Clues to Earth's Interior



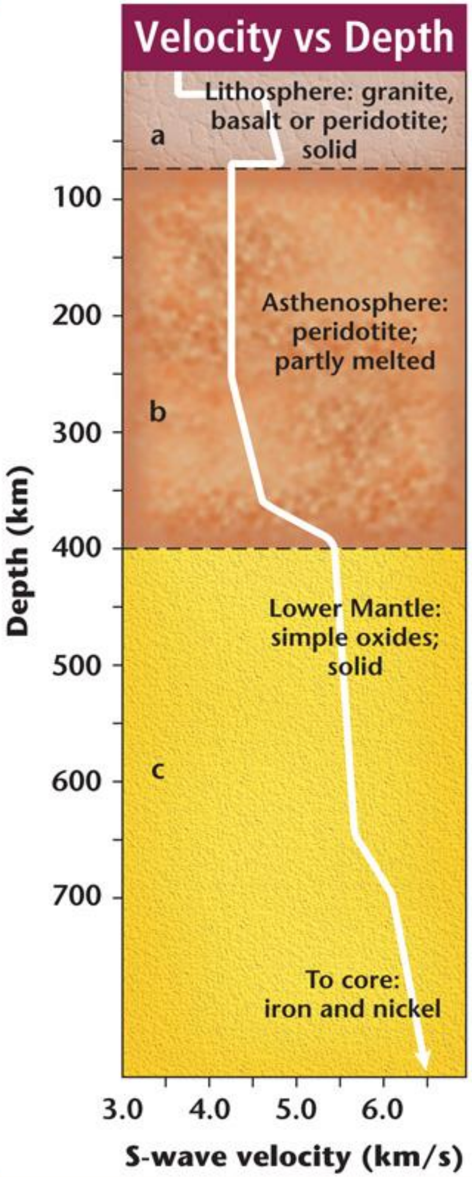
Clues to Earth's Interior

- This disappearance of S-waves has allowed seismologists to reason that Earth's outer core must be liquid.
- Detailed studies of how other seismic waves reflect deep within Earth show that Earth's inner core is solid.

Clues to Earth's Interior

Earth's Internal Structure

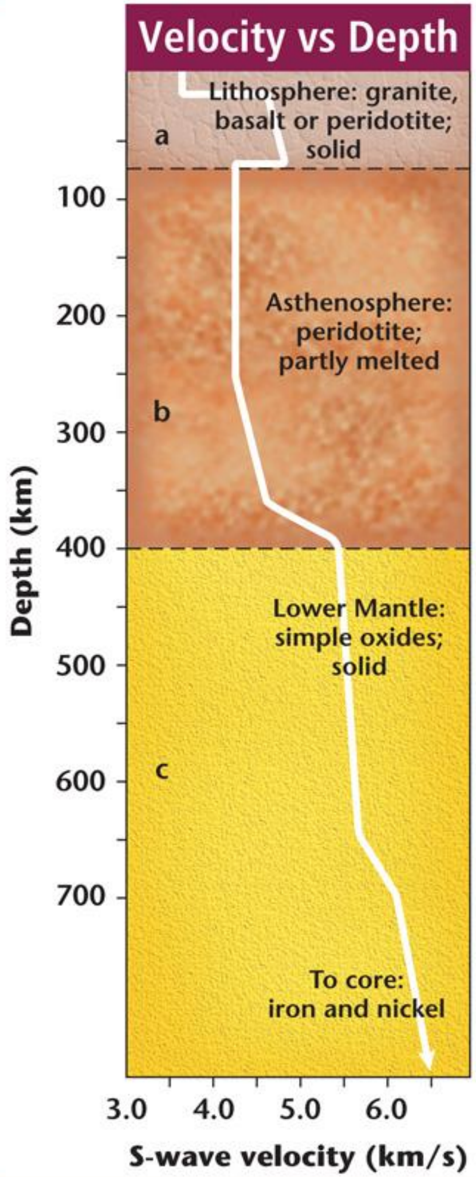
- The travel times and behavior of seismic waves provide a detailed picture of Earth's internal structure.
- The lithosphere is made up primarily of the igneous rocks granite, basalt, and peridotite.
- Much of the partially molten asthenosphere, is thought to be peridotite.



Clues to Earth's Interior

Earth's Internal Structure

- Earth's lower mantle is solid and is probably composed of simple oxides containing iron, silicon, and magnesium.
- The core is probably made of a mixture of iron and nickel.



Clues to Earth's Interior

Earth's Composition

- The composition data obtained from seismic waves is supported by studies of meteorites.
- Meteorites are pieces of asteroids, which are thought to have formed in much the same way and at the same time as the planets in our solar system.
- Meteorites consist mostly of iron, nickel, and chunks of rock similar to peridotite in roughly the same proportions as the rocks thought to make up Earth's core and mantle.

Section Assessment

1. What happens to P-waves when they enter Earth's core?

   P-waves are refracted when they pass through Earth's core, which causes a shadow zone where no direct P-waves can be detected by seismometers.

Section Assessment

2. How can the distance to an earthquake's epicenter be determined?

Seismologists have been able to construct global time-travel curves for the initial P-waves and S-waves of an earthquake. The difference in time between the arrival of the initial P-waves and S-waves indicates the distance from the seismometer to the earthquake's epicenter.

Section Assessment

3. Identify whether the following statements are true or false.

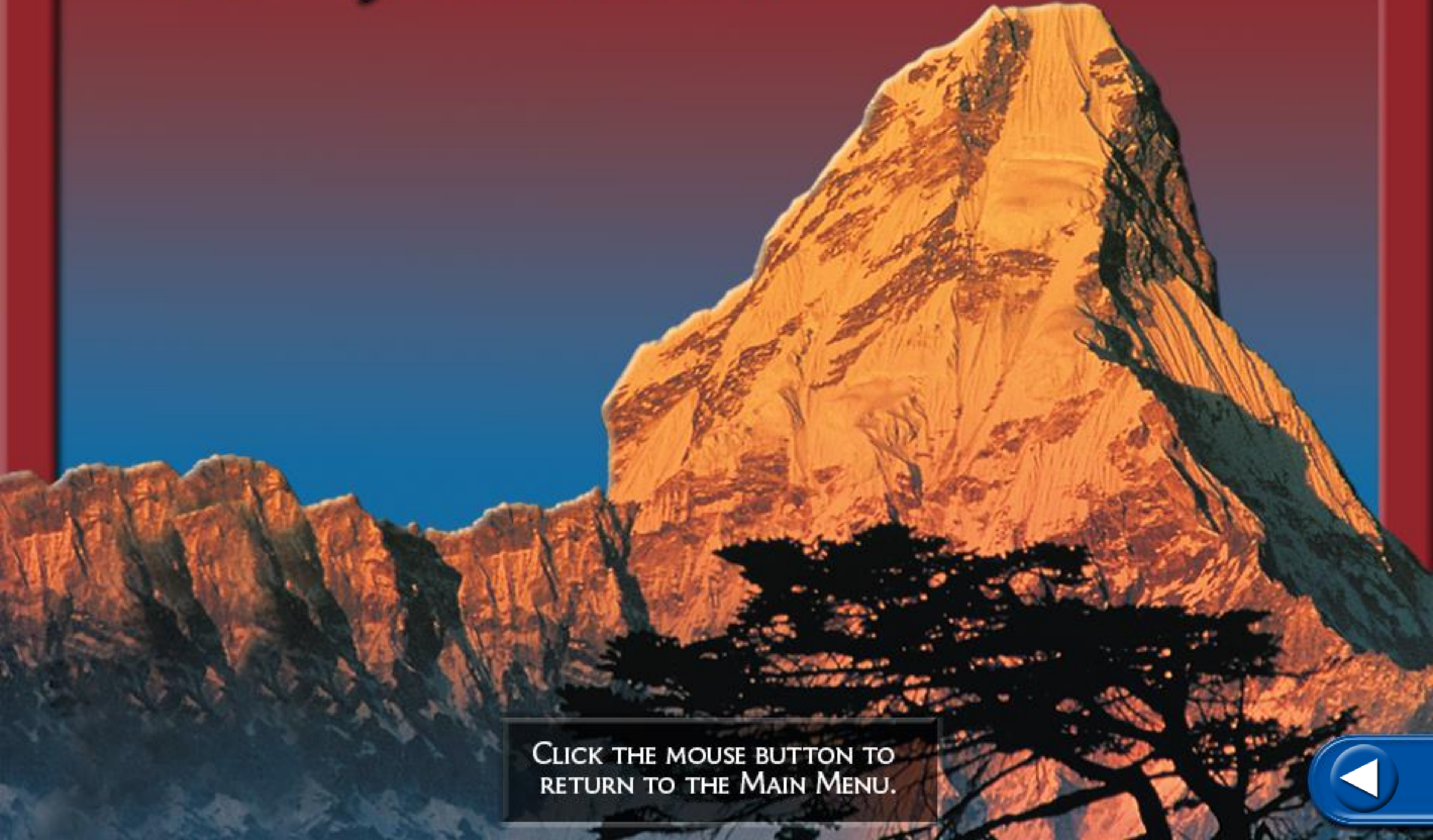
false Direct S-waves are present in a P-wave shadow zone.

false Earth's inner core is probably liquid.

true A 4-minute, 30-second separation between the arrival of P-waves and S-waves would indicate that the epicenter was about 3000 km away.

true Meteorites are believed to similar in composition to Earth's core.

End of the Section



Click the mouse button to return to the Main Menu.

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.

Vocabulary

– magnitude

– Richter scale

– movement magnitude scale

– modified Mercalli scale

Measuring and Locating Earthquakes

- More than one million earthquakes occur each year.
- More than 90 percent of earthquakes are not felt and cause little, if any, damage.

Earthquake Magnitude and Intensity

- **Magnitude** is the measurement of the amount of energy released during an earthquake.
- The **Richter scale** is a numerical scale based on the size of the largest seismic waves generated by a quake that is used to describe its magnitude.
  - Each successive number in the scale represents an increase in seismic-wave size, or amplitude, of a factor of 10.
  - Each increase in magnitude corresponds to about a 32-fold increase in seismic energy.

Earthquake Magnitude and Intensity

Moment Magnitude Scale

- The **moment magnitude scale**, widely used by seismologists to measure earthquake magnitude, takes into account the size of the fault rupture, the amount of movement along the fault, and the rocks' stiffness.
- Moment magnitude values are estimated from the size of several types of seismic waves produced by an earthquake.

Earthquake Magnitude and Intensity

Modified Mercalli Scale

- The **modified Mercalli scale**, which measures the amount of damage done to the structures involved, is used to determine the intensity of an earthquake.
- This scale uses the Roman numerals I to XII to designate the degree of intensity.
- Specific effects or damage correspond to specific numerals; the higher the numeral, the worse the damage.

Earthquake Magnitude and Intensity

Table 19-1 Modified Mercalli Intensity Scale

I.	Not felt except under unusual conditions.
II.	Felt only by a few persons. Suspended objects may 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 Magnitude and Intensity

Modified Mercalli Scale

- Earthquake intensity depends primarily on the amplitude of the surface waves generated.
- Maximum intensity values are observed in the region near the epicenter; Mercalli values decrease to I at distances very far from the epicenter.
- Modified Mercalli scale intensity values of places affected by an earthquake can be compiled to make a seismic-intensity map.

Earthquake Magnitude and Intensity

Depth of Focus

- Earthquake intensity is related to earthquake magnitude.
- The depth of the quake's focus is another factor that determines the intensity of an earthquake.
- An earthquake can be classified as shallow, intermediate, or deep, depending on the location of the quake's focus.
- A deep-focus earthquake produces smaller vibrations at the epicenter than a shallow-focus quake.

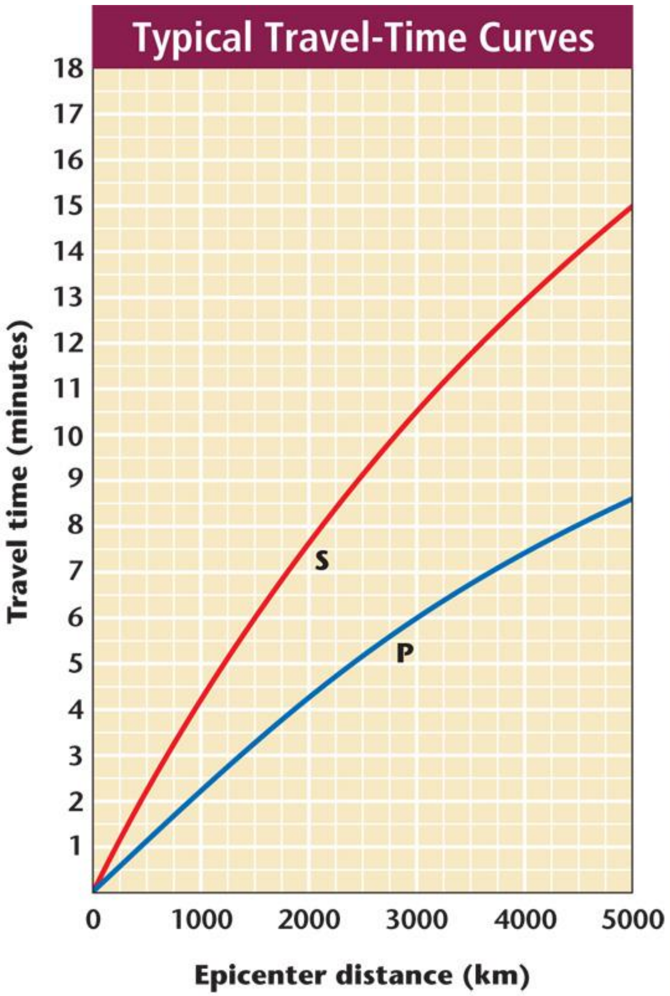
Locating an Earthquake

- All epicenter locations, as well as times of occurrence, however, can be easily determined using seismograms and travel-time curves.

Locating an Earthquake

Distance to an Earthquake

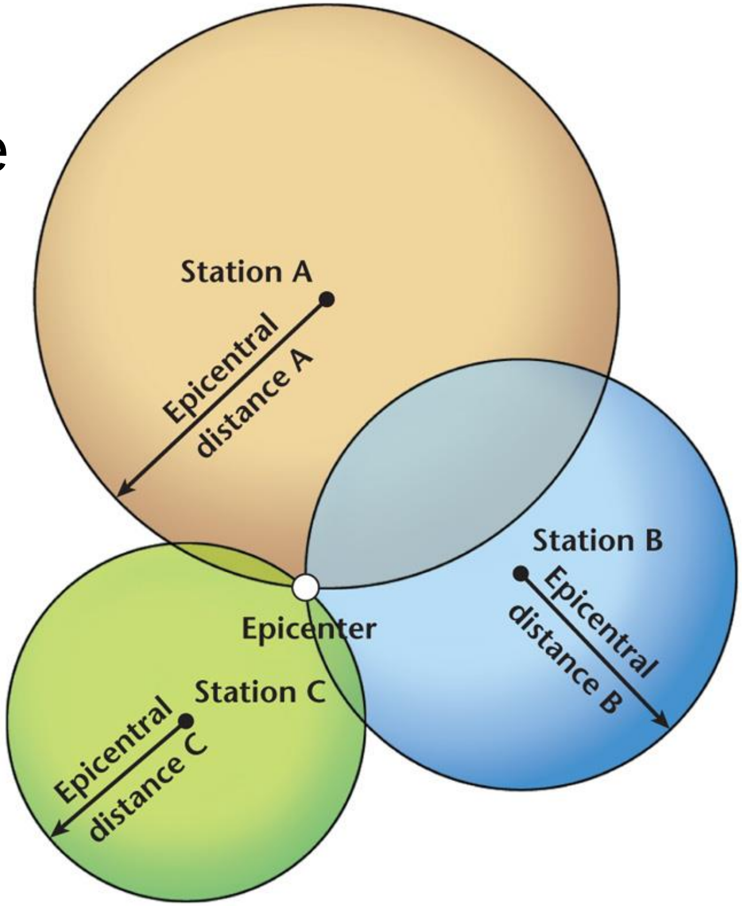
- The P-S separation determines the epicentral distance, or distance to a quake's epicenter from the seismic station that recorded the waves.
- By measuring the separation on a seismogram as well as the distance on a travel-time graph at which the P-curve and S-curve have the same separation, this distance can be determined.



Locating an Earthquake

Distance to an Earthquake

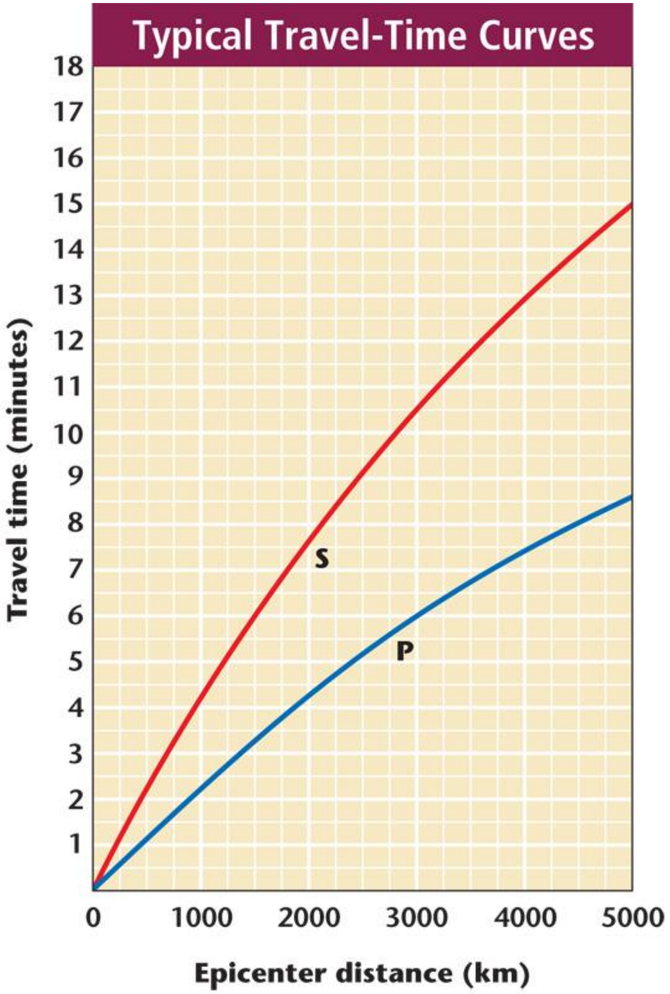
- The earthquake could have occurred anywhere on a circle around the seismic station.
- The radius of the circle is equal to the epicentral distance.
- If the epicentral distances for three or more seismic stations are known, the exact location of the epicenter can be determined.



Locating an Earthquake

Time of an Earthquake

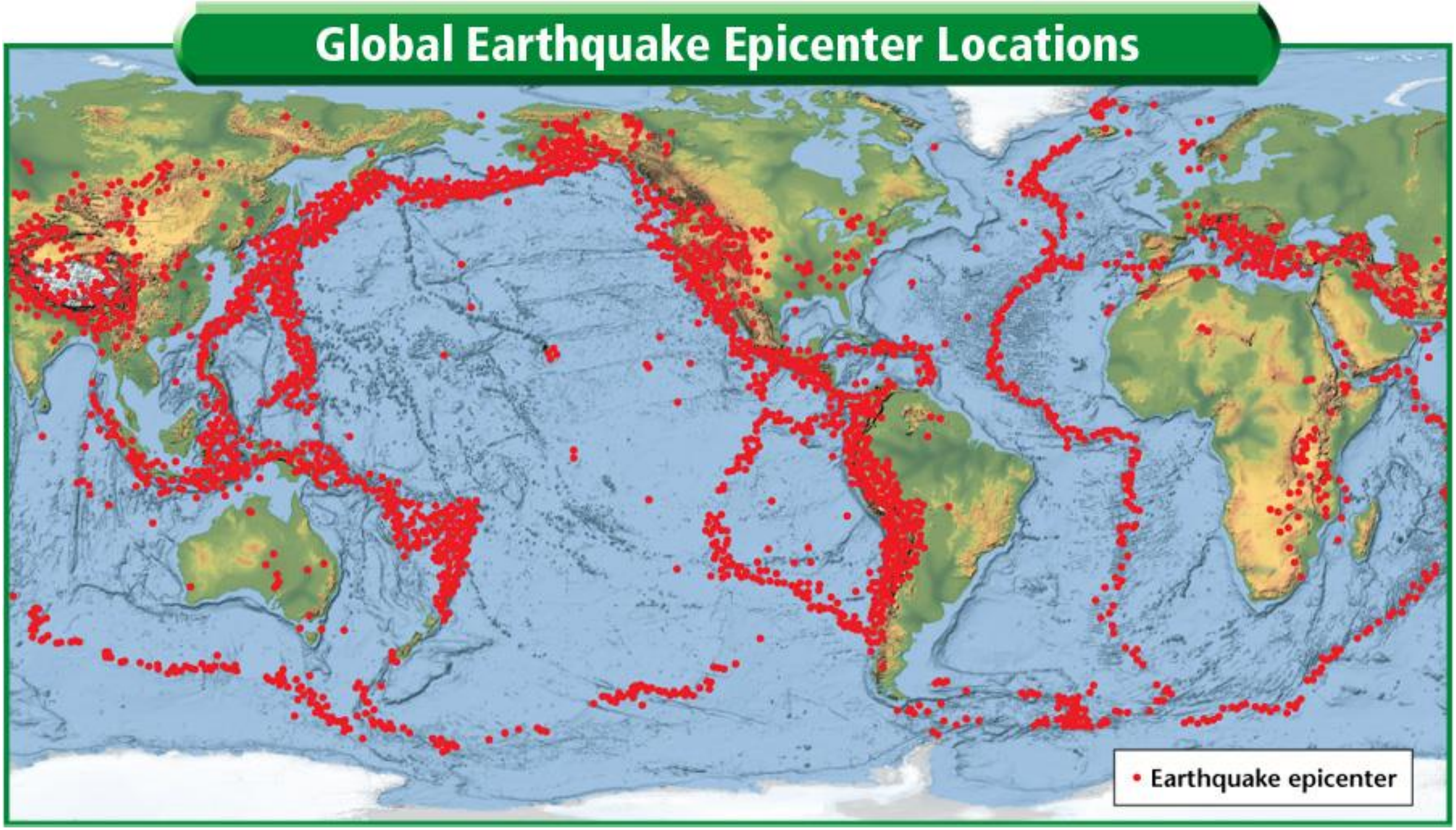
- The travel time of either wave at the epicentral distance of that station can be read from the travel-time graph.
- The time of occurrence of the earthquake is then determined by subtracting the appropriate travel time from the known arrival time of the wave.



Seismic Belts

- The majority of the world's earthquakes occur in relatively narrow seismic belts that are associated with tectonic plate boundaries.
  - Almost 80 percent of all earthquakes occur in the Circum-Pacific Belt.
  - About 15 percent take place across southern Europe and Asia.
  - Most of the remaining earthquakes occur in narrow bands that run along the crests of ocean ridges.
  - A very small percentage of earthquakes happen far from tectonic plate boundaries and are distributed more or less at random.

Seismic Belts



Section Assessment

1. Match the following terms with their definitions.

__D__ magnitude

__C__ Richter scale

__B__ moment magnitude scale

__A__ modified Mercalli scale

A. rates intensity through the type of damage and other effects of an earthquake

B. takes into account the fault rupture, the amount of movement along the fault, and the rock's stiffness

C. describes a quake based on its largest seismic waves

D. the amount of energy released during an earthquake

Section Assessment

2. How can a high magnitude earthquake rank relatively low on the modified Mercalli scale?

The modified Mercalli scale measures the intensity of an earthquake against specific damage that it causes. A high magnitude, deep-focus quake would probably have a lower Mercalli rating than a moderate, shallow-focus quake. The Mercalli rating will generally go down with distance from the epicenter, regardless of the magnitude.

Section Assessment

3. Identify whether the following statements are true or false.

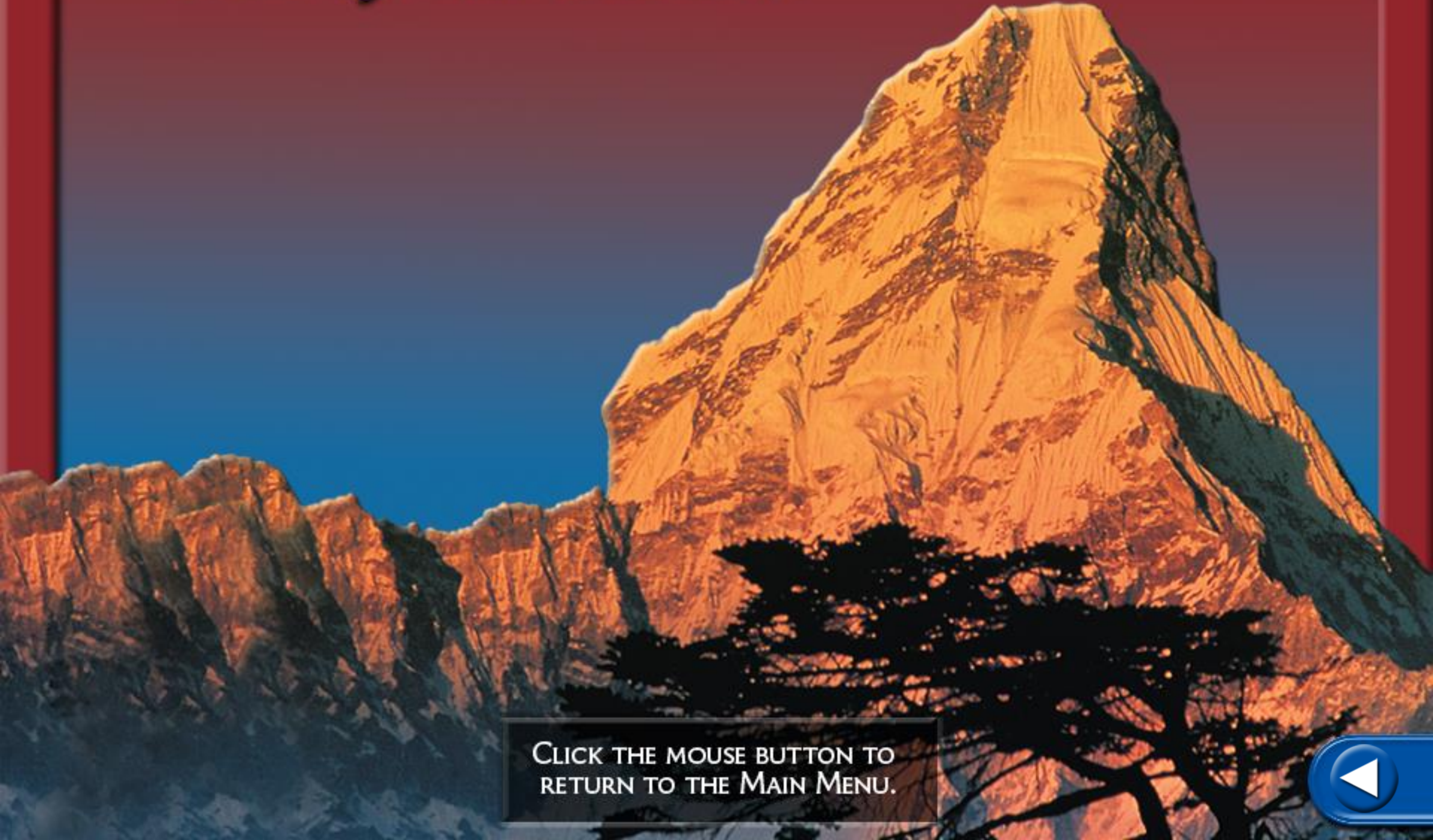
true A Mercalli rating of VI would indicate less damage than a rating of VIII.

false A quake with a magnitude of 7 on the Richter scale would have 10 times the amount of seismic energy as magnitude 6 quake.

true Most earthquakes occur along plate boundaries.

false Less than 10 000 earthquakes occur in an average year.

End of the Section



Click the mouse button to return to the Main Menu.

Objectives

- **Discuss** factors that affect the amount of damage done by an earthquake.
- **Explain** some of the factors considered in earthquake probability studies.
- **Define** seismic gaps.

Vocabulary

– tsunami

– seismic gap

Some Earthquake Hazards

- The damage produced by an earthquake is directly related to the strength or quality of the structures involved.
- The most severe damage occurs to unreinforced buildings made of stone, concrete, or other brittle building materials.
- Wooden structures and many modern high-rise, steel-frame buildings sustain little damage during an earthquake.

Some Earthquake Hazards

Structural Failure

- In many earthquake-prone areas, buildings are destroyed as the ground beneath them shakes.
- “Pancaking” occurs when the supporting walls of the ground floor fail, causing the upper floors to fall and collapse as they hit lower floors.
- When shaking caused by a quake has the same period of vibration as the natural sway of a building, they will sway violently.
- The natural sway of a building is related to height; longer waves affect taller buildings and shorter waves affect shorter buildings.

Some Earthquake Hazards

Land and Soil Failure

- Earthquakes may trigger massive landslides in sloping areas.
- In areas with fluid-saturated sand, seismic vibrations may cause subsurface materials to liquefy and behave like quicksand.
- Wave size and earthquake intensity are amplified in soft, unconsolidated sediments and are dampened in hard, resistant rocks such as granite.

Some Earthquake Hazards

Fault Scarps

- Fault movements associated with earthquakes can produce fault scarps.
- Fault scarps are areas of great vertical offset where the fault intersects the ground surface.

Some Earthquake Hazards

Tsunami

– A **tsunami** is a large ocean wave generated by vertical motions of the seafloor during an earthquake.

– These motions displace the entire column of water overlying the fault, creating bulges and depressions in the water.

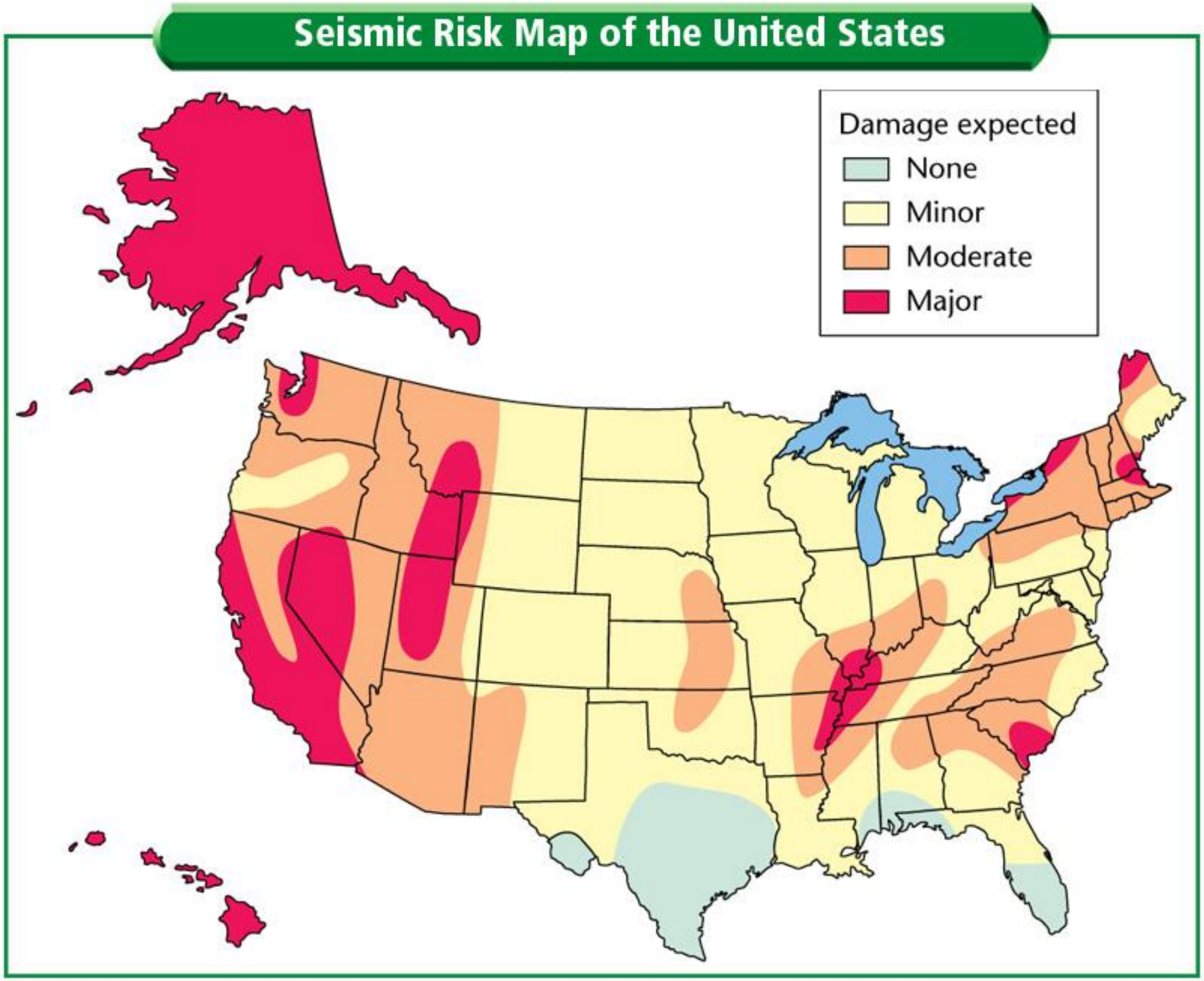
– The disturbance spreads out from the epicenter in the form of extremely long waves that can travel at speeds of between 500 and 800 km/h

– When the waves enter shallow water they may form huge breakers with heights occasionally exceeding 30 m.

Seismic Risk

- The probability of future quakes is much greater in seismic belts than elsewhere around the globe.
- The past seismic activity in any region is also a reliable indicator of future earthquakes and can be used to generate seismic-risk maps.

Seismic Risk



Earthquake Prediction

- Earthquake prediction research is largely based on probability studies.
- The probability of an earthquake's occurring is based on two factors:
  - The history of earthquakes in an area
  - The rate at which strain builds up in the rocks

Earthquake Prediction

Earthquake History

- Earthquake recurrence rates can indicate that the fault involved ruptures repeatedly at regular intervals to generate similar quakes.
- Probability forecasts are also based on the location of seismic gaps.
- **Seismic gaps** are sections of active faults that haven't experienced significant earthquakes for a long period of time.

Earthquake Prediction

Strain Accumulation

- The rate at which strain builds up in rocks is another factor used to determine the earthquake probability along a section of a fault.
- To predict when a quake might occur, scientists make several measurements.
  - Accumulation of strain in a particular part of the fault
  - Amount of strain released during the last quake along that section of the fault
  - Amount of time that has passed since an earthquake has struck that section of the fault

Section Assessment

1. Why might only buildings that are between 5 and 10 stories tall be seriously affected during an earthquake?

   If the shaking caused by the quake had the same period of vibration as the natural sway of buildings at that height, they would be more violently affected than either taller or shorter buildings.

Section Assessment

2. What is a seismic gap, and how would it possibly affect the prediction of earthquakes for the area?

A seismic gap is a section of an active fault that hasn’t experienced a significant earthquake for a log period of time. A seismic gap would generally have a higher probability of a future earthquake.

Section Assessment

3. Identify whether the following statements are true or false.

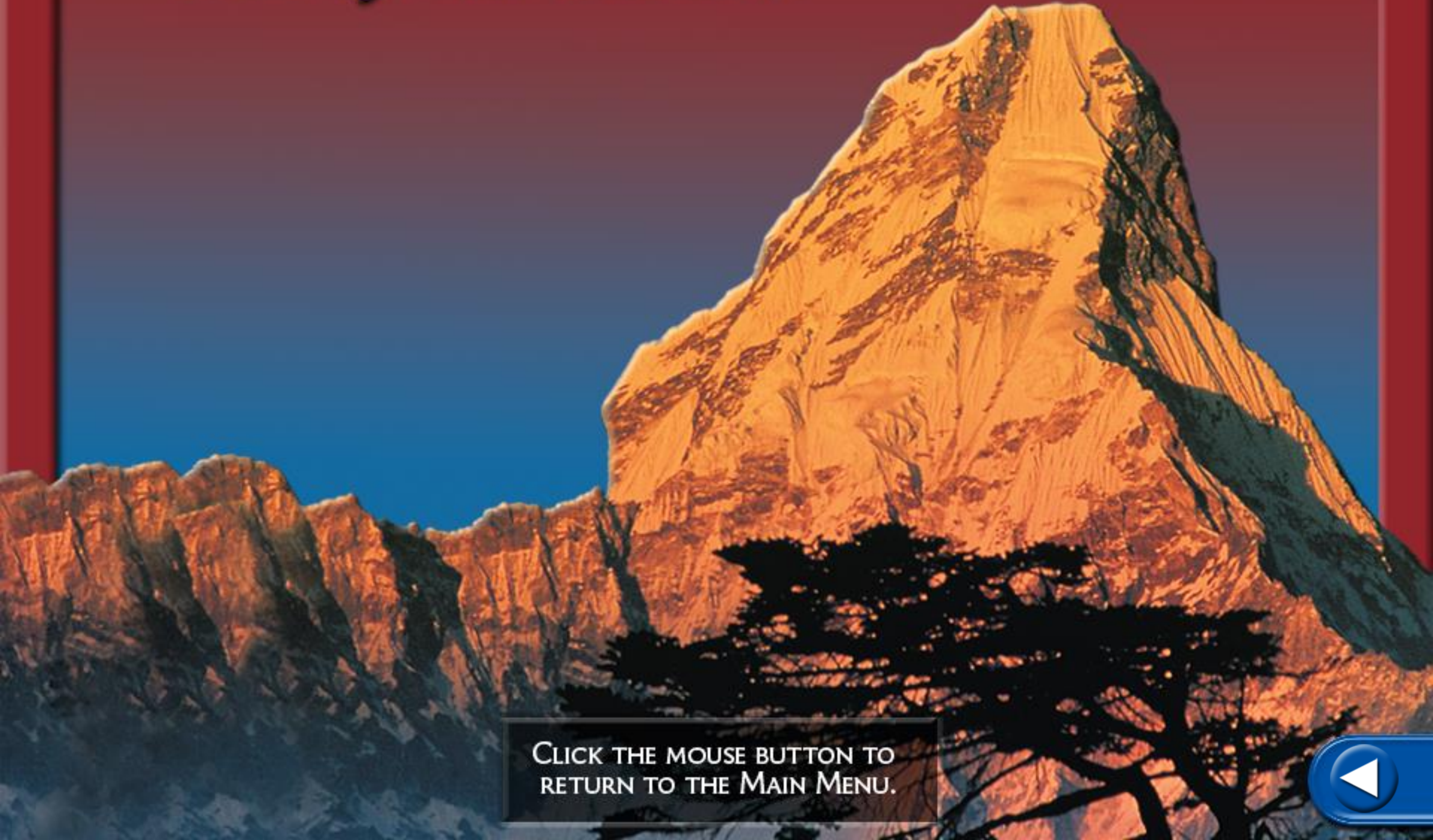
false All high seismic risk areas in the United States are located on the Pacific coast.

false Fault scarps are areas of horizontal offset.

true Wooden structures generally fair better in an earthquake than do stone structures.

true San Francisco sits above a seismic gap.

End of the Section



Study Guide

Section 19.1 Main Ideas

- Stress is the force per unit area that acts on a material. The deformation of materials in response to stress is called strain.
- Reverse faults form as a result of horizontal compression; normal faults, horizontal tension; strike-slip faults, horizontal shear.
- P-waves squeeze and pull rocks in the same direction along which the waves travel. S-waves cause rocks to move at right angles to the direction of the waves. Surface waves cause both an up-and-down and a side-to-side motion as they pass through rocks.

Section 19.2 Main Ideas

- A seismometer has a frame that is anchored to the ground and a suspended mass. Because of inertia, the mass tends to stay at rest as the ground and, thus, the frame vibrates during a quake. The motion of the mass in relation to the frame is registered and recorded.
- Seismic waves are reflected and refracted as they strike different materials. Analysis of these waves has enabled scientists to determine the structure and composition of Earth's interior.

Section 19.3 Main Ideas

- Earthquake magnitude is a measure of the energy released during a quake and can be measured on the Richter scale. Intensity is a measure of the damage caused by a quake 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 areas associated with plate boundaries called seismic belts.

Section 19.4 Main Ideas

- Earthquakes cause structural collapse, landslides, soil liquefaction, fissures, fault scarps, uplift or subsidence, and tsunamis. Factors that affect the extent of damage done by a quake include the type of subsurface as well as the quality, height, and structure of buildings and other structures involved.
- The probability of an earthquake is based on the history of quakes in an area and the rate at which strain builds in the rocks.
- Seismic gaps are places along an active fault that haven’t experienced significant earthquakes for a long period of time.

Multiple Choice

1. Which type of fault extends the crust?

a. reverse

b. normal

c. elastic

d. strike-slip

A *normal fault* is a result of horizontal tension. *Reverse faults* form as a result of horizontal compression and tend to shorten the crust. *Strike-slip faults* are caused by horizontal shear and results in an offset of the crust. *Elastic* refers to a type of deformation, not a fault type.

Multiple Choice

2. If S-waves arrive at a seismic station 6 minutes after the P-waves arrived, what is the epicentral distance?

a. 2500 km
b. 3750 km
c. 4500 km
d. 5000 km

According to the *Typical Travel-Time Curves* chart in your textbook, the *P-waves* would arrive 8 minutes after the earthquake and the *S-waves* would arrive 14 minutes after the quake. The time difference corresponds to 4500 km.

Multiple Choice

3. Which measurement scale would the depth of an earthquake's focus most affect?

a. Richter

b. modified Mercalli

c. moment magnitude

d. all of the above

The depth of an earthquake's focal point does not determine how much total energy is released. The *Richter scale* and the *moment magnitude scale* both measure the magnitude of a quake. The *modified Mercalli scale* measures intensity based on observed damages, which is highly dependent on the focal depth.

Multiple Choice

4. Which of the following is not true about S-waves?

a. They generally cause vertical movement

b. They easily penetrate liquids

c. Their shadow zone is larger than P-waves

d. Their travel time always lags P-waves

Because S-waves cannot penetrate liquids and S-waves do not penetrate Earth's outer core, seismologists reason that it must be liquid.

Multiple Choice

5. A magnitude 6 on the Richter scale represents how much more energy than a magnitude 5?

a. 10 X

b. 32 X

c. 100 X

d. over 1000 X

Each number increase in the Richter scale represents a 32-fold increase in seismic energy.

Short Answer

6. What is the difference between an earthquake’s focus and its epicenter?

An earthquake’s focus is the point of initial fault rupture which is often located deep underground. The epicenter is the point on Earth’s surface directly above the focus.

Short Answer

7. How does elastic deformation differ from ductile deformation?

Elastic deformation is proportional to the amount of stress on the material. If the stress is reduced to zero, the deformation disappears. Material undergoes ductile deformation when the stress exceeds the elastic limit. At this point the deformation is permanent even if the stress is eliminated.

True or False

8. Identify whether the following statements are true or false.

__false__ Earth's lower mantle is most likely liquid.

__false__ At least two seismic stations are required to pinpoint the location of an earthquake.

__true__ The P-wave shadow zone is smaller than that for S-waves.

__true__ A tsunami can travel at over 500 km/h.

__true__ The moment magnitude scale is the most widely used scale to measure magnitude in the scientific community.

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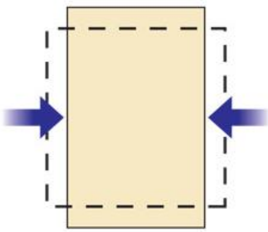
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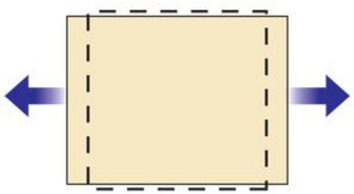
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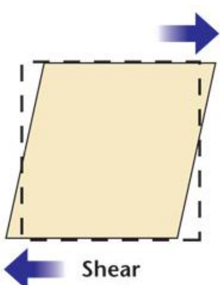
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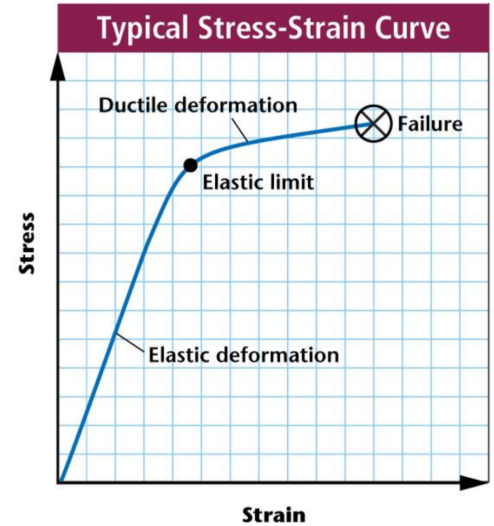
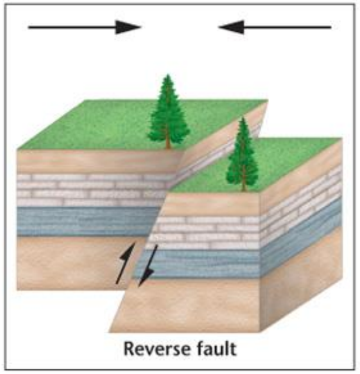
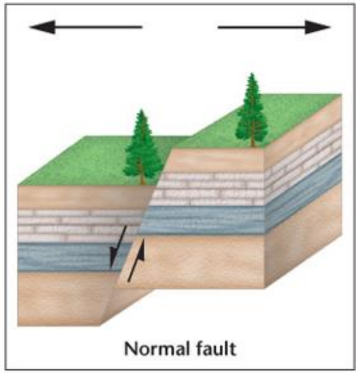



Reverse fault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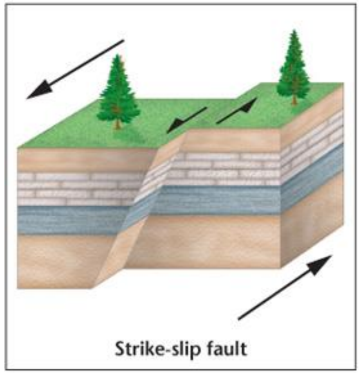
Strike-slip fault

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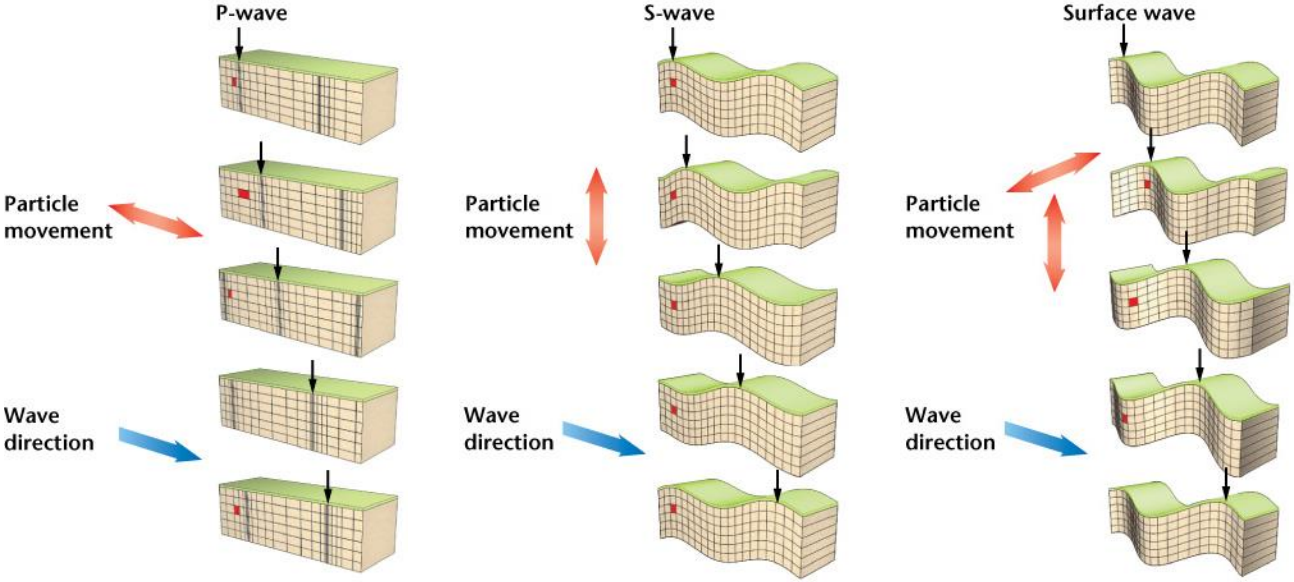

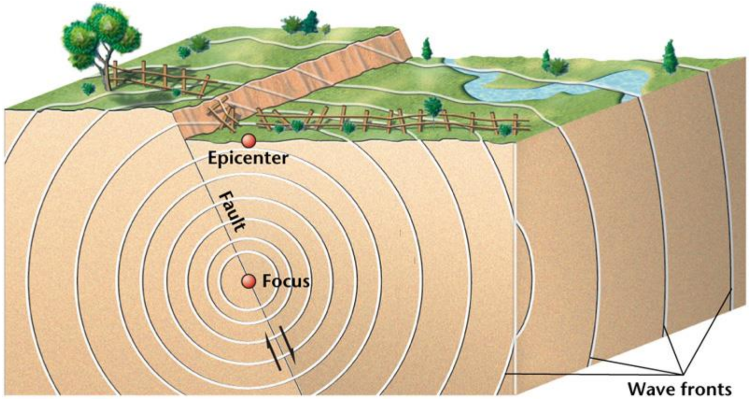

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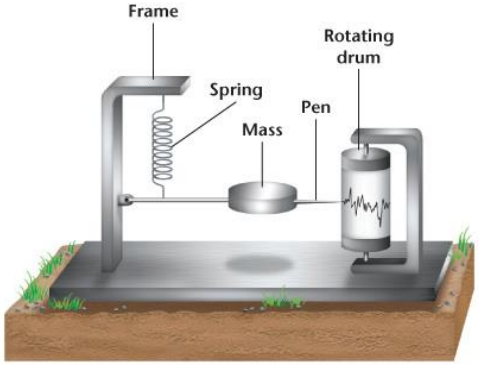

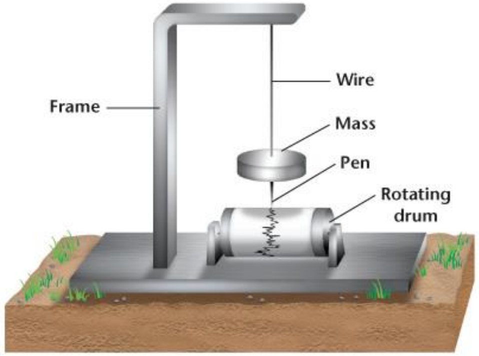

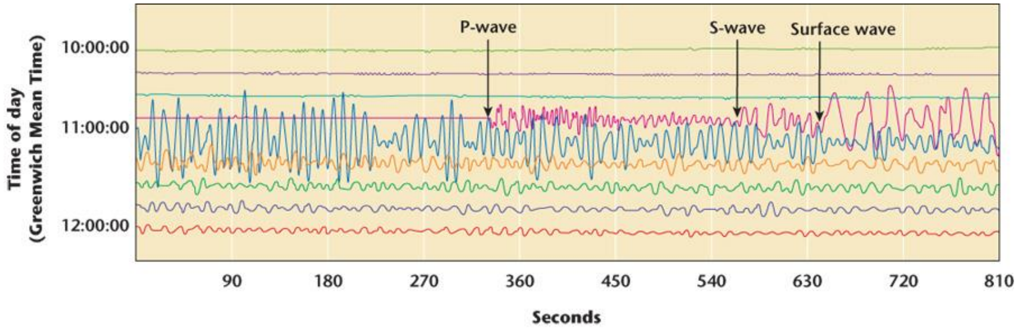

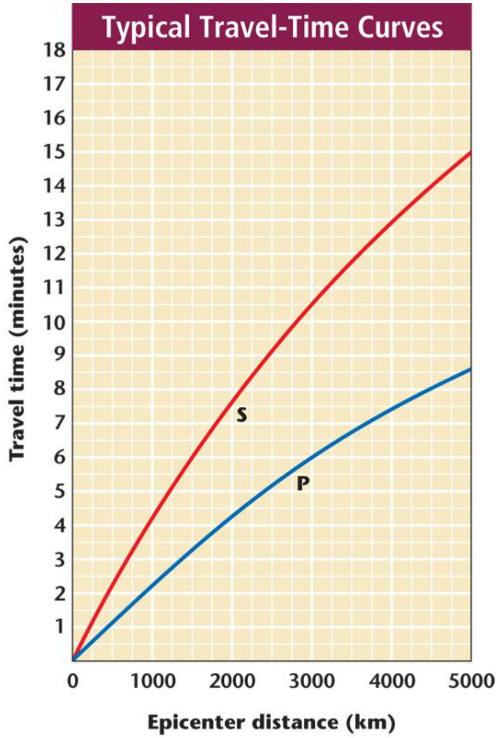

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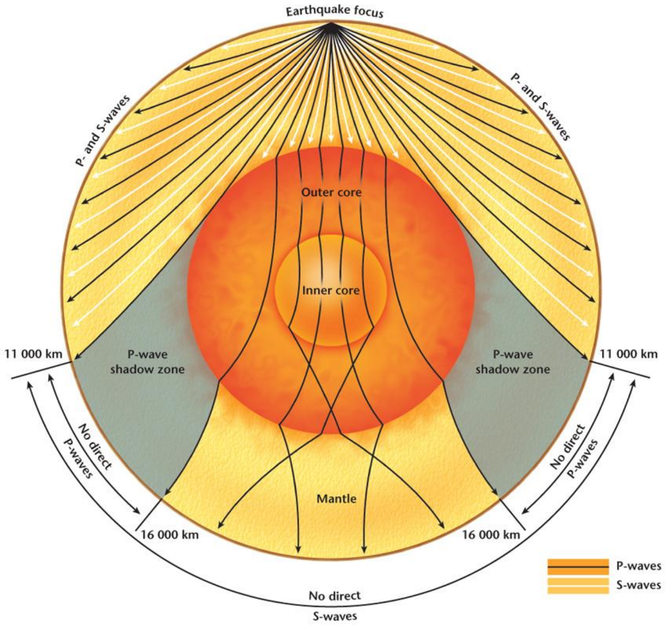

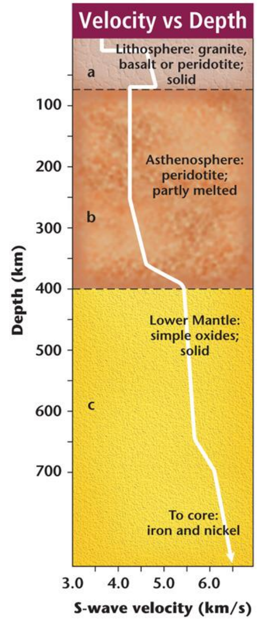

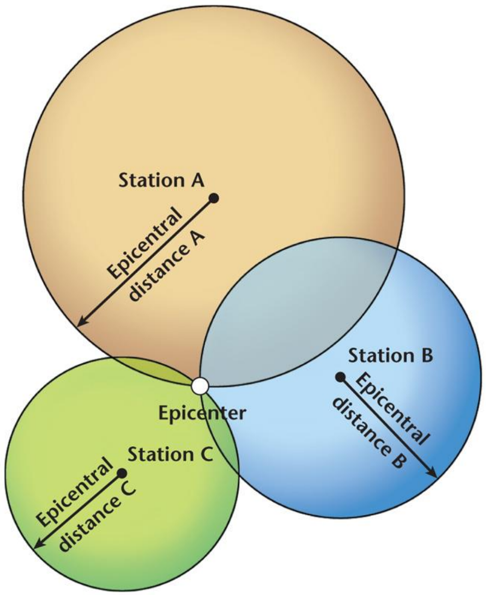

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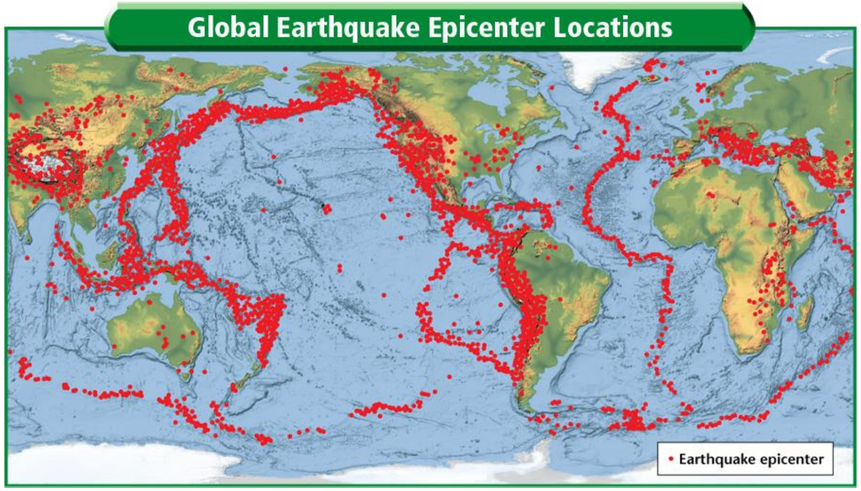

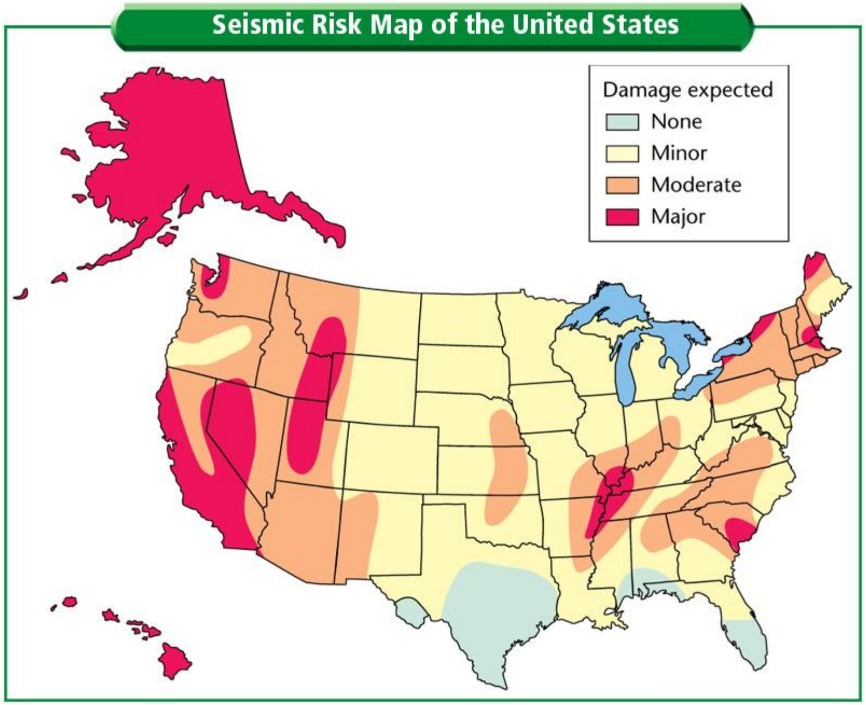

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