10.5 Seismic Waves

tsunami an enormous sea wave or a series of enormous sea waves caused by an earthquake or other disturbance

seismic waves waves of energy that travel through Earth

On December 26, 2004, in one of the worst natural disasters in recorded history, a deadly tsunami (su-NAH-me) devastated several countries, including Indonesia, Sri Lanka, India, and Thailand, killing over 230 000 people (**Figure 1**). A **tsunami** is an enormous sea wave or a series of enormous sea waves caused by an earthquake or other disturbance. The waves generated in the 2004 tsunami were as high as 30 m. In this section, you will study the physics of earthquakes and seismic waves, as well as how seismic waves can be used in geophysical exploration. **Seismic waves** are waves that carry energy through Earth.

Figure 1 The 2004 tsunami as it hit the coast of Thailand

Earthquakes

Earth's crust (surface) is made up of several large tectonic plates that fit together like a spherical puzzle. These tectonic plates are slowly moving, and they can move apart, push together, or slide against each other along regions called fault lines (**Figure 2**). However, these plates have jagged edges that can catch on each other as they press together along fault lines, building up tremendous pressure. The pressure builds up to the point where the plates slip along the fault lines, causing an earthquake.

Once two plates slip faster than usual along a fault line, seismic waves are created that can travel either along Earth's surface (surface waves) or into Earth itself (body waves). Whenever waves pass through Earth's surface or reach the surface, they shake the ground, causing an earthquake. The speed of these waves increases with depth but also depends on the materials present.

There are two types of body waves—primary waves (P-waves) and secondary waves (S-waves). These waves follow curved paths through Earth because they refract (bend) due to variations in density and stiffness. This is similar to the way light refracts when it passes through transparent media. P-waves are longitudinal waves and move almost twice as fast as S-waves. S-waves are transverse waves that arrive after the P-waves because of the S-waves' slower speed.

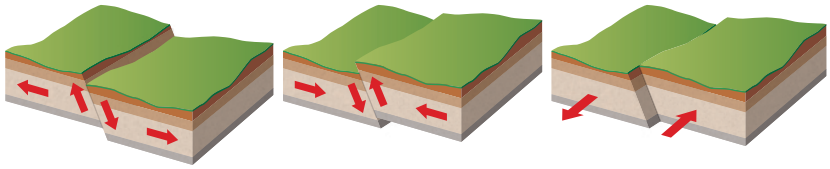

Figure 2 The relative motions of tectonic plates along fault lines

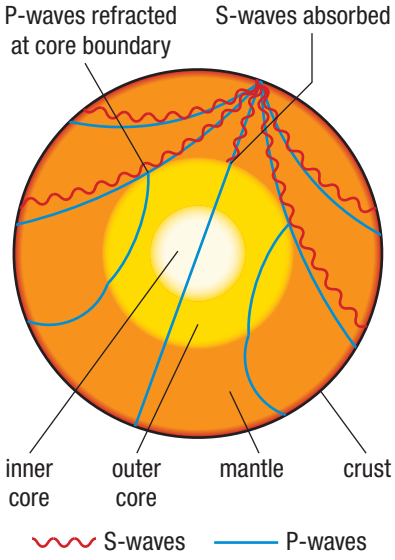

Figure 3 Body waves provide information about Earth's interior.

Surface waves are similar to water waves, and they move more slowly than body waves. They are more destructive than body waves because they tend to last longer, have a lower frequency, and have a larger amplitude.

As P-waves and S-waves move through Earth, they refract and curve back toward the surface. In addition, P-waves can move through both solid and liquid material, but S-waves can only travel through solid material. Using this information, scientists have determined much about Earth's interior. For example, scientists now believe Earth has a liquid outer core because S-waves cannot reach regions around the globe that P-waves can (**Figure 3**).

Seismic Waves and Tsunamis

When underwater tectonic plates shift suddenly and produce an earthquake underwater, a tsunami can be generated. As one plate slides over the other, it bulges. This bulging stores a tremendous amount of energy. When the plates start to move during an earthquake, the energy stored in the plates is transferred to the water. The energy in the water is transferred because a large volume of Earth is displaced, which causes a large volume of water to be displaced, creating conditions for the generation of a tsunami (**Figure 4**). Tsunamis gain amplitude as they approach shore.

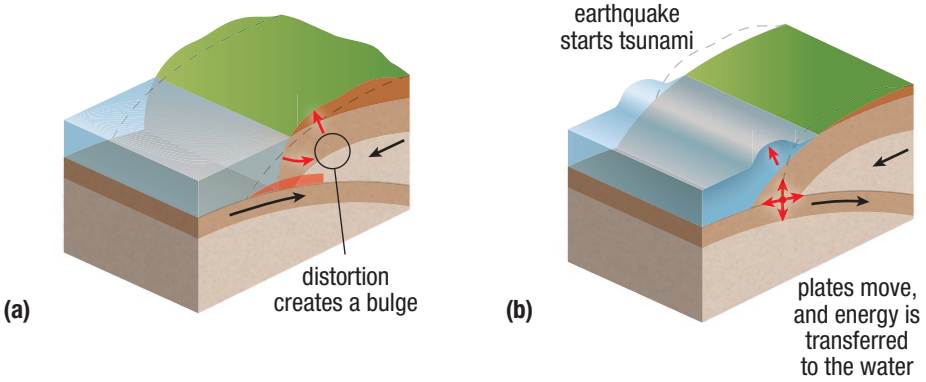

Figure 4 (a) Pressure builds up between two tectonic plates. (b) The energy is released, creating a tsunami.

Research This

Tsunami-Warning Systems

Skills: Researching, Analyzing, Evaluating, Communicating, Defending a Decision

SKILLS HANDBOOK A5

Many coastal areas have tsunami-warning systems in place that help warn coastal residents about possible tsunamis. Such systems give residents time to move inland before the tsunami hits the coast. Nothing can warn residents of a sudden tsunami that occurs very close to shore, however.

1. Research tsunamis and tsunami-warning systems using Internet and/or print resources.

A. What impact can tsunamis have on coastal regions? K/U

B. Tsunami-warning systems are based on what fact? T/I

C. How effective are such systems in reducing death tolls and property destruction? T/I

D. Should all coastal regions have some sort of tsunami-warning system? Explain. C A

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Seismic Geophysical Exploration

Most minerals and fuels are deep underground—1000 m down or deeper. Drilling is time-consuming and expensive, so companies will not drill until they are reasonably sure something of value is beneath the ground. Different methods can be used to determine the nature of the materials underground without digging. Measuring changes in gravity and magnetic fields are two examples. We will focus on methods that use seismic waves to study Earth's interior. Enormous insight has been gained through seismic exploration in understanding Earth's internal structure.

When waves travel from one medium into another, the wave splits into two (Section 9.2). One part of the wave is reflected and the other part is transmitted. The same thing happens when a wave is produced underground. When a large vibration is produced in the ground from a small explosion or even just a heavy object striking the ground, sound waves move away from the source of vibration in all directions through the ground. These waves then pass through soil and rock and partially reflect and partially refract whenever they pass into a new layer. Information can be collected at the surface by recording channels that have different groups of extremely sensitive geophones (microphones that detect seismic waves) placed along the channel at regular intervals (**Figure 5**). This information is used to examine Earth's interior by tracing the rays backwards from the many sources to determine the location of the

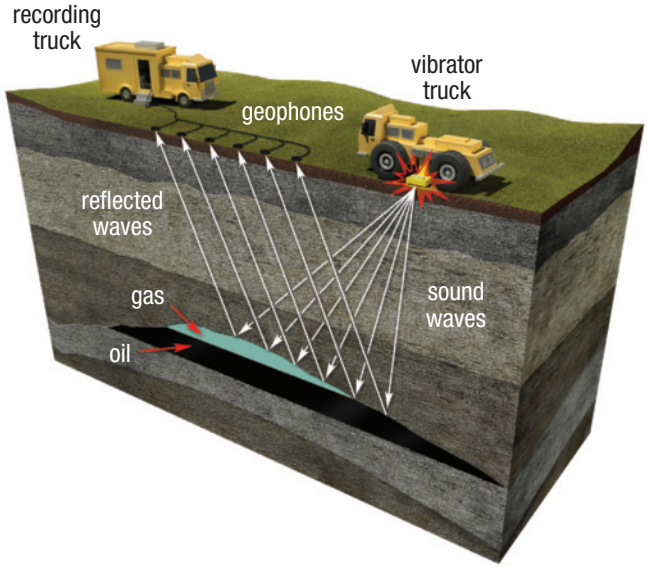

Figure 5 Sound waves produced by a vibrator truck travel through Earth and reflect off the various layers. The reflections eventually reach the surface, where they are recorded by geophones. Typically, the waves partially reflect off each layer beneath the surface. The process has been simplified in this diagram.

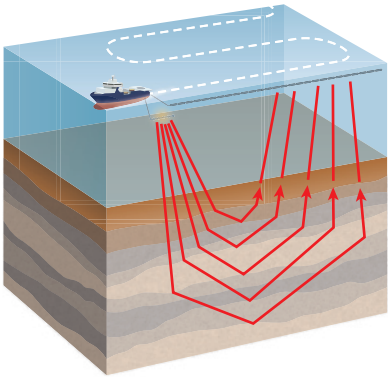

Figure 6 A ship using waves to search for oil beneath the ocean floor

layer that caused the reflection. Because of its complexity, the process is completely computerized.

Researchers then use the reflected seismic waves and computers to produce a detailed image of the underground layers. They examine the image to see how the waves reflected and how long the reflections took. From this examination, researchers determine the probable composition of the underground layers.

Using this information, researchers identify the depth of any valuable deposits, the size of the deposits, and where drilling should take place. This reduces the amount of drilling required, saving time and money. A similar method is used to find oil underneath the ocean floor using a ship moving in a zigzag pattern across the ocean surface (**Figure 6**).

A similar method has been used to explore the Moon. During the Apollo missions, sensitive seismic equipment was left on the Moon to collect seismic data about its interior. Other Apollo missions intentionally smashed booster rockets into the Moon's surface to cause vibrations, which were used to analyze the interior of the Moon.

UNIT TASK BOOKMARK

As you carry out the Unit Task on page 486, apply what you have learned about how seismic waves can influence the design of your researched structure.

10.5 Summary

- Earthquakes cause different types of waves that move through Earth and across the surface. Underwater earthquakes can cause tsunamis, which can damage coastal land and properties, as well as cause loss of life.
- Seismic waves can have a negative impact on society, but technologies can help reduce this impact.
- Seismic geophysical exploration can be used to form computerized images of layers of rock, liquids, and mineral deposits underground and under the ocean floor. These images can be used to determine depth, composition, and size of deposits and where to drill. This method of exploration saves both time and money.
- Similar seismic techniques involving waves have been used to study Earth's interior. Enormous insight has been gained through this method in understanding Earth's interior structure.

10.5 Questions

1. Explain the difference between (a) a surface wave and a body wave, and (b) a P-wave and an S-wave. K/U
2. Describe how P-waves and S-waves are useful in determining the nature of Earth's interior. K/U C
3. Scientists can detect both P-waves and S-waves and then use them to determine the location of the epicentre (the point of origin on the surface of the earthquake). Describe a procedure that could be used to determine the location of the epicentre if you know the speed of each wave. Assume that the waves have been detected at several different positions close to the epicentre. T/I
4. List three reasons why geophysical exploration is an important part of obtaining natural resources, such as oil and natural gas. K/U
5. Sound waves are used to map different layers of Earth. K/U
   (a) Describe the technology used to form a computerized image of the layers of rock and mineral deposits underground.
   (b) How are sound waves used to gather information to form these images?
6. **Figure 7** represents several layers of rock beneath Earth's surface. Copy the diagram into your notebook. A vibration is created at the surface at the point shown. Use your diagram to show how waves from the source could be reflected off the various layers of rock. K/U C

Figure 7

7. Research helioseismology. T/I
   (a) Explain what helioseismology means.
   (b) Explain how the Sun "rings like a bell."
   (c) Explain why we cannot hear the Sun's vibrations.

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