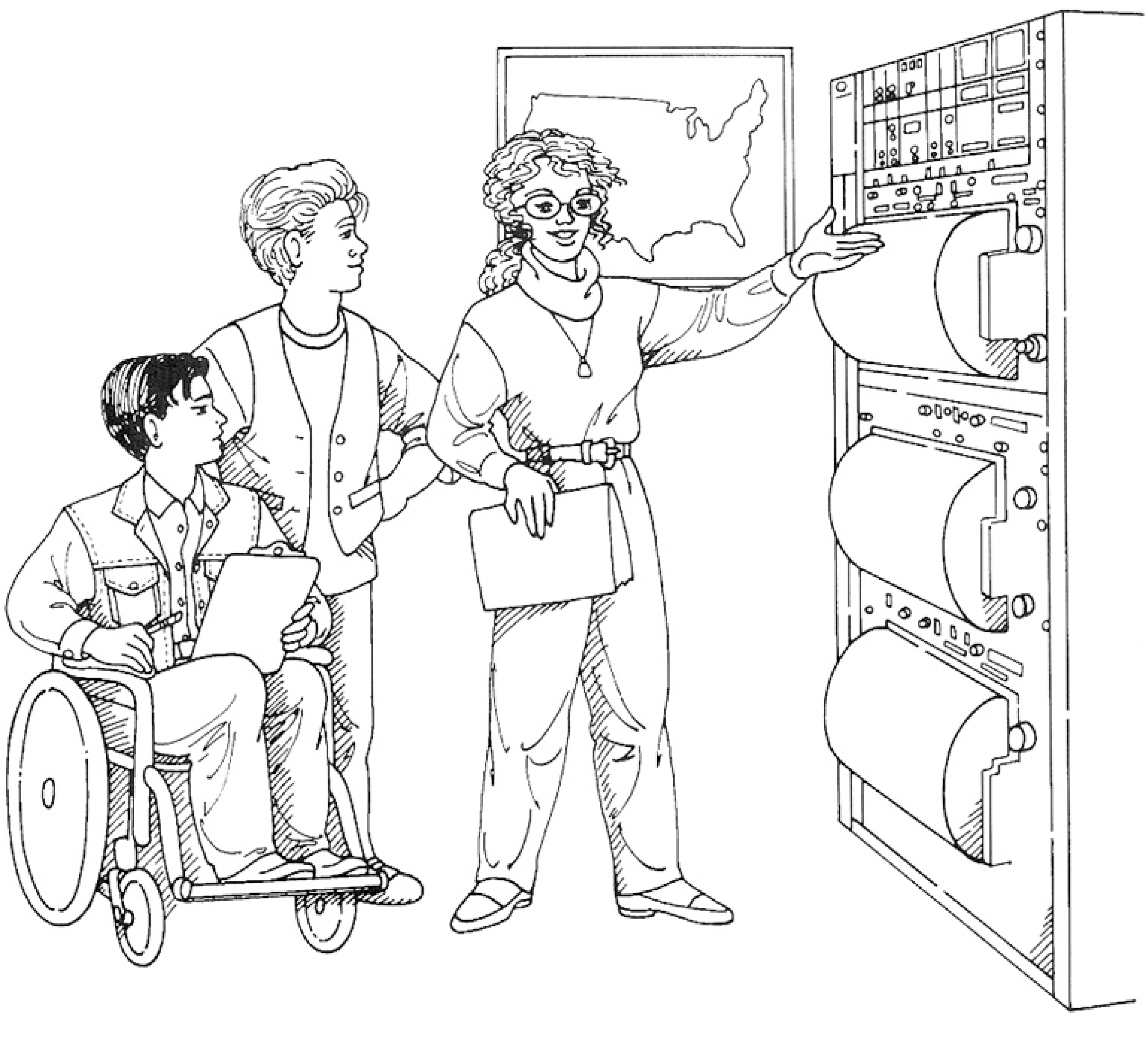
U N I T T H R E E



How Do People Learn about EARTHQUAKES?

In the first lesson, students will learn about the movement of earthquake waves in our Earth and on its surface. It was the study of this movement, by Mohorovicic, Lehmann, and others, that developed our current understanding of the interior of the Earth. Activities illustrate the movement of P and S waves. Background material on Love and Rayleigh waves is also provided.

The second lesson in Unit 3 is built around biographical sketches of three individuals who made major contributions to our knowledge of the Earth's inner structure: the German meteorologist Alfred Wegener, who amassed evidence for the controversial theory of continental drift; the Croatian seismologist Andrija Mohorovicic, who demonstrated the existence of the discontinuity between crust and mantle that bears his name; and the Danish seismologist Inge Lehmann, who demonstrated the existence of the inner core. A timetable of other relevant discoveries is included as teacher background material.

Lesson 3 begins with a pair of activities that contrast the two systems most commonly used to characterize earthquakes—the Modified Mercalli scale, which assigns a number on the basis of observed effects, and the Richter scale, which assigns a number on the basis of instrument readings. Students draw isoseismals on a map in the first activity. In the second they compare Richter magnitudes from several seismograph stations for the same earthquake. In the third activity, they practice reading seismograms.

Lesson 4 has three parts, moving from the worldwide distribution of earthquakes to one seismically active area of Japan and then home to the United States. At all three stages, students plot actual earthquake data in order to gain an experiential understanding of where earthquakes occur. In the second activity they construct a plot in three dimensions. Most students will be surprised to learn that earthquakes are everyday occurrences on a global scale, and that they may originate from foci as deep as 700 km inside the Earth—1/9 of the way to its center.

Like the previous unit, this one offers a variety of experiences in scientific observation, computation, and the application of social science principles. It also presents factual information that will stand students in good stead as consumers of media information and as future property owners.

Social studies teachers may be especially interested in the second lesson of this unit. Mathematics teachers will find applications of algebra and geometry in many of the others. The lessons in this unit can stand on their own, but taken together, they provide an excellent preparation for learning to mitigate the effect of earthquakes on the human environment, in Unit 4.

3.1

The Waves of QUAKES

RATIONALE

To understand earthquakes and their effects on Earth's surface, and to understand how scientists have learned about Earth's interior, students must begin to understand the properties of waves.

FOCUS QUESTIONS

How does matter transmit energy in the form of waves?

OBJECTIVES

Students will:

1. Compare and contrast the two main types of earthquake waves and draw sketches to illustrate them.
2. Describe the manner in which each of the two types transfers energy and moves Earth particles.

PART ONE

PRIMARY WAVES (P WAVES)

MATERIALS

- Student copies of Master 3.1a, Earthquake Wave Background
- Slinky toys (One for every two students is ideal.)
- White plastic tape
- String
- Unlined paper
- Pencils

PROCEDURE

Teacher Preparation

Put the Slinky toys and the tape in a central location where they will be available to students. Students will mark the coils so they can see the movement of energy along their length.

TEACHING CLUES AND CUES

Metal Slinkies will be more effective than plastic ones for this activity. If you use plastic Slinkies, tape two together, with about 7.5 cm of overlap, for each pair of students.

It will be helpful to refer to Master 2.2b, Earth Cross Section, as you talk about waves moving through the Earth. You may want to project the transparency.

A. Introduction

Explain: It is the energy from earthquakes that puts human beings and human structures in danger. This energy is transmitted through the Earth in the form of waves. Distribute copies of Master 3.la, Earthquake Wave Background. Go over the Body Waves section of the background material with the class.

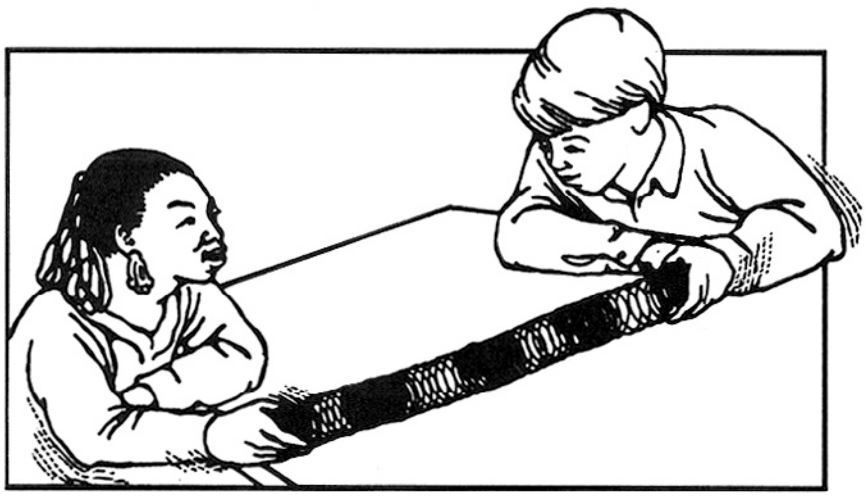
B. Lesson Development

1. Ask students:

- Where is the energy of an earthquake released? (along the fault plane where tectonic stress is released)
- In what form is the energy from an earthquake released? (in the form of waves)

2. Divide students into pairs or groups of even numbers, depending on the number of Slinkies available. Direct students to pick up their Slinkies and mark two spots on each, near the center of the coil, with white plastic tape. The two pieces of tape should be at the tops of adjacent loops.

3. Two students will hold each Slinky, one on either end. Instruct them to stretch it out to a length of approximately three meters on the floor or a long counter. Have students take turns compressing between 10 and 20 coils and then releasing them rapidly while they continue to hold the Slinky.



4. After several repetitions, ask students to describe what they saw happen with the coil and the tape. Then ask:

- What kind of earthquake waves does this movement resemble? (longitudinal body waves, or P waves)
- How is the movement of the spring like the movement of the waves? (It moves by contracting and expanding—by compression and expansion.)

VOCABULARY

Body waves: waves that move through the body (rather than the surface) of the Earth. P waves and S waves are body waves.

Compression: squeezing, being made to occupy less space. P waves are also called compressional waves because they consist of alternating compressions and expansions.

Longitudinal waves: waves that move particles back and forth in the some line as the direction of the wave (P waves).

P waves: primary waves, arrive at a station first because they travel faster than S waves, or secondary waves. These waves carry energy through the Earth in the form of longitudinal waves.

S waves: secondary waves; waves that carry energy through the Earth in the form of very complex patterns of transverse waves. These waves move more slowly than P waves (in which the ground moves parallel to the direction of the wave). In an earthquake S waves are usually bigger than Ps.

Transverse waves: waves that vibrate particles in a direction perpendicular to the wave's direction of motion (S waves).

TEACHING CLUES AND CUES

Activity 3 in lesson 2.4 deals with tsunami, destructive water waves often caused by earthquakes. If you have not taught this lesson, refer to it now.

- In what direction does the energy move? (It moves out from the point at which the energy is released—the focus.)
- What happens within the body of the Earth when energy moves through it in this way? (Energy is transmitted from any material near the focus to particles away from the source in the form of waves.)

C. Conclusion

Challenge pairs of students to decide what a P wave would look like and draw one on the top half of a sheet of paper. Tell them to use pencil, so if they change their minds later they can revise the drawing. (There are several acceptable ways to do this.)

ADAPTATIONS AND EXTENSIONS

1. With students who show special interest, assign all of the reading on Master 3.1a and add Rayleigh waves and Love waves to your discussion.

2. Research and discuss (a) the intermolecular forces that provide the means of transmitting energy in longitudinal waves and (b) the speed of P waves traveling in the Earth's crust. Ask:

- How does the density of materials affect the speed of P waves? (The more dense the material, the faster the waves move.)
- As P waves travel deeper into the Earth, does their speed change? (P waves, like S waves, move faster in the mantle than in the crust, because the mantle is more dense. The rocks that compose the Earth at great depths, however, are plastic, so they slow down the waves.)
- Why can P waves travel through liquids, while S waves cannot? (P waves travel by compression, and S waves travel by shearing at right angles to the direction of motion. Water cannot spring back after it is sheared, so the S waves die out in water.)
- How are P waves similar to sound waves? (A sound wave in the ground is a P wave; a P wave in the air is a sound wave. Both are compressional waves.)

PART TWO

SECONDARY, OR SHEAR WAVES (S WAVES)

MATERIALS

- 7.6 m (25 ft) of coiled telephone cord, available at electronics or phone stores and some discount stores
- Two different colors of plastic tape, about 1 cm (.5 in.) wide
- Masking tape
- Two empty soda cans

TEACHING CLUES AND CUES

Point out that in a P wave the movement of each coil of the Slinky is parallel to the wave motion (the length of the Slinky). In an S wave, the movement is perpendicular to the length of the Slinky. This difference may be easier for students to see than compression and dilation.

PROCEDURE

A. Introduction

Ask students:

- What type of body wave did the Slinky exercise illustrate? (P waves, also known as compressional waves or longitudinal waves)
- What is the other type of body wave? (S waves, also known as waves or transverse waves)

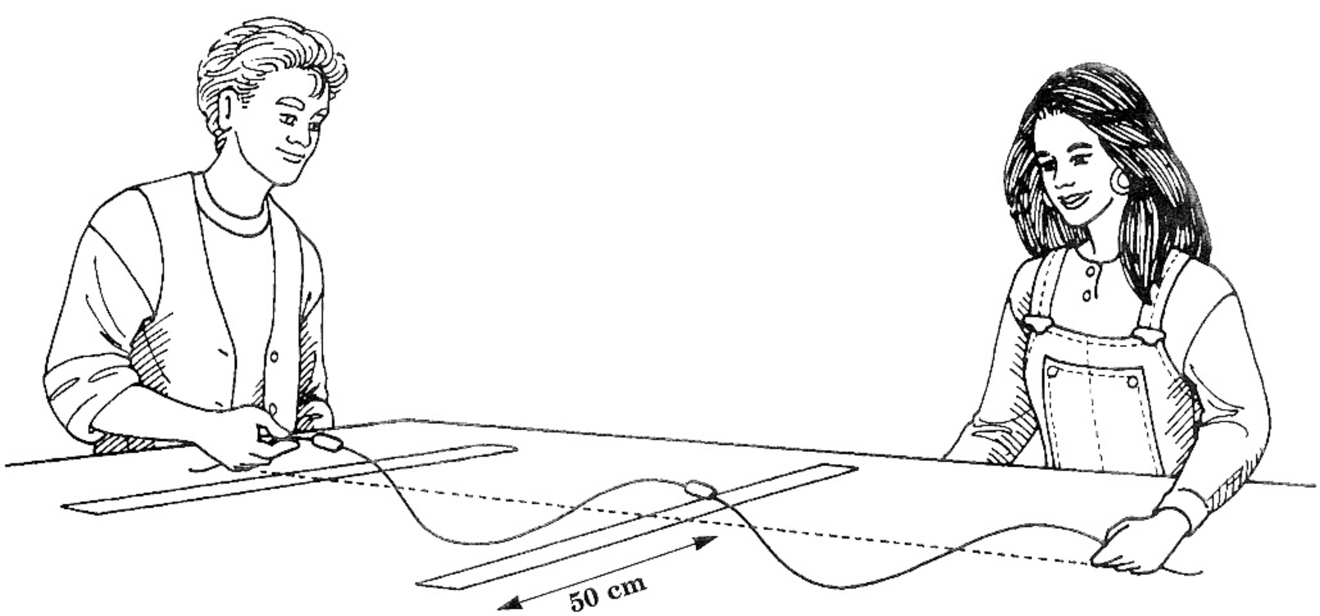
B. Lesson Development

1. Give these instructions for demonstrating single shear waves (S waves).

a. Place a band of bright colored tape halfway along the coiled telephone cord. Place another band close to one end. Lay the cord straight along a smooth surface. Have two students hold the ends of the cord firmly so it will not move.

b. With plain masking tape, mark a 50-cm line perpendicular to one end of the cord. Mark another line of the same length at the cord's halfway point, directly under the center band of tape. This will provide you with a reference line.

c. Pick up the end of the rope at the center of the first perpendicular tape line, then move your hand back and forth quickly along the masking tape. As you expected, a wave travels down the rope (or transmitting medium). Observe the motion of the colored tape while waves are moving by. Students may take turns holding the ends of the cord.



TEACHING CLUES AND CUES

Students may be confused by the array of synonyms for P waves and S waves. Help them to understand that each term provides additional information about one type of wave. P waves, or primary waves, are also called compressional waves and longitudinal waves. S waves, or secondary waves, are also called shear waves and transverse waves. Both P and S waves are body waves.

d. Place two empty soda cans upright on either side of the cord on the center tape line. Both cans should be the same distance from the cord—about 30 cm (1 ft). When a wave of sufficient amplitude is sent along the cord between these cans, what will happen? (The same piece of cord, as indicated by the colored tape marker, will knock over both cans.)

2. Point out that although students may only see motion in one direction, the transverse wave they have just observed vibrates in a direction perpendicular to its direction of motion. Remind students that S waves within the Earth are not just in one plane, and don't all have the same frequencies and amplitudes. In an earthquake, a jumble of S waves passes through a particular volume of Earth at the same time. Since S waves reach the surface from below, a special pendulum seismograph would show ground motion for S waves as a very complex, seemingly random pattern of horizontal (back and forth) motions.

C. Conclusion

Ask students:

- Which type of wave does this activity illustrate? (S waves)
- What are some differences between P waves and S waves? (P waves are longitudinal and S waves are transverse. P waves can be transmitted through solids, liquids, and gases, while S waves can only be transmitted through solids.)

Now ask students, working in the same pairs as for part one, to decide what a diagram of an S wave would look like and draw one on the other half of the page they used in part one. They may want to revise their drawings of a P wave at this time. When they have finished, ask each pair of students to exchange their drawings with another pair and discuss the similarities and differences.

ADAPTATIONS AND EXTENSIONS

1. If students have also discussed Rayleigh waves and Love waves, ask them to draw these on the backs of their pages at this time and follow the procedure for exchanging diagrams as above.

2. Invite students to research and discuss the intermolecular forces that provide the means of transmitting energy in transverse waves, and why S waves can not be transmitted through liquids, including Earth's outer core. ▲

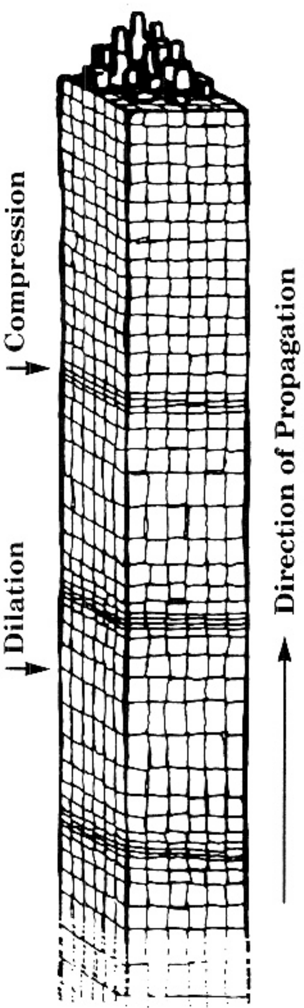
Earthquake Wave Background

The major types of seismic waves are classified as body waves and surface waves. The two have different shapes and properties. All waves in matter depend upon the interaction of forces among the particles of some material. These forces transmit movement of one particle to movement in adjacent particles.

Body Waves

Body waves, so called because they travel through the body of the Earth, consist of two types: primary (P) and secondary (S). S waves are also called shear waves and transverse waves.

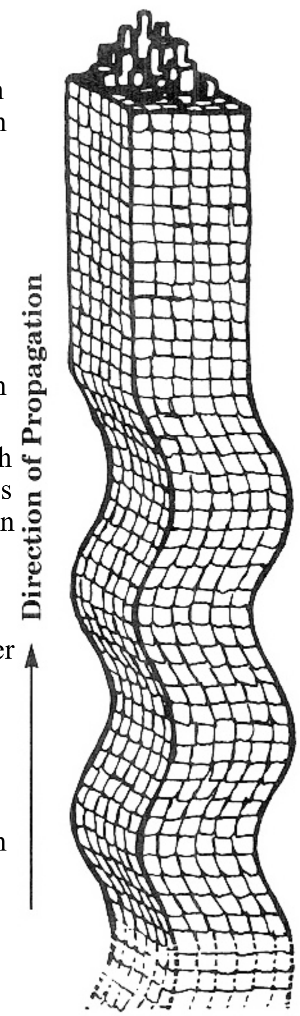
Primary (P) waves consist of alternating compressions and expansions (dilations), so they are also referred to as compressional waves. P waves are longitudinal; they cause particle motion that is back and forth, in the same linear direction as energy transfer. These waves carry energy through the Earth, usually at the rate of 3.5–7.2 km/sec in the crust and 7.8–8.5 km/sec in the mantle.



P Waves

Secondary (S) waves are transverse; the particle motion they cause is perpendicular to the direction of energy transfer. Their usual speed is 2.0–4.2 km/sec in the crust and 4.5–4.9 km/sec in the mantle.

Longitudinal (P) waves can be transmitted through solids, liquids, and gases, while transverse (S) waves (with the exception of electromagnetic waves) can only be transmitted by solids. Waves can be reflected and refracted (bent) when they move from material of one density to that of another density. Wave energy can also be changed to other forms. As they move through the Earth, the waves decrease in strength, or attenuate. Waves attenuate more slowly in solid rocks than in the basins full of sediment so common in the West. Because of this, an earthquake in the crust of the eastern United States is felt over a wider area than a quake the same size in the rocks of the western states.



S Waves

Surface Waves

Seismograph stations detect surface waves from many, but not all, quakes. Whether a station detects them or not depends on the strength of the quake's energy release, the depth of the quake, and the station's distance from the focus.

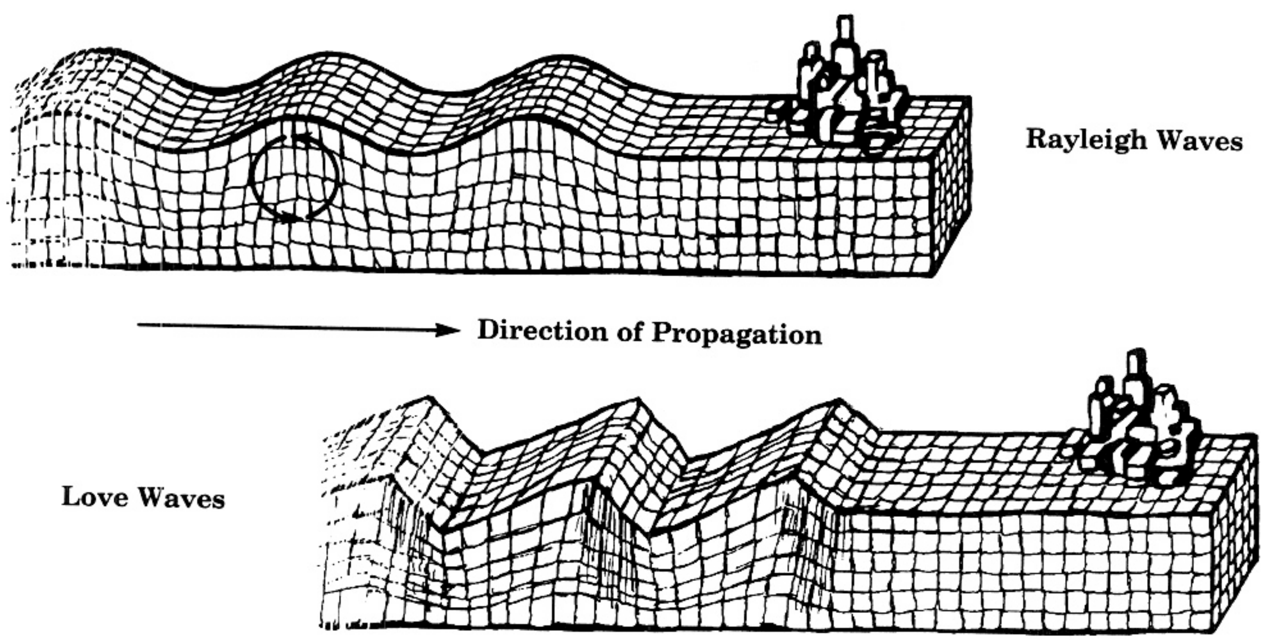
Unlike body waves, which travel through the Earth, surface waves travel around it. The two main types of surface waves are called Rayleigh waves and Love waves. These surface waves travel more slowly than S and P waves, and attenuate more quickly.

Within Rayleigh waves, Earth particles move in elliptical paths whose plane is vertical and set in the direction of energy transfer. When an Earth particle is at the top of the ellipse, it moves toward the energy source (seemingly backwards), then around, downward, and forward, away from the source. It then moves around and upwards back to its original position. This produces a ripple effect at the Earth's surface that is similar to ripples on a pond. The orbits, or paths, of these particles become smaller and finally die out at a certain depth within the Earth.

Love waves move particles in a back and forth horizontal motion as the energy moves forward. If you could see a Love wave inside the Earth, you would notice a zigzag horizontal motion.

Putting Them Together

Since these four types of waves shake a location on Earth's surface in various ways and directions, a seismic station needs at least three seismographs to glean a reasonably good image of ground shaking at that location. One seismograph is built to measure vertical motions, and two others, aligned perpendicular to each other, measure horizontal motions. Although P, S, and Rayleigh waves may be recorded on all three seismographs, P waves are best recorded on the vertical component and S waves on the horizontal. Love waves are only recorded on the horizontal components, but Rayleigh waves are recorded on all three.



3.2

Pioneering Ideas

RATIONALE

The people who have shaped our idea of the Earth are pioneers, just as truly as those who struck out in new directions across its surface. This idea may be new to students.

FOCUS QUESTIONS

Could a person be a pioneer without leaving home?

OBJECTIVES

Students will:

1. Read a biographical sketch about a pioneer of earth science.
2. Identify the characteristics of a pioneer.
3. Be able to tell why Wegener, Mohorovicic, and Lehman were pioneers.

MATERIALS

- Student copies of Master 3.2a, Three Pioneers (3 pages)
- Master 3.2b, Chronology: The Beginnings of the Seismological Age
- Overhead projector and transparencies (*optional*)
- Reference books for research (See Unit Resources.)
- Paper and pens

PROCEDURE

Teacher Preparation

Assemble a classroom reference shelf of biographical encyclopedias, studies on continental drift and plate tectonics, and books on earth- quakes. (See Unit Resources.)

A. Introduction

Tell students that you would like them to explore the notion of *pioneer*. Write the word on the chalkboard or overhead projector and ask the class to brainstorm about the meaning of the word and its implications. Be prepared to accept any reasonable suggestion. Such ideas as risk-taker, adventurer, initiator, innovator, frontier person, and explorer are likely to come forward. You may want to use these terms to build a concept map.

VOCABULARY

Continental drift: the theory, first advanced by Alfred Wegener, that Earth's continents were originally one land mass, split off and gradually form the continents we know.

Epitaph: an inscription on a tombstone, often intended to sum up the achievements of a person's life.

Meteorology: the study of Earth's atmosphere.

Pioneer: a person who moves into new and uncharted territory.

Plate tectonics: the theory that Earth's crust and upper mantle (the lithosphere) are broken into a number a more or less rigid, but constantly moving, segments, or plates.

Seismology: the scientific study of earthquakes.

Topography (adj. topographic): the shape of the land; the contours and the arrangement of surface features that characterize a region.

During the course of the brainstorming, remind the class that in a historical sense, we tend to think of pioneers as men and women who have moved beyond the edge of settlement. Daniel Boone was such a person, and so were Lewis and Clark and Matthew Henson, the polar explorer. There are other types of pioneers, however—those who are willing to advance new ideas and suggest new theories to explain physical or cultural phenomena. Albert Einstein, with his theory of relativity, is a good example of this kind of pioneer. So is Marie Curie, who worked to develop radium therapy and conducted some of the earliest experiments with radiation.

B. Lesson Development

1. When the brainstorming session has ended, ask each student to write a one-sentence definition of the term *pioneer*, using the list generated by the class as a reference. Then have students share their responses to learn if a consensus has developed about the meaning of the term. From the collection of definitions presented by class members, write what seems to be a representative definition on either the board or the overhead. Here are some likely definitions:

A pioneer is a person who is on the cutting edge, someone with the courage and the vision to try something new.

A pioneer is the first person to suggest a new idea or to try something that has never been tried before.

A pioneer is a person who prepares the way for others because of his/her courage and foresight.

2. Divide the class into groups of three students each. Provide each group with one copy of Master 3.2a, Three Pioneers. Each of the students may read one essay. When students have finished reading, ask them to give the essay a title and to write a two- or three-sentence summary of the essay in the space provided.

3. With this as context, remind students that when each of these discoveries was first published, it created discussion and even controversy. To understand the kind of excitement each advance in science causes, have half of the students who read about each scientist research the evidence that person offered to support the new theory and the other half research the views of his or her critics or the reasons why it may not have been accepted immediately. Later in the same period or the next day, invite the groups to present and discuss opposing points of view culled from their reading.

C. Conclusion

Return to the consensus definition of pioneer that the class developed and ask students to apply that definition to these three individuals. To do this, they should write epitaphs for the tombstones of the three scientists. Remind students that the purpose of an epitaph is to summarize a person's life in a brief and pithy fashion. Post the epitaphs on the bulletin board to present the variety of impressions class members have about Wegener, Mohorovicic, and Lehmann.

TEACHING CLUES AND CUES

Use Master 3.2b, Chronology: The Beginnings of the Seismological Age, for your own reference and to help students place the work of these three scientists in the context of other dis-

ADAPTATIONS AND EXTENSIONS

1. Make a time line from the information on Master 3.2b, Chronology: The Beginnings of the Seismological Age. You could do this either before class or during class with student participation.

2. As a class, brainstorm suitable epitaphs for some of the other pioneers mentioned in this lesson and those students know about from other areas of study.

3. Encourage students to read biographies of intellectual explorers and learn about some of the challenges pioneers have faced. ▲

Three Pioneers

Name ____ Date _____________________

1. In 1912, when Alfred Wegener proposed in print that Earth's continents floated on denser and more stable material below, he was openly ridiculed and even scorned by his colleagues. Not until several decades later did his ideas receive any acceptance. Today he stands as the forefather of modern plate tectonics because of his theory of continental drift. His widely accepted theory of land displacement holds that Earth's continents have been in motion throughout geological time.

Wegener believed that there was once a single supercontinent, which he called Pangea (or Pangaea). He said that Pangea broke apart millions of years ago to form two large continents. He called the one in the northern hemisphere Laurasia and the one in the southern hemisphere Gondwanaland. After a very long span of centuries, Wegener said, Laurasia split to form North America, most of Asia, Greenland, and a large section of Europe. Gondwanaland became Africa, South America, Australia, India, and Antarctica. Wegener believed that the land masses drifted for millions of years before assuming their present shapes and arriving at their present locations. He was led to this notion by the congruity he observed in the shorelines of the lands bordering the Atlantic Ocean and several other kinds of evidence. Further, he said, the process of continental drift is still going on—the continents are still on the move.

Alfred Wegener, who was educated to be a meteorologist and an Arctic climatologist, insisted that his theory was correct because of the evidence he saw. To support his ideas about continental drift, Wegener pointed to the similarities in the fossils of the southern continents. Fossils of the same sort from ferns and freshwater reptiles had been found in all of the southern continents. He saw this as evidence that all the lands south of the equator has once been part of a single land mass. He argued that such land-based life forms could never have crossed the thousands of miles of open ocean that now separate these land masses. His critics scoffed because the physical model that Wegener proposed to explain the movement of continents did not fit what was then known about the physics of the Earth.

For the next 30 years or so, scientists paid little attention to Wegener's theory. In the 1960s, however, geologists discovered that the ocean floors had been spreading, thus influencing the shapes and sizes of the continents. This new theory, called plate tectonics, provided a mechanism that made sense in physical terms to account for Wegener's idea of continental drift.

Although the continents themselves do not drift, as Wegener proposed, he was correct in his thesis that Earth's surface is not fixed. He was a man well ahead of his time whose insight went beyond safe and conventional thinking. So important is Wegener to our current understanding of plate tectonics that in the 1970s a crater on the dark side of the moon was named for him, to honor his courage and vision.

Tragically, Alfred Wegener never lived to see his ideas accepted by the scientific community. He perished while attempting to cross Greenland from a camp on the ice cap in the winter of 1930. His purpose was to learn more about atmospheric conditions in the Arctic in order to better predict world weather patterns.

What title would you give this essay?

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Three Pioneers

Write a two- or three-sentence summary of the essay, then add a one-sentence comment.

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Name ____ Date ______________________

2. *"In the earth's interior, where seismic waves travel invisibly and inaudibly, they can be followed only by mathematical equations."*

Dragutin Skoko, Mohorovicic's biographer

The boundary separating Earth's crust from its upper mantle is called the Mohorovicic discontinuity, or the Moho, for short, in honor of the Croatian seismologist Andrija Mohorovicic. In 1909, he used data on the travel tame of earthquake waves to demonstrate that their velocity changes at about 50 km beneath the surface. Others later refined the study of crust and upper mantle and applied new, methods, but Mohorovicic paved their way.

Mohorovicic's father, also named Andrija (or Andrew), was a maker of anchors. The young Mohorovicic loved the sea, and married a sea captain's daughter. He taught for nine years at the Royal Nautical School in Baka. After becoming director of the Meteorological Observatory in Zagreb, in 1891, he studied and wrote primarily about clouds, rainstorms, and high winds. After a severe earthquake in 1901, however, Mohorovicic and his colleagues petitioned their government to establish a seismic station in Zagreb. In 1910, Mohorovicic published his account of the earthquake of November 9, 1880. In it, he plotted a now-standard transit time graph-arrival time versus epicenter distance to recording station-using the data for 29 stations that ranged to a distance of 2,400 km from the epicenter.

After plotting data for a large number of earthquakes over a wide area, he had begun to notice that the P wave arrivals required two curves on his graph. Because it was not possible to have P waves traveling in the same medium at different velocities, and the earlier P arrivals were only seen at some distance from the epicenter, he reasoned that the two (different arrival times represented two different phases of P waves traveling different paths. After working out the refraction equations and tests to determine optimal values for the depth of the focus, the ray paths of the two P waves, the corresponding two S phases, and their reflection paths, he concluded that at approximately 50 km there must be an abrupt change in the material that composes the interior of the Earth, because he observed an abrupt change in the velocity of the earthquake waves. Although this conclusion was not accepted immediately, Beno Gutenberg was able to confirm it with his own research as early as 1915.

Even after earthquakes became one of his primary interests, as chief of the observatory, Mohorovicic was responsible for recording all the meteorological data for Croatia and Slovenia—precipitation, tornadoes, whirlwinds, thunderstorms, and more—with only an occasional assistant. He was responsible for all the mathematics involved in keeping records and for answering hundreds of letters and requests for assistance, as well as teaching classes at the University. He was patient and precise in his collection and analysis of data, but he loved good scientific instruments, and was frequently frustrated at the inadequacy of the instruments available and the difficulty of obtaining new ones. An accurate clock was particularly important to his research, because in studying earthquakes, an error of one second in the time of arrival means an error of 5.6 km in estimating the length of its travel making it impossible to accurately locate the focus of an earthquake. By 1913 he had finally obtained a crystal clock with a radio receiver that allowed him to synchronize with the Paris Observatory, but in 1914, during World War I, the army commandeered it for military use. When the dock was returned to him after the war, he also received a new radio receiver that took two railroad cars to transport.

Mohorovicic published a paper in 1909 on the effect of earthquakes on buildings that described periods of oscillation (see lesson 4.3). In this he was at least 50 years ahead of the times both in his own country and elsewhere. Croatia's first national Provisional Engineering Standards for Construction in Seismic Areas were published in 1964.

During his lifetime, Mohorovicic maintained contacts with seismologists all over the world. He retired in 1922, but remained active until shortly before his death in 1936. His only grandchild, Andre, remembers that he was always good natured—a kind and peaceful man. Mohorovicic, like Alfred Wegener, received the honor of having his name given to a crater on the dark side of the moon.

What title would you give this essay?

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Write a two- or three-sentence summary of the essay, then add a one-sentence comment.

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Name ____ Date ________________________

3. By 1936, scientists had learned from the study of earthquake waves that the Earth has three layers, crust, mantle, and core. Denmark's Inge Lehmann was the first to demonstrate the existence of a change in composition midway through the core, dividing it into an inner core and an outer core. This division is now known as the Lehmann discontinuity.

As a girl, at the turn of the century, Lehmann attended the first coeducational school in Denmark, which was founded and run by Hanna Adler. (Adler's nephew, Neils Bohr, was the first to describe the physical makeup of the atom.) At that school, Lehmann wrote many years later, "No difference between the intellect of boys and girls was recognized—a fact that brought me disappointments later in life when I found that this was not the general attitude."

Lehmann studied at Oxford, earned a master's degree in mathematics from the University of Copenhagen, and went to work as an actuary, calculating life expectancies and statistical risks for insurance companies. Beginning in 1925, however, she also served as a staff member of the Danish Geodetic Institute, helping to establish seismological stations in Greenland and in Copenhagen—a part of the world not noted for its seismicity. Seismology soon became her life work, and for 25 years, until just before her retirement, she was the only Danish seismologist.

As early as 1910 scientists had noticed a shadow zone in the Earth's interior, but seismographs had not been refined enough to explain this observation. In the course of the 1930s more and more sensitive seismographs were being developed. At the Copenhagen Seismological Observatory, Lehmann studied waves reflected through the core from earthquakes in Japan. In 1936, after 10 years of studying seismograms, she interpreted the newly revealed data to confirm the existence of a relatively small inner core in the center of the Earth. The paper in which she reported her findings has one of the shortest titles in the history of seismology, if not of all science: It was called "P."

Lehmann was among the founders of the Danish Geophysical Society in 1936, and served as its president from 1941 until 1944. She helped to formulate the constitution of the European Seismological Federation and was elected its first president in 1950. She found time to attend most of the meetings of the International Union of Geodesy and Geophysics, and served on the executive committee of the International Seismological Association from 1936 to 1944, from 1951 to 1954, and from 1957 to 1960. International cooperation in the sciences was one of her passions. She was active in national and international scientific organizations, and traveled in France, the Netherlands, Belgium, and Germany, where she worked with some of the leading seismologists of the day. In Canada, she worked at Ottawa's Dominion Observatory, and in the United States she conducted research at the Seismological Laboratory, California Institute of Technology; the University of California at Berkeley; and the Lamont-Doherty Geological Observatory, Columbia University, New York.

She loved hiking, skiing, and mountain climbing. Her favorite place indoors, aside from her own cottage in Denmark, was an art gallery. She loved to visit galleries and look at paintings whenever she traveled, and she traveled widely, especially after her retirement in 1953. She also loved music and gardening. Inge Lehmann died in February, 1993, at the age of 105, leaving a worldwide network of friends.

What title would you give this essay?

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Write a two- or three-sentence summary of the essay, then add a one-sentence comment.

Chronology: The Beginnings of the Seismological Age

■1883: The English seismologist John Milne hypothesized that with the proper equipment, it should be possible to detect seismic waves from a large earthquake occurring anywhere on Earth.

■1889: Milne's 1883 hypothesis was proven correct when E. von Rebeur Paschwitz used delicate pendulum seismographs to record the April 18, 1889, Tokyo earthquake in Potsdam and Wilhemshaven, Germany.

■1897: Richard Dixon Oldham noticed that seismograms from earthquakes consistently showed three different disturbances, the first and second "preliminary tremors" (now known as P waves and S waves, respectively) and the "large waves" that followed the preliminary tremors, and that the difference in arrival time between the "large waves" and the "preliminary tremors" increased in a predictable fashion with increasing distance from the earthquake.

■1900: Oldham established that the "preliminary tremors" (P and S waves) have travel paths that take them through the body of Earth (we now call them body waves), and that the "large waves" (now called surface waves) travel along Earth's surface.

■1906: Oldham used evidence from earthquake waves to demonstrate the existence of a large central core at a depth of about 3,821 km beneath the surface.

■1909: Andrija Mehorovicic, a Croatian seismologist, used seismic waves to discover a discontinuity at a depth of about 50 km beneath the surface. This marks the boundary between what we now call the Earth's crust and the underlying mantle. In his honor, we call the boundary separating the crust from the mantle the Mohorovicic discontinuity, or the Moho for short.

■1914: Beno Gutenberg used an extensive data set of earthquake wave travel times to compute the average distance to the top of the core at about 2,900 km.

■1926: Harold Jeffreys' measurements of tides in the solid Earth suggested that the Earth was less rigid than had been previously assumed. This led to the assumption that the core is fluid.

■1936: Inge Lehmann, Danish seismologist, demonstrated the presence of an inner core.

3.3

Sizing Up EARTHQUAKES

ACTIVITY ONE

THE MERCALLI SCALE: CALLING STATION KWAT

RATIONALE

Students need to know how seismologists establish earthquake intensity in order to understand how much damage earthquakes can cause and how building codes are developed.

FOCUS QUESTIONS

How do seismologists determine the intensity of an earthquake?

OBJECTIVES

Students will:

1. Interpret the Modified Mercalli scale and assign values on the basis of descriptions by citizen observers during and after a quake.
2. Use the assigned values to construct an isoseismal map.

MATERIALS

- Overhead projector
- Student copies of Master 3.3a, Modified Mercalli Intensity Scale
- Transparency made from Master 3.3a, Modified Mercalli Intensity Scale
- Back of Master 3.3a, Teacher Background Reading: Richter vs. Mercalli
- Student copies of Master 3.3b, Wattsville Map
- Transparency made from Back of Master 3.3b, Wattsville Map Key
- One copy of Master 3.3c, KWAT Television Script, cut into strips
- Student copies of Master 3.3c, KWAT Television Script
- Colored pencils and lead pencils

VOCABULARY

Epicenter: the point on Earth's surface directly above the focus of an earthquake.

Focus (pl. foci): the point within the Earth that is the origin of an earthquake where stored energy is first released as wave energy.

Intensity: a subjective measure of the amount of ground shaking an earthquake produces at a particular site, based on geologic effects, impact on human structures, and other human observations. Mercalli intensity is expressed in Roman numerals.

Isoseismal line: a line on a map that encloses areas of equal earthquake intensity.

Magnitude: a number that characterizes the size of an earthquake by measuring the motions on a seismograph and correcting for the distance to the epicenter of the earthquake. Magnitude is expressed in Arabic numbers.

PROCEDURE

A. Introduction

Ask students on what basis scientists classify earthquakes. Many students may be aware of the Richter Scale and some may be aware of the Mercalli Scale. Explain that the Richter Scale is a quantitative measure of the energy released by an earthquake, while the Mercalli Scale is a qualitative measure of the amount of damage it does. The Richter rating is referred to as a quake's magnitude, and the Mercalli rating is referred to as its intensity. The original Mercalli Scale was developed in 1902 by the Italian geologist Giuseppi Mercalli. Wood and Neumann adapted it to U.S. conditions and introduced the Modified Mercalli Scale in 1931. Both the Richter and the Mercalli scales have their uses. Have students give other examples of quantitative vs. qualitative measurements.

B. Lesson Development

1. Project the transparency of the Modified Mercalli Scale and distribute student copies. Share the background information about the two earthquake scales (back of Master 3.3a) with the class and discuss the importance of intensity in establishing building codes. Briefly discuss each of the values assigned on the Mercalli scale. If some students in the class have experienced an earthquake, ask them to estimate its intensity from the scale.

2. Have the students compare and contrast the differences between the two types of measurements. Ask: Why do you think magnitude is more often reported than intensity? (Most earthquake-prone areas have equipment already in place to determine magnitudes, so this measurement can be quickly established. Mercalli ratings are sometimes not arrived at until several days later, when a full estimate of the damage can be made.) Point out to students that the lack of news accounts reporting intensity does not diminish its value to city planners and engineers.

3. Tell students that in this activity they will be using data adapted from reports of an earthquake that struck California in 1971. Distribute copies of Master 3.3b, Wattsville Map. Appoint one student to be Jake Wilde, the television news anchor, and tell the other students that they are citizens of Wattsville and the surrounding area. The town has just been struck by an earthquake.

4. Distribute the strips cut from Master 3.3c and have students take turns reading them in order, starting with the news anchor's report. Distribute student copies of the script as well.

5. As each student reads a part, have the other students locate the site of the report on their maps, scan the Modified Mercalli Intensity Scale, and mark a Mercalli intensity in pencil next to the location.

6. After the last student has read, have students draw blue lines enclosing areas with equal intensity ratings to develop an isoseismal map. (They will be drawing a series of concentric lines.)

VOCABULARY

Modified Mercalli scale of 1931: a qualitative scale of earthquake effects that assigns an intensity number to the ground shaking for any specific location on the basis of observed effects. Mercalli intensity is expressed in Roman numerals.

Qualitative: having to do with perceived qualities; subjective. Examples: large, cold.

Quantitative: having to do with measurable quantities; objective. Examples: 10 m long, 5º C.

TEACHING CLUES AND CUES

Have students listen carefully for significant phrases in the callers' reports. They will be found in the Mercalli scale (Master 3.3a).

It may take class discussion to reach agreement on the values for some of the reports. Have students read the descriptions on the Mercalli scale carefully, and reread them as necessary, checking with the script as they proceed.

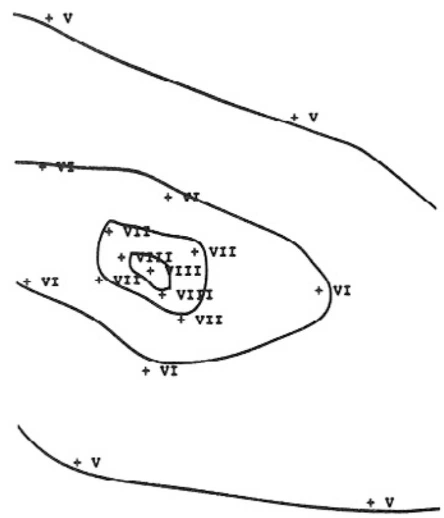
7. Project the transparency of Master 3.3b, Wattsville Map, and have students take turns giving you the values to draw on the transparency. Then draw in the isoseismals according to their interpretation of the data.

C. Conclusion

Ask students to find the area where the damage was most intense and color this area red. Then build a class discussion around these questions:

- Where do you think the epicenter of the earthquake is located? (Most students will think that the area with the most damage is the epicenter. In certain cases this is a false assumption. Damage may be related to siting or construction practices. An example of this is the 1985 Mexico City earthquake in which the fault was over 350 km away.)
- Why did some buildings near the epicenter withstand the shocks better than others? (perhaps because their structures were sounder or the soil under them was more firm)
- What are some advantages of the Mercalli rating procedure? (In ideal conditions, it can be done quickly, and it doesn't require any instruments. It describes the impact in human terms: on human beings and their structures.)
- What are some disadvantages to this procedure? (It requires human observers, so it could not assign an intensity to an earthquake in the middle of an ocean or in a deserted place. It also requires the exchange of information over a fairly wide area. To arrive at Mercalli ratings today, an official survey is conducted through the U.S. mail. It is not as precise or objective as instrument readings; different people might describe the same situation differently.)

Now place the answer key transparency on the overhead so it overlays student data. If there is a discrepancy between the isoseismals shown on the master and those students produced, they will see one of the drawbacks to this system of measurement. Ask students for suggestions to solve this problem.



ADAPTATIONS AND EXTENSIONS

1. Write a modern-day version of the 1931 Mercalli Intensity Scale.

2. Go to the library and search newspapers for qualitative information on an earthquake in your area. Construct an isoseismal map for the earthquake.

ACTIVITY TWO

RICHTER MAGNITUDE

RATIONALE

To determine Richter magnitude, we need to know both the maximum wave amplitude as recorded on the seismogram and the distance between the seismograph station and the earthquake, which can be calculated by finding the lag time.

FOCUS QUESTIONS

How do scientists determine the size of an earthquake?

OBJECTIVES

Students will:

1. Interpret seismograms to calculate Richter magnitude.
2. Compare Richter magnitudes from several seismograph stations for the same earthquake.

MATERIALS

- Transparency made from the first page of Master 3.3d, Five Seismograms
- Overhead projector
- Transparency marker
- Copies of Master 3.3d, Five Seismograms (simplified) (3 pages), one set for every two students
- Copies of Master 3.3e, Distance, Magnitude, Amplitude, one for every two students
- Paper and pencils or pens
- Rulers or straightedges
- Transparency made from Master 3.3e, Distance, Magnitude, Amplitude
- Transparency made from back of Master 3.3d (page 2), Richter Data Table, Answer Key

PROCEDURE

A. Introduction

Tell students that Richter magnitude is a quantitative measure that is related to the amount of energy released during the earthquake and is not attracted by factors such as population, building materials, or building design. Ask them to name some other kinds of quantitative measures (minutes, hours, centimeters, dollars). Be sure they understand the distinction between quantitative and qualitative description.

B. Lesson Development

1. Divide students into pairs. Give each pair a ruler and copies of Master 3.3d, Five Seismograms, and Master 3.3e, Distance,

VOCABULARY

Amplitude: a measurement of the energy of a wave. Amplitude is the displacement of the medium from zero or the height of a wave crest or trough from a zero point.

Duration: the length of time that ground motion at a given site shows certain characteristics. Most earthquakes have a duration of less than one minute in terms of human perceptions, but waves from a large earthquake can travel around the world for hours.

Lag time: the difference between the arrival time of P waves (T_p) and S waves (T_s).

Magnitude: a number that characterizes the size of an earthquake by recording ground shaking on a seismograph and correcting for the distance to the epicenter of the earthquake. Magnitude is expressed in Arabic numbers.

Richter magnitude: the number that expresses the amount of energy released during an earthquake, as measured on a seismograph or a network of seismographs, using the scale developed by Charles Richter in 1935.

Seismogram: the record of earthquake ground motion recorded by a seismograph.

Magnitude, Amplitude. Tell students that they are going to be working with five seismograms, all recorded for one earthquake on September 2, 1992, with its epicenter at St. George, Utah. Explain that the seismographs have been enlarged and simplified for their use but that this has also changed the scale, so they must use the vertical scale for all measurements. You will be demonstrating the steps to determine magnitude by using the first seismogram on Master 3.3d. They will record their data on the bottom of the third page of seismograms.

2. Project a transparency of Master 3.3d, page 1, and demonstrate how to measure amplitude. (See vocabulary definition.) Using the scale on the left side of the graph (the y axis) determine the greatest deflection in millimeters above or below zero of the largest seismic wave. Record this measurement in the amplitude column on the data table.

3. After all students have measured amplitude, start the next part of the activity by asking them which earthquake wave travels fastest and therefore should be the first wave recorded on the seismogram. Most of them should be aware from previous lessons that it is the P wave. On the transparency of Master 3.3d, page 1, point out the arrival of the P and S waves. Ask students what the difference between the arrival of the two waves is called (lag time (T_s-T_p). Ask students what should happen to the lag time recorded at stations farther from the earthquake. Offer a hint by comparing the progress of the waves to a race between the family car and a race car. The longer the race is, the more of an advantage the race car will have.

4. Using the projection of Master 3.3d, page 1, demonstrate how to determine distance to the earthquake recorded by the first seismogram. Using the scale at the top of the graph (the x axis), measure the difference between P wave and S wave arrival times in seconds. Use the formula

$$\text{Distance} = (T_s - T_p) \times (8 \text{ km/sec}) \text{ or } (4.96 \text{ mi/sec})$$

to convert time to distance. Have students record this in their data tables. Give students time to calculate the distances for the other four seismograms, following the procedure you have modeled.

5. Project the transparency of Master 3.3e and demonstrate how to find the magnitude of the earthquake. To do this, place the left end of the ruler on the left scale at the distance calculated in step 4. Holding the left edge of the ruler in place, move the right edge of the ruler to the correct point for the base-to-peak amplitude. Read the Richter magnitude on the center scale where the ruler crosses the graph and record it in the data table. Have students repeat this process on their own for the other stations. Average the magnitudes from the five locations to determine the final magnitude for this earthquake, and record it in the data table.

TEACHING CLUES AND CUES

The seismograms on Master 3.3d are seismograms that have been simplified and enlarged for classroom use. The printed millimeter scale has also been enlarged proportionately.

Do not use rulers for this step or the measurement will be inaccurate. (Be sure they make all their measurements on the same wave cycle, not the crest from one and the trough from another. The diagram on p.116 will be helpful.)

To measure the amplitude, have students lay a piece of paper across the wave and mark the high and low peaks, then use the scale on the y axis or the scale printed at the bottom of the seismogram to measure the amplitude or distance.

C. Conclusion

Project the back of Master 3.3d, Richter Data Table, Answer Key, and allow students to compare their calculations with the actual data. Ask students how a more accurate magnitude could be calculated. (by collecting more data points or by averaging the class averages of the calculated magnitude)

ADAPTATIONS AND EXTENSIONS

Seismologists today use a variety of magnitude scales and many types of instruments to record precise information on earthquakes. Interested students can read about P wave or body wave magnitude (called M_b), surface wave magnitude (M_s), moment magnitude (M_w), as well as the concept of seismic moment, drawing on materials in the unit resources list and others from local libraries.

ACTIVITY THREE

FIND THE EPICENTER: DECODING SEISMOGRAMS

RATIONALE

Students can find the location of an earthquake by triangulation if they know the distances from at least three seismograph stations.

FOCUS QUESTION

How do seismologists use seismograms to locate the epicenter of an earthquake?

OBJECTIVES

Students will:

1. Calculate the distance from an earthquake to a seismograph station.
2. Use five calculated distances to triangulate the location of the earthquake's epicenter.

MATERIALS

- Student copies of Master 3.3f, Several Seismographs
- Student copies of Master 3.3g, Sample Seismograms
- Student copies of Master 3.3h, Map of Station locations
- Transparency made from one page of Master 3.3g, Sample Seismograms
- Overhead projector
- Transparency made from Master 3.3h, Map of Station Locations
- Student copies of Master 3.3i, Time/Distance Reference Table
- Drawing compasses
- Metric rulers with millimeter scales

PROCEDURE

Teacher Preparation
Make one copy of each of the masters (3.3f through 3.3i) for every two students in your class.

A. Introduction
Ask students chosen at random to explain the difference between an earthquake's focus and its epicenter and between a seismograph and a seismogram. Review these distinctions if necessary.

Distribute copies of Master 3.3f, Several Seismographs, then project a transparency of Master 3.3f and describe their operation.

B. Lesson Development
1. Divide the class into pairs of students. Distribute a set of seismograms (Master 3.3g, 3 pages), one map (Master 3.3h), and copies of the Time/Distance Reference Table (Master 3.3i) to each

VOCABULARY

Epicenter: the point on Earth's surface directly above the focus of an earthquake.

Focus (pl. foci): the point within the Earth that is the origin of an earthquake, where stored energy is first released as wave energy.

Seismogram: the record of earthquake ground motion recorded by a seismograph.

Seismograph: an instrument that records vibrations of the Earth, especially earthquakes.

Triangulation: using data from three or more known points to locate an unknown point, in this case the epicenter of an earthquake.

pair. Tell students that all the seismograms are from the same earthquake, a quake that occurred on January 14, 1993, with a magnitude of 3.3, but each was recorded by a different seismograph in the seismograph network.

2. Project transparencies of one seismogram and the map. Model the procedure for students as necessary.

3. Give these directions for finding the epicenter of the earthquake recorded on the five seismograms:

a. On the first seismogram, use the second scale to measure the time- distance from the nearest 10-second mark to the P wave arrival of the earthquake. Record the P wave arrival times in the table to the nearest second.

b. Repeat for the S wave, measuring from the same minute mark.

c. Find the T_s- T_p time by subtracting the arrival time of the P wave from the arrival time of the S wave. Record this time in the table.

d. Use the time/distance table on Master 3.3i to determine the distance to the epicenter.

e. Repeat this procedure for all of the stations.

f. For each seismogram, draw a circle on the map with the compass, using the distance you calculated as the radius of the circle. Place the point of the compass at zero on the map scale and adjust the compass width to the calculated distance. With the distance set, place the point of the compass on the station and draw a circle. Mark the outer edge of each circle with a letter to identify the station.

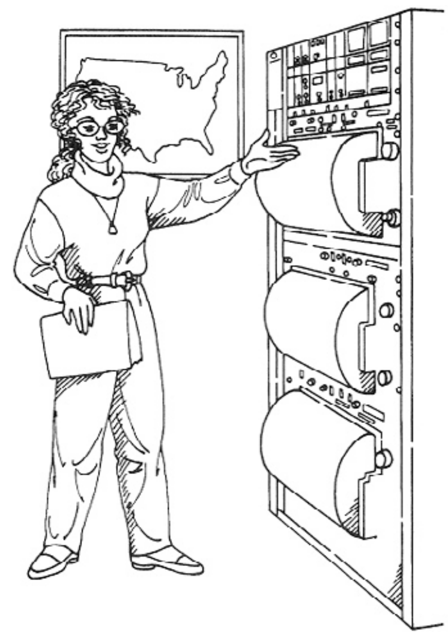
g. Repeat, setting the compass and drawing circles for 0 five stations.

4. Instruct students to circle the area where all the circles intersect. Ask: What is this area called? (It is the epicenter of the earthquake.)

C. Conclusion

Build a class discussion around these questions:

- What information can be obtained from one seismogram? (The distance from that seismograph in a 360º circle.)
- After the arcs for stations TRYN and FGTN were drawn, where was the epicenter of this earthquake? Explain. (We don't know yet. It could be at either place where the two arcs cross. They are the common points.)
- After all the stations were drawn, where was the actual epicenter of this earthquake? Where was its focus? (In the area where the arcs cross just south of station BHT. Directly under the epicenter.)
- Why is it necessary to have measurements from at least three different stations to locate the epicenter of an earthquake? (Answers will vary but should relate to the above questions.)
- Why don't all of the arcs pass through the same point? (Answers will vary. Accuracy in measurement and drawing should be two



TEACHING CLUES AND CUES

Emphasize the importance of accurate measurement, particularly the need to set the compass accurately for distance. Don't worry if the circles don't intersect perfectly, however. Remind students that an earthquake actually occurs along a fault, not at one single point.

most common. Also, an earthquake does not occur at one point but along a fault surface. Have students speculate as to the location and strike of the fault.

- Which station was closer to the earthquake's epicenter, BBG or FGTN? Cite two kinds of evidence from the seismograms to support your conclusion. (BBG. Evidence: amount of lag time and amplitude difference.)
- Would it be possible for an earthquake at this location to be felt where you live? Why or why not? (Answers will vary; will depend on distance from the focus and the magnitude of the quake.)
- P waves travel at an average velocity of 6 km/sec in the Earth's crust. How long would it would take for the P waves from this quake to reach a seismic station in your city, if they continued to travel at a constant speed? (Answers will vary. Multiply 6 km/sec times the distance to your city.)

ADAPTATIONS AND EXTENSIONS

1. Challenge students to research these questions:

- Would a seismograph work on the moon?
- Have scientists placed seismographs on the moon and other planets?
- If so, which planets? Have quakes been detected there?

2. Interested students may research several types of seismographs and build their own models. ▲