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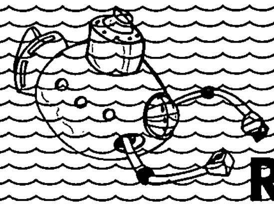
ABSTRACT

This activity is designed to introduce to students the processes of plate tectonics and volcanism that resulted in the formation of the Hawaiian Islands and the difference between S waves and P waves. Students are expected to explain how seismic data recorded at different locations can be used to determine the epicenter of an earthquake, infer a probable explanation for the existence of ultra-low velocity zones, and explain how these zones may be related to the Hawaiian hotspot. The activity provides learning objectives, a list of needed materials, key vocabulary words, background information, day-to-day procedures, internet connections, career ideas, integrated subject areas, evaluation tips, extension ideas, and National Science Education Standards connections. (KHR)

Roots of the Hawaiian Hotspot

Northwestern Hawaiian Islands Exploration –
Grades 9-12 (Earth Science)
Seismology and Geological Origins of the Hawaiian Islands

National Oceanic and Atmospheric Administration
U.S. Department of Commerce



Roots of the Hawaiian Hotspot

FOCUS

Seismology and geological origins of the Hawaiian Islands

GRADE LEVEL

9-12 (Earth Science)

FOCUS QUESTION

How can scientists obtain information on geological processes deep within the Earth?

LEARNING OBJECTIVES

Students will be able to explain the processes of plate tectonics and volcanism that resulted in the formation of the Hawaiian Islands.

Students will be able to describe, compare, and contrast S waves and P waves.

Students will be able to explain how seismic data recorded at different locations can be used to determine the epicenter of an earthquake.

Students will be able to infer a probable explanation for the existence of ultra-low velocity zones, and explain how these zones may be related to the Hawaiian hotspot.

ADDITIONAL INFORMATION FOR TEACHERS OF DEAF STUDENTS

In addition to the words listed as key words, the following words should be part of the vocabulary list.

Atolls
Nautical
SCUBA
Explorations
ROV
Corals
Consumed
Basalt
Archipelago
Hypothesized
Seismology
Rayleigh waves
Love waves
Compressional waves
Analogous
Shear Waves
Ripple
Seismograph

The words listed as key words are important to the unit. There are no formal signs in American Sign Language for any of these words and many are difficult to lipread. Having the vocabulary list on the board as a reference during the lesson will be extremely helpful. Also give the list as a handout to the students to refer to after the lesson.

Copy the definitions of Compressional waves and Shear waves listed in Part 2 of the Learning Procedure and distribute as a handout. The activity requires a number of students to complete. You will need to be flexible depending on the number of students in your class. For example, Step 3, Part a. calls for three students to be assigned as timekeepers, three students to simulate S waves, three to simulate P waves, and one to record the data. That is 10 students. If you do not have 10 students in your class, you can have students double up the S and P waves.

Part d. requires averaging travel times. The data can be listed on the board and averages done individually or as a group. Part h. requires a large number of students. You will need to look at your numbers and adjust accordingly.

The second activity begins in Step 4. The first activity suggests having two groups of six students. You can use one group of six; have them stand with their shoulders and upper arms touching. You can complete that demonstration and then switch to the linking arms activity. This will take longer, but it allows you to complete the activity with a smaller group and also gives the students an opportunity to experience both sections. The "Me" Connection can be used as an evaluation tool for the activity.

Materials

- ❒ Meter stick
- ❒ Stopwatches (3)
- ❒ Masking tape
- ❒ Drawing compasses
- ❒ Ruler
- ❒ Graph paper
- ❒ Colored pencils
- ❒ Copies of "Time-Distance Data Sheet" and "6m x 6m Grid," one for each student group

Audio/Visual Materials

- ❒ Marker board or overhead transparency projector

Teaching Time

Two 45-minute class periods

Seating Arrangement

Groups of 4-5 students

Maximum Number of Students

32

Key Words

Tectonic plate
Mantle
Asthenosphere
Lithosphere
Magma
Rift
Subduction
Hotspots
P wave
S wave
Ultra-low velocity zone

Background Information

Nearly 70% of all coral reefs in U.S. waters are found around the Northwestern Hawaiian Islands, a chain of small islands and atolls that stretches for more than 1,000 nautical miles (nm) northwest of the main Hawaiian Islands. While scientists have studied shallow portions of the area for many years, almost nothing is known about deeper ocean habitats below the range of SCUBA divers. Only a few explorations have been made with deep-diving submersibles and remotely-operated vehicles (ROVs), and these have led to the discovery of new species and species previously unreported in Hawaiian waters. These islands are regularly visited by Hawaiian monk seals, one of only two species of monk seals remaining in the world (the Caribbean monk seal was declared extinct in 1994). Waters around the Northwestern Islands may be an important feeding area for the seals, which appear to feed on fishes that find shelter among colonies of deep-water corals. These corals are also of interest, because they include several species that are commercially valuable for jewelry. The possibility of discovering new species also has commercial importance as well as scientific interest, since some of these species may produce materials of importance to medicine or industry.

The islands of the Hawaiian archipelago were formed by a series of volcanic eruptions that began more than 80 million years ago. Volcanoes are often associated with movement of the tectonic plates that make up the Earth's crust. The outer shell of the Earth (called the lithosphere) consists of about a dozen large plates of rock (called tectonic plates) that move several centimeters per year relative to each other. These plates consist of a crust about 5 km thick, and the upper 60 - 75 km of the Earth's mantle. The plates that make up the lithosphere move on a hot flowing mantle layer called the asthenosphere, which is several hundred kilometers thick. Heat within the asthenosphere creates convection currents (similar to the currents that can be seen if food coloring is added to a heated container of water). These convection currents cause the tectonic plates to move. Plates may slide horizontally past each other at transform plate boundaries. The motion of the plates rubbing against each other sets up huge stresses that can cause portions of the rock to break, resulting in earthquakes. Places where these breaks occur are called faults. A well-known example of a transform plate boundary is the San Andreas fault in California.

Where tectonic plates move apart (for example, along the mid-ocean ridge in the middle of the Atlantic Ocean) a rift is formed, which allows magma (molten rock) to escape from deep within the Earth and harden into solid rock known as basalt. Where tectonic plates come together, one plate may descend beneath the other in a process called subduction, which generates high temperatures and pressures that can lead to explosive volcanic eruptions (such as the Mount St. Helens eruption which resulted from subduction of the Juan de Fuca tectonic plate beneath the North American tectonic plate). Volcanoes can also be formed at hotspots, which are thought to be natural pipelines to reservoirs of magma in the Earth's mantle. Hot, solid rock rises to the hot spot from greater depths. As the rock rises, pressure is reduced and the rock begins to melt, forming magma. The Hawaiian hotspot is presently located beneath the Big Island of Hawaii at the southeastern end of the archipelago.

The Pacific tectonic plate is presently moving over the asthenosphere toward the northwest at a rate of 5 to 10 cm per year. As the plate moves over the Hawaiian hotspot, magma periodically erupts to form volcanoes that become islands. The oldest island is Kure at the northwestern end of the archipelago. The youngest is the Big Island of Hawaii at the southeastern end. Loihi, east of the Big Island, is the newest volcano in the chain and may eventually form another island. As the Pacific plate moves to the northwest, islands are carried farther away from the hot spot, and the crust cools and subsides. At the same time, erosion gradually shrinks the islands, and unless there is further volcanic activity (or a drop in sea level) the islands eventually submerge below the ocean surface. To the northwest of Kure, the Emperor Seamounts are the submerged remains of former islands that are even older than Kure.

Scientists have realized for some time that the geochemistry of Hawaiian volcanoes is different from that of volcanoes produced by hotspots in other parts of the world, and have hypothesized that the plumes of molten rock that form some hotspots may extend much more deeply into the Earth's mantle than the plumes that feed other hotspots. It is difficult to test his sort of hypothesis, since the Earth's mantle extends nearly 3,000 km from the surface to the upper portion of the Earth's core. In recent years, earthquakes have provided one of the most useful tools for obtaining information about the Earth's inner structure!

Most people are at least vaguely familiar with seismometers that can record earthquakes (and other vibrations in the solid parts of the Earth). This activity focuses on how these instruments can also provide information about the deep structure of the Earth, and what some observations suggest about the roots of the Hawaiian hotspot.

Learning Procedure

1. Introduce the location of the Northwestern Hawaiian Islands, and point out some of the features that make this area important (discussed above). Introduce (or review) the concept of plate tectonics and the processes (subduction and hotspots) that result in volcanic activity. Be sure students understand the relative locations of the Earth's crust, mantle, and core.
2. Introduce the overall concept of seismology. Tell the students that most earthquakes occur because of movements of the Earth's tectonic plates. Point out that an earthquake produces vibrations that travel away from the source in all directions. Vibrations that travel on the Earth's surface are Rayleigh waves or Love waves (named after the scientists who first described them).

   This activity is concerned with vibrations that pass through the Earth's interior. These vibrations are called body waves, and are grouped into two categories:

   Compressional waves (also called P waves), in which the vibration is parallel to the direction in which the wave is travelling. Imagine a long spring (like a spring used to close a screen door) stretched between two people. If one person pushes one end of the spring in the direction of the other person, a compression wave moves along the spring. This is analogous to a P wave.
   Shear waves (also called S waves), in which the vibration is parallel to the direction in which the wave is travelling. Imagine a length of rope stretched between two people. If one person lifts and lowers one end of the rope, a "ripple" wave is generated that travels toward the other end of the rope. This is analogous to an S wave.

   P waves and S waves can travel along many different paths within the Earth, and may be reflected one or more times from the Earth's surface or core. These waves are divided into additional categories depending upon the path that they travel. If you have a device that can detect these vibrations located somewhere on the Earth's surface, each path will be associated with a characteristic travel-time; the time required for the vibration to travel from the source (an earthquake), along its specific path, to the detecting device (such as a seismograph). This means that a recording of the vibrations will show a series of waves: those with the shortest travel-times will arrive at the seismograph first, followed by waves with progressively longer travel-times.

Tell students that they will conduct two activities that demonstrate how specific types of information can be obtained from seismic waves. The first activity illustrates how the source of an earthquake can the determined. The second activity illustrates how seismic waves can gives clues about the type of material present in the deep interior of the Earth. These activities are based on activities developed by L. W. Braile and S. J. Braile (http://www.eas.purdue,edu/~braile/edumod/walkrun/walkrun.htm), and by Keith Young (http://hyper.versun.org/HyperNews/nherr/get/csp_lesson_plans_2001/24.html), respectively.

3. In the first activity, students will simulate the motion of two seismic waves travelling through the Earth at different speeds, construct a travel-time/distance graph for these waves, and use this graph to locate the source of a simulated earthquake.
   a. Clear a space about 8m x 8m in the room where students will do the activity, and mark off a 6 m line on the floor with masking tape. Place marks at 2 m and 4 m along the line. Assign three students as timekeepers, three students to simulate S waves, and three other students to simulate P waves. Assign one student as the data recorder.
   b. Station students with stopwatches at 2 m, 4 m, and 6 m along the line.
   c. Tell students who will simulate S and P waves that they each will walk the 6-m line at an assigned pace, and time keepers will record the times at which the students pass the 2 m, 4 m, and 6 m marks. Students simulating S waves will walk heel-to-toe, while students simulating P waves will walk with a normal stride. Have the first student stand at the beginning of the 6-m line, and say "Go" when you are ready to begin. You should establish a cadence by counting "one banana, two banana, three banana..." Each time you say "banana" the student should take one step; either a heel-to-toe step or a normal stride, depending upon which type of wave the walker is simulating. After a student has walked the entire 6-m line, the data recorder should record the times in the appropriate spaces on the "Time-Distance Data Sheet." Repeat this procedure until all six students have walked the 6-m line.
   d. Have the data recorder average the travel-times to 2 m, 4 m, and 6 m and record the averages on the "Time-Distance Data Sheet." List these averages on a marker board or overhead transparency.
   e. Have each student group construct a graph with distance in meters on the x-axis and time in seconds on the y-axis.

Each group should plot points corresponding to 2 m, 4 m, and 6 m for average S wave time, average P wave time, and for (average S wave time) - (average P wave time). Draw a straight line that best fits each set of data points. Use different colors or symbols for S wave times, P wave times, and (S wave time) - (P wave time).

f. Ask students to calculate the speed of the simulated S and P waves (simulated S wave speed should be approximately 0.3 m/sec and simulated P wave speed should be approximately 1.0 m/sec). Compare these speeds to the speed of actual S and P waves (3,500 - 4,500 m/sec and 6,000 - 8,000 m/sec respectively).

g. Mark the corners of a 6m x 6m square. Have students who will represent S and P waves (three students for each wave type) agree on a location within the square that will be the epicenter of a simulated earthquake. Station three timekeepers at different locations on the perimeter of the square, and mark these positions with masking tape. Tell students that these timekeepers represent seismograph stations.

h. Have the six students who are simulating S and P waves stand on the selected epicenter. Assign one P wave simulator and one S wave simulator to each of the three timekeepers. When you say "Go," all six wave simulators should begin walking toward their assigned timekeeper. P wave simulators should walk with a normal stride, S wave simulators should walk heel-to-toe. Establish a cadence by saying "One banana, two banana, three banana…" as before. This represents the propagation of S and P waves from the site of an earthquake to various sensing stations around the world. Be sure students realize that these waves are actually propagated in all directions, but we are simplifying the simulation by using only enough wave simulators to reach the three sensing stations (timekeepers). Have timekeepers start their stopwatches when the P wave arrives and stop their stopwatches when the S wave arrives to measure the length of time between the arrival of the P wave and the arrival of the S wave.

i. Record the (S wave time) - (P wave time) measured by each of the three sensing stations on a marker board or overhead transparency.

j. Have each student group determine the distance from the sensing station to the epicenter using the graph they constructed in Step #3e by:
   (1) locating the (S wave time) - (P wave time) on the y-axis;
   (2) drawing a horizontal line to the point of intersection with the graphed line representing (average S wave time) - (average P wave time); and
   (3) drawing a vertical line from the intersection point to the x-axis, and reading the distance on the x-axis scale.

k. Have each student group construct a map of the 6m x 6m area on the "6m x 6m Grid." Students should mark the positions of the sensing stations on the perimeter, and use a compass to draw a circle around each sensing station location. The center of the circle should be the sensing station location, and the radius should be the distance from the sensing station to the epicenter inferred in Step #3i. The point at which the three circles intersect is the inferred epicenter location (all three circles may not intersect precisely because of plotting errors). Measure the actual distances on the 6m x 6m area laid out in Step #3g, and compare these distances to those calculated by Step #3i.

4. The second activity illustrates how seismic waves can gives clues about the type of material present in the deep interior of the Earth.
   a. Select 12 students, and have them stand side-by-side in two groups of six. Have one group stand with their shoulders and upper arms touching. Have the other group link their arms at the elbow. Tell the students that those with linked arms represent solid rock, and the students whose arms are just touching represent liquid which could be water or liquid rock (magma).
   b. Tell the students that P waves are compression waves and their vibration moves in the direction in which the wave travels. Demonstrate this by gently pushing the end person in the linked-arm line toward the next person in line. The disturbance (vibration) will eventually travel the entire length of the line. Repeat this process for the line of students whose arms are just touching. Again, the disturbance will eventually travel the entire length of the line. Students should infer that P waves will move through liquid as well as solid rock.
   c. Tell the students that S waves are shear waves and their vibration moves in a direction that is perpendicular to the direction in which the wave travels. Demonstrate this on the linked-arm line by gently pushing the shoulders of the end person forward and backward. Eventually the disturbance will travel the entire length of the line. Next, repeat this process for the line of students whose arms are just touching. This time, the disturbance does not travel the entire length of the line because the liquid particles slip past each other. Students should infer that S waves will move through solids, but not through liquids.

5. Tell students that seismologists can identify S waves that are reflected from the region in the Earth where the mantle meets the Earth's core. Recently, scientists have discovered that parts of this region cause dramatic reductions in the velocity of S waves; these areas are called "ultra-low velocity zones." One of these ultra-low velocity zones has been discovered beneath the Hawaiian plume, and another beneath a similar plume off the coast of Iceland. Ask students to infer an explanation for why the velocity of S waves might be reduced using their knowledge of S wave propagation in different media. Students should suggest that the mantle or core might be partially liquid in the ultra-low velocity zones, which would be expected to reduce the propagation of S waves. Actual observa-

tions show that the velocity of P waves is reduced as well, though not nearly as much as is the case for S waves.

6. Ask the students to hypothesize whether there might be a connection between the Hawaiian hotspot and the ultra low velocity zone in the same general area. They should suggest that the suspected area of partial melting near the mantle-core junction could be the source of magma for the Hawaiian hotspot, which would account for the unusual chemical composition of basalts from the Hawaiian hotspot compared to basalts from other hotspots that may have their roots in shallower parts of the mantle.

The BRIDGE Connection

www.vims.edu/bridge/pacific.html

The "Me" Connection

Have students write a short essay about their personal exposure to natural hazards, and whether their potential exposure to such hazards would affect their choices of places to live.

Connections to Other Subjects

English/Language Arts, Geography, Biology, Physics

Evaluation

Develop a grading rubric that includes the graphs constructed in Step #3g and the map constructed in Step #3k. You may also choose to have students prepare individual written responses to questions posed in Steps #5 and #6 prior to discussion of these questions by the entire class.

Extensions

1. Visit these sites for many more activities and links related to plate tectonics, earthquakes and seismology:
http://www.ldeo.columbia.edu/~mwest/WS4instructors/primer.html
http://lasker.princeton.edu/ScienceProjects/curr.htm
http://mae.ce.uiuc.edu/Education/Teachers/high.htm

2. Visit
http://explorers.bishopmuseum.org/nwhi/geoact.shtml for others activities relevant to the Northwestern Hawaiian Islands.

Resources

http://oceanexplorer.noaa.gov – Follow the Northwestern Hawaiian Islands Expedition as documentaries and discoveries are posted each day for your classroom use.

http://www.soest.hawaii.edu/GGHCV/haw_formation.html – Hawaii Center for Volcanology website about the formation of the Hawaiian Islands

http://www.hawaiireef.noaa.gov/maps/maps.html – Information about the Northwestern Hawaiian Islands region

http://volcano.und.edu/vwdocs/vwlessons/atg.html – Teacher's guide and geology of Hawaii Volcanoes National Park

National Science Education Standards

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard B: Physical Science

- Structure and properties of matter
- Interactions of energy and matter

Content Standard D: Earth and Space Science
- Energy in the Earth system
- Origin and evolution of the Earth system

Content Standard E: Science and Technology
- Understanding about science and technology

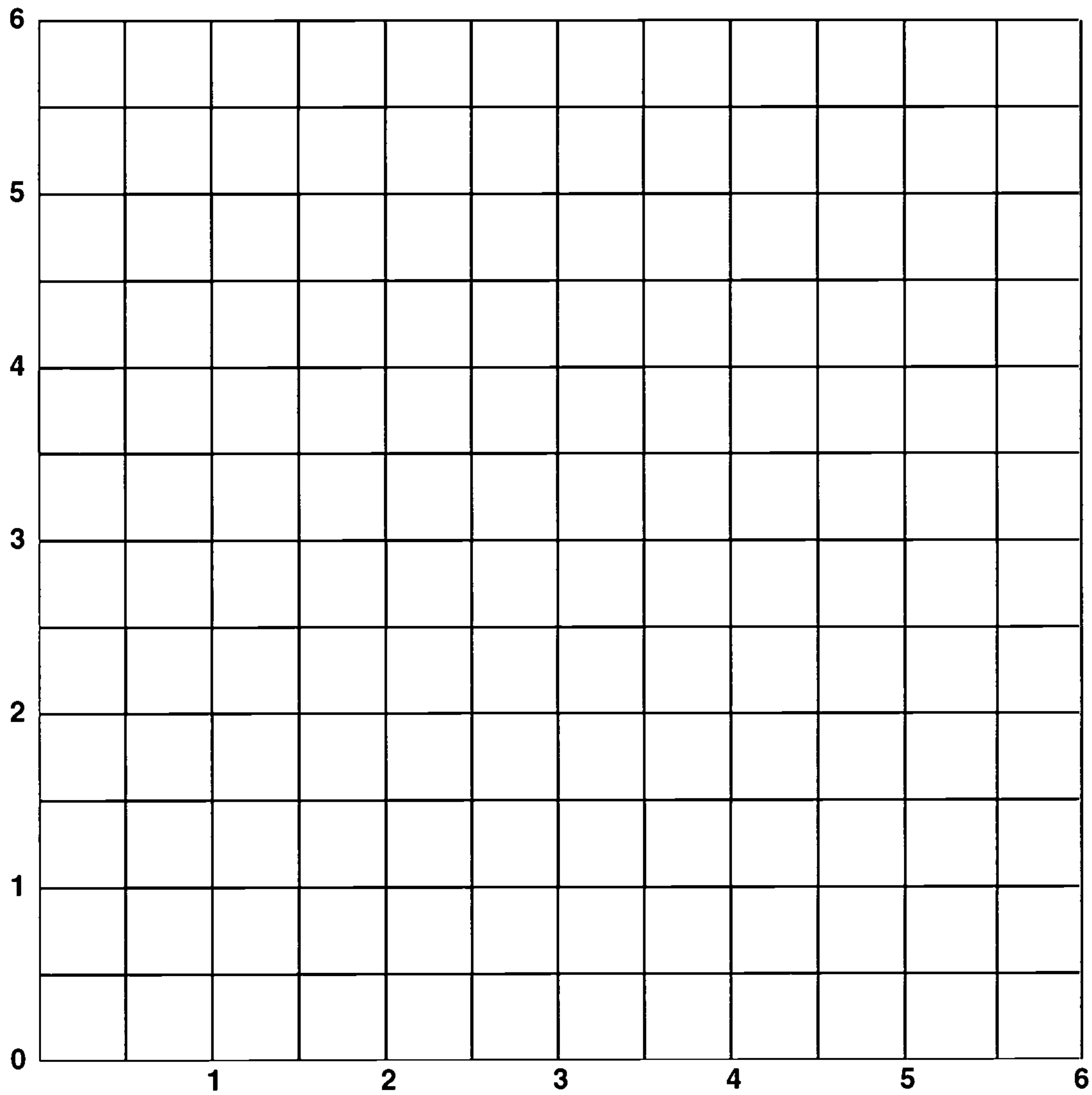
Content Standard F: Science in Personal and Social Perspectives
- Natural and human-induced hazards

Activity developed by Mel Goodwin, PhD, The Harmony Project, Charleston, SC

Student Worksheet
Time-Distance Data Sheet

Distance	Trial #	S wave	P wave	(S wave) - (P wave)
2 m	1			
	2			
	3			
	average			
4 m	1			
	2			
	3			
	average			
6 m	1			
	2			
	3			
	average			

Student Worksheet
6m x 6m Grid
(each square = 0.5 m)



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