

**Cradle of the Earthquake:
Exploring the Underwater San Andreas Fault 2010 Expedition**

Sound Pictures

(adapted from the Lophelia II 2009 Deepwater Coral Expedition: Reefs, Rigs and Wrecks)



Image captions/credits on Page 2.

lesson plan

Focus

Sonar

Grade Level

9-12 (Physical Science)

Focus Question

How can scientists obtain information about the bathymetry of the seafloor?

Learning Objectives

- Students will be able to explain the concept of sonar.
- Students will be able to describe the major components of a sonar system.
- Students will be able to explain how multibeam and side-scan sonar systems are useful to ocean explorers.
- Students will be able to simulate sonar operation using a motion detector and a graphing calculator.

Materials

- Copies of *Sonar Inquiry Guide*; one copy for each student group
- Graphing calculator, data logger, and motion sensor (e.g., Lego™ NXT system with ultrasonic sensor; Vernier™ motion detector, logger, and graphing calculator); may be shared among several students groups; NOTE: an alternative method is also provided that does not require this equipment (see Learning Procedure, Step 1)
- Boxes, cans, and other objects to create a model seafloor
- String
- Meter stick
- Masking tape
- Felt tip marker for marking string

Audio-Visual Materials

- None

Teaching Time

One or two 45-minute class periods, plus time for student research

Seating Arrangement

Groups of 2-4 students

Maximum Number of Students

32

Key Words

San Andreas Fault
Sonar
Side-scan sonar
Bathymetry

Background Information

NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

At 5:12 am on April 18, 1906, Ernest Adams was thrown violently from his bed and watched in disbelief as the side of his San Francisco home crumbled to the ground. "I fell and crawled down the stairs amid flying glass and timber and plaster. When the dust cleared away I saw nothing but a ruin of a house and home that it had taken twenty years to build. I saw the fires from the city arising in great clouds and it was no time to mourn my loss so getting into what clothing I could find, I started on a run for Kearny St., five miles away..." (Adams, 1906).

In 1906, modern plate tectonic theory was several decades in the future, so no one who lived through the Great San Francisco Earthquake could know that their terrifying experience resulted from interaction between two large pieces of Earth's crust now known as the Pacific and North America Plates. These tectonic plates are portions of the Earth's outer crust (the lithosphere) about 5 km thick, as well as the upper 60 - 75 km of the underlying mantle. They 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). Movement of convection currents causes tectonic plates to move several centimeters per year relative to each other.

Where tectonic plates slide horizontally past each other, the boundary between the plates is known as a transform plate boundary. As the plates rub together, huge stresses are set up that can cause portions of the rock to break, resulting in earthquakes. Places where these breaks occur are called faults. The San Andreas fault exists along the transform plate boundary between the Pacific and North America Plates in California. The 1906 San Francisco Earthquake was caused by a

Images from Page 1 top to bottom:

San Francisco, California, Earthquake April 18, 1906. Downtown San Francisco showing residents watching fire after the 1906 earthquake. Photo by Ralph O. Hotz. April 1906. Image courtesy USGS.

http://libraryphoto.cr.usgs.gov/cgi-bin/show_picture.cgi?ID=ID.%20Hotz%2C%20P.E.%20%20104

A small bush of tubeworms. When tubeworm bushes are young, only endemic species of animals can colonize them. The presence of the mussels (*Bathymodiolis childressi*) in the center of the bush means that methane is seeping just below. Image courtesy Gulf of Mexico 2002, NOAA/OER.

<http://oceanexplorer.noaa.gov/explorations/02mexico/background/communities/media/2tubesmussels.html>

San Francisco, California, Earthquake April 18, 1906. Fault trace 2 miles north of the Skinner Ranch at Olema. View is north. 1906. Plate 10, U.S. Geological Survey Folio 193; Plate 3-A, U.S. Geological Survey Bulletin 324. Image courtesy USGS. (Note: you may need to paste the link below into your browser to get to the image.)

http://libraryphoto.cr.usgs.gov/cgi-bin/show_picture.cgi?ID=ID.%20Gilbert%2C%20G.K.%202933

Iceworms (*Hesiocaeca methanicola*) infest a piece of orange methane hydrate at 540 m depth in the Gulf of Mexico. During the Paleocene epoch, lower sea levels could have led to huge releases of methane from frozen hydrates and contributed to global warming. Today, methane hydrates may be growing unstable due to warmer ocean temperatures. Image courtesy Ian MacDonald.

http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/iceworms_600.jpg

296 mile-long rupture along the San Andreas fault from the Mendocino Triple Junction to San Juan Bautista. A triple junction is a place where three of Earth's tectonic plates intersect. At the Mendocino Triple Junction, the Pacific Plate and North American Plate intersect with the Juan de Fuca Plate. Other types of plate boundaries include convergent boundaries, which are formed when tectonic plates collide more or less head-on; and divergent boundaries, which occur where plates are moving apart. View animations of different types of plate boundaries at: http://www.seed.slb.com/flash/science/features/earth/livingplanet/plate_boundaries/en/index.html.

Understanding that the 1906 quake resulted from the movement of tectonic plates leads quickly to the realization that these plates are still in motion; in fact, the San Andreas fault is the fastest moving fault in western North America. This realization inevitably leads to the question, "When will a major earthquake like the 1906 quake strike again?"

To help answer this question, geologists study the history of past earthquakes along the San Andreas fault system. These studies, as well as thousands of years of historical records from China and Japan, tell us that giant earthquakes on faults like the San Andreas tend to occur every few hundred years. This interval is thought to be the time required for motion between tectonic plates to build stresses to levels that produce large quakes. In general, this evidence suggests that a 1906-size earthquake is not likely to strike Northern California for at least 100 years. Still, studies also show that stress has built up again along the San Andreas Fault system. For 70 years following the 1906 earthquake, there were only low levels of seismic activity in Northern California. Then, between 1979 and 1984, there were three quakes with magnitudes of about 6; and in 1989 a major (Loma Prieta) earthquake with a magnitude of 6.9. A similar pattern of earthquake activity took place during the 70 years prior to the 1906 quake.

The Cradle of the Earthquake: Exploring the Underwater San Andreas Fault 2010 Expedition will improve our understanding of the history of great earthquakes and how they are interrelated by investigating portions of the great plate boundary fault that lie offshore; areas that have virtually never been observed or explored. The first step in this exploration is to prepare detailed maps of the entire offshore fault using multibeam and side-scan sonar. These maps, in turn, will help scientists identify areas within the fault to be investigated in greater detail using an autonomous underwater vehicle and a remotely operated vehicle to obtain high resolution photographs as well as samples of sediments and hard corals. For additional discussion about sonar systems, see the Expedition Education Module for this expedition. In this lesson, students will learn about side-scan sonar, and use mock sonar set-ups to experience some of the difficulties encountered when trying to locate objects or map the ocean floor.

Learning Procedure

NOTE: Portions of this lesson are adapted from the National Ocean Service lesson, “See That Sound,” http://oceanservice.noaa.gov/education/classroom/lessons/23_hydrosurvey_see.pdf. A similar activity using a Calculator-Based Laboratory® system was developed by Steven Stevenoski of Lincoln High School, Wisconsin Rapids, WI as part of the Teachers Experiencing Antarctica and the Arctic Program (see http://tea.armadaproject.org/teainfo/TEA_flyer_0203AA.pdf for information on the TEA program, and http://tea.armadaproject.org/activity/stevenoski/seeingtheseafloorusingsoundmultibeamsonar_main.html) for Stevenoski’s lesson.

Depending upon the length of your class period, at least two periods will probably be needed to complete this lesson. Part A of the *Sonar Inquiry Guide* may be assigned as homework, or may be done in class if suitable library or Internet research resources are available. Introductory discussion and instructions may take place during part of a class period prior to the day on which students begin working on Part B of the *Inquiry Guide*. In this way, an entire period may be devoted to completing Part B. Wrap-up discussions can then take place during part of a subsequent class period.

1. To prepare for this lesson:

- Review background essays for the Cradle of the Earthquake: Exploring the Underwater San Andreas Fault 2010 Expedition (<http://oceanexplorer.noaa.gov/explorations/10sanandreas>)
- Review procedures and questions on the *Sonar Inquiry Guide*;
- Collect materials needed for the sonar simulation activity;
- Identify locations (usually on your classroom floor) where students will create their “ocean floors,” and mark two points two to four meters apart with masking tape (see *Inquiry Guide* Step B1); and
- Run through the sonar simulation activity with the equipment you plan to use, and make notes of any additional directions needed for this specific equipment. If graphing calculators and motion sensors are not available, you can have your students do an alternative bathymetry simulation using the “traditional” (i.e., pre-sonar) technique for measuring depth with a lead line.

2. Lead an introductory discussion of the Cradle of the Earthquake: Exploring the Underwater San Andreas Fault 2010 Expedition. You may want to show students some images from the U.S. Geological Survey’s Photographic Library (<http://libraryphoto.cr.usgs.gov/>; click on “Earthquakes” in the left column). Discuss the importance of studying the timing and impacts of past earthquakes to help prepare for similar events in the future. Describe the role of side-scan sonar in surveying underwater portions of the San Andreas Fault.

3. Ask students how hydrographic data on depth bottom topography are obtained by modern hydrographers. Some students will probably be familiar with the concept of sonar. If not, they may have heard about this technology in connection with submarine warfare. Give each student group a copy of the *Sonar Inquiry Guide*, and explain that their assignment is to learn about sonar and work with other groups to conduct a simulation of a bathymetric survey using sonar techniques (or lead line techniques if you plan to use the alternative simulation procedure). Assign Part A as homework, or have students complete this work during part of a class period.

Provide any additional instructions needed for the simulation equipment, then have students begin Part B or C of the *Inquiry Guide*. When each group has collected depth soundings from their model ocean floor, have them exchange their data with another group. Instruct students NOT to look at other groups' models until they have plotted the depth data and recorded their predictions about the objects.

4. Lead a discussion of the results of students' background research.

(1) "SONAR" is an acronym for "SOund NAVigation and Ranging"

(2) The basic components of a sonar system are:

- A transmitter capable of emitting an acoustic signal;
- A receiver capable of detecting echoes from the transmitted signal; and
- A processing unit to interpret the reflected signal.

Students may also mention:

- A cable to connect the processor with the transmitter and receiver;
- A transducer (which is analogous to the antenna on a radio transmitter or receiver); and
- A towfish to allow the transducer(s) to be towed behind the survey vessel.

(3) Transducers for side-scan sonar are often towed behind the survey vessel because:

- Being able to tow the transducer at some depth below the surface means that there is less water through which the acoustic signal must travel, so there is less absorption and scattering of the acoustic energy, and consequently, the signal is stronger;
- The transducer is less affected by the surface motion of the survey vessel (particularly rolling motion); and
- The transducer can be towed beneath a thermocline (the boundary between two water masses of different temperature) which can interfere with the acoustic signal.

(4) Higher frequencies give better image resolution (more detail) but travel shorter distances than lower frequencies.

(5) Side-scan and multibeam sonars both transmit a fan-shaped pattern of acoustic signals. Side-scan systems continuously record the strength of the return echo caused by the transmitted signal bouncing off of the sea floor or other object. Multibeam systems, on the other hand, record depth by measuring the time elapsed between transmission of a sound signal and detection of the reflected signal by the sonar's receiver. Multibeam sonar transmitters are generally attached to a vessel, rather than being towed as is typical of side-scan systems.

The simulations illustrate the importance of sample interval in obtaining an accurate "picture" of the bottom, as well as the difficulty of drawing inferences about three-dimensional shapes from two-dimensional data. You may want to show one or two images produced by side-scan sonar, which provides three-dimensional bottom data (see <http://oceanexplorer.noaa.gov/technology/tools/sonar/sonar.html> for more information about side-scan sonar).

The BRIDGE Connection

www.vims.edu/bridge/ - Click on "Ocean Science Topics" in the navigation menu to the left, then "Geology" for resources on marine geology and plate tectonics.

The "Me" Connection

Show students a description of the ultrasonic sensor used in the Lego™ NXT system, or the Vernier™ motion detector. Explain that these devices are based on the same principle as sonar, but may be useful in ways that have nothing to do with detecting underwater objects. Have students write a brief essay describing one example of how sound ranging techniques might be of personal benefit. If they need a hint you may want to mention devices that warn backing vehicles of the presence of objects, or ultrasound medical imaging devices.

Connections to Other Subjects

English/Language Arts, Mathematics

Assessment

Students' responses to *Inquiry Guide* questions and class discussions provide opportunities for assessment.

Extensions

1. See the Cradle of the Earthquake: Exploring the Underwater San Andreas Fault 2010 Expedition Education Module for additional information, activities, and media resources about deepwater ecosystems and earthquakes associated with the San Andreas Fault.

2. Visit http://www.education-world.com/a_lesson/00-2/lp2083.shtml for other activities about sonar.

Multimedia Discovery Missions

<http://oceanexplorer.noaa.gov/edu/learning/welcome.html> - Click on the link to Lessons 1, 2, and 4 for interactive multimedia presentations and Learning Activities on Plate Tectonics, Mid-Ocean Ridges, and Subduction Zones.

Other Relevant Lesson Plans from NOAA's Office of Ocean Exploration and Research

Tools of Discovery - Multibeam Sonar

(PDF, 1.6 Mb) (from the INDEX SATAL 2010 Expedition)

<http://oceanexplorer.noaa.gov/oceanos/explorations/10index/background/edu/media/multibeam.pdf>

Focus: Technology for deep ocean exploration: Multibeam Sonar (Earth Science/Physical Science)

Students will describe multibeam sonar, discuss the advantages of multibeam sonar bathymetry compared to two-dimensional topographic bathymetry, and interpret three-dimensional multibeam bathymetric data.

Other Resources

The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.

<http://oceanexplorer.noaa.gov/explorations/10sanandreas> - Web site for the Cradle of the Earthquake: Exploring the Underwater San Andreas Fault 2010 Expedition

<http://celebrating200years.noaa.gov/edufun/book/welcome.html#book> - A free printable book for home and school use

introduced in 2004 to celebrate the 200th anniversary of NOAA; nearly 200 pages of lessons focusing on the exploration, understanding, and protection of Earth as a whole system

<http://earthquake.usgs.gov/regional/nca/1906/18april/index.php> - U.S. Geological Survey Web page about the 1906 San Francisco earthquake

Adams, E. 1906. Letter to Reed and Barton. The Virtual Museum of the City of San Francisco; <http://www.sfmuseum.net/1906/ew3.html>

http://www.ess.washington.edu/SEIS/PNSN/HAZARDS/CASCADIA/cascadia_event.html - Web page about the January, 1700 Cascadia

Subduction Zone earthquake and tsunami from the Pacific Northwest Seismic Network; includes discussion of various lines of evidence that help pinpoint the date of past earthquakes

<http://www.sciencecourseware.com/eec/Earthquake/> – Web site for Virtual Earthquake, an interactive activity designed to introduce concepts of how an earthquake epicenter is located and how the magnitude of an earthquake is determined

National Science Education Standards

Content Standard A: Science As Inquiry

- Understandings about scientific inquiry

Content Standard B: Physical Science

- Structure and properties of matter

Content Standard E: Science and Technology

- Abilities of technological design
- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Natural resources
- Natural and human-induced hazards
- Science and technology in local, national, and global challenges

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.

The Earth has one big ocean with many features.

Fundamental Concept h. Although the ocean is large, it is finite and resources are limited.

Essential Principle 6.

The ocean and humans are inextricably interconnected.

Fundamental Concept b. From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.

Fundamental Concept e. Humans affect the ocean in a variety of ways. Laws, regulations and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (such as point source, non-point source, and noise pollution) and physical modifications (such as changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.

Fundamental Concept f. Coastal regions are susceptible to natural hazards (such as tsunamis, hurricanes, cyclones, sea level change, and storm surges).

Fundamental Concept g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

Essential Principle 7.

The ocean is largely unexplored.

Fundamental Concept a. The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation’s explorers and researchers, where they will find great opportunities for inquiry and investigation.

Fundamental Concept b. Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.

Fundamental Concept c. Over the last 40 years, use of ocean resources has increased significantly, therefore the future sustainability of ocean resources depends on our understanding of those resources and their potential and limitations.

Fundamental Concept d. New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.

Fundamental Concept f. Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

Send Us Your Feedback

We value your feedback on this lesson.

Please send your comments to:

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Acknowledgements

This lesson was developed by Mel Goodwin, PhD, Marine Biologist and Science Writer. Design/layout by Coastal Images Graphic Design, Charleston, SC. If reproducing this lesson, please cite NOAA as the source, and provide the following URL: <http://oceanexplorer.noaa.gov/>

Student Worksheet

Sonar Inquiry Guide

A. Background Research

1. SONAR is an acronym. What does it mean?

2. What are the basic components of a sonar system?

3. Why are transducers for side-scan sonar often contained in a towfish that is towed behind the survey vessel?

4. What are the advantages and disadvantages of high frequency (500 kHz and up) sonar signals compared to lower frequency (50 kHz or 100 kHz) signals?

5. What is the difference between side-scan sonar and multibeam sonar?

Student Worksheet

Sonar Inquiry Guide - pg 2

B. Sonar Simulation

1. **Create an Ocean Floor Model** – In the location identified by your teacher, arrange at least six objects of varying height and shape between two points two to four meters apart. Using chairs or stools for support, stretch a string between these points, 1.0 to 1.5 meters above the floor.
2. **Map an Ocean Floor Model** – Your assignment is to use sound waves to create images of objects on an ocean floor model. Your teacher will explain specific instructions for the ultrasonic ranging system that you will use to complete this assignment. Here are the rest of the steps for creating your bathymetric map:
 - a. Your ranging system should be set up to collect distance data as a function of time.
 - b. Go to the ocean floor model assigned by your teacher, and have one member of your group hold the ultrasonic sensor (or motion detector) at one end of the string.
 - c. Trigger the system to begin data collection, and move the sensor smoothly along the string to the other end. It is important that the sensor is moved at a constant rate of speed, which should be slow enough to allow the system to collect enough data points to adequately map the objects. If the motion detector is moved slowly, more data points (distance measurements) will be collected and a more detailed image will be produced.
 - d. Exchange depth data with another group, and graph the depth measurements as a function of time. Since the elapsed time is proportional to the linear distance along the string, the series of distance measurements should create a profile of the objects beneath the string. Actually, a reverse profile will be created, since taller objects will be closer to the string, so the distance to tall objects will be smaller than the distance to shorter objects. You can correct this distortion with a simple data transformation that calculates object height as the absolute value of the difference between the measured distance (from your ranging system) and the height of the string above the floor:

$$\text{object height} = |(\text{measured distance}) - (\text{height of string})|$$

Write your predictions about these objects, then look at the ocean floor model to see how accurate your predictions were.

Student Worksheet

Sonar Inquiry Guide - pg 3

C. Alternative Bathymetric Simulation (optional)

1. Set up an ocean floor model as described in Step B.1. above, but mark the string at three-inch intervals before stretching it above the objects.
2. Mark a second string about 2 m long at one-inch intervals and attach a weight (fishing sinker, metal nut, etc) to one end of the string.
3. Using the ocean floor model created in Step B.1., use the weighted string to obtain depth measurements at three-inch intervals.
4. Exchange depth data with another group and graph the depth measurements as a function of position on the string. Since these are point measurements, you will have to guess about the actual shape of the objects on the simulated ocean floor. Write your predictions about these objects, then look at the Model to see how accurate your predictions were.