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

Whole Lotta Shaking Going On

Image captions/credits on Page 2.

lesson plan

Focus
Earthquake prediction

Grade Level
9-12 (Earth Science)

Focus Question
Is it possible for scientists to accurately predict future earthquakes?

Learning Objectives
- Students will discuss how stresses between tectonic plates can produce earthquakes.
- Students will describe approaches and limitations to earthquake prediction.
- Students will use a model earthquake machine to explore hypotheses about earthquakes.

Materials
- "Spring and rider" earthquake simulation machine (see Figure 1 and http://earthquake.usgs.gov/research/modeling/earthquakemachine.php#Model%20Description)
  - Plywood board, approximately 30 cm x 120 cm x 1.8 cm
  - Small trailer winch (from an auto parts store, trailer supply store, or home improvement store)
  - Wire cable, approximately 3 mm diameter, 3 m long
  - Guide pulley
  - Hardware for mounting winch and guide pulley
  - Adhesive-backed sandpaper or nonskid tape (from a boating supply store)
  - Rubber surgical tubing, two pieces, approximately 8 mm outside diameter, 20 cm long
  - Two bricks
  - Two hose ("worm drive") clamps long enough to reach around the perimeter of the bricks (for attaching surgical tubing)
  - Talcum powder
  - Stopwatch
  - Screwdriver to fit hose clamps
- Copies of *Earthquake Prediction Inquiry Guide*, one copy for each student group

❑ Copies of "Parkfield's unfulfilled promise" (see "Other Resources")

Audio-Visual Materials
❑ None

Teaching Time
One or two 45-minute class periods

Seating Arrangement
Groups of 2-4 students

Maximum Number of Students
32

Key Words
San Andreas Fault
Earthquake prediction

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

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

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 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.

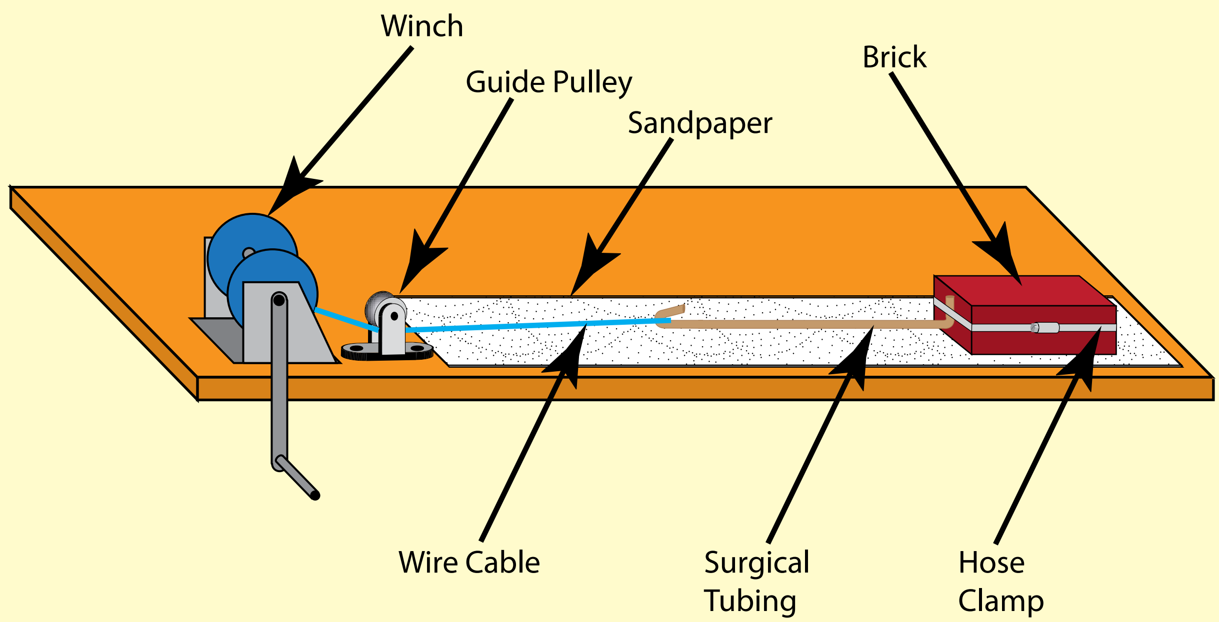
The Cradle of the Earthquake: Exploring the Underwater San Andreas Fault 2010 Expedition will improve our understanding of the history of great earthquakes and how they are interrelated by investigating portions of the great plate boundary fault that lie offshore; areas that have virtually never been observed or explored.In this lesson, students will learn about some of the constraints to accurate earthquake prediction.

Learning Procedure

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)
- Assemble an earthquake simulation machine as indicated in Figure 1 and in http://earthquake.usgs.gov/research/modeling/earthquakemachine.php#Model%20Description.
- Review the "Parkfield's unfulfilled promise" article (http://profile.usgs.gov/myscience/upload_folder/ci2010Jul011449314296623%20Stein%20Nature%202002.pdf), and procedures on the *Earthquake Prediction Inquiry Guide*.

Figure 1. Earthquake simulation machine



Because student groups must use the earthquake simulation machine one-at-a-time, it is recommended that this activity be scheduled over one or two weeks, with each student group having a specific assigned time in which to complete portions of the activity requiring use of the simulation machine.

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). Point out that the severity of earthquake impacts makes it highly desirable to find some means for predicting future events of this kind.

3. Provide each student group with copies of the *Earthquake Prediction Inquiry Guide* and "Parkfield's unfulfilled promise" article. Students may have difficulty with some of the language in the article, but the concepts are straightforward. You may want to review some vocabulary and phrases before students read the article, or have them highlight problematic portions for subsequent group discussion as suggested in the *Inquiry Guide*.

   The phrases "seismic moment" and "moment deficit" may be unfamiliar to many students. Moment has a variety of meanings in physics and engineering, which can add to the confusion. Seismic moment (as the article states) is a measure of the size of an earthquake, and refers to the amount of energy that is released when the earthquake occurs. Moment deficit, as used in the article, refers to an accumulation of energy; in other words, the seismic moment of an earthquake that has not yet taken place.

4. When all student groups have completed Part I of the *Inquiry Guide*, lead a discussion of their results. The following points should be included:
   - The Parkfield Earthquake Experiment is a long-term earthquake research project on the San Andreas fault. The purpose of the project is to better understand the physics of earthquakes by measuring what actually happens on the fault and in the surrounding region before, during and after an earthquake; and, if possible, to provide a way to predict earthquakes.

   - Three hypotheses described about the behavior of earthquakes are:

     Hypothesis 1:
     Earthquakes are periodic, and happen at more or less regular intervals.

     Hypothesis 2:
     Earthquakes are 'time-predictable,' which means that the interval between earthquakes depends upon earthquake size; so if an earthquake is large, the interval to the next earthquake will be longer than if the earthquake were smaller.

     Hypothesis 3:
     Earthquakes occur at random intervals and their size varies randomly as well (this is the 'Poisson' hypothesis).

   - Moderate sized earthquakes occurred on the Parkfield section of the San Andreas Fault in 1857, 1881, 1901, 1922, 1934 and 1966; corresponding to intervals of 24, 20, 21, 12, and 32 years respectively.

- The observed periodicity of earthquakes on the Parkfield section of the San Andreas Fault might provide support for Hypothesis 2.

- Stein says Parkfield's promise is unfulfilled, because according to the time-predictable hypothesis, a moderate size earthquake should occur about every 22 years; so the next earthquake in the Parkfield series should have happened around 1988. But by 2002, when the Stein article was written, the next earthquake still had not occurred.

- On September 28, 2004, a Mw 6.0 (moderate size) earthquake occurred on the San Andreas fault near the Parkfield location. This event supports the idea that moderate size earthquakes occur in this area at intervals, but the interval is not regular enough to provide a reliable basis for prediction.

5. When all student groups have completed Part II of the *Inquiry Guide*, lead a discussion of their results. During the Basic Earthquake Simulation, students generally will find that the distance moved by the brick and the interval between movements are not consistent, even with a constant cranking speed (counting the number of revolutions of the winch handle provides a way to check on the consistency of cranking speed from one trial to the next). This is similar to actual behavior of earthquakes in many locations.

   In the High Friction Earthquake Simulation, the interval between brick movements is generally longer than in the Basic Simulation and the amount of movement is greater. This corresponds to the time-predictable hypothesis, and roughly mimics behavior of recent earthquakes in the San Francisco Bay area.

   During the Low Friction "Creep" Simulation, students should observe an almost continuous brick motion that models "creeping" faults in which accumulated stresses are not sufficient to produce large earthquakes.

   The Interactive Earthquake Simulation demonstrates how one earthquake may increase or decrease the stresses that produce a second earthquake.

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

Have students write a short essay describing how they use patterns in the occurrence of natural events to make predictions about when such events will occur in the future, and why these predictions are personally useful.

Connections to Other Subjects

English/Language Arts, Earth Science

Assessment

Experimental notes and class discussions provide opportunities for assessment.

Extensions

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.

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/okeanos/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.

Tools of Discovery - Remotely Operated Vehicles
(PDF, 1.3 Mb) (from the INDEX SATAL 2010 Expedition)
http://oceanexplorer.noaa.gov/okeanos/explorations/10index/background/edu/media/rov.pdf

Focus: Technology for deep ocean exploration: Remotely Operated Vehicles (Earth Science/Physical Science)

Students will describe systems and capabilities of science-class remotely operated vehicles (ROVs), typical applications and limitations of imagery obtained with ROVs, and use ROV imagery to make inferences about deep ocean habitats.

The Ridge Exploring Robot
(PDF, 1.6 Mb) (from the INSPIRE: Chile Margin 2010 Expedition)
http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/robot.pdf

Focus: Autonomous Underwater Vehicles/Marine Navigation

Students will explain a three-phase strategy that uses an autonomous underwater vehicle (AUV) to locate, map, and photograph previously undiscovered hydrothermal vents, design a survey program to provide a photomosaic of a hypothetical hydrothermal vent field, and calculate the expected position of the AUV based on speed and direction of travel.

My Wet Robot
(PDF, 300 kb) (from the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition)
http://oceanexplorer.noaa.gov/explorations/08bonaire/background/edu/media/wetrobot.pdf

Focus: Underwater Robotic Vehicles

In this activity, students will be able to discuss the advantages and disadvantages of using underwater robots in scientific explorations, identify key design requirements for a robotic vehicle that is capable of carrying out specific exploration tasks, describe practical approaches to meet identified design requirements, and (optionally) construct a robotic vehicle capable of carrying out an assigned task.

Where's My 'Bot?
(PDF, 492 kb) (from the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition)
http://oceanexplorer.noaa.gov/explorations/08bonaire/background/edu/media/wheresbot.pdf

Focus: Marine Navigation (Earth Science/Mathematics)

In this activity, students will estimate geographic position based on speed and direction of travel, and integrate these calculations with GPS data to estimate the set and drift of currents.

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

Stein, R.S., 2002. Parkfield's unfulfilled promise. Nature 419:257-258; http://profile.usgs.gov/myscience/upload_folder/ci2010Jul011449314296623%20Stein%20Nature%202002.pdf

National Science Education Standards

Content Standard A: Science As Inquiry
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science
- Motions and forces

Content Standard D: Earth and Space Science
- Energy in the Earth system
- Geochemical cycles

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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Student Worksheet

Earthquakes Prediction Inquiry Guide

Part I – Background

Read the article by geologist Ross Stein, "Parkfield's unfulfilled promise." Highlight unfamiliar words or phrases for class discussions. Using the Internet or other research resources, answer the following questions:

1. What is the Parkfield Earthquake Experiment?

2. The article describes three alternative hypotheses about the behavior of earthquakes. What are these hypotheses?

3. Beginning in 1957, six moderate sized earthquakes have occurred on the Parkfield section of the San Andreas Fault. In what years did these earthquakes occur, and what is the interval between these earthquakes?

4. The observations described in Question 3 might provide support for which of the three hypotheses identified in Question 2?

5. Why does Stein say Parkfield's promise is unfulfilled?

6. What happened on September 28, 2004, and how does this affect the "Parkfield promise?"

Part II – Earthquake Simulations

Use the "Earthquake Machine" to perform the following simulations:

1. Basic Earthquake --
   - (a) Place the brick on the sandpaper near the right edge. One member of your team should hold the stopwatch and act as Timekeeper. Another team member should serve as Winch Operator, and prepare to crank the winch. Other team members are Observers, and should watch the motion of the brick.
   - (b) The Timekeeper says, "Start," and starts the stopwatch. At the same time, the Winch Operator slowly cranks the winch handle, keeping the cranking speed as constant as possible, and counts the number of revolutions. The Observers note what happens to the surgical tubing as the winch is cranked, and record the time whenever the brick moves.
   - (c) When the winch cable is almost completely wound onto the winch drum, the Timekeeper says, "Stop," and stops the stopwatch. At the same time, the Winch Operator stops cranking, and reports the total number of revolutions to the Observers who record this information along with total elapsed time reported by the Timekeeper.
   - (d) Repeat Steps (a) through (c) at least twice.

2. High Friction Earthquake --
   Repeat the procedure for the Basic Earthquake, but place a second brick on top of the brick attached to the surgical tubing.

3. Low Friction "Creep" --
   Repeat the procedure for the Basic Earthquake, but sprinkle a layer of talcum powder on the board next to the sandpaper, and place the brick on the talcum powder.

4. Interactive Earthquakes --
   Repeat the procedure for the Basic Earthquake, but attach a second brick end to end to the first brick with a second piece of surgical tubing (loosen the hose clamps around the bricks with a screwdriver, slip the surgical tubing between the brick and the clamp, and re-tighten the clamp).

Review your results, and discuss their relationship to actual earthquakes.

Earthquake simulation machine designed by Ross Stein, U.S. Geological Survey
(http://earthquake.usgs.gov/research/modeling/earthquakemachine.php#Model%20Description)