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

Puzzle of the Plates

Image captions/credits on Page 2.

lesson plan

Focus

Plate tectonics

Grade Level

5-6 (Physical Science)

Focus Question

How do tectonic plates move, and what are the consequences of these movements?

Learning Objectives

- Students will describe the motion of tectonic plates.
- Students will compare and contrast three typical boundary types that occur between tectonic plates.
- Students will describe the plate boundaries that occur at the San Andreas Fault.
- Students will explain why motion of tectonic plates adjacent to the San Andreas Fault may be associated with earthquakes and tsunamis.

Materials

- Copies of U.S. Geological Survey's Plate Tectonic Puzzle, printed on cover stock or glued onto poster board for jigsaw puzzles (see Learning Procedure, Step 2; download a letter-size puzzle PDF from http://earthquake.usgs.gov/research/modeling/puzzle/puzzle_letterbase.pdf, or a poster-size pdf from http://earthquake.usgs.gov/research/modeling/puzzle/puzzle(A0).jpg)
- (Optional) Food coloring and container of hot water to demonstrate convection currents (see Learning Procedure, Step 3)
- Materials to make oobleck (see Learning Procedure, Step 3 and Appendix A); about 1.5 cups for each student group
- Pieces of rigid foam insulation or Foamcore, approximately 3″ x 3″; two for each student group
- Ceramic tiles or pieces of hardboard, approximately 3″ x 3″; two for each student group
- Serving trays or cake pans (to contain oobleck during Learning Procedure Step 4); one for each student group

Audio-Visual Materials

- ❑ (Optional) video or computer projection equipment; see Learning Procedure Step 1(b).

Teaching Time

One or two 45-minute class periods

Seating Arrangement

Groups of 3-4 students

Maximum Number of Students

32

Key Words

San Andreas Fault
Tectonic plate
Plate boundaries

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 activity, students will create models to accompany explanations of the motion and types of boundaries that occur between tectonic plates, as well as the unique tectonic conditions at the San Andreas Fault.

Learning Procedure

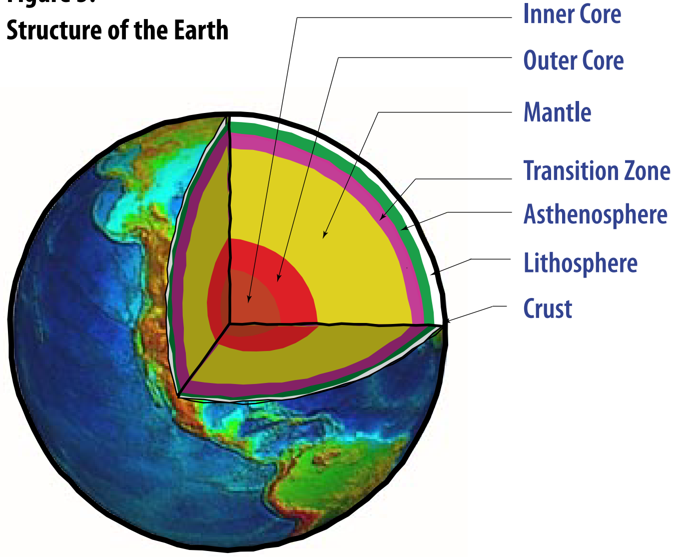
Note: This lesson uses a plate tectonic puzzle developed by Ross Stein and Chuck Wicks of the U.S. Geological Survey; for additional ideas about how to use this puzzle, see http://earthquake.usgs.gov/research/modeling/puzzle/puzzle.pdf. Portions of this lesson are adapted from the "When Plates Collide" lesson from the INSPIRE: Chile Margin 2010 Expedition.

1. To prepare for this lesson:
   (a) Review background essays for the Cradle of the Earthquake: Exploring the Underwater San Andreas Fault 2010 expedition http://oceanexplorer.noaa.gov/explorations/10sanandreas
   (b) Review illustrations and explanations of plate tectonics in "This Dynamic Earth" and/or "This Dynamic Planet" (see Resources section) for possible use in Step 2. If video or computer projection facilities are available, you may also want to download some images from these materials to show your students.
   (c) Review Multimedia Discovery Missions http://oceanexplorer.noaa.gov/edu/learning/welcome.html Lessons 1, 2, and 4 on Plate Tectonics, Mid-Ocean Ridges, and Subduction Zones. Decide how much of this material to use with your students.
   (d) Decide whether you will make jigsaw puzzles (for Step 2) in advance or have students make them.
   (e) Experiment with oobleck recipes (Appendix A) and procedures in Step 4. Decide whether to prepare oobleck for this step in advance or to do this as part of student activities. Note that similar activities have been described using frosting, fruit rollups and graham crackers (e.g., http://www.windows.ucar.edu/tour/link=/teacher_resources/teach_snacktectonics.html), but public health concerns and basic laboratory safety practices do not favor using edible materials in a classroom setting (though you may suggest that students might use such materials to repeat this demonstration at home).

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 Earth's layered structure diagrammed in Figure 1. Be sure students understand the spatial relationship of core, mantle, and crust. Explain the concept of plate tectonics, emphasizing that the plates are solid pieces of Earth's crust that float on a layer of the upper mantle that is partially melted rock. Have student groups make jigsaw puzzles (if you have not made these yourself in advance), and have a contest to see which group can correctly assemble their puzzle in the shortest amount of time. You may also want to have student groups research the names of major plates, and write these on the puzzle pieces. Alternatively, you may want to have the entire class assemble a single, larger puzzle using poster-size pieces.

Figure 3:
Structure of the Earth



3. Tell students that heat from Earth's core causes currents in the molten rock of the mantle (you can demonstrate similar currents by adding food coloring to a heated container of water), and these currents cause movement among Earth's tectonic plates. Introduce the concept of continental drift. Ask students what they think the red arrows on the puzzle pieces signify. Tell students that the junction of two tectonic plates is called a plate boundary, and describe the motion of plates at convergent, divergent, and transform boundaries. Remind students that these plates are huge pieces of rock, and ask them what they think happens when these plates collide.

   Ask students to locate the San Andreas Fault, and describe the motion of tectonic plates adjacent to the fault. Explain the relationship of earthquakes, tsunamis, and volcanoes to tectonic plate movements. You may want to point out that convergent, divergent, and transform boundaries are each associated with particular types of earthquake and volcanic activity: strong earthquakes and explosive volcanoes at convergent boundaries; slow-flowing volcanoes and weaker earthquakes at divergent boundaries; strong earthquakes, rare volcanoes at transform boundaries. You may also want to discuss some of the energy transfers involved in plate motions, earthquakes, and volcanoes (e.g., heat energy from Earth's core; kinetic energy of plate movements and volcanic eruptions; heat of friction when plates collide with each other). Description and discussion of subduction at convergent plate boundaries also provides an opportunity to introduce the rock cycle.

4. Tell students that their assignment is to model convergent, divergent, and transform boundaries using oobleck, pieces of rigid foam insulation or Foamcore, and tiles or pieces of hardboard. The lighter materials should be used to represent continental tectonic plates, which are less dense than oceanic tectonic plates that should be represented by pieces of tile or hardboard.

   A divergent boundary may be modeled by placing two pieces of heavier material side-by-side on a layer of oobleck, then moving them apart while pressing down slightly. This movement should cause the oobleck to be exposed and pushed up where the plates are separated, demonstrating how magma comes to the surface where tectonic plates are moving apart at divergent plate boundaries.

   A convergent boundary may be modeled by placing a piece of the heavier material next to a piece of the lighter material on a layer of oobleck, and gently pushing the two pieces together until they overlap so that the lighter material (continental plate) is on top and the heavier material (oceanic plate) has been subducted.

   A transform boundary may be modeled by placing two pieces of lighter (continental) material next to each other on a layer of oobleck, then pushing the pieces in opposite directions perpendicular to the direction of the junction.

The BRIDGE Connection

www.vims.edu/bridge/ - Click on "Ocean Science Topics" in the menu on the left side of the page, then select "Geology" for activities and links about plate tectonics.

The "Me" Connection

Have students write a first-hand account of a visit to a plate boundary, describing conditions at the boundary and what they might see in this area.

Connections to Other Subjects

English/Language Arts, Earth Science

Assessment

Written reports, modeling activities 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. Have students repeat their modeling demonstrations at home using edible materials, and submit reports that include comments from family members about their demonstration.
3. See http://earthquake.usgs.gov/research/modeling/puzzle/puzzle.pdf for additional ideas about how to use the U.S.G.S. plate tectonic puzzle.

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

Call to Arms (PDF, 756 Kb)
(from the Bermuda: Search for Deep Water Caves 2009 Expedition)
http://oceanexplorer.noaa.gov/explorations/09bermuda/background/edu/media/09call.pdf (paste url into browser)

Focus: Buoyancy (Physical Science)

In this activity, students will describe the types of motion found in the human arm, and describe four common robotic arm designs that mimic some or all of these functions.

The Robot Ranger (PDF, 964 kb)
(from the *Lophelia* II 2009: Deepwater Coral Expedition: Reefs, Rigs, and Wrecks Expedition)
http://oceanexplorer.noaa.gov/explorations/09lophelia/background/edu/media/09ranger.pdf (paste url into browser)

Focus: Robotic Analogues for Human Structures (Life Science/Physical Science)

In this activity, students will describe how humans are able to estimate the distance to visible objects, and describe a robotic system with a similar capability.

Entering the Twilight Zone (PDF, 468 kb)
(from the 2002 Gulf of Mexico Expedition)
http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_twilight.pdf

Focus: Deep-sea habitats (Life Science)

In this activity, students will be able to describe major features of cold seep communities, and list at least five organisms typical of these communities and will infer probable trophic relationships within and between major deep-sea habitats. Students will also be able to describe in the process of chemosynthesis in general terms, contrast chemosynthesis and photosynthesis, and describe major deep-sea habitats and list at least three organisms typical of each habitat.

InVENT a Deep-Sea Invertebrate (PDF, 460 kb)
(from the 2002 Galapagos Rift expedition)
http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr5_6_l3.pdf

Focus: Galapagos Rift Ecosystem (Structure and Function in Living Systems)

In this activity, students will design an invertebrate capable of living near deep-sea hydrothermal vents, and in doing so, will learn about the unique adaptations that organisms must have in order to survive in the extreme environments of the deep sea.

Let's Make a Tubeworm! (PDF, 464 kb)
(from the 2002 Gulf of Mexico Expedition)
http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_tube_gr56.pdf

Focus: Symbiotic relationships in cold seep communities (Life Science)

In this activity, students will be able to describe the process of chemosynthesis in general terms, contrast chemosynthesis and photosynthesis, describe major features of cold seep communities, and list at least five organisms typical of these communities. Students will also be able to define symbiosis, describe two examples of symbiosis in cold seep communities, describe the anatomy of vestimentiferans, and explain how these organisms obtain their food.

Animals of the Fire Ice (PDF, 364 kb)
(from the 2003 Windows to the Deep Expedition)
http://oceanexplorer.noaa.gov/explorations/03windows/background/education/media/03win_fireice.pdf

Focus: Methane hydrate ice worms and hydrate shrimp (Life Science)

Students will be able to define and describe methane hydrate ice worms and hydrate shrimp, infer how methane hydrate ice worms and hydrate shrimp obtain their food, and infer how methane hydrate ice worms and hydrate shrimp may interact with other species in the biological communities of which they are part.

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

http://pubs.usgs.gov/publications/text/dynamic.html#anchor19309449 – On-line version of "This Dynamic Earth," a thorough publication of the U.S. Geological Survey on plate tectonics written for a non-technical audience

http://pubs.usgs.gov/pdf/planet.html – "This Dynamic Planet," map and explanatory text showing Earth's physiographic features, plate movements, and locations of volcanoes, earthquakes, and impact craters

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
- Properties and changes of properties in matter
- Motions and forces
- Transfer of energy

Content Standard D: Earth and Space Science
- Structure of the Earth system
- Earth's history

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

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.
The Earth has one big ocean with many features.
Fundamental Concept b. An ocean basin's size, shape and features (such as islands, trenches, mid-ocean ridges, rift valleys) vary due to the movement of Earth's lithospheric plates. Earth's highest peaks, deepest valleys and flattest vast plains are all in the ocean.

Essential Principle 2.
The ocean and life in the ocean shape the features of the Earth.
Fundamental Concept a. Many earth materials and geochemical cycles originate in the ocean. Many of the sedimentary rocks now exposed on land were formed in the ocean. Ocean life laid down the vast volume of siliceous and carbonate rocks.
Fundamental Concept e. Tectonic activity, sea level changes, and force of waves influence the physical structure and landforms of the coast.

Essential Principle 5. The ocean supports a great diversity of life and ecosystems.
Fundamental Concept g. There are deep ocean ecosystems that are independent of energy from sunlight and photosynthetic organisms. Hydrothermal vents, submarine hot springs, and methane cold seeps

rely only on chemical energy and chemosynthetic organisms to support life.

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 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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Appendix A
Recipes for Oobleck

Oobleck is a non-Newtonian fluid whose name comes from the Dr. Seuss book, *Bartholomew and the Oobleck*. There are a variety of recipes for making oobleck, which include:

Option 1:

The simplest recipe is to slowly add approximately two cups of cornstarch to one cup of water, continuously mixing until the mixture is semi-solid (http://www.instructables.com/id/Oobleck/).

Option 2:

A less sticky version can be made from borax and glue (http://education.jlab.org/beamsactivity/6thgrade/oobleck/overview.html). Make a glue solution with equal volumes of white glue and water. Make a second solution by dissolving 60 ml of dry borax powder in one liter of water (the borax may not dissolve completely). Make oobleck by mixing 30 ml of the glue solution with 10 ml of the borax solution.

Option 3:

Mix 1/2 cup of liquid starch with 1 cup of white glue (http://www.ehow.com/how_2384117_create-oobleck-school-glue.html).

Food coloring may be added to any of these recipes if desired.