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lesson plan

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

Life is Weird!

(adapted from the 2003 Windows to the Deep Expedition)

Focus
Biological organisms in cold seep communities

Grade Level
7-8 (Life Science)

Focus Question
What organisms are typically found in cold seep communities, and how do these organisms interact?

Learning Objectives
- Students will be able to describe major features of cold seep communities and list at least five organisms typical of these communities.
- Students will be able to infer probable trophic relationships among organisms typical of cold seep communities and the surrounding deep-sea environment.
- Students will be able to describe in the process of chemosynthesis in general terms and will be able to contrast chemosynthesis and photosynthesis.

Materials
- ❑ 5 x 7 index cards
- ❑ Drawing materials
- ❑ Corkboard, flip chart, or large poster board

Audio-Visual Materials
- ❑ None

Teaching Time
Two 45-minute class periods, plus time for individual group research

Seating Arrangement
Groups of four students

Maximum Number of Students
32

Key Words

San Andreas Fault
Cold seeps
Methane hydrate
Chemosynthesis

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 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

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

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. Information about past earthquakes is often obtained by studying proxies. Proxies are natural records of biological and geological ecosystem features that are affected by certain events. Tree rings are a well-known proxy for year-to-year weather conditions, since the size of each ring is affected by growing conditions during the year in which each ring is formed. In fact, tree rings are sometimes used to obtain information about the history of earthquakes, since earthquakes cause stresses that can affect the growth of trees (for example, see http://www.ess.washington.edu/SEIS/PNSN/HAZARDS/CASCADIA/tree_rings.html).

A similar proxy for earthquake information is provided by deepwater corals. These corals build their skeletons from calcium and carbonate ions which they extract from sea water. During the Ocean Explorer 2002 Continuing The Legacy of Lewis And Clark Expedition, scientists found that skeletons of the bamboo coral (*Isidella* sp.) contained ring-like structures that probably are growth layers associated with changes in food supply. There were also gaps and other changes in the ring patterns that may correspond to specific disturbances.

Earthquakes can also trigger changes in geologic structures. One structure of particular interest is hydrocarbon deposits within the sea floor. Hydrocarbons may exist as gases, liquids, or ice-like solids called hydrates. These hydrocarbons can provide an energy source for unique chemosynthetic ecosystems called cold seep communities (for more information about methane hydrates, see Appendix I). In addition, active gas and fluid venting can indicate areas where earthquake shaking has taken place.

The first chemosynthetic communities were discovered in 1977 near the Galapagos Islands in the vicinity of underwater volcanic hot springs called hydrothermal vents, which usually occur along ridges separating the Earth’s tectonic plates. Hydrogen sulfide is abundant in the water erupting from hydrothermal vents, and is used by chemosynthetic bacteria that are the base of the vent community food chain. These bacteria obtain energy by oxidizing hydrogen sulfide to sulfur:

$$CO_2 + 4H_2S + O_2 > CH_2O + 4S + 3H_2O$$

(carbon dioxide plus sulfur dioxide plus oxygen yields organic matter, sulfur, and water).

Visit http://www.pmel.noaa.gov/vents/ for more information and activities on hydrothermal vent communities.

Cold seep communities are similar in that they are based upon energy produced by chemosynthesis; but while energy for hydrothermal vent communities is derived from underwater hot springs, cold seep communities are found in areas where gases (such as methane and hydrogen sulfide) and oil seep out of sediments. These areas are commonly found along continental margins, and (like hydrothermal vents) are home to many species of organisms that have not been found anywhere else on Earth. Typical features of cold seep communities that have been studied so far include mounds of frozen crystals of methane and water called methane hydrate ice, that are home to polychaete worms.

In addition to investigating the history of past earthquakes, another question for the Cradle of the Earthquake: Exploring the Underwater San Andreas Fault 2010 Expedition is “What unique ecosystems are associated with active fluid and gas venting, topographic complexity, and continuous change associated with the fast-moving and active San Andreas fault system?” This activity focuses on relationships between some inhabitants of cold seep communities.

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); and Chemosynthetic Communities in the Gulf of Mexico (http://oceanexplorer.noaa.gov/explorations/02mexico/background/communities/communities.html).

   You may want to visit http://www.bio.psu.edu/cold_seeps for a virtual tour of a cold seep community.

2. Lead a discussion of deep-sea chemosynthetic communities. Contrast chemosynthesis with photosynthesis. In both processes, organisms build sugars from carbon dioxide and water. This process requires energy; photosynthesizers obtain this energy from the sun, while chemosynthesizers obtain energy from chemical reactions. Point out that there are a variety of chemical reactions that can provide this kind of energy. Contrast hydrothermal vent communities with cold seep communities.

   Review the concepts of food chains and food webs, including the concept of trophic levels (primary producer, primary consumer, secondary consumer, and tertiary consumer).

3. Assign each student group one or more of the following groups to research:
   Methanotrophic bacteria
   Thiotrophic bacteria
   Xenophyophores (see also genus *Syringammina*)
   Anthozoa (sea anemones)
   Turbellaria (a flatworm)
   Nautiliniella (a genus of polychaetes)
   Maldanidae (a family of polychaetes)
   Chaetopteridae (a family of polychaetes)
   Capitellidae (a family of polychaetes)
   Sipunculida (peanut worms)
   Bathymodiolus heckerae (a species of mussel)
   Vesicomya (a genus of clams)
   Octopoda (octopus)
   Munidopsis (a genus of crustacean)
   Alvinocaris (a genus of crustacean)
   Nematoda (a round worm)
   Sarsiaster greigi (a species of sea urchin)
   Chiridota (a genus of sea cucumber)
   Ophioctenella (a genus of brittle star)
   Brisingia (a genus of sea star)

In addition to written reference materials (encyclopedia, periodicals, and books on the deep sea), the following Web sites contain useful information:

http://www.bio.psu.edu/cold_seeps
http://biodidac.bio.uottawa.ca/
http://www.fishbase.org/search.cfm
http://www.mbari.org/staff/vrijen/PDFS/VanDover_2003DSR.pdf (this document also contains a food web model for the Blake Ridge, so you may want to provide only selected portions of this reference!)

Each student group should try to determine the energy (food) source(s) of their assigned organisms. It may not be possible to precisely determine specific foods for all groups, but students should be able to draw reasonable inferences from information about related organisms and anatomical features that may give clues about what the animals eat. Students should prepare a 5 x 7 index card for each organism with an illustration of the organism (photocopies from reference material, downloaded internet pictures, or their own sketches), notes on where the organism is found, approximate size of the organism, and its trophic level (whether it is a primary producer, primary consumer, secondary consumer, or tertiary consumer).

4. Have each student group orally present their research results to the entire class. On a corkboard, flip chart, or piece of poster board, arrange the cards to show organisms that inhabit cold seep communities, organisms from deep-sea environments outside cold seep communities, and the trophic (feeding) relationships between these organisms. You may want to arrange the organisms by habitat first, then draw lines indicating which organisms probably provide an energy source (food) for other organisms. Painting tape or sticky notes can be used to temporarily anchor the cards until you have decided on the best arrangement, then tape or glue the cards in place.

5. Lead a discussion of the food web the students have created. Which groups show the greatest variety of anatomical types and feeding strategies? Which groups are responsible for primary production? What would the students infer about the relative abundance of each trophic level? In the simplest analysis, organisms at lower trophic levels (primary producers and primary consumers) must be more abundant than those on higher trophic levels. If this does not appear to be true, then there must be additional energy sources for the higher trophic levels.

The BRIDGE Connection

www.vims.edu/bridge/ - Click on “Ocean Science Topics” in the navigation menu to the left, then “Biology,” then “Plankton” for resources on ocean food webs. Click on "Ocean Science Topics," then "Habitats," then "Deep Sea" for resources on deep-sea communities.

The "Me" Connection

Have students write a short essay on their favorite deep-sea or cold seep community organism, stating why they like it and at least three interesting facts about it. Have students discuss how deep-sea communities such as those found near the San Andreas Fault may someday affect their lives.

Connections to Other Subjects

English/Language Arts, Earth Science

Assessment

Results and presentation of the research component of this activity provide a basis for group evaluation. In addition, individual written interpretations of the pooled results may be required prior to Step 5 to provide a means of individual 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.

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

Monsters of the Deep (6 pages, 464 KB)

http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/monsters.pdf

Focus - Predator-prey relationships between cold seep communities and the surrounding deep-sea environment (Life Science)

Students describe major features of cold seep communities, list at least five organisms typical of these communities, and infer probable trophic relationships among organisms typical of cold seep communities and the surrounding deep-sea environment. Students also describe the process of chemosynthesis in general terms, contrast chemosynthesis and photosynthesis, and describe at least five deep-sea predator organisms.

One Tough Worm (8 pages, 476 KB)

http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/worm.pdf

Focus - Physiological adaptations to toxic and hypoxic environments (Life Science)

Students explain the process of chemosynthesis, explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps, and describe three physiological adaptations that enhance an organism's ability to extract oxygen from its environment. Students also describe the problems posed by hydrogen sulfide for aerobic organisms, and explain three strategies for dealing with these problems.

Mapping the Deep Ocean Floor (PDF, 1.5 Mb)
(from the INSPIRE: Chile Margin 2010 Expedition)
http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/mapping.pdf

Focus: Bathymetric Mapping

Students create a two-dimensional topographic map from bathymetric survey data, create a three-dimensional model of seafloor topography from a two-dimensional topographic map, and interpret two- and three-dimensional topographic data.

I, Robot, Can Do That! (PDF, 315 kb)
(from the Lost City 2005 Expedition)
http://oceanexplorer.noaa.gov/explorations/05lostcity/background/edu/media/lostcity05_i_robot.pdf

Focus: Underwater Robotic Vehicles for Scientific Exploration (Physical Science/Life Science)

Students describe and contrast at least three types of underwater robots used for scientific explorations, discuss the advantages and disadvantages of using underwater robots in scientific explorations, and identify robotic vehicles best suited to carry out certain tasks.

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

Paull, C.K., B. Hecker, C. Commeau, R.P. Feeman-Lynde, C. Nuemann, W.P. Corso, G. Golubic, J. Hook, E. Sikes, and J. Curray. 1984. Biological communities at Florida Escarpment resemble hydrothermal vent communities. Science 226:965-967 – Early report on cold seep communities.

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
- Transfer of energy

Content Standard C: Life Science
- Structure and function in living systems
- Populations and ecosystems

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 3.
The ocean is a major influence on weather and climate.
Fundamental Concept f. The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon and water.

Essential Principle 5.
The ocean supports a great diversity of life and ecosystems.
Fundamental Concept c. Some major groups are found exclusively in the ocean. The diversity of major groups of organisms is much greater in the ocean than on land.
Fundamental Concept d. Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.
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 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 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 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 I
More About Methane Hydrates

Methane is produced in many environments by a group of Archaea known as the methanogenic Archaeobacteria. These Archaeobacteria obtain energy by anaerobic metabolism through which they break down the organic material contained in once-living plants and animals. When this process takes place in deep ocean sediments, methane molecules are surrounded by water molecules, and conditions of low temperature and high pressure allow stable ice-like methane hydrates to form.

Methane hydrate is a type of clathrate, a chemical substance in which the molecules of one material (water, in this case) form an open lattice that encloses molecules of another material (methane) without actually forming chemical bonds between the two materials (visit http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/about-hydrates/about_hydrates.htm to see a model of a methane hydrate clathrate).

Scientists are interested in methane hydrates for several reasons. A major interest is the possibility of methane hydrates as an energy source. The U.S. Geological Survey has estimated that on a global scale, methane hydrates may contain roughly twice the carbon contained in all reserves of coal, oil, and conventional natural gas combined. In addition to their potential importance as an energy source, scientists have found that methane hydrates are associated with unusual and possibly unique biological communities that may be sources of beneficial pharmaceutical materials.

While such potential benefits are exciting, methane hydrates may also cause big problems. Although methane hydrates remain stable in deep-sea sediments for long periods of time, as the sediments become deeper and deeper they are heated by the Earth's core. Eventually, temperature within the sediments rises to a point at which the clathrates are no longer stable and free methane gas is released (at a water depth of 2 km, this point is reached at a sediment depth of about 500 m). The pressurized gas remains trapped beneath hundreds of meters of sediments that are cemented together by still-frozen methane hydrates. If the overlying sediments are disrupted by an earthquake or underwater landslide, the pressurized methane can escape suddenly, producing a violent underwater explosion that may result in disastrous tsunamis.

The release of large quantities of methane gas can have other consequences as well. Methane is one of a group of the so-called "greenhouse gases." In the atmosphere, these gases allow solar radiation to pass through to the surface of the Earth, but absorb heat radiation that is reflected back from the Earth's surface, thus warming the atmosphere. Many scientists have suggested that increased carbon dioxide in the atmosphere produced by burning fossil fuels is causing a "greenhouse effect" that is gradually warming the atmosphere and the

Earth's surface. A sudden release of methane from deep-sea sediments could have a similar effect, since methane has more than 30 times the heat-trapping ability of carbon dioxide. In 1995, Australian paleoceanographer Gerald Dickens suggested that a sudden release of methane from submarine sediments during the Paleocene epoch (at the end of the Tertiary Period, about 55 million years ago) caused a greenhouse effect that raised the temperatures in the deep ocean by about 6° C. The result was the extinction of many deep-sea organisms known as the Paleocene extinction event. More recently, other scientists have suggested that similar events could have contributed to mass extinctions during the Jurassic period (183 million years ago), as well as to the sudden appearance of many new animal phyla during the Cambrian period (the "Cambrian explosion, about 520 million years ago).

For a lesson about methane hydrates and instructions for building a model of a methane hydrate molecule, see "The Methane Circus," http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/09methanecircus.pdf.