ocean explorer
www.oceanexplorer.noaa.gov

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

Living on the Ridge

Image captions/credits on Page 2.

lesson plan

Focus
Cold seep communities on Hydrate Ridge

Grade Level
9-12 (Life Science/Chemistry)

Focus Question
What are some characteristics of biological communities associated with methane hydrates?

Learning Objectives
- Students will define methane hydrates.
- Students will explain how methane hydrates are formed.
- Students will describe biological communities associated with Hydrate Ridge.
- Students will discuss some of the adaptations found among organisms that inhabit methane hydrate communities.

Materials
- ❑ Copies of *Hydrate Ridge Ecosystems Inquiry Guide*, one for each group
- ❑ (Optional) Materials for constructing a methane hydrate molecule model:

  For constructing a pentagon:
  - Paper, unlined 8-1/2" X 11"
  - Pencil
  - Protractor or compass

  For constructing the dodecahedron, clathrate cage, methane molecule and methane hydrate model:
  - Scissors
  - Cardboard or card stock (enough to make 13 pentagons)
  - Ruler, 12-inch
  - 11 - Bamboo skewers, 12" long
  - 20 - Styrofoam balls, 1/2" diameter
  - 4 - Styrofoam balls, 1-1/2" diameter
  - 1 - Styrofoam ball, 1" diameter
  - Tape, wrapping or strapping
  - Spray paint, water-based latex; dark blue, light blue, red, & black
  - Fishing line, 8 lb test; or light colored thread

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
Hydrate Ridge
Methane hydrate
Cold seep
Authigenic carbonate
Methanotroph

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.

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

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 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.

The association of spectacular natural disasters such as earthquakes and volcanoes with tectonic plate movements often overshadows the fact that these movements are also associated with unusual and complex ecosystems. The Cradle of the Earthquake: Exploring the Underwater San Andreas Fault 2010 expedition is focused on investigating portions of the great plate boundary fault that lie offshore; areas that have virtually never been observed or explored. While a major emphasis of the expedition is improving our understanding of the history of great earthquakes, scientists also expect to find unique ecosystems associated with the active fluid and gas venting, topographic complexity, and continuous change that characterize the fast-moving and active San Andreas fault system. In this lesson, students will learn about some of these ecosystems.

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)
   - Review the *Hydrate Ridge Ecosystems Inquiry Guide*, and discussion points in Step 4, below; and
   - Decide whether to have students construct methane hydrate molecules; if you decide to do this, copy instructions from http://oceanexplorer.noaa.gov/okeanos/edu/lessonplans/media/09bigdeal.pdf.

   The content of this lesson is based almost entirely upon student inquiry, with very little information presented by the educator. Depending upon your students' knowledge and research skills, you may want to modify this approach by presenting some information as background in class discussions prior to having students answer the remaining questions on their own.

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). Briefly review the motion of tectonic plates associated witht the San Andreas Fault, and explain that while the relationship to earthquakes is a conspicuous feature of the expedition, scientists are also interested in unusual ecosystems that are associated with these geological features.

3. Provide each student group with a copy of the *Hydrate Ridge Ecosystems Inquiry Guide*, and provide any additional background information that you have decided to offer. You may want to guide students to the key references (Suess, *et al.*, 2001; Boetius and Suess, 2004) or allow students to discover these through their own research.

4. Lead a discussion of students' answers to questions on the *Inquiry Guide*. The following points should be included:
   - 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.

   - At Hydrate Ridge, methane hydrates are found both in a highly porous form and in a more dense, massive form with no visible pore space.

   - The "chloride anomaly" associated with methane hydrates is an apparent reduction in chloride concentration in water from gas hydrates that have been brought to the sea surface. This anomaly is the result of water being released from the solid hydrate, which causes pore water within the hydrate to become diluted.

   - Anaerobic oxidation removes most of the methane seeping from the subsurface, and the precipitation of carbonate (discussed below) creates a permanent carbon sink. So methanotrophic microbial communities provide an efficient filter for methane that would otherwise enter the atmosphere.

   - Floating chunks of methane hydrate provide a mechanism for directly transferring methane gas to Earth's atmosphere. If large quantities of low density methane hydrates are buried, they could cause slopes to become unstable. This could result in underwater landslides and possibly tsunamis.

- Cold seeps are underwater areas where gases (such as methane and hydrogen sulfide) and oil seep out of sediments.

- Motions of tectonic plates are related to the presence of cold seep communities on Hydrate Ridge because plate convergence results in compression and rapid burial of sediments. In combination with microbial and/or thermal processes, this produces hydrocarbons. Faulting caused by tectonic plate motion may open pathways that allow methane to escape.

- The chaotic appearance of the Hydrate Ridge landscape is the result of methane seepage and chunks of low-density methane hydrate that become detached from the bottom and float to the surface. Where gas flows are high, bubbles erupt from the surface. Areas with more moderate flows are covered with patchworks of thick dense white or orange microbial mats, while slow flows are associated with fields of clams. Carbonate towers and pinnacles (discussed below) provide additional topographic variety.

- Primary producers at Hydrate Ridge include organisms that consume methane (methanotrophs) and others that gain energy from the oxidation of sulfide. Another group of organisms, the methanogens, may also be included since they are responsible for degrading hydrocarbons to yield methane gas and carbon dioxide.

- Hydrate Ridge is populated by large communities of giant sulfide-oxidizing bacteria (*Beggiatoa*), vesicomyid clams, and tubeworms. Polychaetes in the family Dorvilleidae are abundant within sediments.

- Cold seep communities include areas where there are high concentrations of hydrogen sulfide, which is toxic to many organisms, and near-zero dissolved oxygen concentrations. Only a few organisms, including dorvilleid polychaetes and bacteria such as *Beggiatoa*, are adapted to tolerate these conditions.

- The absence of predators resulting from extreme conditions in habitats occupied by Dorvilleidae may have released these organisms from considerable evolutionary pressure, and allowed multiple species to evolve (Levin has identified as many as 17 dorvilleid species occurring in the same area, including 10 in a single genus).

- "Authigenic carbonates" are limestone mineral structures that are formed in place, as opposed to being created in one location and transported to another. Anaerobic methanotrophic organisms oxidize methane and reduce sulfate to form sulfide. Carbonates are deposited in association with this process according to the reaction:

$$CH_4 + SO_4^{-2} + Ca_2 > CaCO_3 + H_2S + H_2O$$

- Methane is transported in the form of free gas bubbles through vertical channels, which explains the abundance of porous hydrates at Hydrate Ridge. Large chemoherms and chimney-like carbonate structures are the result of anaerobic oxidation of methane and formation of carbonates described above. This process provides a permanent carbon sink and thus influences the global carbon cycle and the role of carbon dioxide and methane in climate change. Note that it is not clear whether anaerobic methanotrophs are directly involved in carbonate precipitation.

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; click "Habitats," then "Deep Sea" for links to resources about hydrothermal vents and chemosynthetic communities.

The "Me" Connection

Have students write a short essay describing how methane hydrate communities such as Hydrate Ridge might be of personal importance.

Connections to Other Subjects

English/Language Arts, Earth Science

Assessment

Class discussions and answers to *Inquiry Guide* questions offer 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

The Tell-Tale Plume
(PDF, 1.2 Mb) (from the INSPIRE: Chile Margin 2010 Expedition)
http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/plume.pdf

Focus: Hydrothermal Vent Chemistry (Earth Science/Chemistry/Mathematics)

Students will describe hydrothermal vents, identify changes that they cause to the physical and chemical properties of seawater, and use oceanographic data to recognize a probable plume from hydrothermal activity.

Reduced Fare
(PDF, 1 Mb) (from the INSPIRE: Chile Margin 2010 Expedition)
http://oceanexplorer.noaa.gov/explorations/10chile/background/edu/media/reducedfare.pdf

Focus: Deep-Sea Reducing Environments (Biology/Chemistry)

Students will describe oxidation and reduction, explain the meaning of "reducing environment," give at least three examples of deep-sea reducing environments, and demonstrate a flow of electric current produced by a redox reaction.

Chemosynthesis for the Classroom
(PDF, 274 kb) (from the 2002 Gulf of Mexico Expedition)
http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_chemo_gr912.pdf

Focus: Chemosynthetic bacteria and succession in chemosynthetic communities (Chemistry/Biology)

In this activity, students will observe the development of chemosynthetic bacterial communities and will recognize that organisms modify their environment in ways that create opportunities for other organisms to thrive. Students will also be able to explain the process of chemosynthesis and the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.

The Big Burp: Where's the Proof?
(PDF, 364 kb) (from the Expedition to the Deep Slope 2007 Expedition)
http://oceanexplorer.noaa.gov/explorations/07mexico/

background/edu/media/burp.pdf

Focus: Potential role of methane hydrates in global warming (Earth Science)

In this activity, students will be able to describe the overall events that occurred during the Cambrian explosion and Paleocene extinction events and will be able to define methane hydrates and hypothesize how these substances could contribute to global warming. Students will also be able to describe and explain evidence to support the hypothesis that methane hydrates contributed to the Cambrian explosion and Paleocene extinction events.

This Life Stinks

(PDF, 276 kb) (from the 2003 Windows to the Deep expedition)

http://oceanexplorer.noaa.gov/explorations/03windows/background/education/media/03win_lifestinks.pdf (paste URL into browser)

Focus: Methane-based chemosynthetic processes (Physical Science)

In this activity, students will be able to define the process of chemosynthesis, and contrast this process with photosynthesis. Students will also explain the process of methane-based chemosynthesis and explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.

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

Boetius, A. and E. Suess. 2004. Hydrate Ridge: a natural laboratory for the study of microbial life fueled by methane from near-surface gas hydrates. Chemical Geology 205:291–310; available online at http://www.mumm-research.de/download_pdf/boetiussuess.pdf

Suess, E., Torres, M.E., Bohrmann, G., Collier, R.W., Rickert, D., Goldfinger, C., Linke, P., Heuser, A., Sahling, H., Heeschen, K.U., Jung, C., Nakamura, K., Greinert, J., Pfannkuche, O., Trehu, A.M., Klinkhammer, G.P., Whiticar, M.J., Eisenhauer, A., Teichert, B. and Elvert, M. 2001. Sea floor methane hydrates at Hydrate Ridge, Cascadia margin. In, Paull, C. and Dillon, W.P. (eds.) Natural gas hydrates: occurrence, distribution and detection. Washington DC, USA, American Geophysical Union, 87-98. (AGU Geophysical Monograph 124); available online at http://users.ugent.be/~jgreiner/papers/Suess_etal_2001_AGU_Mon.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
- Structure and properties of matter
- Chemical reactions

Content Standard C: Life Science
- Biological evolution
- Interdependence of organisms
- Behavior of organisms

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

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

Content Standard F: Science in Personal and Social Perspectives

- Natural resources
- Natural and human-induced hazards

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:
oceanexeducation@noaa.gov

For More Information

Paula Keener, Director, Education Programs
NOAA's Office of Ocean Exploration and Research
Hollings Marine Laboratory
331 Fort Johnson Road, Charleston SC 29412
843.762.8818 843.762.8737 (fax)
paula.keener-chavis@noaa.gov

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

Hydrate Ridge Ecosystems Inquiry Guide

1. What are methane hydrates?

2. What two forms of methane hydrate are commonly found at Hydrate Ridge?

3. What is the "chloride anomaly" that is associated with methane hydrates? What causes this anomaly?

4. Methane is a greenhouse gas, so the presence of large quantities of methane at areas such as Hydrate Ridge might have a significant influence on Earth's climate. How do cold seep communities affect the potential atmospheric effects of methane at Hydrate Ridge?

5. Suess *et al.* (2001) reported sighting large chunks of floating methane hydrates. How might the existence of large quantities of low-density methane hydrates affect Earth's atmosphere, and the stability of submarine slopes?

6. What is a cold seep?

7. How are motions of tectonic plates related to the presence of cold seep communities on Hydrate Ridge?

8. Suess *et al.* (2001) describe Hydrate Ridge as a "chaotic landscape." What processes contribute to this chaotic appearance?

9. What organisms are at the base of the food chain in cold seep communities on Hydrate Ridge?

10. What organisms are typical of cold seep communities on Hydrate Ridge?

11. Cold seep communities on Hydrate Ridge are often described as extreme environments. What adaptations are needed for organisms to be able to survive these "extreme" conditions?

12. Lisa Levin, of the Scripps Institution of Oceanography, studies the ecology and evolution of polychaetes in the family Dorvilleidae at cold seeps. She has found that in some areas these are the only metazoan inhabitants that can tolerate the high concentrations of hydrogen sulfide and the near absence of oxygen. How might the absence of predators affect speciation among Dorvilleidae in these areas?

Student Worksheet
Hydrate Ridge Ecosystems Inquiry Guide

13. What are "authigenic carbonates," and how are they related to anaerobic metabolism of methane?

14. Boetius and Suess (2004) report that there is a high abundance of different carbonate structures at Hydrate Ridge, including large reef-like mounds (chemoherms) and chimney-like structures up to 40 m high. What process is responsible for these structures, and how may these structures be significant to the global carbon cycle?