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Lophelia II 2010:
Cold Seeps and Deep Reefs

What's the Connection?

Image captions/credits on Page 2.

lesson plan

Focus
Relationship of hardground communities in the Gulf of Mexico to physical and chemical environmental features

Grade Level
9-12 (Life Science/Chemistry/Earth Science)

Focus Question
Why are deep-sea ecosystems in the Gulf of Mexico associated with petroleum deposits?

Learning Objectives
- Students will define hardgrounds and explain how they are formed in the Gulf of Mexico.

- Students will discuss the relationships between hydrocarbon seeps, chemosynthetic communities, and deep-water coral communities in the Gulf of Mexico.

Materials
- ❑ Copies of *Gulf of Mexico Deep-Sea Ecosystems Inquiry Guide*, one copy for each student group

- ❑ Copies of the article by Fisher *et al*. (2007) on cold-seep communities of the Gulf of Mexico and essays on Chemosynthetic Communities in the Gulf of Mexico and The Ecology of Gulf of Mexico Deep-Sea Hardground Communities (see Learning Procedure, Step 1); one copy for each student group, or Internet access so that students can obtain these articles on their own

Audio-Visual Materials
- ❑ (Optional) Video projection or other equipment to show downloaded images (see Learning Procedure, Step 1).

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

30

Key Words

Gulf of Mexico
Hardground
Cold seep
Deepwater coral
Carbonate

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.

Around 10:00 pm CDT on April 20, 2010, about 40 miles southeast of the Louisiana coast, a gas explosion occurred on the mobile offshore drilling unit Deepwater Horizon. The explosion killed 11 workers, injured 17 others, ignited an intense fire that burned until the Deepwater Horizon sank 36 hours later, and resulted in a massive release of crude oil that is now considered the greatest environmental disaster in U.S. history. The total volume of oil released into the Gulf of Mexico is estimated to have been 205 million gallons (4.9 million barrels), dwarfing the 11-million-gallon *Exxon Valdez* spill of 1989. Ecological impacts of the released oil have received extensive media attention, particularly those affecting beaches, marshes, birds, turtles, and marine mammals; but other, less visible, organisms may be affected as well. Many scientists are particularly concerned about the unusual and biologically-rich deep-sea ecosystems on the Gulf of Mexico seafloor.

For the past four years, NOAA's Office of Ocean Exploration and Research (OER) has sponsored expeditions to locate and explore deep-sea ecosystems in the Gulf of Mexico. These expeditions were targeted toward broad questions that included:

- Where are cold-seep and deepwater coral communities associated with hard-bottom environments in the deep Gulf of Mexico?
- What organisms are characteristic of cold-seep and deepwater coral communities in the deep Gulf of Mexico?
- What are the relationships between coral communities and artificial and natural substrates?
- What processes control the occurrence and distribution of cold-seep and deepwater coral communities in the Gulf of Mexico?

Working from NOAA Ship *Ronald H. Brown*, the *Lophelia* II 2010: Cold Seeps and Deep Reefs Expedition is a continuation of exploration efforts to answer these questions, as well as a new question that has been added to the list:

Images from Page 1 top to bottom:
Lophelia pertusa on the seafloor. Note extended polyp on the right. Image courtesy of Ian MacDonald, NOAA.
http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/sept1/media/lophelia_insitu_close.html

Video monitors inside Jason control van allow scientists and Jason crew to see all seafloor operations. Tim Shank (right) records observations using the "Virtual Van" software. Image courtesy Troy Kitch, NOAA.
http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug31/media/controlvan.html

Preserved specimens collected during *Lophelia* II 2009. Image courtesy Troy Kitch, NOAA.
http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug23/media/species_jar.html

Viosca Knoll Wreck: The stempost of the wreck is covered in *Lophelia*, Stalk Barnacles, *Acesta* clams and Anemones. A little *Eumunida picta* is also evident in the lower corner. Image courtesy Stephanie Lessa, NOAA.
http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/sept6/media/7_biostem.html

NOAA Ship *Ronald H. Brown* at sunrise in the Gulf of Mexico. Image courtesy of Dana Mancinelli, NOAA, *Lophelia* II 2009.
http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug27/media/ronbrownship.html

Jason II on the deck of the NOAA Ship *Ronald H. Brown*. Image courtesy of Sheli Smith, NOAA, *Lophelia* II 2009.
http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/sept6/media/1_jason_ll.html

CTD rosette on deck ready for deployment. Image courtesy of NOAA, *Lophelia* II 2009.
http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/sept1/media/ctd_on_deck.html

- What impacts, if any, have occurred in deep-sea communities as a result of the Deepwater Horizon blowout?

The Deepwater Horizon blowout highlighted the vulnerability of deep-sea ecosystems to impacts from human activity. Ironically, these ecosystems are closely linked with the same petroleum deposits that are the focus of human activities that may cause such impacts. In this lesson, students will investigate why deep-sea ecosystems in the Gulf of Mexico are often associated with areas where hydrocarbons seep through the seafloor.

Learning Procedure

1. To prepare for this lesson:
   - Review introductory essays for the *Lophelia* II 2010: Cold Seeps and Deep Reefs Expedition at http://oceanexplorer.noaa.gov/explorations/10lophelia/welcome.html. You may also want to consider showing students some images of deep-sea ecosystems from http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/photolog/photolog.html. You can find a virtual tour of a cold-seep community at http://www.bio.psu.edu/cold_seeps.
   - Review procedures and questions on the *Gulf of Mexico Deep-Sea Ecosystems Inquiry Guide*.
   - Obtain copies of:
     – Article by Fisher *et al*. (2007) on cold-seep communities of the Gulf of Mexico (see Other Resources and Links; available online at http://www.tos.org/oceanography/issues/issue_archive/20_4.html);
     – Chemosynthetic Communities in the Gulf of Mexico, essay by Erik Cordes (http://oceanexplorer.noaa.gov/explorations/02mexico/background/communities/communities.html); and
     – The Ecology of Gulf of Mexico Deep-Sea Hardground Communities essay by Erik E. Cordes (http://oceanexplorer.noaa.gov/explorations/06mexico/background/hardgrounds/hardgrounds.html)

   Alternatively, ensure that students will be able to access these on their own.

2. Briefly introduce the *Lophelia* II 2010: Cold Seeps and Deep Reefs Expedition, and describe cold-seep and deepwater coral communities. If desired, show images from the Web page referenced in Step 1. Depending upon students' background, you may also want to review the overall geology of the Gulf of Mexico that contributes to extensive petroleum deposits (you can find a discussion of this in the Gulf of Mexico Deep-Sea Ecosystems Educators' Guide at http://oceanexplorer.noaa.gov/edu/guide/gomdse_edguide.pdf)

3. Lead a brief discussion about the Deepwater Horizon blowout. Ask students whether they think it is just coincidence that unusual deep-sea ecosystems happened to be close to the Deepwater Horizon wellhead. Tell students they are going to investigate this question, using information from a technical journal article and two essays from the Ocean Explorer Web site. Point out that some terms in the article may be unfamiliar, but they should be able to find out what these terms mean through Internet research and/or by reading the essays. Provide each student group with a copy of the *Gulf of Mexico Deep-Sea Ecosystems Inquiry Guide* and the background articles, or instruct students to obtain the latter using links provided in the *Inquiry Guide*.

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

   - A cold seep is a place where hydrocarbons are seeping through the seafloor.
   - Rapid venting of hydrocarbons and brine solutions is associated with muddy features; slow seepage is associated with mineral formation and carbonate rocks.
   - An authigenic carbonate is a limestone rock that is formed where it is found (formed in place), as opposed to being formed elsewhere then transported to another location by geologic processes.
   - Authigenic carbonates are formed when microorganisms consume hydrocarbons under anaerobic conditions, produce bicarbonate which reacts with calcium and magnesium ions in seawater, and precipitates as carbonate rock.
   - Microbial activity is the primary connection between geological processes and cold-seep communities.
   - Microbial mats are the first visually recognizable biological inhabitant of cold seeps.
   - The dominance of mussels and tubeworms at cold seeps in the Gulf of Mexico is the result of symbiosis with chemautotrophic and/or methanotrophic microbes.
   - The habitat provided by mussel beds differ from the habitat provided by bacterial mats in that mussel beds are more three-dimensional and provide grazing surfaces as well as small spaces that provide other organisms with refuge from predators.

- When tubeworm larvae settle near cold seeps, young tubeworms are protected from predators by high concentrations of chemicals that are toxic to many other species.
- Animals are normally scarce in the deep sea below the photic zone because they can only feed on whatever floats down from the surface waters.
- The primary food (energy) source for cold-seep communities is hydrocarbons.
- The primary consumer organisms that are able to use hydrocarbons as an energy source are bacteria.
- Bacteria that utilize hydrocarbons as an energy source are fed upon by small, grazing animals, such as snails and shrimp that are able to withstand high concentrations of methane and sulfide.
- An endemic species is a species that only lives in a particular geographic location.
- Non-endemic species are eventually able to move into cold-seep communities when seepage rates decline and the amounts of toxic chemicals in the environment diminish. It is possible that the "roots" of tubeworms may fill in the cracks in the rock, and this may interfere with chemicals migrating to the sediment surface.
- Tubeworms in chemosynthetic communities may not have many predators because they live in symbiosis with bacteria that use sulfide as an energy source, which may cause the tubeworm to be too toxic for predators to consume.
- Predators use tubeworms as shelter to hide in wait for potential prey.
- When cold-seep communities decline because hydrocarbon seepage has slowed, deepwater corals may colonize hardgrounds once occupied by the cold-seep communities.
- Most of the deep sea floor in the Gulf of Mexico is soft, featureless, muddy sediment.
- Formation of carbonate rocks could lead to the presence of deepwater corals by providing a hard substrate on which coral larvae might attach.

The BRIDGE Connection

www.vims.edu/bridge/ - Click on "Gulf of Mexico" in the "Search" box on the left for resources and links about the Gulf.

The "Me" Connection

Have students write a brief essay discussing whether deep-sea ecosystems or petroleum resources in the Gulf of Mexico are of greater personal importance.

Connections to Other Subjects

Social Studies, English/Language Arts

Assessment

Written answers to *Inquiry Guide* questions and class discussions provide opportunities for assessment.

Extensions

See http://www.education.noaa.gov/Ocean_and_Coasts/Oil_Spill.html for links to multimedia resources, lessons & activities, data, and background information from NOAA's Office of Education.

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html - Click on the links to Lessons 3, 5, 6, and 12 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals, Chemosynthesis and Hydrothermal Vent Life, Deep-Sea Benthos, and Medicine from the Sea.

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

Off Base

(from the *Lophelia* II 2009 Expedition)

http://oceanexplorer.noaa.gov/explorations/09lophelia/background/edu/media/09offbase.pdf

Focus: pH, buffers, and ocean acidification (Life Science/Chemistry)

Students will define pH and buffer, and explain in general terms the carbonate buffer system of seawater; explain Le Chatelier's Principle, predict how the carbonate buffer system of seawater will respond to a change in concentration of hydrogen ions; identify how an increase in atmospheric carbon dioxide might affect the pH of the ocean; and discuss how this alteration in pH might affect biological organisms.

A Tale of Deep Corals
(from the *Lophelia* II 2009 Expedition)
http://oceanexplorer.noaa.gov/explorations/09lophelia/background/edu/media/09tale.pdf

Focus: Deep-sea corals and hydrocarbon seeps (Life Science/Earth Science)

In this activity, students will analyze data on deep-sea corals and evaluate hypotheses to explain why these corals are often found in the vicinity of hydrocarbon seeps.

Cool Corals
(from the Expedition to the Deep Slope 2007)
http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/corals.pdf

Focus: Biology and ecology of *Lophelia* corals (Life Science)

In this activity, students will describe the basic morphology of *Lophelia* corals and explain the significance of these organisms, interpret preliminary observations on the behavior of *Lophelia* polyps, and infer possible explanations for these observations. Students will also discuss why biological communities associated with *Lophelia* corals are the focus of major worldwide conservation efforts.

The Benthic Drugstore
(from the Cayman Islands Twilight Zone 2007 Expedition)
http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/drugstore.pdf

Focus: Pharmacologically-active chemicals derived from marine invertebrates (Life Science/Chemistry)

Students will identify at least three pharmacologically-active chemicals derived from marine invertebrates, describe the disease-fighting action of at least three pharmacologically-active chemicals derived from marine invertebrates, and infer why sessile marine invertebrates appear to be promising sources of new drugs.

Watch the Screen!
(from the Cayman Islands Twilight Zone 2007 Expedition)
http://oceanexplorer.noaa.gov/explorations/07twilightzone/background/edu/media/watchscreen.pdf

Focus: Screening natural products for biological activity (Life Science/Chemistry)

Students will explain and carry out a simple process for screening natural products for biological activity, and will be able to infer why organisms such as sessile marine invertebrates appear to be promising sources of new drugs.

Living in Extreme Environments
(from the 2003 Mountains in the Sea Expedition)
http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_extremeenv.pdf

Focus: Biological Sampling Methods (Biological Science)

In this activity, students will understand the use of four methods commonly used by scientists to sample populations; students will understand how to gather, record, and analyze data from a scientific investigation; students will begin to think about what organisms need in order to survive; students will understand the concept of interdependence of organisms.

Chemosynthesis for the Classroom
(from the 2006 Expedition to the Deep Slope)
http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/gom_06_chemo.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.

This Life Stinks
(from the 2006 Expedition to the Deep Slope)
http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/gom_06_stinks.pdf

Focus: Methane-based chemosynthetic processes (Physical Science)

Students will 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/10lophelia/welcome.html – Web site for the *Lophelia* II 2010: Cold Seeps and Deep Reefs Expedition

http://oceanexplorer.noaa.gov/edu/guide/gomdse_edguide.pdf – *Gulf of Mexico Deep-Sea Ecosystems Education Materials Collection Educators' Guide*

http://oceanexplorer.noaa.gov/edu/development/online_development.html – Online professional development opportunities, including *Lessons from the Deep: Exploring the Gulf of Mexico's Deep-Sea Ecosystems*

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://www.piersystem.com/go/site/2931/ – Main Unified Command Deepwater Horizon response site

http://response.restoration.noaa.gov/deepwaterhorizon – NOAA Web site on Deepwater Horizon Oil Spill Response

http://docs.lib.noaa.gov/noaa_documents/NESDIS/NODC/LISD/Central_Library/current_references/current_references_2010_2.pdf – Resources on Oil Spills, Response, and Restoration: a Selected Bibliography; document from NOAA Central Library to aid those seeking information concerning the Deepwater Horizon oil spill in the Gulf of Mexico and information on previous spills and associated remedial actions; includes media products (Web, video, printed and online documents) selected from resources available via the online NOAA Library and Information Network Catalog (NOAALINC)

http://www.gulfallianceeducation.org/ – Extensive list of publications and other resources from the Gulf of Mexico Alliance; click "Gulf States Information & Contacts for BP Oil Spill" to download the Word document

Fisher, C., H. Roberts, E. Cordes, and B. Bernard. 2007. Cold seeps and associated communities of the Gulf of Mexico. *Oceanography* 20:118-129; available online at http://www.tos.org/oceanography/issues/issue_archive/20_4.html

Kellogg, C. A., 2009, Gulf of Mexico deep-sea coral ecosystem studies, 2008–2011: U.S. Geological Survey Fact Sheet 2009–3094, 4 pp. available at http://pubs.usgs.gov/fs/2009/3094/

Sulak, K. J., M. T. Randall, K. E. Luke, A. D. Norem, and J. M. Miller (Eds.). 2008. Characterization of Northern Gulf of Mexico Deepwater Hard Bottom Communities with Emphasis on *Lophelia* Coral - *Lophelia* Reef Megafaunal Community Structure, Biotopes, Genetics, Microbial Ecology, and Geology. USGS Open-File Report 2008-1148; http://fl.biology.usgs.gov/coastaleco/OFR_2008-1148_MMS_2008-015/index.html

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

- Chemical reactions
- Interactions of energy and matter

Content Standard C: Life Science

- Interdependence of organisms

Content Standard D: Earth and Space Science

- Energy in the earth system
- Geochemical cycles

Content Standard F: Science in Personal and Social Perspectives

- Natural resources
- Environmental quality

- 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 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 4.
The ocean makes Earth habitable.
Fundamental Concept a. Most of the oxygen in the atmosphere originally came from the activities of photosynthetic organisms in the ocean.
Fundamental Concept b. The first life is thought to have started in the ocean. The earliest evidence of life is found in the ocean.

Essential Principle 5.
The ocean supports a great diversity of life and ecosystems.
Fundamental Concept f. Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is "patchy". Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.
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 f. Coastal regions are susceptible to natural hazards (such as tsunamis, hurricanes, cyclones, sea level change, and storm surges).

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:
oceanexeducation@noaa.gov

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Gulf of Mexico
Deep-Sea Ecosystems Inquiry Guide

Your assignment is to investigate a possible connection between deep-sea ecosystems in the Gulf of Mexico and petroleum deposits. The following resources will help you complete this assignment:

- Fisher, C., H. Roberts, E. Cordes, and B. Bernard. 2007. Cold seeps and associated communities of the Gulf of Mexico. *Oceanography* 20:118-129; available online at http://www.tos.org/oceanography/issues/issue_archive/20_4.html;
- Chemosynthetic Communities in the Gulf of Mexico, essay by Erik Cordes (http://oceanexplorer.noaa.gov/explorations/02mexico/background/communities/communities.html); and
- The Ecology of Gulf of Mexico Deep-Sea Hardground Communities ,essay by Erik E. Cordes (http://oceanexplorer.noaa.gov/explorations/06mexico/background/hardgrounds/hardgrounds.html)

Here are some questions to guide your inquiry:

1. What is a cold seep?

2. Hydrocarbons and brine solutions may emerge from the seafloor of the Gulf of Mexico slowly (seeps) or rapidly (vents). What seafloor characteristics are associated with rapid venting? What characteristics are associated with slow seepage?

3. What is an authigenic carbonate?

4. How are authigenic carbonates formed (Hint: What is anaerobic oxidation of methane)?

5. What is the primary connection between geological processes and cold-seep communities?

6. What is the first visually recognizable biological inhabitant of cold seeps?

7. What leads to the dominance of mussels and tubeworms at cold seeps in the Gulf of Mexico?

8. How does the habitat provided by mussel beds differ from the habitat provided by bacterial mats?

9. When tubeworm larvae settle near cold seeps, what protects the young tubeworms from predators?

10. Why are animals normally scarce in the deep sea below the photic zone?

11. What is the primary food (energy) source for cold-seep communities?

12. What primary consumer organisms are able to use this energy source (in other words, what organisms are at the bottom of the food web)?

13. What kind of organisms are able to feed on these primary consumers?

14. What is an endemic species?

15. What allows non-endemic species to eventually move into cold-seep communities?

16. Many predators do not eat tubeworms in chemosynthetic communities. What is a possible explanation for this?

17. Do predators derive any benefit from tubeworms?

18. When hydrocarbon seepage stops, cold-seep communities are deprived of their energy source. What organisms may colonize hardgrounds once the cold-seep communities are gone?

19. Describe the appearance of most of the deep seafloor in the Gulf of Mexico.

20. How could the formation of carbonate rocks lead to the presence of deepwater corals?