Lessons from the Deep:

Exploring the Gulf of Mexico's Deep-Sea Ecosystems

Education Materials Collection

Image captions/credits on Page 2.

lesson plan

A Tale of Deep Corals

(adapted from the *Lophelia* II 2009 Expedition)

Focus

Deep-sea corals and hydrocarbon seeps

Grade Level

9-12 (Life Science/Earth Science)

Focus Question

Why are deep-sea corals frequently found in the vicinity of hydrocarbon seeps?

Learning Objectives

- Students will be able to describe and explain two alternative hypotheses for the frequent occurrence of deep-sea corals in the vicinity of hydrocarbon seeps.
- Students evaluate relevant experimental data, and explain how these data may support or refute these hypotheses.
- Students will define and contrast coincidence and causality, and will explain the relevance of these terms to hypotheses such as those related to deep-sea corals and hydrocarbon seeps.

Materials

- Copies of *Deep Corals and Hydrocarbons Inquiry Guide*; one copy for each student group

Audio/Visual Materials

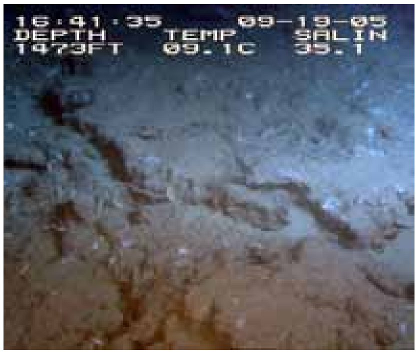
- None

Teaching Time

One or two 45-minute class periods, plus time for student inquiry

Seating Arrangement

Groups of 2-4 students



Areas of active, if subdued, hydrocarbon seeps are notably devoid of large sessile invertebrates. A fluffy gray biofilm coats the underlying rock, dotted with small white patches of the cold-seep-associated bacteria *Beggatoia*. Image courtesy Ken Sulak USGS 2004-2006 *Lophelia* program Chief Scientist.
http://fl.biology.usgs.gov/images/pictures/CHEMO_SEEP_BIOTOPE.jpg

This group of very old tubeworms (*Lamellibrachia luymesi* and *Seepiophila jonesi*) live on the same piece of carbonate rock as large colonies of the gorgonian *Callogorgia Americana*. Note the brittle stars and a galatheid crab crawling on the gorgonians. Image courtesy Derk Bergquist.
http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/signature_600.html

Images from Page 1 top to bottom:

A close-up mussel aggregation with *Chirodota heheva* sea cucumbers. Image courtesy of Expedition to the Deep Slope 2007.
http://oceanexplorer.noaa.gov/explorations/07mexico/logs/july3/media/cuke_600.html

A CTD rosette being recovered at the end of a cast. Note that the stoppers on the sample bottles are all closed. Image courtesy of INSPIRE: Chile Margin 2010.
http://oceanexplorer.noaa.gov/explorations/10chile/logs/summary/media/2summary.html

A methane hydrate mound on the seafloor; bubbles show that methane is continuously leaking out of features like this. If bottom waters warmed, this entire feature may be destabilized and leak methane at a higher rate.
http://oceanexplorer.noaa.gov/explorations/10chile/background/methane/media/methane4.html

Lophelia pertusa create habitat for a number of other species at a site in Green Canyon. Image courtesy of Chuck Fisher.
http://oceanexplorer.noaa.gov/explorations/08lophelia/logs/sept24/media/green_canyon_lophelia.html

Maximum Number of Students

32

Key Words

Gulf of Mexico
Deep-sea coral
Lophelia
Cold seep

Background Information

Deepwater ecosystems in the Gulf of Mexico are often associated with rocky substrates or "hardgrounds." Most of these hard bottom areas are found in locations called cold seeps where hydrocarbons are seeping through the seafloor. Microorganisms are the connection between hardgrounds and cold seeps. When microorganisms consume hydrocarbons under anaerobic conditions, they produce bicarbonate which reacts with calcium and magnesium ions in the water and precipitates as carbonate rock. Two types of ecosystems are typically associated with deepwater hardgrounds in the Gulf of Mexico: chemosynthetic communities and deep-sea coral communities. Hydrocarbon seeps may indicate the presence of undiscovered petroleum deposits, so the presence of these ecosystems may indicate potential sites for exploratory drilling and possible development of offshore oil wells. At the same time, these are unique ecosystems whose full importance is presently unknown.

Deepwater coral reefs were discovered in the Gulf of Mexico nearly 50 years ago, but very little is known about the ecology of these communities or the basic biology of the corals that produce them. These corals are usually found on hardbottom areas where there are strong currents and little suspended sediment (but extremely strong currents may interfere with feeding and cause breakage). *Lophelia pertusa*, the best-known deepwater coral species, prefers water temperatures between 4-12 °C, dissolved oxygen concentrations above 3 ml/l, and salinity between 35 and 37 ppt. The influence of other factors, including pH, is not known. Recent studies suggest that deepwater reef ecosystems may have a diversity of species comparable to that of corals reefs in shallow waters, and have found deepwater coral species on continental margins worldwide. One of the most conspicuous differences between shallow- and deepwater corals is that most shallow-water species have symbiotic algae (zooxanthellae) living inside the coral tissue, and these algae play an important part in reef-building and biological productivity. Deepwater corals do not contain symbiotic algae (so these corals are termed "azooxanthellate"). Yet, there are just as many species of deepwater corals (slightly more,

Viosca Knoll is an elevated salt dome with dormant and active cold seeps. Where hydrocarbons are actively escaping from the substrate, dense clusters of tightly entwined vestimentiferan tubeworms grow. As the submersible approaches, it disturbs a blackbelly rosefish (*Helicolenus dactylopterus*), and a conger eel (*Conger oceanicus*). Image courtesy Ken Sulak USGS 2004-2006 *Lophelia* program Chief Scientist.
http://fl.biology.usgs.gov/images/pictures/CHEMO_TUBE-WORM_BUSH.jpg

These methane mussels (*Bathymodiolus childressi*) live at the edge of Brine Pool NR1 at 650 m depth in the Gulf of Mexico. The pool of brine in the foreground is nearly four times as salty as seawater and is so dense that the submersible can float on the pool to take pictures such as this. Image courtesy Stephane Hourdez.
http://oceanexplorer.noaa.gov/explorations/06mexico/background/plan/media/mussels_600.html

Lophelia pertusa coral, with opened polyps, attached to an authigenic carbonate rock. Seep-dependent tubeworms are visible behind the coral. Image courtesy of, *Lophelia* II 2009: Deepwater Coral Expedition: Reefs, Rigs and Wrecks.
http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/aug25/media/lophelia_insitu_.html

in fact) as there are species of shallow-water corals. Sulak, *et al.* (2008) provides extensive information on deepwater hard bottom coral communities at Viosca Knoll in the Northern Gulf of Mexico, including illustrations of fishes, benthic invertebrates, and typical biotopes associated with these communities.

The major deepwater structure-building corals belong to the genus *Lophelia*, but other organisms contribute to the framework as well, including antipatharians (black corals), gorgonians (sea fans and sea whips), alcyonaceans (soft corals), anemones, and sponges. While these organisms are capable of building substantial reefs, they are also quite fragile, and there is increasing concern that deepwater reefs and their associated resources may be in serious danger. Many investigations have reported large-scale damage due to commercial fishing trawlers, and there is also concern about impacts that might result from exploration and extraction of fossil fuels. These impacts are especially likely in the Gulf of Mexico, since the carbonate foundation for many deepwater reefs is strongly associated with the presence of hydrocarbons. Potential impacts include directly toxic effects of hydrocarbons on reef organisms, as well as effects from particulate materials produced by drilling operations. Since many deepwater reef organisms are filter feeders, increased particulates could clog their filter apparatus and possibly smother bottom-dwelling organisms.

Why are deepwater coral reefs in the Gulf of Mexico so often associated with hydrocarbon seeps? This lesson guides a student inquiry into hypotheses related to this question and recent data that may support or refute these hypotheses.

Learning Procedure

[Note: This inquiry was suggested by "Deep Sea Corals and Methane Seeps," a Web essay written buy Kevin Zelnio; http://deepseanews.com/2009/07/seeps-lophelia-carbonate-2/]

1.To prepare for this lesson:

(a) Review the following essays:

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

The Ecology of Gulf of Mexico Deep-Sea Hardground Communities (http://oceanexplorer.noaa.gov/explorations/06mexico/background/hardgrounds/hardgrounds.html).

Geological Setting (http://oceanexplorer.noaa.gov/explorations/02mexico/background/geology/geology.html)

(b) You may also want to review the following visual resources and consider presenting some of these to your students:

- Image collections from Sulak, *et al.* (2008). Master Appendix D of this large report contains many images of deep-water coral communities. Download the PDF files "Master Appendix D - Megafaunal Invertebrates of Viosca Knoll, *Lophelia* Community Investigation," and "Key to Plates in Master Appendix D" from http://fl.biology.usgs.gov/coastaleco/OFR_2008-1148_MMS_2008-015/index.html

- Video showing some of the extraordinary biological diversity of the Gulf of Mexico (http://oceanexplorer.noaa.gov/explorations/03mex/logs/summary/media/ngom_biodiversity_cm3.html)

- Videos of deepwater corals and coral communities (http://oceanexplorer.noaa.gov/explorations/09lophelia/logs/photolog/photolog.html)

- Virtual tour of a cold-seep community (http://www.bio.psu.edu/cold_seeps)

- Slideshow of highlights from Expedition to the Deep Slope 2006 (http://oceanexplorer.noaa.gov/explorations/06mexico/background/media/slideshow/slideshow.html)

- Slideshow of images from the Expedition to the Deep Slope 2007 (http://oceanexplorer.noaa.gov/explorations/07mexico/logs/summary/media/slideshow/html_slideshow.html)

(c) Review procedures and questions on the *Deep Corals and Hydrocarbons Inquiry Guide*, and make copies for student groups.

2. Lead a discussion of deep-sea coral communities in the Gulf of Mexico. Tell students that while deepwater coral reefs were discovered in the Gulf nearly 50 years ago, very little is known about the ecology of these communities or the basic biology of the corals that produce them. Emphasize that a primary purpose of the *Lophelia* II 2009 Expedition was to provide information needed to protect these deepwater coral ecosystems from negative impacts associated with exploration and extraction of fossil fuels. Explain that one of the most important types of information is the exact location of these ecosystems, so that these sites can be avoided when exploring for fossil fuel resources. Point out that avoiding deep-sea reefs might be difficult, since these reefs are often found near hydrocarbons seeping out of the seafloor.

3. Tell students that their assignment is to investigate possible reasons for the apparent association between deep-sea corals reefs and hydrocarbon seeps. Provide each student group with a copy of the *Deep Corals and Hydrocarbons Inquiry Guide*. Be sure students understand that this inquiry extends beyond the information included in the two abstracts, so they should not expect to find answers to all of the questions (such as definitions) in those documents; but the answers can easily be found by searching keywords on the Web.

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

A. Hypothesis and Background

- A carbonate reef is a rock formation composed of limestone from the skeletal remains of marine plants and animals.

- A bioherm is a mass of rock that results from the growth of marine organisms such as corals.

- The primary energy source for deep-ocean vent communities is hydrogen sulfide, which is abundant in water erupting from hydrothermal vents and is used by chemosynthetic bacteria that are the base of the vent community food chain.

- Hovland hypothesized that seeping hydrocarbon fluids provide an energy source for bacteria and other microorganisms, which in turn provide a source of energy and carbon for deep-sea reef ecosystems.

- Deep-ocean vent communities and deep-water coral reefs need a source of energy and carbon that is independent of photosynthesis because photosynthesis requires sunlight, but sunlight does not penetrate to the depths where these communities are found.

- Corals such as *Lophelia pertusa* are filter feeders and obtain food from suspended particles (living and non-living) in the surrounding seawater. If Hovland's model is correct, these corals would potentially benefit from the abundance of bacteria and other suspended organisms that obtain energy from seeping hydrocarbon fluids.

B. Research

- Local trophic interactions means feeding relationships between species in a confined area such as a reef community.

- Seep signature refers to the a stable isotope composition that is characteristic of hydrocarbon seeps.

- No temporal trend detected in the skeleton isotope values means that different parts of the coral skeleton had the same isotope composition, and since different parts of the coral skeleton are formed at different times as the coral grows, this implies that isotope composition does not change over time.

- A vestimentiferan is a marine tubeworm found in deep-sea hydrothermal vent or cold-seep communities.

- The research showed that vestimentiferans become less dependent upon seep primary production as they grow older.

- Authigenic refers to a rock or mineral that was formed in the same location where it is found. So, authigenic carbonate substrata means limestone rocks that were formed where they are found.

C. Analysis

- The research results reported by Becker *et al.* do not support Hovland's hypothesis, since they do not suggest that the food chain of corals includes organisms that obtain energy from seeping hydrocarbon fluids.

- Becker *et al.* say their data suggest that *L. pertusa* is found in the vicinity of hydrocarbon seeps because of the presence of limestone substrates resulting from microorganisms that used the seeps as an energy source at some time in the past. Through their Web inquiries, students may have learned that when microorganisms consume hydrocarbons under anaerobic conditions, they produce bicarbonate which reacts with calcium and magnesium ions in the water and precipitates as carbonate rock. This rock, in turn, may provide a substrate where larvae of many other bottom-dwelling organisms may attach, including the larvae of *L. pertusa.*

- Correlation means that two events occur at the same time or in the same place. Causality means that one event causes another event to happen or increases the likelihood that another event will happen.

- Hovland observed that the presence of *L. pertusa* was correlated with the presence of hydrocarbon seeps, and suggested a causality mechanism through which hydrocarbon seeps would make the presence of *L. pertusa* more likely. Becker *et al.* presented evidence that supports a different causality mechanism that is consistent with the same correlation observed by Hovland.

- The research results reported by Becker *et al.* do not prove that Hovland's hypothesis is wrong. These results suggest that Hovland's hypothesis is not consistent with evidence from the Gulf of Mexico; it might be entirely correct in other locations, but there are no data to support that possibility.

  In fact, scientists almost never claim to prove or disprove a hypothesis, because such statements imply that every possible case has been investigated. Instead, scientists refer to probabilities that hypotheses are correct or incorrect. If there is no experimental evidence for or against a hypothesis, there is no way to measure these probabilities. But if the results of repeated experiments are not consistent with a hypothesis, it is less and less likely that the hypothesis is correct.

The Bridge Connection

www.vims.edu/bridge/ – Click on "Ocean Science" in the navigation menu to the left, then "Habitats," then "Deep Sea" for resources on deep-sea communities.

The "Me" Connection

Have students write a brief essay describing how deep-sea coral communities might be of personal importance.

Connections to Other Subjects

English/Language Arts, Earth Science

Assessment

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

Extensions

See the "Resources" section of *Lessons from the Deep: Exploring the Gulf of Mexico's Deep-sea Ecosystem Education Materials Collection Educators Guide* for additional information, activities, and media resources about deepwater ecosystems in the Gulf of Mexico.

Multimedia Discovery Missions

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

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

From the Gulf of Mexico to the Moons of Jupiter (6 pages, 207 KB)

http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_moons.pdf

Focus - Adaptations to unique or "extreme" environments (Earth Science)

In this activity, students will be able to explain the process of chemosynthesis, explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps, and will be able to compare physical conditions in deep-sea "extreme" environments to conditions thought to exist on selected moons of Jupiter. Students will also discuss the relevance of chemosynthetic processes in cold seep communities to the possibility of life on other planetary bodies.

Biochemistry Detectives (8 pages, 480 K)

http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_biochem.pdf

Focus - Biochemical clues to energy-obtaining strategies (Chemistry)

In this activity, students will be able to explain the process of chemosynthesis, explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps, and describe three energy-obtaining strategies used by organisms in cold-seep communities. Students will also be able to interpret analyses of enzyme activity and ^{13}C isotope values to draw inferences about energy-obtaining strategies used by organisms in cold-seep communities.

This Old Tubeworm (10 pages, 484 KB)

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

Focus - Growth rate and age of species in cold-seep communities (Life Science)

In this activity, students will be able to explain the process of chemosynthesis, explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps, and construct a graphic interpretation of age-specific growth, given data on incremental growth rates of different-sized individuals *of the same species. Students will also be able to estimate the age of an individual of a specific size, given information on age specific growth in individuals of the same species.*

C.S.I. on the Deep Reef (Chemotrophic Species Investigations, That Is) (6 pages, 444 KB)

http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/gom_06_csi.pdf

Focus: Chemotrophic organisms (Life Science/Chemistry)

In this activity, students will describe at least three chemotrophic symbioses known from deep-sea habitats and will identify and explain at least three indicators of chemotrophic nutrition.

Gellin (4 pages, 372 KB)

http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_gellin.pdf

Focus - DNA analysis (Life Science)

In this activity, students will explain and carry out a simple process for separating DNA from tissue samples, explain and carry out a simple process for separating complex mixtures, and explain the process of restriction enzyme analysis.

Hot Food (4 pages, 372 KB)

http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_hotfood.pdf

Focus - Energy content of hydrocarbon substrates in chemosynthesis (Chemistry)

In this activity, students will compare and contrast photosynthesis and chemosynthesis as processes that provide energy to biological communities, and given information on the molecular structure of two or more substances, will make inferences about the relative amount of energy that could be provided by the substances. Students will also be able to make inferences about the potential of light hydrocarbons as an energy source for deep-water coral reef communities.

How Does Your (Coral) Garden Grow? (6 pages, 456 KB)

http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_growth.pdf

Focus - Growth rate estimates based on isotope ratios (Life Science/Chemistry)

In this activity, students will identify and briefly explain two methods for estimating the age of hard corals, learn how oxygen isotope ratios are related to water temperature, and interpret data on oxygen isotope ratios to make inferences about the growth rate of deep-sea corals.

What's the Difference? (20 pages, 300 kb)
http://oceanexplorer.noaa.gov/explorations/08lophelia/background/edu/media/difference.pdf
Focus - Identification of biological communities from survey data (Life Science)
In this activity, students will be able to calculate a simple similarity coefficient based upon data from biological surveys of different areas, describe similarities between groups of organisms using a dendrogram, and infer conditions that may influence biological communities given information about the groupings of organisms that are found in these communities.

The Big Burp: Where's the Proof? (5 pages, 364 KB)
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.

Other Links and 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/ – Ocean Explorer Web site

Roberts, S. and M. Hirshfield. Deep Sea Corals: Out of sight but no longer out of mind. http://diffeomorphism.com/~carrie/courses/BIOL_309/deepseacorals.pdf

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

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

http://www.netl.doe.gov/technologies/oil-gas/FutureSupply/MethaneHydrates/maincontent.htm – Web site for the National Methane Hydrate Research and Development Program

http://marine.usgs.gov/fact-sheets/gas-hydrates/title.html – Gas (Methane) Hydrates—A New Frontier; Web page from the U.S. Geological Survey's Marine and Coastal Geology Program

Van Dover, C.L., P. Aharon, J.M. Bernhard, E. Caylord, M. Doerriesa, W. Flickinger, W. Gilhooly, S.K. Goffredi, K.E. Knick, S.A. Macko, S. Rapoport, E.C. Raulfs, C. Ruppel, J.L. Salerno, R.D. Seitz, B.K. Sen Gupta, T. Shank, M. Turnipseed, R. Vrijenhoek. 2003. Blake Ridge methane seeps: characterization of a soft-sediment, chemosynthetically-based ecosystem. Deep-Sea Research Part I 50:281–300. (Available as a PDF file at http://www.mbari.org/staff/vrijen/PDFS/VanDover_2003DSR.pdf)

MacDonald, I. and S. Joye. 1997. Lair of the "Ice Worm." Quarterdeck 5(3); http://www-ocean.tamu.edu/Quarterdeck/QD5.3/macdonald.html; article on cold-seep communities and ice worms

Siegel, L. J. 2001. Café Methane. http://nai.arc.nasa.gov/news_stories/news_detail.cfm?ID=86; article on cold-seep communities and ice worms from NASA's Astrobiology Institute

Kirschvink, J. L. and T. D. Raub. 2003. A methane fuse for the Cambrian explosion: carbon cycles and true polar wander. Comptes Rendus Geoscience 335:65-78. Journal article on the possible role of methane release in rapid diversification of animal groups. Also available on-line at http://www.gps.caltech.edu/users/jkirschvink/pdfs/KirschvinkRaubComptesRendus.pdf

Simpson, S. 2000. Methane fever. *Scientific American* (Feb. 2000) pp 24-27. Article about role of methane release in the Paleocene extinction event

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 disaster 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

http://rucool.marine.rutgers.edu/deepwater/ – Deepwater Horizon Oil Spill Portal from the Integrated Ocean Observing System at Rutgers University

http://www.darrp.noaa.gov/southeast/deepwater_horizon/ index.html – Information about damage assessments being conducted by NOAA's Damage Assessment Remediation and Restoration Program

http://response.restoration.noaa.gov/ – Click "Students and Teachers" in the column on the left for information, fact sheets, and activities about oil emergencies, habitats, and other ocean issues

http://www.noaa.gov/sciencemissions/bpoilspill.html – Web page with links to NOAA Science Missions & Data relevant to the Deepwater Horizon/BP Oil Spill

http://ecowatch.ncddc.noaa.gov/jag/data.html – Data Links page on the Deepwater Horizon Oil Spill Joint Analysis Group Web site

http://ecowatch.ncddc.noaa.gov/jag/reports.html – Reports page on the Deepwater Horizon Oil Spill Joint Analysis Group Web site

http://www.education.noaa.gov/Ocean_and_Coasts/Oil_Spill.html - "Gulf Oil Spill" Web page from NOAA Office of Education with links to multimedia resources, lessons & activities, data, and background information

http://www.geoplatform.gov/gulfresponse/ - Web page for GeoPlatform.gov/gulfresponse—an online map-based tool developed by NOAA with the EPA, U.S. Coast Guard, and the

Department of Interior to provide a "one-stop shop" for spill response information; includes oil spill trajectory, fishery area closures, wildlife data, locations of oiled shoreline and positions of deployed research ships

National Science Education Standards

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard B: Physical Science

- Chemical reactions

Content Standard C: Life Science

- Interdependence of organisms
- Matter, energy, and organization in living systems

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

Content Standard G: History and Nature of Science

- Science as a human endeavor
- Nature of scientific knowledge

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 5.
The ocean supports a great diversity of life and ecosystems.

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 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 g. Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustainthe 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 e-mail 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

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Deep Corals and Hydrocarbons Inquiry Guide

Most of us have seen colorful pictures of coral reefs found in shallow tropical waters around the world, and are aware of the impressive variety of species that inhabit these ecosystems. Deep-sea coral reefs are much less well-known, even though they are found on continental margins worldwide and may have a diversity of species comparable to that of corals reefs in shallow waters. Deepwater reefs can be quite large, but they are also very fragile and there is increasing concern that these reefs and their associated resources may be in serious danger. Many investigations have reported large-scale damage due to commercial fishing trawlers, and there is also concern about impacts that might result from exploration and extraction of fossil fuels. These impacts are especially likely in locations such as the Gulf of Mexico, where deepwater reefs are often found in locations where hydrocarbons are close to the surface of the sea floor.

What is the reason for the apparent association of deepwater reefs and hydrocarbons? Is this just coincidence, or is it something else? Your task is to examine two hypotheses about this relationship, consider some of the evidence provided by deep-sea researchers, and decide whether the evidence supports or refutes the hypotheses. The hypotheses can be found on page 19 of this lesson.

A. Hypothesis and Background

Read the abstract by Hovland (1989), and answer the following questions (Note: The abstracts do not contain answers to all of the questions, but you can easily find these answers by searching keywords on the Web):

1. What is a carbonate reef?

2. What is a bioherm?

3. Hovland mentions that his "new model for carbonate reef formation" is based on ecological studies at deep-ocean vent communities. What is the primary energy source for deep-ocean vent communities?

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4. According to the model suggested by Hovland, how do seeping hydrocarbon fluids contribute to the growth of deepwater reefs?

5. Why do deep-ocean vent communities and deepwater coral reefs need a source of energy and carbon that is independent of photosynthesis?

6. How do corals such as *Lophelia pertusa* (the major reef-building deepwater coral) obtain energy (food) ? If Hovland's model is correct, what benefit would these corals obtain from seeping hydrocarbon fluids?

B. Research

So, how could we test Hovland's hypothesis? One possibility is a technique known as stable isotope analysis. Recall that isotopes are forms of an element that have different numbers of neutrons. For example, carbon-13 (^{13}C) contains one more neutron than carbon-12 (^{12}C). Both forms occur naturally, but carbon-12 is more common. Lighter isotopes tend to be metabolized more readily, so the ratio of heavy to light isotopes changes due to metabolic processes. Different food sources have characteristic ratios of stable isotopes of carbon, nitrogen, and sulfur, and these ratios can be used as an indicator of the type of food source, as well as an organism's position in a food web. For additional discussion of stable isotope analysis, see "Who Is Eating Whom?" an article by Erin Becker written for the 2007 Expedition to the Deep Slope which explored deep-sea coral reefs in the Gulf of Mexico (http://oceanexplorer.noaa.gov/explorations/07mexico/logs/june15/june15.html).

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In 2009, Erin Becker and three of her colleagues published the results of research in which they used stable isotope analysis to look for evidence that *Lophelia pertusa* corals eat organisms that feed on hydrocarbons. Read the abstract of their paper to find out what they learned.

1. What are local trophic interactions?

2. What is a seep signature?

3. What does "no temporal trend detected in the skeleton isotope values" mean?

4. What is a vestimentiferan?

5. What did the research show about the relationship between seep primary production and vestimentiferans?

6. What is authigenic carbonate substrata?

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C. Analysis

1. Do the research results reported by Erin Becker and her colleagues support Hovland's hypothesis?

2. According to Becker et al., what do their data suggest about the reasons for the presence of *L. pertusa* in the vicinity of hydrocarbon seeps?

3. What is the difference between correlation and causality?

4. How do the terms correlation and causality apply to Hovland's hypothesis and the results reported by Becker *et al.*?

5. Do the research results reported by Erin Becker and her colleagues prove that Hovland's hypothesis is wrong? Why?

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Abstract #1

Do carbonate reefs form due to fluid seepage?

Martin Hovland (1989)
Abstract from *Terra Nova*, Vol 2(1), pp 8 - 18

Buried carbonate reefs are favoured hydrocarbon prospecting targets, mainly due to their high porosity and potential for containing large quantities of petroleum. The question of the true relationship between reef structure and the internally trapped fluids (hydrocarbons) is here raised as one of cause and effect. In other words, which came first, the hydrocarbons or the carbonate reef itself?

Modern bioherms and seabed carbonate reefs in, amongst other locations, the North Sea and the Gulf of Mexico, are shown to form in close association with active hydrocarbon seepages. Mainly based on results from ecological studies at deep-ocean vent communities, a new model for carbonate reef formation is promoted: that such reefs form at locations containing high concentrations of bacteria and other microorganisms suspended in the water column as a result of seeping fluids (solutions and gases) that provide some of the energy basis and carbon source for ecosystems independently of photosynthesis. Therefore, on burial and effective sealing ('capping'), these carbonate reefs become hydrocarbon reservoirs, trapping and accumulating the very minerals on which they—in the first place—were dependent.

Abstract #2

Importance of seep primary production to *Lophelia pertusa* and associated fauna in the Gulf of Mexico

Erin L. Becker, Erik E. Cordes, Stephen A. Macko, and Charles R. Fisher (2009)
Abstract from *Deep Sea Research* Part I: Oceanographic Research Papers
Vol 56(5), pp 786-800

To investigate the importance of seep primary production to the nutrition of *Lophelia pertusa* and associated communities and examine local trophic interactions, we analyzed stable carbon, nitrogen, and sulfur compositions in seven quantitative *L. pertusa* community collections. A significant seep signature was only detected in one of the 35 species tested (*Provanna sculpta*, a common seep gastropod) despite the presence of seep fauna at the three sample sites. A potential predator of *L. pertusa* was identified (*Coralliophila* sp.), and a variety of other trophic interactions among the fauna occupying the coral framework were suggested by the data, including the galatheid crab *Munidopsis* sp. 2 feeding upon hydroids and the polychaete *Eunice* sp. feeding upon the sabellid polychaete *Euratella* sp. Stable carbon abundances were also determined for different sections of *L. pertusa* skeleton representing different stages in the growth and life of the aggregation. There was no temporal trend detected in the skeleton isotope values, suggesting that *L. pertusa* settles in these areas only after seepage has largely subsided. Isotope values of individual taxa that were collected from both *L. pertusa* and vestimentiferan habitats showed decreasing reliance upon seep primary production with average age of the vestimentiferan aggregation, and finally, no seep signature was detected in the coral collections. Together our data suggest that it is the presence of authigenic carbonate substrata, a product of past seep microbial activity, as well as hydrodynamic processes that drive *L. pertusa* occurrence at seep sites in the Gulf of Mexico, not nutritional dependence upon primary production by seep microbes.