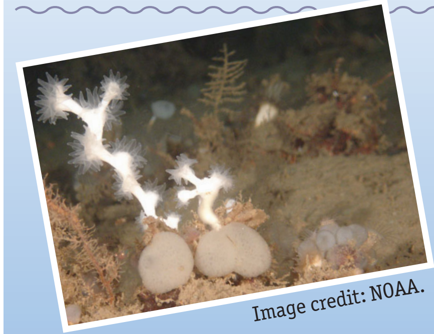
Lophelia II 2009:
Deepwater Coral Expedition: Reefs Rigs, and Wrecks

A Tale of Deep Corals



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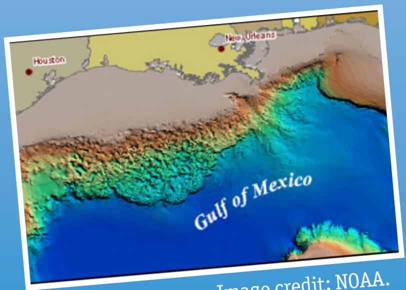

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Image captions on Page 2.

lesson plan

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 will be able to 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 two to four students

Maximum Number of Students
32

Key Words

Bioherm
Deep-sea coral
Lophelia
Hydrocarbon seep

Background Information

Deepwater coral ecosystems on hard substrates in the Gulf of Mexico are often found in locations where hydrocarbons are seeping through the seafloor. Hydrocarbon seeps may indicate the presence of undiscovered petroleum deposits, and make these locations potential sites for exploratory drilling and possible development of offshore oil wells. Responsibility for managing exploration and development of mineral resources on the Nation's outer continental shelf is a central mission of the U.S. Department of the Interior's Minerals Management Service (MMS). Besides managing the revenues from mineral resources, an integral part of this mission is to protect unique and sensitive environments where these resources are found.

For the past three years, NOAA's Office of Ocean Exploration and Research (OER) has collaborated with MMS on a series of expeditions to locate and explore deep-sea chemosynthetic communities in the Gulf of Mexico. These communities not only indicate the potential presence of hydrocarbons, but are also unique ecosystems whose importance is presently unknown. To protect these ecosystems from negative impacts associated with exploration and extraction of fossil fuels, MMS has developed rules that require the oil and gas industry to avoid any areas where geophysical survey data show that high-density chemosynthetic communities are likely to occur. Similar rules have been adopted to protect archeological sites and historic shipwrecks.

OER-sponsored expeditions in 2006, 2007, and 2008 were focused on discovering seafloor communities near seeping hydrocarbons on hard bottom in the deep Gulf of Mexico; detailed sampling and mapping at selected sites; studying relationships between coral communities on artificial and natural substrates; and gaining a better understanding of processes that control the occurrence and distribution of these communities. The *Lophelia* II 2009: Deepwater Coral Expedition: Reefs, Rigs, and Wrecks will take place aboard the NOAA Ship *Ronald H. Brown*, and is directed toward exploring deepwater natural and artificial hard bottom habitats in the northern Gulf of Mexico with emphasis on coral communities, as well as archeological studies of selected shipwrecks in the same region. Expedition scientists will:

- Make collections of *Lophelia*, other corals, and associated organisms from deepwater reefs;
- Collect quantitative digital imagery of characterization of deepwater reef sites and communities;

Images from Page 1 top to bottom:
Lophelia pertusa colony with polyps extended.
http://oceanexplorer.noaa.gov/explorations/08lophelia/logs/sept24/media/green_canyon_lophelia.html

The ROV from SeaView Systems, Inc., is prepared for launch.
http://oceanexplorer.noaa.gov/explorations/08lophelia/logs/sept20/media/rov_prep.html

Multibeam bathymetry allows terrain models to be created for large areas of the seafloor.
http://oceanexplorer.noaa.gov/explorations/08lophelia/logs/sept21/media/gomex_multibeam.html

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

- Conduct archeological/biological investigations on deep water shipwrecks.
- Deploy instruments to measure currents and sedimentation in several sites for a period of approximately one year.

Although deep-sea coral reefs are frequently associated with the presence of hydrocarbons, the reasons for this association are not clear. 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:
- Review introductory essays for the *Lophelia* II 2009: Deepwater Coral Expedition: Reefs, Rigs, and Wrecks at http://oceanexplorer.noaa.gov/explorations/09lophelia/welcome.html;
- Review procedures and questions on the *Deep Corals and Hydrocarbons Inquiry Guide*, and make copies for student groups.

2. Briefly introduce the *Lophelia* II 2009: Deepwater Coral Expedition: Reefs, Rigs, and Wrecks and describe deepwater coral communities. You may want to show images from http://oceanexplorer.noaa.gov/gallery/livingocean/livingocean_coral.html. Tell students that while deepwater coral reefs were discovered in the Gulf of Mexico 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 this expedition is to provide information needed to protect these deepwater coral ecosystems from negative impacts associated with exploration and extraction of fossil fuels. Say 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 sea floor.

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

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

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

3. 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.

4. 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.

5. 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.

6. 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

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

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

3. 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.

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

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

6. 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

1. 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.

2. 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 micro-organisms 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*.

3. 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.

4. 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.

5. 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

http://www.vims.edu/bridge/ – Scroll over "Ocean Science Topics," then "Habitats," then "Deep Sea" for links to resources and activities related to chemosynthetic communities in the deep ocean.

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

Follow daily events of the *Lophelia* II 2009: Deepwater Coral Expedition: Reefs, Rigs, and Wrecks at http://oceanexplorer.noaa.gov/explorations/09lophelia/welcome.html.

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

What's the Difference?
(PDF, 300 kb) (from the *Lophelia* II 2008 Expedition)
http://oceanexplorer.noaa.gov/explorations/08lophelia/background/edu/media/difference.pdf

Focus: Identification of biological communities from survey data (Life Science)

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.

My Wet Robot
(300kb) (from the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition)
http://oceanexplorer.noaa.gov/explorations/08bonaire/background/edu/media/wetrobot.pdf

Focus: Underwater Robotic Vehicles

In this activity, students will be able to discuss the advantages and disadvantages of using underwater robots in scientific explorations, identify key design requirements for a robotic vehicle that is capable of carrying out specific exploration tasks, describe practical approaches to meet identified design requirements, and (optionally) construct a robotic vehicle capable of carrying out an assigned task.

The Big Burp: Where's the Proof?
(5 pages, 364k) (from the Expedition to the Deep Slope 2007)
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.

What's the Big Deal?
(5 pages, 364k) (from the Expedition to the Deep Slope 2007)
http://oceanexplorer.noaa.gov/explorations/07mexico/background/edu/media/deal.pdf

Focus: Significance of methane hydrates (Life Science)

Students will be able to define methane hydrates and describe where these substances are typically found and how they are believed to be formed. Students will also describe at least three ways in which methane hydrates could have a direct impact on their own lives, and describe how additional knowledge of methane hydrates expected from the Blake Ridge expedition could provide human benefits.

Cool Corals
(7 pages, 476k) (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.

This Old Tubeworm
(10 pages, 484k) (from the Expedition to the Deep Slope 2007)
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/Mathematics)

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.

The Benthic Drugstore
(8 pages; 278kb PDF) (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 be able to 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!
(8 pages; 278kb PDF) (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)

In this activity, students will be able to 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.

Biochemistry Detectives
(8 pages, 480k) (from the 2002 Gulf of Mexico Expedition)
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.

Hot Food
(4 pages, 372k) (from the 2003 Gulf of Mexico Deep Sea Habitats Expedition)
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 deepwater coral reef communities.

What Was for Dinner?
(5 pages, 400k) (from the 2003 Life on the Edge Expedition)
http://oceanexplorer.noaa.gov/explorations/03edge/background/edu/media/dinner.pdf
Focus: Use of isotopes to help define trophic relationships (Life Science)

In this activity, students will describe at least three energy-obtaining strategies used by organisms in deep-reef communities and interpret analyses of ^{15}N, ^{13}C, and ^{34}S isotope values.

Chemosynthesis for the Classroom
(9 pages, 276k) (from the 2006 Expedition to the Deep Slope)
http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/GOM%2006%20Chemo.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.

C.S.I. on the Deep Reef
(Chemotrophic Species Investigations, That Is)
(11 pages, 280k) (from the 2006 Expedition to the Deep Slope)
http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/GOM%2006%20CSI.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.

This Life Stinks
(9 pages, 280k) (from the 2006 Expedition to the Deep Slope)
http://oceanexplorer.noaa.gov/explorations/06mexico/background/edu/GOM%2006%20Stinks.pdf

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 – Web site for NOAA's Ocean Exploration Program

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.gomr.mms.gov/index_common.html - Minerals Management Service Web site

http://www.gomr.mms.gov/homepg/lagniapp/chemcomp.pdf (PDF) - "Chemosynthetic Communities in the Gulf of Mexico" teaching guide to accompany a poster with the same title, introducing the topic of chemosynthetic communities and other ecological concepts to middle and high school students

http://www.gomr.mms.gov/homepg/lagniapp/lagniapp.html - Kids Page on the Minerals Management Service Web site, with posters, teaching guides and other resources on various marine science topics

http://www.coast-nopp.org/ - Resource Guide from the Consortium for Oceanographic Activities for Students and Teachers, containing modules, guides, and lesson plans covering topics related to oceanography and coastal processes

http://cosee-central-gom.org/ - Web site for The Center for Ocean Sciences Education Excellence: Central Gulf of Mexico (COSEE-CGOM)

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

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 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

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Acknowledgements

This lesson plan was produced by Mel Goodwin, PhD, The Harmony Project, Charleston, SC for the National Oceanic and Atmospheric Administration. If reproducing this lesson, please cite NOAA as the source, and provide the following URL: http://oceanexplorer.noaa.gov

A Tale of Deep Corals

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 18 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?

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2. What is a bioherm?

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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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A Tale of Deep Corals

Deep Corals and Hydrocarbons Inquiry Guide - continued

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

5. Why do deep-ocean vent communities and deep-water 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 deep-water 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 organisms 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).

A Tale of Deep Corals

Deep Corals and Hydrocarbons Inquiry Guide – continued

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?

A Tale of Deep Corals

Deep Corals and Hydrocarbons Inquiry Guide – continued

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?

A Tale of Deep Corals

Deep Corals and Hydrocarbons Inquiry Guide

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.