2006 Gulf of Mexico Expedition

CSI on the Deep Reef

(Chemotrophic Species Investigations, that is...)

(adapted from the 2003 Gulf of Mexico Deep Sea Habitats Expedition)

Focus
Chemotrophic organisms

Grade Level
9-12 (Life Science/Chemistry)

Focus Question
What factors are indicative of chemotrophic nutritional strategies?

Learning Objectives
Students will be able to describe at least three chemotrophic symbioses known from deep-sea habitats.

Students will be able to identify and explain at least three indicators of chemotrophic nutrition.

Materials
- ❒ Copies of "C.S.I. (Chemotrophic Species Investigations) Worksheet," one for each student or student group

Audio/Visual Materials
- ❒ Chalkboard, marker board with markers, or overhead transparencies for group discussions

Teaching Time
One or two 45-minute class periods plus time for student research

Seating Arrangement
Groups of 4-6 students

Maximum Number of Students
30

Key Words
Methanotrophic
Methylotrophic
Chemolithoautotrophic
Facultative chemoautotroph
Polytrophic
Symbiosis

Background Information
On August 28, 2005, Hurricane Katrina swept across the Gulf of Mexico, gathering strength to become a Category 3 storm that proved to be the most costly—and one of the most deadly—hurricanes in U.S. history. Four days later, the Department of the Interior's Minerals Management Service (MMS) reported that oil production in the Gulf of Mexico had been reduced by over 90 percent, and that natural gas production had been reduced by more than 78 percent. In the weeks that followed, fuel shortages and soaring prices underscored the importance of the Gulf of Mexico to petroleum supplies in the United States.

In fact, the Gulf of Mexico produces more petroleum than any other region in the nation, even though its proven reserves are less than those in Alaska and Texas. The San Francisco *Chronicle* reports that oil companies are spending billions to find more crude oil and drill more wells. Even with the threat of more hurricanes, the Gulf of Mexico has advantages: oil workers are not in danger of being kidnapped by armed insurgents as is the case in Nigeria; no foreign president threatens to raise oil companies' taxes, as has happened in Venezuela; and OPEC doesn't control oil production in the Gulf of Mexico. As of August 1, 2005, a total of 41,188 wells had been drilled in the Gulf, and 1,259 petroleum fields had been discovered.

Much of this new exploration is focussed on some of the deepest regions of the Gulf, made possible by improved technology and increasing crude oil prices (which have doubled in the last three years). In addition to new petroleum fields, this exploration has led to other discoveries as well. Some of the same conditions responsible for petroleum deposits also provide the basis for biological communities that receive energy from chemicals through a process called chemosynthesis (in contrast to photosynthesis that provide energy to terrestrial and shallow-water communities through processes in which sunlight is the basic energy source).

The first chemosynthetic communities were discovered in 1977 near the Galapagos Islands in the vicinity of underwater volcanic hot springs called hydrothermal vents, which usually occur along ridges separating the earth's tectonic plates. Chemosynthetic communities in the Gulf of Mexico were found by accident in 1984. These communities are similar in that they are based upon energy produced by chemosynthesis; but while energy for the Galapagos communities is derived from underwater hot springs, deep sea chemosynthetic communities in the Gulf of Mexico are found in areas where hydrocarbon gases (often methane and hydrogen sulfide) and oil seep out of sediments. These areas, known as cold seeps, are commonly found along continental margins, and (like hydrothermal vents) are home to many species of organisms that have not been found anywhere else on Earth. Typical features of communities that have been studied so far include mounds of frozen crystals of methane and water called methane hydrate ice, that are home to polychaete worms. Brine pools, containing water four times saltier than normal seawater, have also been found. Researchers often find dead fish floating in the brine pool, apparently killed by the high salinity.

Deepwater chemosynthetic communities are fundamentally different from other biological systems, and there are many unanswered questions about the individual species and interactions between species found in these communities. Similarly, deep-water 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. Most deepwater coral reefs in the Gulf of Mexico were the discovered by explorers investigating hydrocarbon seepage and/or chemosynthetic communities. Scientists studying deep-water reefs on the Norwegian continental shelf have found that many large deepwater coral banks occur at sites where there are relatively high levels of light hydrocarbons present in the sediments. The reason for this correlation is not known, nor is it known whether a similar correlation exists in the hydrocarbon-rich Gulf of Mexico. Many species found in deepwater bottom communities are new to science, and may prove to be important sources of unique drugs for the treatment of human diseases. Because their potential importance is not yet known, it is critical to protect these systems from adverse impacts caused by human activities.

Ironically, one of the most likely sources of such impacts is the same activity that led to the discovery of these systems in the first place: exploration and development of petroleum resources. MMS has the dual responsibility of managing these resources as well as protecting the environment from adverse impacts that might result from development activities. In 1988, MMS issued regulations specifically targeted toward protecting deepwater chemosynthetic communities. An essential part of the protection strategy requires identification of seafloor areas that could support chemosynthetic communities. These areas must be avoided by drilling, anchoring, pipeline installation, and other activities that involve disturbing the seafloor. Describing deepwater biological communities and evaluating their sensitivity to impacts from human activities are key objectives of the 2006 Gulf of Mexico Expedition.

Because natural conditions for deep-reef organisms are hard to re-create in the laboratory and because bottom time in manned submersibles is extremely limited, it is difficult for scientists to make direct observations of nutritional behavior in deep-sea organisms. Instead, scientists rely on a variety of clues that indicate nutritional strategy. In this lesson, students will learn about some of these clues, and about some of the chemotrophic strategies used by deep-sea organisms.

Learning Procedure

1. To prepare for this lesson, review
   - Introductory essays for the 2006 Gulf of Mexico Expedition at http://oceanexplorer.noaa.gov/explorations/06mexico/

2. Briefly review and contrast chemosynthesis with photosynthesis. Be sure students understand the term "chemosynthesis" encompasses a variety of chemical reactions that can provide energy to biological organisms. Point out that until recently it was well-accepted that photosynthesis was the basis of all major biological communities on Earth. Recognition of chemosynthetic communities has changed this view dramatically; indeed, many biologists now favor the idea that life on Earth may have begun in communities like those found near hydrothermal vents and cold seeps. (You may want to visit http://www.pmel.noaa.gov/vents/home.html for more information and activities on hydrothermal vent communities; http://www.bio.psu.edu/cold_seeps and http://www.bio.psu.edu/hotvents offer virtual tours of cold seep and hydrothermal vent communities.)

   Briefly discuss deepwater reefs as an example of another type of deep sea community. Be sure students understand that these reefs have a high diversity of species and large number of individual organisms like coral reefs in shallower water, but are virtually unexplored in the Gulf of Mexico. Visit http://oceanexplorer.noaa.gov/explorations/islands01/background/islands/sup10_lophelia.html for more background on deepwater coral reefs.

   Discuss the importance of the Gulf of Mexico to U.S. petroleum resources, as well as the potential importance of deepsea biological communities that might be adversely affected by exploration and development of petroleum resources. Ask students to brainstorm steps that might be taken to avoid adverse impacts. Briefly describe MMS regulations that require petroleum development companies to locate potentially sensitive biological communities and avoid these during exploration and development activities. Tell students that the overall purposes of the 2006 Gulf of Mexico Expedition are to develop ways to more easily locate such communities, and to learn more about how these communities work.

3. Provide individual students or student groups with copies of the "C.S.I. (Chemotrophic Species Investigations) Worksheet." Assign each group three of the organisms listed in part III. Tell students that each group is to submit a written report that will include answers to all of the questions on the worksheet.

4. Lead a discussion of group reports, which should include the following information:

   Part I:

   methanotrophic – an organism that obtains energy from methane

   methylotrophic – an organism that obtains energy from a compound containing the methyl radical

chemolithoautotrophic – an organism that obtain energy and cellular carbon from inorganic chemicals

facultative chemoautotroph – an organism that is capable of obtaining food from inorganic sources, but that may also obtain food from other sources as well

polytrophic – the ability to obtain food from several different sources

Part II:

Symbiosis – an association between two organisms; chemotrophy in the deep sea often involves a symbiosis between a chemotrophic bacterium and another animal

Gram negative bacteria – bacteria that have a negative reaction to the Gram staining procedure; these bacteria have an outer lipoprotein membrane and thin cell walls; all autotrophic bacteria are Gram negative (but all Gram negative bacteria are not autotrophic!)

Lipopolysaccharide – a compound that occurs naturally only in the outer cell walls of Gram negative bacteria

Trophosome – a large organ found in vestimentifera that contains chemosynthetic bacteria

Calvin-Benson cycle – a series of reactions in which carbon dioxide is converted to glucose; occurs only in autotrophic organisms

Ribulose-1,5-bisphosphate carboxylase-oxygenase – the enzyme that catalyzes the first reaction in the Calvin-Benson cycle

Part III:

Riftia pachyptila – giant tubeworm (vestimentiferan) found in the vicinity of hydrothermal vents; no mouth, gut, or anus; trophosome contains large numbers of chemosynthetic bacteria

Alvinella pompejana – polychaete worm found only at hydrothermal vents; epidermis has numerous bacteria, some of which are chemotrophic

Phallodrilus leukodermatus (=***Inanidrilus leukodermatus***) – Oligochaete worm found in reducing sediments; worms are mouthless and gutless; contain subcutaneous chemautotrophic bacteria

Lucinidae – family of bivalves, many of which contain chemautotrophic bacteria in vacuoles in their gills

Bathymodiolus thermophilus – hydrothermal vent mussel; gills contain chemautotrophic bacteria in bacteriocytes

Solemya reidi – gutless bivalve found in anaerobic sediments; gills contain chemautotrophic bacteria

Vesicomyidae – family of deep-sea bivalves, all found in habitats containing sulfide, including hydrothermal vents, saline seeps, and hydrocarbon seeps; contain chemautotrophic bacteria in their large gills

Alviniconcha hessleri – gastropod found near hydrothermal vents; gills contain chemautotrophic bacteria

Part IV:

The absence of a mouth, gut, and anus suggests that the organism is either absorbing nutrient directly from the surrounding water, or that it may be receiving nutrition from a symbiont, perhaps living within the tissues of the new organism. The presence of large quantities of lipopolysaccharides suggests the presence of large numbers of Gram negative bacteria. Large amounts of ribulose-1,5-bisphosphate carboxylase-oxygenase suggest the presence of autotrophic organisms. The term "large" is important here, because the smoothie almost certainly contained many different bacteria; but indications of large number of Gram negative bacteria and autotrophic organisms suggest that the new species may be part of a chemotrophic symbiosis.

Point out that science often involves these kinds of inferences, using a series of clues that together lead to conclusions about processes that cannot be directly observed.

The Bridge Connection

http://www.vims.edu/bridge/reef.html; www.vims.edu/bridge/vents.html; and www.vims.edu/bridge/geology.html

The "Me" Connection

Have students investigate whether they have symbiotic bacteria in their own bodies, and write a short essay describing the results of their investigation.

Connections to Other Subjects

English/Language Arts, Earth Science

Assessment

Written reports prepared in Step 3 provide an opportunity for assessment.

Extensions

1. Visit http://oceanexplorer.noaa.gov/explorations/06mexico/ for daily logs and updates about discoveries being made by the 2006 Gulf of Mexico Expedition.

2. Have students investigate more about ancient bacteria and recent findings about physical conditions on some of Jupiter's moons, and report on the implications of chemosynthetic bacteria for the origins of life on Earth and extraterrestrial life (http://www.ocean.udel.edu/deepsea/level-2/chemistry/bacteria.html and http://pubs.usgs.gov/publications/text/dynamic.html#anchor19309449 are useful for this).

Resources

NOAA Learning Objects

http://www.learningdemo.com/noaa/ 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 the Ocean Exploration Program

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)

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 13C isotope values to draw inferences about energy-obtaining strategies used by organisms in cold-seep communities.

This Old Tubeworm (10 pages, 484k)) (from the 2002 Gulf of Mexico Expedition) [http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_oldtube.pdf]

Focus: Growth rate and age of species in cold-seep communities

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.

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)

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.

Cool Corals (7 pages, 476k) (from the 2003 Life on the Edge Expedition) [http://oceanexplorer.noaa.gov/explorations/03edge/background/edu/media/cool.pdf]

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

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.

Submersible Designer (4 pages, 452k) (from the 2002 Galapagos Rift Expedition) [http://oceanexplorer.noaa.gov/explorations/02galapagos/background/education/media/gal_gr9-12_l4.pdf]

Focus: Deep Sea Submersibles

Students will understand that the physical features of water can be restrictive to movement; students will understand the importance of design in underwater vehicles by designing their own submersible; Students will understand how submersibles such as ALVIN and ABE, use energy, buoyancy, and gravity to enable them to move through the water.

The Benthic Drugstore (4 pages, 360k) (from the 2003 Deep Sea Medicines Expedition) [http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/Meds_Drugstore.pdf]

Focus: Pharmacologically active chemicals derived from marine invertebrates (life science)

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.

How Diverse is That? (6 pages, 552k) (from the 2003 Windows to the Deep Expedition) [http://oceanexplorer.noaa.gov/explorations/03windows/background/education/media/03win_hdiverse.pdf]

Focus: Quantifying biological diversity (Life Science)

Students will be able to discuss the meaning of "biological diversity" and will be able to compare and contrast the concepts of "variety" and "relative abundance" as they relate to biological diversity. Given abundance and distribution data of species in two communities, students will be able to calculate an appropriate numeric indicator that describes the biological diversity of these communities.

What's the Difference? (15 pages, 1Mb) (from the 2003 Mountains in the Sea Expedition) [http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_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.

Living in Extreme Environments (12 pages, 1Mb) (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)

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.

Cut-off Genes (12 pages, 648k) (from the 2004 Mountains in the Sea Expedition)
[http://oceanexplorer.noaa.gov/explorations/04mountains/background/edu/media/MTS04.genes.pdf]

Focus: Gene sequencing and phylogenetic expressions (Life Science)

Students will be able to explain the concept of gene-sequence analysis; and, given gene sequence data, students will be able to draw inferences about phylogenetic similarities of different organisms.

Other Resources and Links

http://www.gomr.mms.gov/index_common.html – Minerals Management Service Web site

http://www.gomr.mms.gov/homepg/lagniapp/chemcomp.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)

http://www.energybulletin.net/4901.html – Article "Out of Gas: Sediments in Northern Gulf of Mexico Not Right for Methane Gas Hydrate Formation, Study Shows" published by Georgia Research Tech News, 21 Mar 2005

http://www.ridge2000.org/eo/index.html – Links to other deep ocean exploration Web sites

http://www-ocean.tamu.edu/education/oceanworld-old/resources/general_links.htm – Links to other ocean-related Web sites

http://oceanica.cofc.edu/activities.htm – Project Oceanica Web site, with a variety of resources on ocean exploration topics

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

Fisher, C. R. 1990. Chemautotrophic and Methanotrophic Symbioses in Marine Invertebrates. Rev. Aquat. Sci. 2:399-436

Roberts, S. and M. Hirshfield. Deep Sea Corals: Out of sight but no longer out of mind. http://www.oceana.org/uploads/oceana_coral_report.pdf — Background on deep-water coral reefs

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

Content Standard D: Earth and Space Science
- Energy in the Earth system
- Geochemical cycles
- Origin and evolution of the Earth system
- Origin and evolution of the universe

Content Standard F: Science in Personal and Social Perspectives
- Natural resources

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.
The Earth has one big ocean with many features.
- *Fundamental Concept h.* Although the ocean is large, it is finite and resources are limited.

Essential Principle 4.
The ocean makes Earth habitable.
- *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 c.* Some major groups are found exclusively in the ocean. The diversity of major groups of organisms is much greater in the ocean than on land.
- *Fundamental Concept d.* Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.
- *Fundamental Concept 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 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 our lesson plans.
Please send your comments to:
oceanexeducation@noaa.gov

For More Information

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

Acknowledgements

This lesson 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

Student Handout
C.S.I. Worksheet
(Chemotrophic Species Investigations)

I. Define:

Methanotrophic

Methylotrophic

Chemolithoautotrophic

Facultative chemoautotroph

Polytrophic

II. Describe how the following are relevant to chemosynthetic activity:

Symbiosis

Gram negative bacteria

Lipopolysaccharide

Trophosome

Calvin-Benson cycle

Ribulose-1,5-bisphosphate carboxylase-oxygenase

III. Briefly describe the overall chemosynthetic process in three of the following:

Riftia pachyptila

Alvinella pompejana

Phallodrilus leukodermatus (=*Inanidrilus leukodermatus*)

Lucinidae

Bathymodiolus thermophilus

Solemya reidi

Vesicomyidae

Alviniconcha hessleri

IV. Your CSI team has discovered a new species! Preliminary observations include the following:

- The organism does not appear to have a mouth, gut, or anus
- A smoothie made by pureeing the organism in a blender contains large quantities of lipopolysaccharides
- The smoothie also contains unusually large amounts of ribulose-1,5-bisphosphate carboxylase-oxygenase

What do these observations suggest about the nutritional strategy employed by the new species? Why?