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2006 Gulf of Mexico Expedition

Chemosynthesis for the Classroom

(adapted from the 2002 Gulf of Mexico Expedition)

Focus
Chemosynthetic bacteria

Grade Level
9-12 (Chemistry/Biology)

Focus Question
What changes affect succession in the development of chemosynthetic bacterial communities?

Learning Objectives
Students will observe the development of chemosynthetic bacterial communities.

Students will recognize that organisms modify their environment in ways that create opportunities for other organisms to thrive.

Students will be able to explain the process of chemosynthesis.

Students will be able to explain the relevance of chemosynthesis to biological communities in the vicinity of cold seeps.

Materials
- ❒ Directions for setting up Winogradsky columns from topex-www.jpl.nasa.gov//education/activities/ts3enac2.pdf
- ❒ Black mud from a local river, lake, or estuary, approximately 500 ml for each student group
- ❒ Water from the same source used to obtain black mud, approximately 3 liters for each student group
- ❒ 500 ml graduated cylinder, two for each student group
- ❒ Calcium sulfate (Plaster of Paris), 80 g for each student group
- ❒ 500 ml jar or beaker
- ❒ Stirring rod
- ❒ Straw or small pieces of filter paper, 50 g for each student group
- ❒ Sodium bicarbonate (baking soda), 4 g for each student group
- ❒ Crushed multivitamin pill, one for each student group
- ❒ Plastic wrap
- ❒ Rubber bands
- ❒ Source of artificial light
- ❒ Tape and markers for labelling graduated cylinders
- ❒ Flashlight with red cellophane over lens
- ❒ Optional: microscopes and materials for making wet mounts

Audio/Visual Materials
None

Teaching Time
One 45-minute class period to set up columns, approximately 15 minutes at weekly intervals for six weeks to make observations, and one 45-minute class period for presentation and discussion of results

Seating Arrangement
Groups of four students

Maximum Number of Students
24

Key Words

Cold seeps
Methane hydrate ice
Chemosynthesis
Brine pool
Vestimentifera
Trophosome
Succession

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. Hydrogen sulfide is abundant in the water erupting from hydrothermal vents, and is used by chemosynthetic bacteria that are the base of the vent community food chain. These bacteria obtain energy by oxidizing hydrogen sulfide to sulfur:

$$CO_2 + 4H_2S + O_2 > CH_2O + 4S + 3H_2O$$

(carbon dioxide plus sulfur dioxide plus oxygen yields organic matter, sulfur, and water). Visit http://www.pmel.noaa.gov/vents/home.html for more information and activities on hydrothermal vent communities.

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.

Where hydrogen sulfide is present, large tubeworms (phylum Annelida) known as vestimentiferans are often found, sometimes growing in clusters of millions of individuals. These unusual animals do not have a mouth, stomach, or gut. Instead, they have a large organ called a trophosome that contains chemosynthetic bacteria. Vestimentiferans have a structure called a plume that consists of filaments (sometimes referred to as "tentacles") that extend into the water. The tentacles are bright red due to the presence of hemoglobin which can absorb hydrogen sulfide and oxygen which are transported to the bacteria in the trophosome. The bacteria produce organic molecules that provide nutrition to the tube worm. A similar symbiotic relationship is found in clams and mussels that have chemosynthetic bacteria living in their gills. Bacteria are also found living independently from other organisms in large bacterial mats. A variety of other organisms are also found in cold seep communities, and probably use tubeworms, mussels, and bacterial mats as sources of food. These include snails, eels, starfish, crabs, lobsters, isopods, sea cucumbers, and fishes. Specific relationships between these organisms have not been well-studied.

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. These species include some of the most primitive living organisms (Archaea) that some scientists believe may have been the first life forms on Earth. Many species 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.

This activity focuses on chemosynthetic bacteria similar to those that are the base of food chains in cold seep communities. Black mud from a local water body is incubated in a glass cylinder (called a Winogradsky column) with a source of chemical energy (calcium sulfate) and organic material (straw or filter paper) to grow a succession of chemosynthetic bacteria over a period of six weeks. This activity was originally developed by the Orange County Marine Institute/San Juan Institute Activity Series, and is available on NASA's Jet Propulsion Laboratory Ocean Planet Web site at topex-www.jpl.nasa.gov//education/activities/ts3enac2.pdf

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/ and
   - Procedures for setting up two Winogradsky

columns at topex-www.jpl.nasa.gov//education/activities/ts3enac2.pdf

2. Lead a discussion of deep-sea chemosynthetic communities. Contrast chemosynthesis with photosynthesis: In both processes, organisms build sugars from carbon dioxide and water. This process requires energy; photosynthesizers obtain this energy from the sun, while chemosynthesizers obtain energy from chemical reactions. Point out that there are a variety of chemical reactions that can provide this kind of energy. Contrast hydrothermal vent communities with cold-seep communities. Visit http://www.bio.psu.edu/cold_seeps for a virtual tour of a cold seep community.

   Discuss the importance of the Gulf of Mexico to U.S. petroleum resources, as well as the potential importance of deep-sea 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. Have each student group follow procedures given at topex-www.jpl.nasa.gov//education/activities/ts3enac2.pdf for setting up two Winogradsky columns using locally collected black mud. Cover each column tightly with plastic wrap and secure with rubber bands. One column should be placed in a darkened area and the other column near a light source (but not in direct sunlight). Students should observe their columns weekly, and record their observations.

   You may have them make wet mounts for microscopic examination at the end of three and six weeks. Use appropriate safety precautions when making wet mounts, including gloves, antibacterial solution for disposing of slides, and hand washing following completion of the activity.

4. Have each group present and discuss their results. Students should have observed a series of changes in the appearance of the mud in the columns caused by a succession of bacterial species. They should infer that changes caused by one species (for example, the production of waste products) create opportunities for other species. Similarly, changes in the chemical composition of the mud, such as formation of hydrogen sulfide, alter the environment in ways that may favor the growth of other bacterial species. The processes observed in the Winogradsky columns roughly models the development of deep-sea chemosynthetic communities. Ask the students to speculate about what other organisms might appear in the community if these processes were taking place in the area from which the mud was collected.

The Bridge Connection

www.vims.edu/bridge/vents.html

The "Me" Connection

Have students write a short essay on why cold seeps might be directly important to their own lives. You may want to offer a hint that perhaps the energy source used by chemosynthetic bacteria could be useful to other species as well (some estimates suggest that there may be more energy locked up in methane hydrate ices than in all other fossil fuels combined!).

Connections to Other Subjects

English/Language Arts, Biology, Earth Science

Assessment

Have students submit records of their observations and their written interpretation of these observations.

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
In this activity, 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)
In this activity, 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

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.

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
- Interactions of energy and matter

Content Standard C: Life Science
- Interdependence of organisms
- Matter, energy, and organization in living systems

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

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 b.* Most life in the ocean exists as microbes. Microbes are the most important primary producers in the ocean. Not only are they the most abundant life form in the ocean, they have extremely fast growth rates and life cycles.
- *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.

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