Windows to the Deep Exploration

This Life Stinks!

Focus
Methane-based chemosynthetic processes

Grade Level
9-12 (Physical Science)

Focus Question
How do organisms in cold seep communities obtain energy from methane?

Learning Objectives
Students will be able to define the process of chemosynthesis, and contrast this process with photosynthesis.

Students will be able to explain the process of methane-based chemosynthesis.

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

Materials
None

Audio/Visual Materials
None

Teaching Time
One-half 45-minute class period for introduction, plus one-half 45-minute class period for discussion; approximately 1-2 hours for research outside of class

Seating Arrangement
Classroom style

Maximum Number of Students
32

Key Words
Cold seeps
Methane hydrate
Clathrate
Chemosynthesis
Ice worm
Vestimentifera
Trophosome

Background Information
One of the major scientific discoveries of the last 100 years is the presence of extensive deep sea communities that do not depend upon sunlight as their primary source of energy. Instead, these communities derive their energy from chemicals through a process called chemosynthesis (in contrast to photosynthesis in which sunlight is the basic energy source). Some chemosynthetic communities have been found near 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. Visit http://www.pmel.noaa.gov/vents/home.html for more information and activities on hydrothermal vent communities.

Other deep sea chemosynthetic communities are found in areas where hydrocarbon gases (often methane and foul-smelling 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. Methane and hydrogen sulfide are produced by the breakdown of organic matter deposited in the sediments. Archea and bacteria gain energy by oxidizing methane and hydrogen sulfide, and then become the base for a "chemosynthetic" food chain, in some cases by being grazed and filtered out of the water and in other cases by functioning as symbionts.

Where hydrogen sulfide is present, large tubeworms (phylum Pogonophora) 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 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. Newly-discovered polychaete and shrimp species have been found living directly on methane hydrate ices. Methane hydrate is a type of clathrate, a chemical substance in which the molecules of one material (water, in this case) form an open lattice that encloses molecules of another material (methane) without actually forming chemical bonds between the two materials. 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, sea stars, crabs, lobsters, isopods, sea cucumbers, and fishes. Specific relationships between these organisms have not been well studied.

The Blake Ridge is a large sediment deposit located approximately 400 km east of Charleston, South Carolina on the continental slope and rise of the United States. The crest of the ridge extends in a direction that is roughly perpendicular to the continental rise for more than 500 km to the southwest from water depths of 2,000 to 4,800 m. Over the past 30 years, the Blake Ridge has been extensively studied because of the large deposits of methane hydrate found in the area. These deposits are significant for several reasons:

- The U. S. Geological Survey has estimated that on a global scale, methane hydrates may contain roughly twice the carbon contained in all reserves of coal, oil, and conventional natural gas combined.
- Methane hydrates can decompose to release large amounts of methane which is a greenhouse gas that could have (and may already have had) major consequences to the Earth's climate.
- Sudden release of pressurized methane gas may cause submarine landslides which in turn can trigger catastrophic tsunamis.
- Methane hydrates are associated with unusual and possibly unique biological communities containing previously unknown species that may be sources of beneficial pharmaceutical materials.

Learning Procedure

1. Lead a discussion of deep-sea chemosynthetic communities. Contrast chemosynthesis with photosynthesis, and be sure students understand 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 and http://www.bio.psu.edu/hotvents for virtual tours of cold seep and hydrothermal vent communities. Point

out that until recently, it was well-accepted that photosynthesis was the basis of all major biological communities on Earth. Recognition of these communities has changed this view dramatically; indeed, many biologists now favor the idea that life on Earth may have begun in chemosynthetic communities like those found near hydrothermal vents and cold seeps.

Tell students that their assignment is to describe the overall chemical processes involved in using methane and hydrogen sulfide to synthesize organic material. You may choose to have students complete this assignment individually or in small groups. Have each student or student group write a brief report in which they:

- Identify the basic oxidation-reduction reactions;
- State which reactants are oxidized and which ones are reduced; and
- Explain whether or not these "chemosynthetic" reactions are totally independent of photosynthesis.

The websites listed under "Resources" may be helpful for this assignment.

2. Lead a discussion of student reports. Students should recognize that chemosynthetic organisms using hydrogen sulfide oxidize this substance to form 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). Sulfur may be subsequently oxidized to form sulfate. The oxygen molecules in these reactions are reduced.

The process appears to be a little more complicated for methane-based chemosynthesis. Despite numerous attempts, the organisms responsible for anaerobic methane oxidation have not yet been identified. Research has shown that maximum anaerobic methane oxidation rates coincide with maximum rates of sulfate reduction. Scientists have hypothesized that at least two different organisms are involved in the process: one that oxidizes methane, and one or more others that reduce sulfate. The overall equation for the process is:

$$CH_4 + SO_4^{2-} > HS^- + HCO_3^- + H_2O$$

(methane plus sulfate yields sulfide plus organic matter plus water).

Students should realize that while these reactions occur in anaerobic environments in the absence of sunlight, they probably are not totally independent of photosynthesis. This is because both methane and hydrogen sulfide are formed as a result of reactions involving organic carbon (buried in the sediments), much of which was produced by "ancient" photosynthesis. Moreover, most of the oxygen dissolved in seawater (needed for sulfide oxidation) is also a product of photosynthesis.

The BRIDGE Connection

www.vims.edu/bridge/vents.html and www.vims.edu/bridge/geology.html

The "Me" Connection

Have students write a brief essay on how processes involving methane hydrates could affect them personally. If you assign this essay, do not discuss information in the last paragraph of "Background Information" until after the essays have been completed.

Connections to Other Subjects

English/Language Arts, Biology, Chemistry

Evaluation

Written reports may be scored according to a rubric based on points identified in Step #1. Thoroughness of research (e.g., inclusion of references not provided by the instructor) may be added to this rubric if desired.

Extensions

Couple this lesson with "What's the Big Deal?" and/or "Life is Weird" to give students opportunities to explore the significance of methane hydrates and biological communities of the Blake Ridge in greater detail.

Resources

http://oceanexplorer.noaa.gov – Follow the Blake Ridge Expedition daily as documentaries and discoveries are posted each day for your classroom use.

http://dbhs.wvusd.k12.ca.us/ChemTeamIndex.html - Website for help with basic chemical concepts including oxidation-reduction reactions

http://www.geol.ucsb.edu/faculty/valentine/Valentine%202002.pdf - Review of methane-based chemosynthetic processes

http://www.accessexcellence.org/BF/bf01/arp/bf01p1.html – Verbatim transcript of a slide show on coping with toxic sulfide environments

http://www.rps.psu.edu/deep/ – Notes from another expedition exploring deep-sea communities

http://www.ridge.oce.orst.edu/links/edlinks.html – Links to other deep ocean exploration web sites

http://www-ocean.tamu.edu/education/oceanworld/resources/ – 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

- 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

For More Information

Paula Keener-Chavis, National Education Coordinator/Marine Biologist
NOAA Office of Exploration
2234 South Hobson Avenue
Charleston, SC 29405-2413
843.740.1338
843.740.1329 (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