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Gulf of Mexico Exploration

One Tough Worm

Focus

Physiological adaptations to toxic and hypoxic environments

Grade Level

7-8 Life Science

Focus Question

How can aerobic organisms cope with environments containing little oxygen and an abundance of respiratory poisons?

Learning Objectives

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.

Students will be able to describe three physiological adaptations that enhance an organism's ability to extract oxygen from its environment.

Students will be able to describe the problems posed by hydrogen sulfide for aerobic organisms, and explain three strategies for dealing with these problems.

Additional Information for Teachers of Deaf Students

In addition to the words listed as key words, the following words should be part of the vocabulary list.
Chemosynthetic
Seep
Organic
Vestimentifera
Poganophora
Adaptation
Sediment
Toxicity
Cyanide
Cytachrome molecule
Metabolism
Anatomical adaptation
Photosynthesis
Orbiniid polychaete
Respiratory membrane
Polychaete worm
Diffusion membrane
Efficient
Extracting
Exposure
Symbiotic relationship
Chemosynthetic bacteria
Simultaneously

The key words are integral to the unit but will be very difficult to introduce prior to the activity. They are really the material of the lesson. There are no formal signs in American Sign Language for any of these words and many are difficult to lipread. Having the vocabulary list on the board as a reference during the lesson will be extremely helpful. This activity may require a bit more time to complete. It would be very helpful to copy the Background Information and hand it out to students to read after the lesson to reinforce what was covered and expand for those who may have had difficulty grasping it. Have the two Web sites set up to view the tours of cold seep communities and hydrothermal communities.

When you reach Step #2, calculate gas flow for the first several together as a class, then assign students the remainder to do on their own. Then discuss results. The "Me" Connection can also be used as an evaluation tool.

Materials

- ☐ Copies of "Comparative Functional Characteristics of Polychaete Gills," one copy for each student group
- ☐ Copies of "Metazoans in Extreme Environments," one copy for each student group (download from or refer students to http://asgsb.indstate.edu/bulletins/v13n2/vol13n2p13-24.pdf

Audio/Visual Materials

None

Teaching Time

One 45-minute class period for first part of activity, plus one-half to one additional 45-minute class period for group reports and discussion

Seating Arrangement

Groups of four students

Maximum Number of Students

20

Key Words

Cold seeps
Methane hydrate ice
Chemosynthesis
Brine pool
Vestimentifera
Trophosome
Fick's equation
Hemoglobin
Hydrogen sulfide
Mitochondria
Aerobic
Anaerobic
Gill

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 web. These bacteria obtain energy by oxidizing hydrogen sulfide to sulfur:
$CO_2 + 4H_2S + O_2 > CH_2O + 4S + 3H_2O$
(carbon dioxide plus hydrogen sulfide 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.

Other deep-sea chemosynthetic communities 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 is 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 pools, apparently killed by the high salinity.

As is the case with hydrothermal vents, chemosynthetic bacteria are also the base of the food web in cold seep communities. Bacteria may form thick bacterial mats, or may live in close association with other organisms. One of the most conspicuous associations exists between chemosynthetic bacteria and large tubeworms that belong to the group Vestimentifera (formerly classified within the phylum Pogonophora; recently Pogonophora and Vestimentifera have been included in the phylum Annelida). Pogonophora means "beard bearing," and refers to the fact that many species in this phylum have one or more tentacles at their anterior end. Tentacles of vestimentiferans are bright red because they contain hemoglobin (like our own red blood cells). Vestimentiferans can grow to more than 10 feet long, sometimes in clusters of millions of individuals, and are believed to live for more than 100 years. They do not have a mouth, stomach, or gut. Instead, they have a large organ called a trophosome, that contains chemosynthetic bacteria. Hemoglobin in the tubeworm's blood transports hydrogen sulfide and oxygen to bacteria living in the trophosome. The bacteria produce organic molecules that provide nutrition to the tubeworm. Similar relationships are found in clams and mussels that have chemosynthetic bacteria living in their gills. 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, isopods, sea cucumbers, and fishes. Specific relationships between these organisms have not been well-studied.

This activity focuses on some of the physiological adaptations that allow cold seep organisms to survive conditions that would be deadly to many other species. Polychaete "ice worms" received a lot of attention when they were first discovered at Gulf of Mexico cold seeps in 1997 because they were found living inside chunks of frozen methane. Another polychaete belonging to the family *Orbiniidae* (previously unknown to science) is often found living among mussel beds that are one of the most conspicuous features of these cold seep communities. These polychaetes are aerobic animals, which means they require oxygen for their metabolism. Yet, these worms live in areas where oxygen is in extremely short supply, and often cannot be detected in the water at all. To make matters worse, sediments around the mussel beds contain large quantities of hydrogen sulfide, which is similar to cyanide in its toxicity. Hydrogen sulfide interferes with cytochrome molecules that are essential to aerobic metabolism, as well as hemoglobin that is used by many organisms to transport oxygen within living tissues. So our cold-seep polychaete has two big problems: getting oxygen to support aerobic metabolism, and avoiding the toxic effects of hydrogen sulfide.

There are several strategies that organisms may use to improve their ability to obtain oxygen from their surrounding environment. Three of the most common strategies are anatomical adaptations that increase an organism's surface area in contact with a source of oxygen, thin membranes between the interior of the organism and an oxygen source, and internal circulatory systems that transport oxygen within the organism. These strategies are related by Fick's equation which describes the passive diffusion of gas molecules across a membrane:

$$F = \frac{A \bullet P \bullet c}{D}$$

where

F = gas flow
A = membrane surface area
P = pressure difference on the two sides of the membrane
c = a mathematical constant
D = distance over which diffusion takes place (at the minimum, thickness of the membrane)

So, gas flow across a membrane will be increased by increasing the membrane's surface area, reducing the membrane's thickness, and/or increasing the pressure difference across the membrane. "Pressure difference" is related to the difference in concentration of a gas on one side of the membrane compared to the other side. If there is no difference, then there will be no net flow of gas (according to Fick's equation, if $P = 0$ then $F = 0$). An organism cannot do much about the concentration of gas in the external environment, but if it has a way to move gas away from the membrane as the gas diffuses in, a pressure difference can be maintained. A circulatory system is a well-known adaptation for maintaining this kind of pressure difference. If the circulatory system includes molecules that can bind the gas as it diffuses in (like hemoglobin binds oxygen), this also helps maintain the pressure gradient.

Three major strategies are common among organisms that must deal with potentially toxic sulfides. The first is to switch from aerobic metabolism to anaerobic metabolism that does not require oxygen. Many invertebrates are capable of doing this for varying periods of time. Another strategy is to bind the sulfide with another material that keeps it from interacting with sensitive molecules involved with aerobic metabolism. Tubeworms from hydro-thermal vents are known to have specialized forms of hemoglobin that bind with sulfide and keep it away from metabolically critical areas. The third strategy is to convert the sulfide molecules to something else that is not toxic to the organism. This strategy has been found in a variety of animals that have mitochondria that are able to oxidize sulfide to thiosulfate (which is relatively nontoxic).

LEARNING PROCEDURE

1. Lead a discussion of deep-sea chemosynthetic communities. Contrast chemosynthesis with photosynthesis. Point out that there are a variety of chemical reactions that can provide energy for chemosynthesis. Visit http://www.bio.psu.edu/cold_seeps for a virtual tour of a cold seep community, and http://www.bio.psu.edu/hotvents for a virtual tour of a hydrothermal vent community.

   Review the problem of oxygen scarcity that challenges the survival of the orbiniid polychaete. Discuss adaptations that enhance an organism's ability to extract oxygen from its environment. Be sure students understand the terms in Fick's equation, and how an increase or decrease in each parameter would affect gas flow across a respiratory membrane. Students should realize that gills are a common adaptation in aquatic animals for increasing respiratory surface area (alveoli serve a similar function in lungs of humans and other animals). Discuss the role of hemoglobin in obtaining and transporting oxygen.

2. Distribute a copy of "Comparative Functional Characteristics of Polychaete Gills" to each student group. Assign one or more species to each group, and have the group calculate gas flow across their species, gills using Fick's equation and assuming that c and P are the same for each species.

3. Have each group discuss their results, and what these results imply about the environment occupied by each species. Students should recognize that polychaetes from hydrothermal vent and cold seep communities have gills with larger surface area and thinner diffusion membranes, which means that gills of these species are much more efficient at extracting oxygen from their environment than the shallow-water species.

4. Distribute copies of "Metazoans in Extreme Environments" or refer students to http://asgsb.indstate.edu/bulletins/v13n2/vol13n2p13-24.pdf. Have each group prepare a written report on the problems posed by hydrogen sulfide for inhabitants of hydrothermal vent and cold-seep communities, and what strategies are used by organisms in these communities to cope with these problems. This article deals with several other problems of "extreme environments" besides sulfide. You may want to direct students to the sulfide section alone, or alternatively, have them address the other problems as well, perhaps assigning one additional problem to each group.
5. Lead a discussion based on student groups' reports. Students should realize that adaptations that favor oxygen extraction can also increase an organism's exposure to hydrogen sulfide. The problem is even trickier for organisms that have a symbiotic relationship with chemosynthetic bacteria that use hydrogen sulfide as an energy source, as these organisms must live close to a source of hydrogen sulfide to provide their sym-

biotic bacteria with this necessary raw material, but must simultaneously avoid being poisoned by the same material. Students should identify the three alternative strategies discussed above for dealing with this problem.

THE BRIDGE CONNECTION

www.vims.edu/bridge/vents.html

THE "ME" CONNECTION

Have students write a short essay on what physiological adaptations would be required to allow them to live near a hydrothermal vent or cold-seep, including a description of a day spent in one of these extreme environments.

CONNECTIONS TO OTHER SUBJECTS

English/Language Arts, Chemistry, Earth Science

EVALUATION

Have students prepare individual written statements of their conclusions prior to oral presentations in Step #3. You may wish to create a grading rubric that includes the individual (from Step #3) and group (from Step #4) components.

EXTENSIONS

If you have not done so as part of Step #4, have students report on other problems of extreme environments in addition to hypoxia and sulfide toxicity, and how organisms deal with these problems.

RESOURCES

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

http://www.bio.psu.edu/People/Faculty?Fisher/thome.htm – Web site for the principal investigator on the Gulf of Mexico expedition.

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

http://asgsb.indstate.edu/bulletins/v13n2/vol13n2p13-24.pdf – Article on adaptations to life in hydrothermal vent and cold-seep communities

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

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.

Hourdez, S., L-A Frederick, A. Schernecke, and C. R. Fisher. Functional respiratory anatomy of a deep-sea orbiniid polychaete from the Brine Pool NR-1 in the Gulf of Mexico. Invertebrate Biology 120:29-40. – Technical journal article upon which this activity is based.

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
- Properties and changes in matter

Content Standard C: Life Science
- Structure and function in living systems
- Diversity and adaptations of organisms

For More Information

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Student Handout

Comparative Functional Characteristics of Polychaete Gills

(modified from Hourdez, et al., 2001)

Species	**Habitat**	**Gill Surface Area (cm2/g Diffusion Distance body wet weight)**	**Minimum (µm)**
Branchipolynoe symmytilida	vent	14.2	10
Branchipolynoe seepensis	vent	10.3	9
Paralvinella grasslei	vent	47	4
Alvinella pompejana	vent	12	1-3
Arenicola marina	shallow mud	4	8-14
Undescribed Orbiniidae	seep	8	4