Understanding Chemosynthesis At the Deep Sea Hydrothermal Vents

Document Overview:

This is a qualitatively based hands-on activity that will have students simulating life at the deep sea hydrothermal vents by building and observing two Winogradsky Columns. The activity is a long term project that will require at least six weeks for the column to reach full growth and subsequently showing bacterial and algal succession. Journaling is a major portion of the assessment.

Minnesota State Academic Science Standards:

Matter cycles and energy flows through different levels of organization of living systems and the physical environment, as chemical elements are combined in different ways:

9.4.2.2.1 Use words and equations to differentiate between the processes of photosynthesis and respiration in terms of energy flow, beginning reactants and end products.

9.4.2.2.2 Explain matter and energy is transformed and transferred among organisms in an ecosystem, and how energy is dissipated as heat in the environment.

Objective:

- Students will build a Winogradsky Column and observe the algal and microbial populations of organisms over time.
- Students will differentiate between photosynthetic and chemosynthetic systems of energy production.

Type of Activity:
This is a hands-on activity will a long term observational follow-up. Qualitative data will be collected over time. A journal could be incorporated as the final product.

Duration:
50 – 55 minutes for the production of the Winogradsky Column.
Weekly observations of the column over a six to nine week period.

Connection to Nobel speakers:
David Gallo, Ph.D., Director of special project, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts.

Teacher Tips:
This is initially planned as a Nobel Conference introductory activity in preparation for the presentation of Dr. David Gallo. However, since the concepts of matter cycles in biology are pervasive, this lab can be incorporated in a variety of places within a biological curriculum. It is my intention to have the lab early in the year and let the Winogradsky Columns operate over an extended period of time with students keeping a journal to record observations, answer questions relating to the topics, and make predictions.

Since each student team will build two columns, one column using photosynthesis and another using a more chemosynthetic system, I envision using the columns later when discussing photosynthesis and respiration concepts.

Concepts:

- Matter cycles
- Energy flow through the environment
- Succession
- Chemosynthesis
- Symbiosis
- Aerobic and Anaerobic Bacterial systems

Description of Activity:

Students will grow and observe succession and chemosynthesis of bacterial colonies: one lighted, the other in the dark. This activity uses the concepts of the Winogradsky column, a device which enriches and isolates certain organisms involved in the sulfur and nitrogen cycles. The activity provides a rough analog to both processes of chemosynthesis and succession; processes which occur at deep sea hydrothermal vents and form the base of the food chain in the absence of sunlight. (Note that the original Winogradsky column was made by a Russian microbiologist Sergei N. Winogradsky.)

Bacteria that are chemosynthetic are the oldest life forms on Earth. The classic Winogradsky column, developed long before vent ecosystems were discovered, provides an excellent illustration of bacterial growth and succession. Around seafloor hydrothermal vents, scientists have discovered communities of different bacteria that draw their energy from chemicals in Earth's crust, rather than from the Sun.

In 1880, the Russian scientist Sergei Winogradsky discovered the bacteria *Beggiatoa*. These bacteria metabolize hydrogen sulfide to produce the energy for making food (simple sugars). They do not need light as a source of energy; they instead use hydrogen sulfide. *Beggiatoa* is among the bacteria found in the deep-sea hydrothermal vent environment, but it is not the only bacteria to take advantage of this chemosynthetic process.

It is difficult to know what bacteria are actually growing in the students' column; however, as an example, at hydrothermal vents the first bacterium present is *Clostridium*. This is an anaerobic heterotroph that uses, in our simulated column, the straw or filter paper as a carbon source to produce food.

In the Winogradsky Column left in the light, students should see green-colored algae in the first week. Then, over a period of six weeks, at least five different bacteria may grow in succession in both columns.

A second bacterium, *Desulfovibrio*, uses the waste of the anaerobic heterotroph as its source of carbon and the $CaSO_4$ as an energy source. This bacterium produces the hydrogen sulfide (H_2S) required by the rest of the ecosystem.

Three other bacteria *Beggiatoa* (white or yellow), *Chlorobium* (green), and *Chromatium* (purple and violet) use hydrogen sulfide as part or all or their energy source to make food. This process requires oxygen so you will find these bacteria near the surface of the sediments.

After the original purple and green patches form, black spots will begin to appear. These black patches are deposits of H_2S (hydrogen sulfide, which has a distinct odor) that are created by the sulfur-oxidizing aerobic cyanobacteria. Chemosynthetic bacteria need the H_2S for energy, and grow soon after these black spots do.

The bacteria that use light as their major energy source with some hydrogen sulfide are heterotrophic and the bacterium that uses hydrogen sulfide as its entire energy source (e.g., *Beggiatoa*) is chemotrophic

Scientists once thought that sunlight was the only source of energy for life and that photosynthesis was the only way to make food. It is now known that another source of energy for life is reduced chemicals from Earth's hot interior.

In the process of chemosynthesis, bacteria oxidize chemicals and use the liberated energy to combine hydrogen and carbon dioxide. This produces sugar in a biochemical process similar to photosynthesis. Unlike photosynthesis, chemosynthesis requires no light and can occur at the extreme temperatures and high pressures characteristic of the deep ocean environment. The chemosynthetic food web supports dense populations of animals. Life in these communities is based on energy available from oxidation-reduction reactions when circulating sea water leaches minerals from the hot rock. High temperatures and high concentrations of dissolved minerals in the seawater cause the formation of compounds such as hydrogen sulfide. Sulfur bacteria are the most prominent chemosynthetic bacteria in the region of hydrothermal vents.

Materials:

For each group:

- Black mud (enough to fill two graduated cylinders). See Preparation section.
- 8 g of $CaSO_4$ (Plaster of Paris: found in any hardware store)
- 2 jars, ice cream pails or large beakers for mixing
- Stirring rods or paint sticks for stirring a muddy mix
- Organic straw or filter paper bits. (Tear strips of lab filter paper or newspaper)
- 3 Liters (about 3 quarts) of pond, salty sea water or swamp water
- 0.5 grams baking soda (sodium bicarbonate: $CHNaO_3$)
- 2 multivitamin pills

- Mortar and pestle (to crush multi vitamins)
- Plastic wrap
- Rubber bands
- A light source that can stay on for six weeks or longer
- Tape and markers for labeling columns
- Flashlight with red cellophane on lighted end (can be attached with rubber band)

Two 500 or 1000 milliliter graduated cylinders or columns. (Preferably not glass cylinders, but clear enough to allow sunlight to positively affect the algae and bacteria. Polymethylpentene, PMP, are excellent choices for clarity and safety from breakage.)

Activity:

1. Add about four grams of $CaSO_4$ to enough mud to fill one graduated cylinder to a depth of about 8.0 cm (3.2 inches). Then dump it into a jar, ice cream pail or beaker and mix it thoroughly with the stirring rod or paint stick.

2. Place the straw or filter paper in the jar with the mud and mix gently. (It may help to add some pond or seawater here to ease stirring.)

3. Transfer the mixture back to the cylinder and add pond or seawater so that the mud is covered with at least 8 centimeters (3.2 in) of water.

4. Add to the cylinder 0.25 grams of baking soda and one crushed vitamin pill. Stir again to make sure all the air bubbles are gone.

5. Set the cylinder aside for 30 minutes to settle.

6. After 30 minutes, if more than two centimeters (0.8 in) of water have pooled at the top, pour off all but one centimeter (0.4 in). If there is less than one centimeter (0.4 in), add more pond water.

7. Repeat steps (1) through (6) for the other graduated cylinder.

8. Label the cylinders with your names.

9. Place one graduated cylinder in a darkened area where it will not be disturbed for at least six weeks. Place the second cylinder under the light source. (You may wish to store both set-ups in the same area with one cylinder in a box. This will help to keep both in similar conditions.)

10. Record smell, color, number of layers of mud, or any other observations.

11. For at least six weeks, examine the columns weekly and look for signs of bacterial growth. You may use a flashlight, covered with red cellophane, to examine the columns being grown in the dark. Record your observations.

12. At the end of the third week take samples for microscopic wet mounts observation from the following locations: (1) surface layers of water, (2) surface layers of the mud, (3) colored layer from the mud. Try using a pipette and be careful not to disturb the column.

13. Observe the wet mounts under high-power magnification, looking for cell shapes that would indicate the types of organisms present.

Extension and Follow-up Activity:

Dr. David Gallo, Director of Special Projects at the Woods Hole Oceanographic Institute specializes in photographing, cataloging and identifying the various organisms at deep sea hydrothermal vents. He has several brief and engaging TED Talk videos that can be used to have students' visual what this activity is attempting to simulate. Here are the video links:

Deep Ocean Mysteries and Wonders:

http://www.ted.com/talks/deep_ocean_mysteries_and_wonders.html

David Gallo on life in the deep oceans:

http://www.ted.com/talks/david_gallo_on_life_in_the_deep_oceans.html

David Gallo shows underwater astonishments:

http://www.ted.com/talks/david_gallo_shows_underwater_astonishments.html

NOAA Monterey Institute Chemosynthesis and Hydrothermal vent video and activities:

http://www.montereyinstitute.org/noaa/lesson05.html

Source:

Adapted from Orange County Marine Institute / San Juan Institute Activity Series and NASA at the *Visit an Ocean Planet website:* http://er.jsc.nasa.gov/seh/Ocean_Planet/activities/ts3enac2.pdf