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Thunder Bay Sinkholes 2008

Chemosysnthesis in the Classroom
(adapted from the 2003 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
For each student group:
- ❒ Directions for setting up Winogradsky columns from http://quest.arc.nasa.gov/projects/astrobiology/fieldwork/lessons/Winogradsky_5_8.pdf (and, optionally, video demonstrations listed under "Resources")
- ❒ Two 2-liter plastic soda bottles
- ❒ Black mud from a local river, lake, or estuary, approximately 2.5 l
- ❒ 2.5 l of water from each mud/sand location used
- ❒ 1 small bucket
- ❒ 250 ml graduated cylinder or 1 cup measure
- ❒ 1 paint stirrer or large spoon
- ❒ 1 sheet of newspaper
- ❒ 1 tablespoon powdered chalk
- ❒ One hard boiled egg yolk or one tablespoon calcium sulfate
- ❒ 1 set measuring spoons
- ❒ Aluminum foil or plastic wrap and rubber band
- ❒ Masking tape and markers for labeling columns
- ❒ (Optional) Pencil sharpener for crushing chalk
- ❒ (Optional) Mortar and pestle for making egg yolk powder
- ❒ (Optional) 1 lamp with 40- to 60-watt light bulb
- ❒ (Optional) Microscopes and materials for making wet mounts

Audiovisual 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
30

Key Words

Cold seeps
Methane hydrate ice
Chemosynthesis
Brine pool
Vestimentifera
Trophosome
Succession

Background Information

In June, 2001, the Ocean Explorer Thunder Bay ECHO Expedition was searching for shipwrecks in the deep waters of the Thunder Bay National Marine Sanctuary and Underwater Preserve in Lake Huron. But the explorers discovered more than shipwrecks: dozens of underwater sinkholes in the limestone bedrock, some of which were several hundred meters across and 20 meters deep. The following year, an expedition to survey the sinkholes found that some of them were releasing fluids that produced a visible cloudy layer above the lake bottom, and the lake floor near some of the sinkholes was covered by conspicuous green, purple, white, and brown mats.

Preliminary studies of the mats have found that where water is shallow (≤ 1.0 m) the mats are composed of green algae. In deeper (about 18 m) waters, mats are formed by filamentous purple cyanobacteria. Mats near the deepest (93 m) sinkholes are white or brown, but their composition is presently unknown. The appearance of mats near the deepest sinkholes is very similar to mats observed in the vicinity of cold seeps and hydrothermal vents in the deep ocean, which are often formed by chemosynthetic bacteria. These bacteria are able to obtain energy from inorganic chemicals, and are a food source for a variety of other organisms that inhabit cold seep and vent communities. Biological communities whose primary energy source comes from chemosynthesis are distinctly different from more familiar biological communities in shallow water and on land where photosynthetic organisms convert the energy of sunlight to food that can be used by other species. Hydrothermal vent and cold seep communities are home to many species of organisms that have not been found anywhere else on Earth, and the existence of chemosynthetic communities in the deep ocean is one of the major scientific discoveries of the last 100 years.

Scientists hypothesize that the source of the fluids venting from the Lake Huron sinkholes is the Silurian-Devonian aquifer beneath the lake's sediments. Aquifers are rocks and sediments that contain large amounts of water. Between 350 and 430 million years ago, during the Paleozoic era, shallow seas covered what is now the border between Canada and the United States between Minnesota and New York. Over thousands of years, sand, minerals, and sediments accumulated on the seafloor, and were gradually compressed to form sandstone, limestone and shale. About 1.8 million years ago, the Great Ice Age of the Pleistocene epoch began and continued until about 10,000 years ago. During this time, four major periods of glaciation occurred, separated by three interglacial periods. As the final glacial period came to a close, retreating glaciers along the U.S.-Canadian border revealed five huge lakes that we now know as the Laurentian Great Lakes. In the Great Lakes region, aquifers are found in deposits of sand and gravel left by glaciers, as well as in porous bedrocks (limestone and sandstone) that were formed much earlier in geologic time. Five major aquifers are recognized in this region: one near the land or lake floor surface (the surficial aquifer) and the others in deeper bedrock named for the geologic time periods when they were formed (the Cambrian-Ordovician, Silurian-Devonian, Mississippian, and Pennsylvanian aquifers). The bedrock that forms the Silurian-Devonian aquifer is primarily limestone and mineral formations from evaporating seawater. Both fresh and saline water are found in the Silurian-Devonian aquifer.

Sinkholes are common features where limestone is abundant, because limestone rocks are soluble in acid. Atmospheric carbon dioxide often dissolves in rainwater to form a weak acid (carbonic acid). Rainwater flowing over land surfaces may also pick up organic acids produced by decaying leaves and other once-living material. The resulting weak acid can slowly dissolve limestone rocks to form caves, springs, and sinkholes. Sinkholes on land are known recharge areas for the Silurian-Devonian aquifer (areas where water flows into the aquifer). But very little is known about the chemistry, geology, and biology of submerged sinkholes that may serve as vents for groundwater in the aquifer. Water samples collected near these sinkholes is very different from the surrounding lake, with much higher concentrations of sulfate, phosphorus, and particulate organic matter, as well as ten times more bacteria compared to nearby lake water. These observations suggest that submerged sinkholes may be biogeochemical "hot spots" inhabited by unusual and possibly unknown life forms. At the same time, water flow through submerged sinkholes depends upon recharge from land. This means that sinkhole ecosystems are likely to be very sensitive to changes in rainfall patterns that may accompany climate change, as well as human alterations of these landscapes surrounding recharge areas. These factors make understanding sensitive sinkhole ecosystems an urgent necessity.

Learning Procedure

1. To prepare for this lesson:
   Review introductory essays for the Thunder Bay Sinkholes 2008 Expedition at http://oceanexplorer.noaa.gov/explorations/08thunderbay/welcome.html

   If students do not have access to the internet, make copies of relevant materials on underwater robotic vehicles from the Web site referenced above.

2. Briefly introduce the Thunder Bay Sinkholes Expedition, highlighting the discovery of fluids emerging from sinkholes on the lake floor, and the variety of mats found in the vicinity of these sinkholes. Be sure students understand the concept of an aquifer, and that the mats are likely to be living organisms (algae and/or bacteria) that can serve as food for many other organisms. Point out that very little is known about the mats in Lake Huron or the biological communities they may support; but since their appearance is very similar to mats found in some deep ocean habitats, these habitats may provide clues for explorations of the Thunder Bay sinkholes.

   Lead a discussion of deep-sea chemosynthetic communities. Contrast chemosynthesis with photosynthesis. The "big picture" of chemosynthesis and photosynthesis is that they are both processes that organisms use to obtain energy needed for life functions (reproducing, locomotion, synthesizing tissues, etc.). Energy in living organisms is stored and transported in the form of adenosine triphosphate (ATP) molecules. The energy used to produce ATP comes from reactions that transfer electrons from an electron donor molecule to an electron acceptor molecule. When these reactions take place, the molecule that loses an electron is said to be "oxidized" and the molecule that gains an electron is said to be "reduced." One basic way to distinguish chemosynthesis from photosynthesis is the source of these electrons.

   In photosynthesis, light energy absorbed by pigments (e.g., chlorophyll) is transferred to electrons in the pigment molecule, and these electrons are transferred to other molecules in a series of oxidation-reduction reactions. What happens to the chlorophyll molecule that loses its electron? In some cases, the electron is eventually recycled to the chlorophyll molecule; a process called "cyclic photophosphorylation." In an alternative process called "noncyclic photophosphorylation" the electron is replaced by splitting another molecule through a process called "photolysis" (which means "light splitting"). The general equation for photosynthetic photolysis is

$H_2X + 2 \text{ photons} > 2e^- + 2H^+ + X$

"X" may be one of several elements. In the most familiar form of photosynthesis, "X" is oxygen, and the photosynthetic photolysis of water produces oxygen gas. In some purple bacteria, however, hydrogen sulfide is oxidized and particles of sulfur are produced. Note that while photosynthesis is often explained as noncyclic photophosphorylation and photolysis of water, some photosynthetic organisms use other pathways.

In chemosynthesis, electrons are also transferred between molecules to provide the energy needed for ATP production. The key difference is that light does not play a part in these reactions. A variety of electron donors are found in chemosynthetic systems; hydrogen sulfide is common in chemosynthetic organisms associated with hydrothermal vents, while methane is often the electron donor in cold seep communities (for a virtual tour of a cold seep community, visit http://www.bio.psu.edu/cold_seeps).

In both photosynthetic and chemosynthetic communities, a significant amount of the energy captured as ATP is used to synthesize organic molecules (note that highly simplified descriptions of photosynthesis imply that light energy is used to combine carbon dioxide and water to form glucose in a single reaction; but the reality is that many reaction sequences are involved). If an organism synthesizes organic molecules from inorganic compounds (such as carbon dioxide), then the organism is called "autotrophic." If an organism can only use organic compounds as "building blocks," then the organism is called "heterotrophic."

3. Tell students that their assignment is to investigate the growth of microbial communities in a Winogradsky (pronounced, "vin-oh-GRAD-ski") column, which was invented in the 1880's by Russian scientist Sergei Winogradsky.

   Have each student group follow procedures given at http://quest.arc.nasa.gov/projects/astrobiology/fieldwork/lessons/Winogradsky_5_8.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.

   If students are curious about the purpose of the materials used in their Winogradsky columns, here are some details:
   - A translucent container is needed to provide light to photosynthetic microbes. Excluding light favors the growth of chemosynthetic bacteria.
   - Mud and water are sources of microbes.
   - Newspaper is a source of cellulose that is degraded by anaerobic bacteria
   - Powdered chalk provides inorganic carbon (carbon dioxide) for synthesis of organic molecules.
   - Egg yolk or calcium sulfate provide a source of sulfur compounds that may be used as electron donors.

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 model 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/ – In the "Site Navigation" menu on the left, click "Ocean Science Topics," then "Habitats," then "Deep Sea" for links to resources about deep ocean ecosystems.

http://www2.vims.edu/bridge/noaa/ – The NOAA collection of education resources on a variety of science topics including oceanography, climate, coral reefs, fishes, and exotic species

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/08thunderbay/welcome.html to keep up to date with the latest Thunder Bay Sinkholes Expedition discoveries, and to find out what researchers are learning about these ecosystems.

2. For additional activities using Winogradsky columns, see "Resources," below.

3. 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/deep-sea/level-2/chemistry/ bacteria.html and http://pubs.usgs.gov/publications/text/dynamic.html#anchor19309449 are useful for this).

Multimedia Learning Objects

http://www.learningdemo.com/noaa/ Lesson 5 for interactive multimedia presentations and Learning Activities on Chemosynthesis and Hydrothermal Vent Life.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

Designing Tools for Ocean Exploration

http://oceanexplorer.noaa.gov/explorations/deepeast01/background/education/dehslessons1.pdf
(14 pages, 80k) (from the 2001 Deep East Expedition)

Focus: Ocean Exploration

In this activity, students will understand the complexity of ocean exploration, learn about the technological applications and capabilities required for ocean exploration, discover the importance of teamwork in scientific research projects; and will develop the abilities necessary for scientific inquiry.

Finding the Way

http://oceanexplorer.noaa.gov/explorations/deepeast01/background/education/dehslessons4.pdf
(10 pages, 628k) (from the 2001 Deep East Expedition)

Focus: Underwater Navigation (Physical Science)

In this activity, students will describe how the compass, Global Positioning System (GPS), and sonar are used in underwater explorations, understand how navigational tools can be used to determine positions and navigate in the underwater environment.

Living in Extreme Environments

http://oceanexplorer.noaa.gov/explorations/deepeast01/background/education/dehslessons5.pdf
(13 pages 140k) (from the 2001 Deep East Expedition)

Focus: Biological Sampling Methods (Biological Science)

In this activity, students will be introduced to four methods commonly used by scientists to sample populations, learn how to gather, record, and analyze data from a scientific investigation, consider what organisms need in order to survive; and understand the concept of the interdependence of organisms.

Submersible Designer

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

Focus: Deep Sea Submersibles

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

Rock Eaters of the Gulf of Alaska

http://oceanexplorer.noaa.gov/explorations/02alaska/background/edu/media/rock_eaters9_12.pdf
(8 pages, 104k) (from the 2002 Exploring Alaska's Seamounts Expedition)

Focus: Chemosynthetic microbes in basalt rocks (Chemistry, Biology, Earth Science)

In this activity, students will be able to compare and contrast the processes of photosynthesis and chemosynthesis, identify and describe sources of energy used by various organisms for chemosynthesis, and predict what chemosynthetic reactions might be possible in selected "extreme" environments.

Calling All Explorers. . . .

http://oceanexplorer.noaa.gov/explorations/02fire/background/education/media/ring_calling_explorers_9_12.pdf
(14 pages, 124k) (from the 2002 Submarine Ring of Fire Expedition)

Focus: Ocean Exploration - Recent explorers of deep-sea environments and the relationship between science and history

In this activity, students will learn what it means to be an explorer, both modern and historic; recognize that not all exploration occurs on land; understand the importance of curiosity, exploration, and the ability to document what one studies; gain insight into the vastness of unexplored places in the deep sea; and gain appreciation of science mentors and role models.

Mystery of the Megaplume

http://oceanexplorer.noaa.gov/explorations/02fire/background/education/media/ring_mystery_9_12.pdf
(7 pages, 104k) (from the 2002 Submarine Ring of Fire Expedition)

Focus: Hydrothermal vent chemistry (Chemistry, Earth Science, Physical Science)

In this activity, students will be able to describe hydrothermal vents and characterize vent plumes in terms of physical and chemical properties, describe tow-yo operations and how data from these operations can provide clues to the location of hydrothermal vents, and interpret temperature anomaly data to recognize a probable plume from a hydrothermal vent.

Candy Chemosynthesis
http://oceanexplorer.noaa.gov/explorations/02fire/background/education/media/ring_candy_chemo_9_12.pdf
(10 pages, 208k) (from the 2002 Submarine Ring of Fire Expedition)

Focus: Biochemistry of hydrothermal vents (Biology, Chemistry)

In this activity, students will differentiate between requirements for life in extreme environments and other environments and will use models to create a visual image of chemicals involved in autotrophic nutrition.

From the Gulf of Mexico to the Moons of Jupiter
http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_moons.pdf
(6 pages, 46468k) (from the 2002 Gulf of Mexico Expedition)

Focus: Adaptations to unique or "extreme" environments (Earth Science)

In this activity, 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 will be able to compare physical conditions in deep-sea "extreme" environments to conditions thought to exist on selected moons of Jupiter. Students will also discuss the relevance of chemosynthetic processes in cold seep communities to the possibility of life on other planetary bodies.

Biochemistry Detectives
http://oceanexplorer.noaa.gov/explorations/02mexico/background/edu/media/gom_biochem.pdf
(8 pages, 480k) (from the 2002 Gulf of Mexico Expedition)

Focus: Biochemical clues to energy-obtaining strategies (Chemistry)

In this activity, 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 ^{13}C isotope values to draw inferences about energy-obtaining strategies used by organisms in cold-seep communities.

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

Focus: Growth rate and age of species in cold-seep communities (Life Science)

In this activity, 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.

Where Did They Come From?

http://oceanexplorer.noaa.gov/explorations/05galapagos/background/edu/media/05galapagos_biogeography.pdf
(7 pages, 196k) (from the 2005 GalAPAGoS: Where Ridge Meets Hotspot Expedition)

Focus: Species variation in hydrothermal vent communities (Life Science)

In this activity, students will define and describe biogeographic provinces of hydrothermal vent communities, identify and discuss processes contributing to isolation and species exchange between hydrothermal vent communities, and discuss characteristics which may contribute to the survival of species inhabiting hydrothermal vent communities.

The Benthic Drugstore

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

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.

Watch the Screen!

http://oceanexplorer.noaa.gov/explorations/03bio/background/edu/media/Meds_WatchScreen.pdf
(5 pages, 428k) (from the 2003 Medicines from the Deep Sea Expedition)

Focus: Screening natural products for biological activity (Life Science)

In this activity, students will be able to explain and carry out a simple process for screening natural products for biological activity, and will be able to infer why organisms such as sessile marine invertebrates appear to be promising sources of new drugs.

C.S.I. on the Deep Reef (Chemotrophic Species Investigations, That Is)

http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_csi.pdf
(6 pages, 444k) (from the 2003 Gulf of Mexico Deep Sea Habitats Expedition)

Focus: Chemotrophic organisms (Life Science/Chemistry)

In this activity, students will describe at least three chemotrophic symbioses known from deep-sea habitats and will identify and explain at least three indicators of chemotropic nutrition.

My Wet Robot

http://oceanexplorer.noaa.gov/explorations/06greece/background/edu/media/wet_robot.pdf
(7 pages, 260 kb) (from the PHAEDRA 2006 Expedition)

Focus: Underwater Robotic Vehicles

In this activity, students will be able to discuss the advantages and disadvantages of using underwater robots in scientific explorations, identify key design requirements for a robotic vehicle that is capable of carrying out specific exploration tasks, describe practical approaches to meet identified design requirements, and (optionally) construct a robotic vehicle capable of carrying out an assigned task.

The Roving Robotic Chemist

http://oceanexplorer.noaa.gov/explorations/06greece/background/edu/media/robot_chemist.pdf
(14 pages, 440 kb) (from the PHAEDRA 2006 Expedition)

Focus: Mass Spectrometry (Chemistry)

In this lesson, students will be able to explain the basic principles underlying mass spectrometry, discuss the advantages of in-situ mass spectrometry, explain the concept of dynamic re-tasking as it applies to an autonomous underwater vehicle, and develop and justify a sampling strategy that could be incorporated into a program to guide an AUV searching for chemical clues to specific geologic features.

Where's My 'Bot?
http://oceanexplorer.noaa.gov/explorations/08bonaire/background/edu/media/wheresbot.pdf
(17 pages, 492kb) (from the Bonaire 2008: Exploring Coral Reef Sustainability with New Technologies Expedition)

Focus: Marine Navigation (Earth Science/Mathematics)

In this activity, students will estimate geographic position based on speed and direction of travel, and integrate these calculations with GPS data to estimate the set and drift of currents.

Outta Gas (from the 2007: Exploring the Inner Space of the Celebes Sea Expedition)
http://oceanexplorer.noaa.gov/explorations/07philippines/background/edu/media/outtagas.pdf
(10 pages, 300 kb)

Focus: Gas Laws (Chemistry/Physics)

In this activity, students will define Boyle's Law, Charles' Law, Gay-Lussac's Law, Henry's Law, and Dalton's Law and will be able to solve practical problems related to SCUBA diving.

Other Resources

The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.

http://oceanexplorer.noaa.gov/explorations/08thunderbay/welcome.html – Follow the Thunder Bay Sinkholes 2008 Expedition daily as documentaries and discoveries are posted each day for your classroom use

http://celebrating200years.noaa.gov/edufun/book/welcome.html#book – A free printable book for home and school use introduced in 2004 to celebrate the 200th anniversary of NOAA; nearly 200 pages of lessons focussing on the exploration, understanding, and protection of Earth as a whole system

http://oceanexplorer.noaa.gov/projects/thunderbay01/thunderbay01.html – Web site for the 2001 Ocean Explorer Expedition to survey "Shipwreck Alley" in Thunder Bay, Lake Huron

http://gvsu.edu/wri/envbio/biddanda/sinkhole.htm – 1 minute ROV video clip of conspicuous white benthic mats interspersed with the brownish mats characterizing the lake floor in the vicinity of the sinkhole, and a dark cloudy nepheloid-like plume layer prevailing just over the site of submarine groundwater seepage

ftp://ftp.glerl.noaa.gov/eos/El_Cajon_Boils_Short.wmv – Underwater video of El Cajon "boils"

ftp://ftp.glerl.noaa.gov/eos/Purple_Mats_40_sec.wmv – Underwater video of the purple benthic mats from the Middle Island Sinkhole

Biddanda, B. A., D. F. Coleman, T. H. Johengen, S. A. Ruberg, G. A. Meadows, H. W. VanSumeren, R. R. Rediske, and S. T. Kendall. 2006. Exploration of a submerged sinkhole ecosystem in Lake Michigan. Ecosystems 9:828-842. Available online at http://www.glerl.noaa.gov/pubs/fulltext/2006/20060020.pdf

Ruberg, S.A., D.F. Coleman, T.H. Johengen, G.A. Meadows, H.W. VanSumeren, G.A. LANG, and B.A. Biddanda. 2005. Groundwater plume mapping in a submerged sinkhole in Lake Huron. Marine Technology Society Journal 39(2):65-69. Available online at http://www.glerl.noaa.gov/pubs/fulltext/2005/20050038.pdf

http://quest.arc.nasa.gov/projects/astrobiology/fieldwork/lessons/demo.html – Five-minute Quick Time video demonstrating how to build a Winogradsky Column, from NASA Quest

http://quest.arc.nasa.gov/projects/astrobiology/fieldwork/lessons/Winogradsky_5_8.pdf – "Building a Winogradsky Column: An Educator Guide with Activities in Astrobiology;" 27-page educator guide from NASA Quest

http://www.woodrow.org/teachers/bi/2000/Winogradsky_Column/winogradsky_column.html – "Investigating Bacteria with the Winogradsky Column;" instructor's guide to teaching about microbial biodiversity; includes detailed discussions and isolation techniques for microbial species commonly found in Winogradsky columns

http://www.kn.pacbell.com/wired/fil/pages/listwindograja.html – Internet hotlist on the Windogradsky column by Jane Orbuch, San Lorenzo Valley High School

http://www.biology.ed.ac.uk/research/groups/jdeacon/microbes/winograd.htm – "The Microbial World: Winogradsky Column- Perpetual Life in a Tube," by Jim Deacon, The University of Edinburgh Institute of Cell and Molecular Biology; designed to teach undergraduate students a simple model system of nutrient cycling in natural waters

http://www.sumanasinc.com/webcontent/anisamples/microbiology/winogradsky.html – Five-minute animated tutorial describing Winogradsky columns

http://www.personal.psu.edu/faculty/j/e/jel5/biofilms/winogradsky.html – Exercise about Winogradsky Columns with emphasis on microbial biofilms; by John Lennox, Pennsylvania State University

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 3.

The ocean is a major influence on weather and climate.

Fundamental Concept e. The ocean dominates the Earth's carbon cycle. Half the primary productivity on Earth takes place in the sunlit layers of the ocean and the ocean absorbs roughly half of all carbon dioxide added to the atmosphere.

Fundamental Concept f. The ocean has had, and will continue to have, a significant influence on climate change by absorbing, storing, and moving heat, carbon and water.

Essential Principle 4.

The ocean makes Earth habitable.

Fundamental Concept a. Most of the oxygen in the atmosphere originally came from the activities of photosynthetic organisms in the ocean.

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 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 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 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 this lesson.
Please send your comments to:
oceanexeducation@noaa.gov

For More Information

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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