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Thunder Bay Sinkholes 2008

The Cells That Changed the World
(adapted from the 2003 Windows to the Sea Expedition)

Focus
Cyanobacteria

Grade Level
9-12 (LIfe Science)

Focus Question
What are cyanobacteria, and how have they been important to life on Earth?

Learning Objectives
Students will compare and contrast cyanobacteria with eukaryotic algae.

Students will discuss differences in photosynthesis by cyanobacteria and green algae.

Students will discuss the role of cyanobacteria in the development of life on Earth.

Materials
- ❒ Copies of "Cyanobacteria Discovery Worksheet," one copy for each student or student group
- ❒ (Optional) Cultures of live cyanobacteria and materials for microscopic examination

Audiovisual Materials
None

Teaching Time
One-half 45-minute class period for introduction, one to two hours for research outside of class, and one 45-minute class period for student reports and discussion

Seating Arrangement
Classroom style or groups of three to four students

Maximum Number of Students
30

Key Words
Cold seeps
Cyanobacteria
Photosynthesis
Chemosynthesis

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.

Preliminary studies show that the composition of the colored mats changes with water depth.

Mats in shallow (≤ 1.0 m) water are composed of green algae. Mats near the deepest (93 m) sinkholes, where there is little or no light, may be composed of bacteria, but their exact composition is presently unknown. Sinkholes in intermediate (about 18 m) depths are surrounded by mats formed by filamentous purple cyanobacteria. This group of microbes includes some of Earth's oldest living species, and are believed to be the "architects" of the modern Earth atmosphere as well as the ancestors of chloroplasts and mitochondria found in the cells of eukaryotic organisms.

In this lesson, students will explore some aspects of Cyanobacteria biology.

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

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. Ask for possible reasons why mats at different depths contain different organisms. Variations in the type of fluids venting from sinkholes is one possibility. Another is declining sunlight penetration with increasing depth. Tell students that the shallowest sinkholes, with abundant light, are surrounded by mats containing green algae. The deepest sinkholes, with almost no light, have mats that probably contain bacteria (though that isn't certain as yet). Mats near sinkholes at depth of approximately 18 m contain "blue-green algae." Tell students that their assignment is to find out more about "blue-green algae," using questions on the "Cyanobacteria Discovery Worksheet" as a guide for inquiry.

3. Provide each student or student group with a copy of the "Cyanobacteria Discovery Worksheet," and assign one of the following species of cyanobacteria:
   Anabaena
   Hapalosiphon
   Lyngbya
   Microcystis
   Nodularia
   Nostoc
   Phormidium
   Spirulina

   Alternatively, you may want to obtain live cultures of these or other cyanobacteria species from biological supply companies and have students make drawings from microscopic examination.

4. Lead a discussion of students' answers to questions on the worksheet. The following points should be included.
   - Although they are often called "blue-green algae," cyanobacteria are not algae; they are bacteria. But they are the only bacteria capable of photosynthesis and in this respect are similar to algae and higher plants.

   - Cyanobacteria are found throughout the world in varied habitats, including tree bark, rocks, soil, fresh and salt waters, and in symbiotic relationships with fungi to form lichens.

   - Stromatolites are fossilized mounds of cyanobacteria. Although cyanobacteria are unicellular, many species grow in colonies or filaments that may be quite large. Stromatolites were widespread on Earth during the Proterozoic Era, and are the first reefs found in the fossil record.

   - Stromatolites are the oldest known fossils, more than 3.5 billion years old.

- During the Archaean Eras before cyanobacteria were abundant, Earth's atmosphere contained very little oxygen and was not suitable for life as we know it today. The modern oxygen atmosphere was generated by large populations of cyanobacteria during the Archaean and Proterozoic Eras.

- The endosymbiont theory hypothesizes that certain organelles found in the cells of eukaryotic organisms are the evolutionary result of a symbiotic relationship between primitive eukaryotic cells and bacteria living inside those cells. According to this theory, the chloroplasts of modern plants originated as symbiotic cyanobacteria (or their ancestors) that lived inside the cells of primitive plant. Similarly, the mitochondria of present-day eukaryotes were derived from other symbiotic bacteria.

- Cyanobacteria are one of very few groups of organisms that can convert atmospheric nitrogen into an organic form that can be used by plants. This process of "nitrogen fixation" cannot occur in the presence of oxygen, but cyanobacteria have specialized cells called heterocysts with a thickened wall that maintains an anaerobic environment inside the cell.

- In addition to creating Earth's oxygen atmosphere, providing the precursors for eukaryotic cell organelles, and "fixing" atmospheric nitrogen, a large proportion of today's oil deposits probably resulted from the decay of Precambrian cyanobacteria.

- *Spirulina* is a cyanobacterium that has long been valued as a food source because of its high protein content. *Spirulina* was regularly eaten by the Aztecs, appears in a variety of Oriental dishes, and is common in many "health food" stores.

- Microcystins, Cylindrospermopsins, and Nodularin are toxins produced by cyanobacteria that may poison humans and other animals. Cyanobacteria that produce toxins are generally freshwater or brackish water species that form outbreaks called '"blooms," usually in the warmer months of the year. Accumulations of algal scum or foam can be highly toxic to livestock and humans.

- Cyanobacteria use the same photosynthetic pathway as eukaryotic cells such as algae and higher plants. Under anaerobic conditions, they are also able to use electron donors other than water (e.g., hydrogen sulfide).

Students' drawings should indicate that cyanobacteria have cell walls and variously colored pigments. These pigments are not contained in chloroplasts (as in true algae), but rather in thalakoid membranes inside the cell wall.

The Bridge Connection

www.vims.edu/bridge/geology.html

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 brief essay on how cyanobacteria might affect them personally, both positively and negatively.

Connections to Other Subjects

English/Language Arts, Biology, Chemistry

Assessment

Students reports provide opportunities for assessment.

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 class activities involving cyanobactera, see http://microbes.arc.nasa.gov/download/pdf/Cyanobacteria_Races.pdf and http://microbes.arc.nasa.gov/download/pdf/Microscope_Activity_Plan.pdf

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://www-cyanosite.bio.purdue.edu/index.html – A webserver for cyanobacterial research from the Department of Biological Sciences at Purdue University

http://www.biology.ed.ac.uk/research/groups/jdeacon/microbes/cyano.htm#Top – Web page on the role of cyanobacteria in environmental processes from Jim Deacon, Institute of Cell and Molecular Biology, The University of Edinburgh

http://microbes.arc.nasa.gov/download/pdf/Cyanobacteria_Races.pdf – "Cyanobacteria Motility Experiment for a Classroom;" by Robin Bucaria, Dartmouth Middle School and Dr. Brad Bebout, NASA Ames Research Center

http://microbes.arc.nasa.gov/download/pdf/Microscope_Activity_Plan.pdf – "Day One Microscope Activity" using cyanobacteria; by Robin Bucaria, Dartmouth Middle School and Dr. Brad Bebout, NASA Ames Research Center

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
- Structure and properties of matter
- Chemical reactions

Content Standard C: Life Science
- The cell
- Biological evolution
- 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

Content Standard F: Science in Personal and Social Perspectives
- Natural resources
- Environmental quality

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

Student Handout

Cyanobacteria Discovery Worksheet

1. Cyanobacteria are sometimes called "blue-green algae." Are they really algae? What do they have in common with algae?

2. Where are cyanobacteria found in nature?

3. What are stromatolites?

4. How old are the oldest stromatolites?

5. What are three major ways that cyanobacteria have influenced life on Earth? Hints: (a) What was Earth's atmosphere like before cyanobacteria became abundant? (b) What is the endosymbiont theory? (c) What are heterocysts?

6. What is *Spirulina* and what is its value to humans?

7. What are Microcystins, Cylindrospermopsins, and Nodularin, and what is their relationship to cyanobacteria?

8. What is the difference between photosynthesis by cyanobacteria and photosynthesis by green algae?

9. Prepare a drawing of your assigned cyanobacterium, based upon photographs from the Internet (there are hundreds available for each genus). Indicate features that distinguish your organism from other bacteria and from true algae.