Submarine Ring of Fire 2012: NE Lau Basin Expedition

The Mysterious Microbial Mats

Image captions/credits on Page 2.

lesson plan

Focus

Ecological role of microbial mats in hydrothermal vent ecosystems

Grade Level

5-6 (Life Science)

Focus Question

What is the role of microbial mats in hydrothermal vent ecosystems?

Learning Objectives

- Students will plan an investigation using a model ecosystem to explain some of the components of an anaerobic ecosystem.
- Students will construct explanations for the potential role of microbial mats in hydrothermal vent ecosystems.

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
- ❑ 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

Audio-Visual Materials

- ❑ (Optional) Interactive whiteboard

Teaching Time

Two 45-minute class periods to design and 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 two to three students

Maximum Number of Students

30

Key Words

Ring of Fire
Lau Basin
Microbial mat
Chemosynthesis
Winogradsky column

Background Information

NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

The Submarine Ring of Fire is an arc of active volcanoes that partially encircles the Pacific Ocean Basin, including the Lau Basin, Kermadec and Mariana Islands in the western Pacific, the Aleutian Islands between the Pacific and Bering Sea, the Cascade Mountains in western North America, and numerous volcanoes on the western coasts of Central America and South America. These volcanoes result from the motion of large pieces of the Earth's crust known as tectonic plates. Along mid-ocean ridges (also called spreading centers), tectonic plates are moving apart. Molten rock rises from Earth's mantle into the gap between the separating plates and produces extensive lava flows. Along oceanic trenches, tectonic plates are colliding so that one plate is descending below another plate. This process is called subduction. The subducting plate is heated as it descends into Earth's mantle, causing gases and water to be released from the heated rock. These gases and water lower the melting temperature of the hot mantle rocks, so that magma (molten rock) is produced. The magma rises and accumulates in areas called magma chambers, and then erupts to form volcanoes.

Beginning in 2002, NOAA Ocean Exploration expeditions have undertaken systematic mapping and study in previously unexplored areas of the Submarine Ring of Fire. Please see the Expedition Education Module for the Submarine Ring of Fire 2012: NE Lau Basin

Images from Page 1 top to bottom:
Tectonic features of the Lau Basin overlaid on satellite altimetry data, modified from Martinez and Taylor Geophysical Monograph 166, 2006.See page 3 for larger image and more information. Image courtesy of NOAA Vents Program.
http://oceanexplorer.noaa.gov/explorations/12fire/background/plan/media/tectonic_features.html

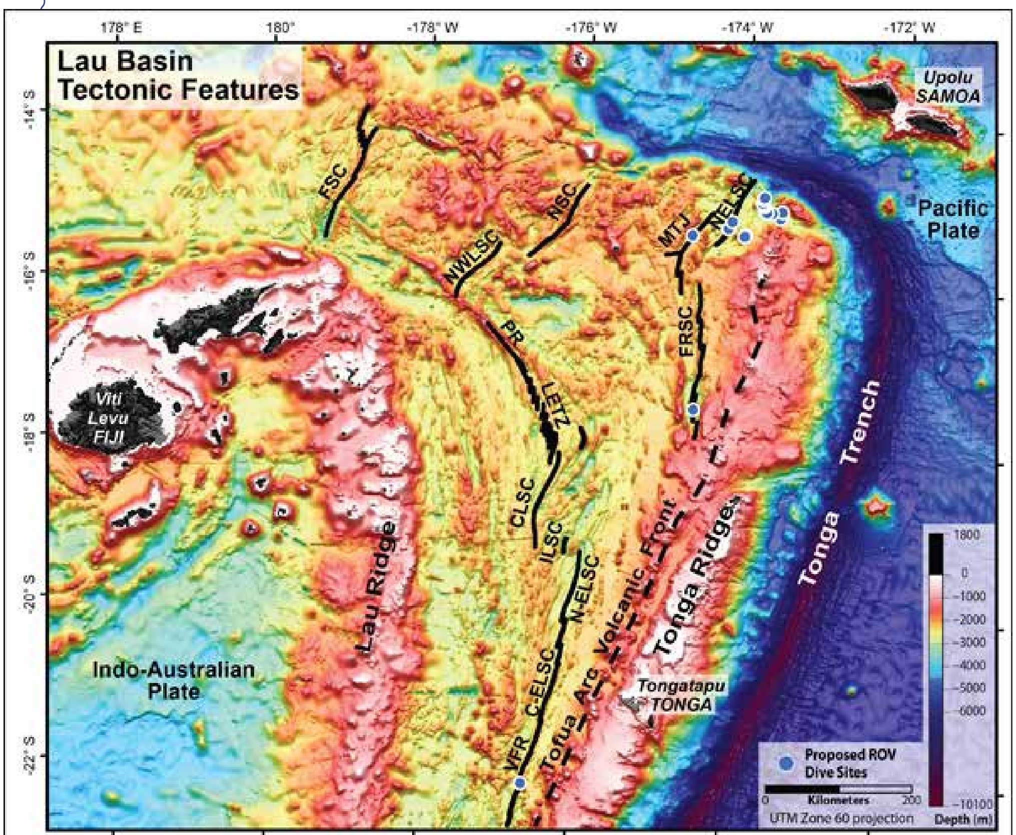
A closeup of a Conductivity, Temperature, Depth profiler (CTD), the primary tool used to map hydrothermal plumes. A ring of plastic sampling bottles surrounds the CTD. The bottles are closed on command from the ship, usually when a scientist monitoring the sensors sees strong evidence of a plume. CTD sensors are visible at the bottom of the pressure case. Image courtesy of NOAA Vents Program.
http://oceanexplorer.noaa.gov/explorations/12fire/background/plumes/media/ctd_closeup.html

An eruption near the summit of the West Mata volcano. The blast (top left) is intense, and broken rock can be seen in the plume. Three glowing bands of superheated "pillow" lava (seen below the blast) are flowing down the volcano's slope. Image courtesy of NSF and NOAA.
http://oceanexplorer.noaa.gov/explorations/09laubasin/logs/hires/eruptive_blast_hires.jpg

The Quest 4000 remotely operated vehicle will be utilized on the SRoF'12 – NE Lau expedition, providing high-definition video and seafloor sampling capabilities. Image courtesy of MARUM.
http://oceanexplorer.noaa.gov/explorations/12fire/background/plan/media/quest4000.html

Expedition at http://oceanexplorer.noaa.gov/explorations/12fire/background/edu/edu.html for additional information and links to information, resources, and lesson plans from these expeditions.

The Northeastern Lau Basin is very unusual, because in addition to volcanic activity associated with the subduction of the Pacific Plate beneath the Indo-Australian Plate, there are also areas in which the Indo-Australian Plate seems to be pulling apart; and these areas are also rich in volcanic and hydrothermal activity. Preliminary surveys of the area between 2008 and 2011 have shown that the Northeastern Lau Basin is one of the most concentrated areas of active submarine volcanism and hot springs anywhere on Earth.

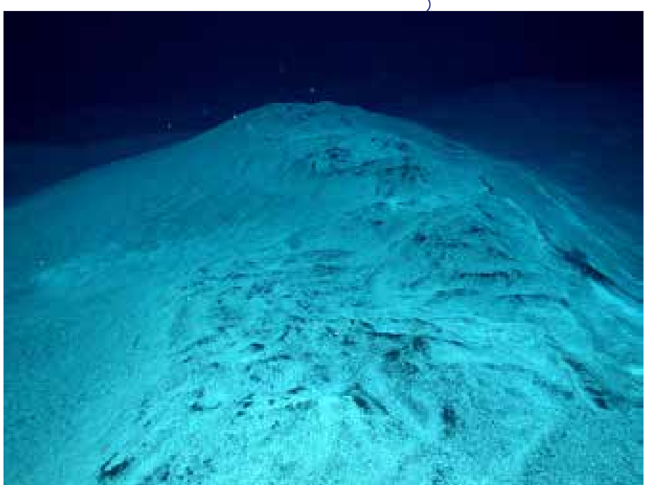


Tectonic features of the Lau Basin overlaid on satellite altimetry data, modified from Martinez and Taylor Geophysical Monograph 166, 2006. The Spreading centers and ridges are shown with black solid lines: Valu Fa Ridge (VFR), Central Eastern Lau Spreading Center (C-ELSC), Intermediate Lau Spreading Center (ILSC), Central Lau Spreading Center (CLSC), Lau Extensional Transform Zone (LETZ), Peggy Ridge (PR), North-West Lau Spreading Center (NWLSC), Niuafo'ou Spreading Center (NSC), Futuna Spreading Center (FSC), Mangatolu Triple Junction (MTJ), Fonualei Rift and Spreading Center (FRSC), North-East Lau Spreading Center (NELSC). Tonga Trench, ridges and tectonic plates are also noted. Image courtesy of NOAA Vents Program.
http://oceanexplorer.noaa.gov/explorations/12fire/background/plan/media/tectonic_features.html

The primary objective of the Submarine Ring of Fire 2012: NE Lau Basin Expedition is to explore and characterize the unique ecosystems in the NE Lau basin through examination of their geology, chemistry, and macro- and microbiology.

Underwater volcanism produces hot springs in the middle of cold, deep ocean waters. These springs (known as hydrothermal vents) were first discovered in 1977 when scientists in the submersible *Alvin* visited an oceanic spreading ridge near the Galapagos Islands, and made one of the most exciting discoveries in 20th century biology. Here they found warm springs surrounded by large numbers of animals that had never been seen before. Since they were first discovered, sea-floor hot springs around spreading ridges have been intensively studied. In contrast, the hydrothermal systems around convergent plate boundaries are relatively unexplored.

The large numbers of unusual animals found around hydrothermal vents has impressed many ocean explorers, but equally impressive is the unusually high biomass and fast growth rates of microscopic organisms that can form large mats around the vents. These thriving biological communities were a complete surprise, because it had been assumed that food energy resources would be scarce in an environment without sunlight to support photosynthesis. Hydrothermal vent communities, however, are based on a different source of energy: the chemical energy contained in hydrothermal vent fluids.



Microbial mats coated in white sulfate material were observed and sampled at several vent sites at West Mata in 2009. These mats were dominated by Epsilonproteobacteria which is a class of bacteria often associated with sulfur oxidation in marine environments. Image courtesy of NOAA /NSF/WHOI.
http://oceanexplorer.noaa.gov/explorations/12fire/background/microbio/media/mat_meadow.html

Photosynthesis and chemosynthesis are similar in that they are both processes that provide energy needed to form molecules that can serve as energy sources (food) for living organisms. This energy is captured and stored in other molecules, and is moved from one molecule to another molecule when electrons are transferred between the molecules. These transfers take place in a series of reactions called an electron transport chain.

Photosynthesis begins when a photon of radiant energy from the sun strikes a molecule of chlorophyll or other photosynthetic pigment. This energy causes the photosynthetic pigment molecule to release an electron that is captured by another organic molecule. This molecule releases an electron to a third organic molecule, and the process continues through several other molecules. Each time an electron is transferred, the molecule that gains the electron also gains energy; and the molecule that loses the electron loses energy. The last molecule in the chain keeps the electron, and has a higher energy content than before it received the electron. Some energy is lost each time an electron moves from one molecule to another, so the last molecule in the chain contains less energy than the energy of the photon that started the process. The photosynthetic pigment regains its lost electron from a water molecule through a series of reactions called photolysis that releases oxygen gas as a by-product. The energy produced by the series of electron transfers is used by photosynthetic organisms to convert carbon dioxide into organic molecules (such as sugars) that can serve as energy sources (food) needed by living organisms.

In chemosynthesis, the electron transport chain begins with the loss of an electron from a substance such as hydrogen sulfide or methane.

Syringe sampler used by ROV manipulators to collect microbial mat samples. Image courtesy of NOAA/NSF/WHOI.
http://oceanexplorer.noaa.gov/explorations/12fire/background/pharmacology/media/syringe_sampler.html

As in photosynthesis, the electron is passed along an electron transport chain, and the energy produced by a series of electron transfers is used by chemosynthetic organisms to convert carbon dioxide into molecules that can serve as energy sources (food) for living organisms. Known chemosynthetic organisms from deep-sea environments are bacteria or Archaea. These microbes often are the basis of complex food webs, and are sometimes referred to as "chemautotrophic" because they feed themselves using energy from chemical compounds.

When an atom or molecule loses an electron it is said to be oxidized, and when an atom or molecule gains an electron it is said to be reduced. A reducing substance is a substance that reduces; in other words, it donates electrons. Similarly, an oxidizing substance is a substance that oxidizes; that is, it receives electrons (note that the terms oxidation, reduction, and redox may also be used in slightly different ways for some types of chemistry, but these distinctions are not important for this discussion). Most of the chemicals that are commonly found in hydrothermal vent fluids are highly reduced. In other words, they are electron-rich. This means that these chemicals can provide a source of electrons for chemosynthetic electron transport chains. Most chemoautotrophic bacteria have evolved to use specific chemicals as a source of electrons. For this reason, microbial communities at hydrothermal vents can be characterized by the types of electron donors that are present in the hydrothermal fluids that nourish these communities.

Laboratory cultures of deep-sea vent microbes: isolation and purification of organisms on solid agar media. Image courtesy of NOAA/NSF/WHOI.
http://oceanexplorer.noaa.gov/explorations/12fire/background/pharmacology/media/lab_cultures.html

Sulfur compounds are probably the most common electron donors at hydrothermal vents where vent fluids are extremely hot (around 300° C). Other compounds at these vents that may also provide energy for chemautotrophs include hydrogen gas, methane, and carbon monoxide. At vents where hydrothermal fluids have lower temperatures, vent fluids often contain reduced metal compounds that can be a source of electrons for chemautotrophs. Compounds containing iron are one example, and microbes that use these compounds as an energy source may form conspicuous reddish-brown mats whose color is the result of large quantities of oxidized iron (rust). For more information about chemautotrophs and microbial mats at hydrothermal vents, please see the microbiology essay linked from http://oceanexplorer.noaa.gov/explorations/12fire/background/laubasin/laubasin.html.

In this lesson, students will create a model ecosystem to explain some components of chemosynthetic communities and the potential role of microbial mats in hydrothermal vent ecosystems.

Learning Procedure

1. To prepare for this lesson:
   a. Read the mission plan and Microbiology background essay for the Submarine Ring of Fire 2012: NE Lau Basin Expedition at http://oceanexplorer.noaa.gov/explorations/12fire/background/laubasin/laubasin.html. You may also want to review 3D imagery and video fly-throughs (also linked from this page) and/or images of microbial mats (http://oceanexplorer.noaa.gov/okeanos/explorations/ex1103/logs/dailyupdates/media/movies/0716_microbial_mat_video.html; http://oceanexplorer.noaa.gov/explorations/05fire/logs/april22/media/orange_mat.html; http://oceanexplorer.noaa.gov/explorations/09laubasin/logs/summary/media/shrimp_summit.html).

   b. Review procedures for setting up Winogradsky columns provided in Step 4. You may also want to review other resources linked from http://serc.carleton.edu/microbelife/topics/special_collections/winogradsky.html. In particular, *Investigating Bacteria with the Winogradsky Column*, by Brian Rogan (http://www.woodrow.org/teachers/bi/2000/Winogradsky_Column/winogradsky_column.html), provides detailed explanations of procedures and discusses a variety of ways to modify the basic procedure to produce extremophile microbes and to isolate and culture some of the common organisms that grow in Winogradsky systems. While it is not necessary to implement all of these alternatives, it will be helpful for educators to understand them as a basis for assisting students with the design portion of this lesson. Another useful resource is *Exploring Biocomplexity in Aquatic Sediments*, by Jennifer Lamkie and Craig Phelps (http://www.envsci.rutgers.edu/~phelps/winogradsky.htm) from Rutgers University. This is a series of lessons adapted for middle school students that use a version of the Winogradsky column to show how living things influence the physical environment and vice versa.

   c. (Optional) Download one or more images of Winogradsky columns (an image search on "Winogradsky column" will produce many examples).

2. Briefly introduce the Submarine Ring of Fire 2012: NE Lau Basin Expedition. If students are not familiar with plate tectonics and time permits, you may wish to use some or all of Multimedia Discovery Missions Lessons 1, 2 and 4, which include interactive multimedia presentations and Learning Activities on Plate Tectonics, Mid-Ocean Ridges, and Subduction Zones [http://oceanexplorer.noaa.gov/edu/

learning/welcome.html].

3. Lead a discussion of hydrothermal vent ecosystems, emphasizing the role of chemautotrophs. 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.). One basic way to distinguish chemosynthesis from photosynthesis is the source of this energy. In photosynthesis, the sun is the energy source; in chemosynthesis, energy in chemical compounds is the source.

4. 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.

   Explain the basic concept of the Winogradsky column, and review set-up procedures given at http://quest.arc.nasa.gov/projects/astrobiology/fieldwork/lessons/Winogradsky_5_8.pdf. You may want to show one or more images of Winogradsky columns downloaded in Step 1c. Discuss the following details about the purpose of the materials used in students' Winogradsky columns:
   - 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.

   Tell students that the first part of their assignment is to design a Winogradsky column that will favor the growth of chemosynthetic bacteria. This will require thought about conditions that favor chemosynthetic bacteria, but do not favor photosynthetic organisms. Students should realize that excluding light from a Winogradsky column will produce these conditions. Depending upon curriculum objectives, available time, and student abilities, you may also want to challenge students to consider additional design requirements that might favor the growth of certain types of chemosynthetic bacteria, such as iron-reducing bacteria instead of sulfur-reducing bacteria. The sources cited in Step 1 will provide some ideas if you want to pursue this option.
   Students should submit a written design plan, including a sketch of their proposed design. You may want to allow enough time for

students to do some independent research on Winogradsky columns to expand their thinking about the assignment.

5. When you have approved proposed designs, have students proceed with the construction of their designed column, as well as a column that will be exposed to a light source (but not 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.

6. 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.

   Ask students what their observations about Winogradsky columns suggest about the role of microorganisms in hydrothermal vent ecosystems. Be sure students understand that microorganisms, particularly bacteria, are a key player in chemosynthetic ecosystems because they are often the organisms that actually convert energy from inorganic chemicals into organic molecules that other species can use as a food (energy) source.

The BRIDGE Connection

www.vims.edu/bridge/ – In the menu on the left, scroll over "Ocean Science Topics," then "Habitats," then click "Deep Sea," for links to information and activities about hydrothermal vents and deep ocean ecosystems.

The "Me" Connection

Have students write a short essay on why chemosynthetic ecosystems 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

Assessment

Students' responses to *Investigation Guide* questions and class discussions provide opportunities for assessment.

Extensions

1. Visit http://oceanexplorer.noaa.gov/explorations/12fire/background/laubasin/laubasin.html. for more information and resources related to the Submarine Ring of Fire 2012: NE Lau Basin Expedition.

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

Multimedia Discovery Missions

http://oceanexplorer.noaa.gov/edu/learning/welcome.html Lessons 1, 2, 4, and 5 for interactive multimedia presentations and Learning Activities on Plate Tectonics, Mid-ocean Ridges, Subduction Zones and Chemosynthesis and Hydrothermal Vent Life.

Other Relevant Lesson Plans from NOAA's Ocean Exploration Program

The Biggest Plates on Earth
(from the New Zealand America Submarine Ring of Fire 2007 Expedition)
http://oceanexplorer.noaa.gov/explorations/07fire/background/edu/media/plates.pdf

Focus: Plate tectonics - movement of plates, results of plate movement, and magnetic anomalies at spreading centers (Physical Science/Earth Science)

Students describe the motion of tectonic plates and differentiate between three typical boundary types that occur between tectonic plates; infer what type of boundary exists between two tectonic plates; and describe plate boundaries and tectonic activity in the vicinity of the Kermadec Arc.

Unexplored!
(from the New Zealand America Submarine Ring of Fire 2007 Expedition)
http://oceanexplorer.noaa.gov/explorations/07fire/background/edu/media/unexplored.pdf

Focus: Scientific exploration of deep-sea volcanoes (Life Science/Physical Science/Earth Science)

Students compare and contrast submarine volcanoes at convergent and divergent plate boundaries; infer the kinds of living organisms that may be found around hydrothermal vents; describe three ways in which scientists may prepare to explore areas that are practically unknown; and explain two types of primary production that may be important to biological communities around hydrothermal vents in the Kermadec Arc.

The Volcano Factory
(from the Submarine Ring of Fire 2006 Expedition)
http://oceanexplorer.noaa.gov/explorations/06fire/background/edu/media/ROF06.VolFactory.pdf

Focus: Volcanism on the Mariana Arc (Earth Science)

Students explain the tectonic processes that result in the formation of the Mariana Arc and the Mariana Trench; and explain why the Mariana Arc is one of the most volcanically active regions on Earth.

Living With the Heat
(from the Submarine Ring of Fire 2006 Expedition)
http://oceanexplorer.noaa.gov/explorations/06fire/background/edu/media/ROF06.LivingHeat.pdf

Focus: Hydrothermal vent ecology and transfer of energy among organisms that live near vents (Earth Science/Life Science)

Students describe how hydrothermal vents are formed and characterize the physical conditions at these sites; explain what chemosynthesis is and contrast this process with photosynthesis; identify autotrophic bacteria as the basis for food webs in hydrothermal vent communities; and describe common food pathways between organisms typically found in hydrothermal vent communities.

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 - Web site for NOAA's Ocean Exploration program

http://oceanexplorer.noaa.gov/explorations/12fire/background/laubasin/laubasin.html - Web page for the Submarine Ring of Fire 2012: NE Lau Basin Expedition http://www.pmel.noaa.gov/vents/index.html - NOAA's hydrothermal vent Web site

http://volcano.oregonstate.edu/ - Volcano World Web site from Oregon State University

http://serc.carleton.edu/microbelife/topics/special_collections/winogradsky.html – Web page from Microbial Life - Educational Resources, a collaborative project of the Marine Biology Laboratory, Woods Hole, MA, and Montana State University, Bozeman, MT; with links to resources and information about building Winogradsky columns

http://www.woodrow.org/teachers/bi/2000/Winogradsky_Column/winogradsky_column.html – *Investigating Bacteria with the Winogradsky Column*, by Brian Rogan; from the Woodrow Wilson Foundation Leadership Program for Teachers 2000 Summer Biology Institute

http://www.envsci.rutgers.edu/~phelps/winogradsky.htm – *Exploring Biocomplexity in Aquatic Sediments*, by Jennifer Lamkie and Craig Phelps from Rutgers University; a series of lessons adapted for middle school students that use a version of the Winogradsky column to help establish the connection between earth and life sciences in students' minds by showing how living things influence the physical environment and vice versa

Relationship to A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas

The objectives of this lesson integrate the following Practices, Crosscutting Concepts, and Core Ideas:

Objective: Students will plan an investigation using a model ecosystem to explain some of the components of an anaerobic ecosystem.

Practices:

2. Developing and using models
3. Planning and carrying out investigations
7. Engaging in argument from evidence

Crosscutting Concepts:

4. Systems and system models
5. Energy and matter: Flows, cycles, and conservation
7. Stability and change

Core Ideas:

LS1.C: Organization for Matter and Energy Flow in Organisms

Objective: Students will construct explanations for the potential role of microbial mats in hydrothermal vent ecosystems.

Practices:

6. Constructing explanations
7. Engaging in argument from evidence

Crosscutting Concepts

4. Systems and system models

Core Ideas:

LS2.A: Interdependent Relationships in Ecosystems

Correlations to Common Core State Standards for English Language Arts

RI.4 – 4. Determine the meaning of words and phrases as they are used in a text, including figurative, connotative, and technical meanings; analyze the impact of a specific word choice on meaning and tone.

W.1 – Write arguments to support claims with clear reasons and relevant evidence.

SL.1 – Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grades 5 and 6 topics, texts, and issues, building on others' ideas and expressing their own clearly.

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.

The Earth has one big ocean with many features.

Fundamental Concept a. The ocean is the dominant physical feature on our planet Earth—covering approximately 70% of the planet's surface. There is one ocean with many ocean basins, such as the North Pacific, South Pacific, North Atlantic, South Atlantic, Indian and Arctic.

Fundamental Concept b. An ocean basin's size, shape and features (such as islands, trenches, mid-ocean ridges, rift valleys) vary due to the movement of Earth's lithospheric plates. Earth's highest peaks, deepest valleys and flattest vast plains are all 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 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

In addition to consultation with expedition scientists, the development of lesson plans and other education products is guided by comments and suggestions from educators and others who use these materials. Please send questions and comments about these materials to: oceanexeducation@noaa.gov.

For More Information

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Acknowledgements

This lesson was developed and written for NOAA's Office of Ocean Exploration and Research (OER) by Dr. Mel Goodwin, PhD, Marine Biologist and Science Writer, Mt. Pleasant, SC.
Design/layout: Coastal Images Graphic Design, Mt. Pleasant, SC.

Credit