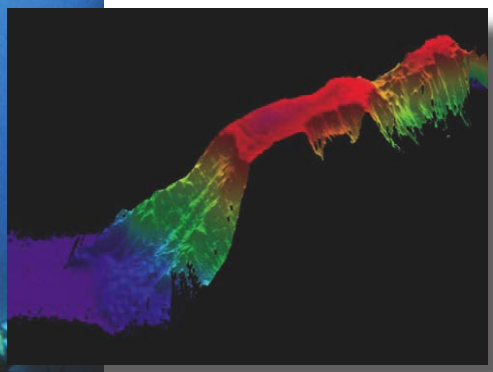
Learning Ocean Science Through Ocean Exploration

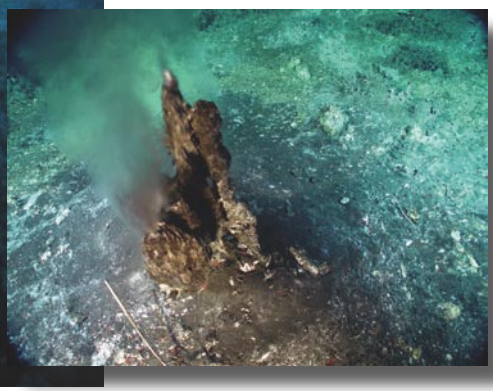
A Curriculum for Grades 6 – 12

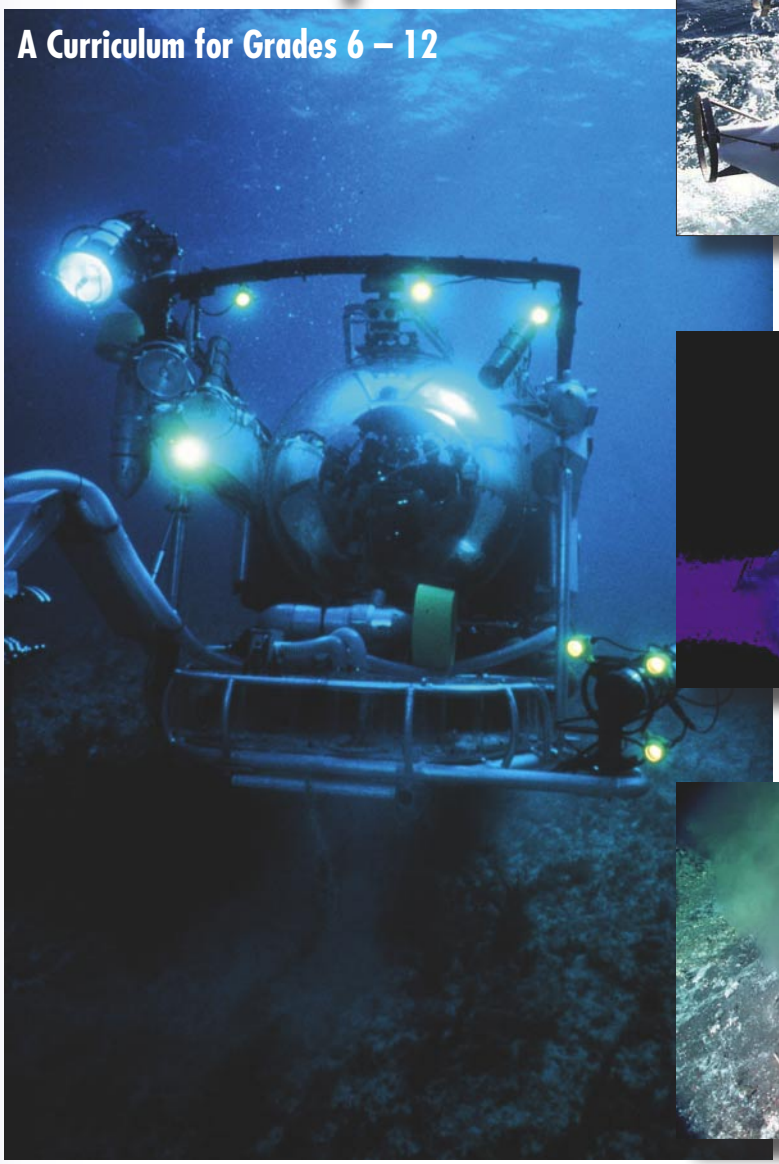
The *Autonomous Benthic Explorer (ABE)*
Courtesy Woods Hole Oceanographic Institution

Partial bathymetry data for Kelvin Seamount
Image by N. Forfinski



A deep-sea vent
Courtesy NOAA Vents Program





Johnson-Sea-Link Submersible
Courtesy Harbor Branch Oceanographic Institution

EXPLORE

National Oceanic and Atmospheric Administration (NOAA)

http://oceanexplorer.noaa.gov

Learning Ocean Science Through Ocean Exploration

A Curriculum for Grades 6–12

Editor: Valerie Chase, Ph.D.

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October 2003

Acknowledgements
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Layout/Design: Sandy Goodwin, Coastal Images Graphic Design

Cover photos courtesy of Harbor Branch Oceanographic Institution, N. Forfinski,
NOAA Vents Program and Woods Hole Oceanographic Institution

This curriculum was produced for the National Oceanic and Atmospheric Administration (NOAA).
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Learning Ocean Science through Ocean Exploration

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Introduction

By Captain Craig N. McLean
Director, Office of Ocean Exploration
National Oceanic and Atmospheric Administration

NOAA is very pleased to bring you this curriculum, and to provide you with useful tools for ocean education. The ocean is a fascinating place. The oceans bring life to our Earth, providing the world with oxygen, renewable resources, and an amazing variety of marine life, though much of it unseen. An exciting world exists beneath the sea, filled with many secrets that are slowly being revealed.

The material in this curriculum provides an opportunity for the same kind of excitement and discovery that our scientists experience during their many journeys to the unknown parts of the sea, and an opportunity to convey that excitement with structured learning experiences. As you will see, while the accomplishments of science are many, there is still much about the oceans that we do not know. Considering that less than five percent of the world's oceans have been truly explored, by working with these ocean science materials, you will be participating in the discovery of a great frontier—the last remaining frontier on Earth.

When NOAA began its program in Ocean Exploration, it determined that it should allocate at least ten percent of its resources to education and outreach. As a result, professional educators participate in discovery missions, in curriculum planning and preparation of mission materials, including the work in this curriculum, and in going to sea. Not everyone can make the actual journey, but by joining NOAA through the material in this curriculum and by visiting our award-winning web site, **http://oceanexplorer.noaa.gov**, you can be part of the amazing world of ocean exploration.

It is very important to provide our young people with an education and awareness about the oceans today so that they can make informed decisions about their world tomorrow. Your role in accomplishing that mission is perhaps the most important. Within the reach of all educators are the scientists and engineers of tomorrow, the future technological strength of our Nation. And within your reach is the power and importance of influencing young minds of all ages about the oceans. That is an important opportunity, and an amazing responsibility.

Thank you for taking the journey with NOAA, at sea for the purpose of discovery, and in the world of education to help change the way America thinks about the ocean. Your job is most important. I hope we can make it a little easier.

Introduction and Guide to the Use of this Curriculum

When the National Oceanic and Atmospheric Administration (NOAA) established its Ocean Exploration Program, the Agency did something unusual for a program focused on scientific ocean discovery as it launched multidisciplinary voyages of discovery to little-known or unknown ocean regions. Following the recommendations put forth in the President's Panel on Ocean Exploration Report entitled *Discovering Earth's Final Frontier: A U.S. Strategy for Ocean Exploration*, the Agency formed partnerships and collaborations among scientists, educators, and others to develop educational and outreach resources tied to these voyages of discovery to reach out in new ways to share ocean discoveries with teachers, students and the general public. Through its Ocean Explorer (OE) web site at http://oceanexplorer.noaa.gov, this curriculum, the supporting professional development for teachers, and strong partnerships, NOAA is embracing unique opportunities to engage explorers of all ages as it takes journeys into a world that few have ever seen.

The National Oceanic and Atmospheric Administration's (NOAA's) Commitment to Share Ocean Exploration and Discovery through Education

The OE web site provides an educational opportunity to anyone wanting to learn about, discover, and virtually explore the ocean realm. Near-real time exchanges with scientists and educators on the voyages of discovery are brought to the web site through educators who are skilled interpreters of information as well as scientists who communicate their enthusiasm and expertise directly to you. Content and media-rich, the web site contains thousands of pages of essays, videos, and images from NOAA's Ocean Exploration voyages of discovery, covering an extensive range of ocean exploration topics. Most of these voyages of discovery have grade-level specific student classroom lesson plans that are posted along with them. Classroom teachers and other educators use these activities to sup-

NOAA Ocean Explorer Web Site

port learning ocean science through ocean exploration. These lessons use the National Science Education Standards (Standards) as a guide and the Standards are referenced on each lesson plan.

The Ocean Explorer Web Site Companion CD-ROM

The OE web site continues to grow each year as new voyages of discovery are added and previous ones are maintained. Since many classrooms are limited in their access to the Internet, NOAA has developed an Ocean Explorer web site companion CD that contains, as of this writing, the entire Ocean Explorer web site through January 2003. The CD operates just like the OE web site, letting students experience the same technology. This OE curriculum is designed to be used in conjunction with the Ocean Explorer web site and/or CD. It is greatly enhanced when students have access to additional ocean science sites on the Internet that are referenced with each activity.

What is *Learning Ocean Science through Ocean Exploration*?

Good science curriculum has scope and sequence. It is focused on a set of grade levels and is organized in such a way that following it supports student learning in a logical developmental sequence in which each part builds on what came before. There are over 100 ocean science activities posted on the OE web site, organized independently by voyage of discovery. *Learning Ocean Science through Ocean Exploration* takes activities selected from the voyages of discovery and presents them in a comprehensive scope and sequence through subject area categories that cut cross the individual voyages of discovery. This curriculum was developed to take advantage of the tremendous resources residing on the Ocean Explorer web site and to present lessons in a manner more conducive to teaching and learning in both formal and informal education settings.

Building *Learning Ocean Science through Ocean Exploration*

In order to build this curriculum, the editor assembled, evaluated and organized by theme all lesson plans posted as part of the 2001 and 2002 NOAA Ocean Exploration

field seasons. Naturally, there was overlap in content among the lesson plans since there was similarity in science focus on the expeditions—seamounts have similar origins, for example. About one third of the lessons were selected for inclusion in this curriculum. Since students show wide ranges of abilities in middle and high school, we did not narrow the grade range suggested beyond secondary. An advanced group of eight graders who have had pre-algebra may perform at the same level as a general science class of high school seniors. Secondary teachers have the technical scientific background and developmental knowledge needed to select from among these activities. The Table of Contents indicates the original author of each exercise. All of the original lessons from the web site that were selected to be included in this curriculum were edited, some more extensively than others.

The themes were arranged in an order that progresses from physical science through earth science to biological and environmental science—ocean sciences include all of these content areas. A content introduction was written for each of the nine themes identified. Each Section Introduction may have text written by one or more of the original lesson plan authors as well as text added by the editor. Each lesson plan on the Ocean Explorer web site assumes that the reader might use that lesson independently of other supporting materials, and so by design, there is a good deal of redundancy in content background supplied within lesson plans developed for and grouped within each voyage of discovery. Here, the activities have been edited, and the general content merged into the Section Introductions.

There is slightly more proportional emphasis on physical and earth sciences in this curriculum than among the lesson plans found on the Ocean Explorer web site. As mentioned above, only about one-third of the 2001 and 2002 lesson plans were used in the development of the *Learning Ocean Science through Ocean Exploration*

curriculum. A listing of all the Ocean Explorer activities that relate to the topic of a particular content section can be found at the end of that content section.

Future Opportunities

Look for Ocean Exploration Professional Development offerings, including courses offered at annual conferences of the National Science Teachers Association (NSTA), at regional and state science teachers' association conferences, as well as in partnership with science centers and aquariums and the National Marine Educators Association conferences. Check the Ocean Explorer web site frequently for new professional development opportunities and new postings of Ocean Exploration voyages of discovery.

Comprehensive Ocean Sciences

This is not a complete ocean science curriculum since it is built around a set of explorations. If you are a teacher wishing to develop a comprehensive ocean science course, you will want to add a good bit more physical science and atmospheric science as well as coastal processes and perhaps an introduction to ocean organisms and their taxonomy. For example, you will not find waves and tides here nor is there intertidal zonation since NOAA Ocean Exploration efforts thus far have focused largely on the deep ocean. Additional web sites referenced in each lesson plan offer additional ocean science activities to complete your ocean science course.

What is unique here is the combination of the Ocean Explorer web site and/or CD and the lessons presented in *Learning Ocean Science through Ocean Exploration* since they are designed to work together. Both give teachers and students a direct connection to the scientists whose work they are modeling in the classroom and a direct connection to the exciting new discoveries on each NOAA Ocean Exploration voyage of discovery.

Editor: Valerie Chase, Ph.D.
Retired in 2002, after almost 23 years at the National Aquarium in Baltimore

Section 1
Ocean Exploration

Ocean Exploration

Ocean exploration has been a human endeavor for as long as humans have designed boats and been able to put to sea. Ocean exploration is not the province of any single culture. Polynesians, Phoenicians, Norsemen—all were fabulous sailors and explorers. Humans managed to reach islands and continents isolated by oceans—sometimes by relatively shorter island hops as in the population of Australia, sometimes by sailing into the unknown across whole oceans to reach distant places like the Hawaiian Islands. In the process they invented technologies that enabled them to explore more effectively and safely—better vessels and navigation systems based on the position of the sun and stars.

Humans are by nature record keepers and collectors of information and materials because knowledge enhances survival. If the explorers returned home, they brought new knowledge as well as materials such as metals, plants and animals. Much of that new information would be called science today.

Most United States students take American history. Hence, their knowledge of ocean exploration may be focused on the discovery and exploration of the New World by Europeans. Portuguese, Spanish, and English explorers from the second half of the last millennium are most familiar to them. These explorers kept journals and records that we still read today. They took artists and natural historians with them to document what they found. For example, Vancouver explored the west coast of

the United States with a science illustrator. Sir Walter Raleigh employed John White to draw species from the Chesapeake and Virginia area. Mark Catesby was sent from England in 1724 to explore the East coast of the colonies for Sir Hans Sloan in England. He water colored over 220 plates and sent back countless specimens during his four-year collecting journey. During the Lewis and Clark Expedition, Merewether Lewis recorded his discoveries though his own scientific illustrations. The work of these men and their artists remains interesting today. They were the first explorers to chart and draw the natural history of what is now the United States.

Challenger Expedition of 1874

Modern ocean science exploration started with the *Challenger* Expedition of 1874—the first focused ocean science expedition. It was much longer than modern expeditions and very expensive. Victorian Great Britain had a fascination with science and scientific discovery that is reflected in their public funding of and interest in natural history museums. The United States' own Smithsonian Institution was funded by an Englishman and named for him. The *Challenger* Expedition was funded by the British government. Its explorers were charged with studying and mapping the oceans of the world. This four-year research expedition produced 50 volumes of scientific writing and illustrations over a 10- year period. Its specimen collections are still archived and studied, its publications still referenced and read.

Technological innovations since the *Challenger* have constantly improved the quality and quantity of scientific information produced by ocean explorers. Victorians' views of ocean creatures were limited to drawings and specimens in jars. Where once water samples were collected in bottles and weather was recorded from instruments by hand, oceanographers now have satellite data and remote sensing from ocean drifting or fixed equipment arrays, and these same data appear on the evening news. The lead line that measured how deep

the water was has been replaced by sonar that is available to recreational boaters. Today we see fabulous video footage of underwater discoveries on television, as IMAX films and in print media. Where Victorians read journals published upon the return of an expedition, we can now follow scientists along in real time on the expedition over the Internet, seeing what they see, discovering what they find. And yet our ocean remains less explored than the backside of the moon. Amazing new discoveries are still waiting to be made.

The National Oceanic and Atmospheric Administration's creation of the Office of Ocean Exploration (OE) launched a new era of ocean exploration. NOAA recognizes that there are many exciting discoveries waiting to be made. Ocean explorers are taking us along with them through the Ocean Explorer (OE) web site and the associated CD. This is your chance to share the excitement of ocean science discoveries with your students.

This section includes:

- *Calling All Explorers* from Deep East 2001.

Additional exercises related to ocean explorers and the theme of exploration are found on the OE web site or OE CD. They are:

- *Why Do We Explore?* from Deep East 2001 and Galapagos Rift in 2002
- *Journey to the Unknown* also found on Deep East 2001 and Galapagos Rift in 2002

Classroom Activities about Ocean Exploration in this Section

Where to Find More Activities on Ocean Exploration

Lesson Plan 1

Calling All Explorers

Focus

The history of ocean exploration with emphasis on recent explorers of deep-sea environments

Learning Objectives

Students will research and write about what it means to be an ocean explorer, both modern and historic.

Students will describe the nature of oceans and ocean exploration.

Students will meet science mentors and role models on-line.

Materials

❒ Web Quest NOAA Site: http://www.oceanexplorer.noaa.gov/explorations/deepeast01 on-line or on OE CD

For each student:

❒ Part I: Team Exploration – *Cooperative Explorers Web Quest Data Sheet*

❒ Part II: Individual Exploration – *Individual Explorers Reflection Sheet*

Teaching Time

Two 45 minute periods, one each for two parts

Seating Arrangement

Part I: groups that work with your computer arrangement

Part II: individual work in a place that lends itself to reflection

Key Words

Exploration
Documentation
Science role models
Biodiversity
Extreme environments

Background Information

The National Oceanic and Atmospheric Administration's Office of Ocean Exploration launched a new era of ocean exploration. Its creation recognizes that there are many exciting discoveries waiting to be made. Ocean explorers are taking us along with them through the OE web site and the associated CD. This exercise introduces your students to the OE web site (or CD) and to the people who are the modern ocean explorers. It is designed to enable them to move at their own pace, in self-directed exploration of the OE site.

Learning Procedure

Part I: Team Exploration

1. Assign students to computers in small groups with one *Cooperative Explorers Web Quest Data Sheet* per student and let them work through the sheet as a group.

Part II: Individual Exploration

1. Provide copies of *Individual Explorers Reflections Sheet*. This individual work may be assigned as homework rather than done in class. Be sure to have a class discussion after the work is turned in to get your students reactions to modern vs. historic explorers.

The BRIDGE Connection

www.vims.edu/bridge

The "Me" Connection

All of Part II: Individual Exploration is the "Me" Connection

Connection to Other Subjects

English/Language Arts, Physical Earth, Life Sciences, Art/Design

Evaluation

Use Student Evaluation Sheets. See *Teacher Key, Part I and Part II*

Extensions

Ask students to investigate career opportunities as ocean explorers, ocean scientists, and others whose careers support ocean science and exploration. Visit the Ocean Exploration Web Site at:
www.oceanexplorer.noaa.gov

National Science Education Standards

Content Standard G – History & Nature of Science

- Science as a human endeavor
- The nature of science

Activity developed by Kimberly Williams, Miller Place High School, Long Island, New York

Student Handout

Part I: Cooperative Explorers Web Quest Data Sheet

Welcome, Ocean Explorers! Please proceed to the following web site:
www.oceanexplorer.noaa.gov/explorations/deepeast01
or use the Ocean Exploration CD to find Deep East ocean explorers

Your first mission is to find the link to the deep-sea explorers.
1) Write that link here: _____

2) List three places in the deep sea where ocean explorers have done their recent research:
a) _____
b) _____
c) _____

3) There are many individuals studying the deep sea. List at least five here and describe their field of research.
a) _____
b) _____
c) _____
d) _____
e) _____

4) Describe what your day might be like if you were a marine chemist:
If I were a marine chemist, I would. . . .

_____
_____
_____
_____
_____
_____
_____

Student Handout

5) In some ways, deep-sea explorers of modern times are similar to historic explorers. They are brave, curious people who are at the cutting edge of their field of interest. They are very unique individuals. One major difference is that women are an important part of ocean science research in modern times. For example, one of the scientists shown in your Web Quest is the only woman certified to pilot the deep sea submersible known as the *Alvin*. Find her name and describe what type of science she does?

Dr. _____ studies _____.

6) Often our first inspiration to be curious and to explore comes from our parents and our teachers. Which explorer's elementary teacher inspired him by having him read *A Half Mile Down*, by William Beebe, a book about the first deep dive? Have you read this book?

Dr. _____

Bonus: List other explorers who were inspired by parents and/or teachers?

Dr. _____
Dr. _____
Dr. _____

7) How do you think that exploring the deep sea is similar to exploring outer space? Different?

_____
_____
_____
_____
_____
_____
_____

8) Which scientist explorer studies biodiversity and believes that extreme environments (such as those in the deep sea) may give us insight into life on other planets?

Dr. _____

Student Handout

9) There is a big world waiting for you to explore it, and the technology to do so gets better every day. Yesterday's discoveries are today's necessities. Which explorer hopes that new compounds from the deep sea will be used in the future to treat diseases?

Dr. _____

10) As we learn more about the vastness of the planet we inhabit, we realize how little we know about the creatures and plants with which we share it. Which scientist studies the relationship between food supply and egg production in deep water invertebrates?

Dr. _____

11) Another group of creatures that shares the Earth with us are beautiful single-celled, shelled protozoans. Name these creatures and the explorer who studies them:

The creatures are known as _____
They are studied by Dr. _____

12) On the back of this data sheet, document your time of exploration on the Deep Sea Explorer Web Quest by drawing something that represents your favorite part of the site. Label your drawing and tell why this part of the site was interesting to you.

Congratulations, Explorers!
You have successfully navigated the Deep Sea Explorer Web Quest!

Teacher Answer Key

Part I Cooperative Explorers Web Quest Data Sheet

The answers are specific to the Deep East 2001 expedition. If the students used the entire OE web site or CD, many more answers are possible!

1) Write that link here:
www.oceanexplorer.noaa.gov/explorations/deepeast01/background/explorers explorers.html

2) List three places in the deep sea where science explorers have done their recent research:
a) George's Bank Canyon
b) Hudson River Canyon
c) Blake Ridge

3) There are many individuals studying the deep sea. List at least five here and describe their field of research.
Answers may vary, some answers include:
Dr. Les Watling, Dr. Scott C. France, Mr. Andrew Shepard
Dr. Peter Auster, Ms. Caren Menard, Dr. Mary Scranton
Dr. Kevin Eckelbarger, Mr. Karl Stanford, Dr. Peter Rona
Dr. Barbara Hecker, Dr. Fred Grassle, Dr. Ellen K. Pikitch
Ms. Diana Payne, Dr. Michael Bothner
Ms. Holly Donovan, Ms. Tanya Podchaski, Ms. Rebecca Cerroni
Dr. Michael DeLuca, Dr. Cindy Lee Van Dover, Dr. Joan Bernhard
Dr. Carolyn Ruppel, Dr. Barun Sen Gupta, Ms. Paula Keener-Chavis

4) Describe what your day might be like if you were a marine chemist: If I were a marine chemist, I would. . . .
Answers will vary-students will probably take information from the interviews of the marine chemists listed above for the descriptions of their imaginary day as a marine chemist.

5) In some ways, deep-sea explorers of modern times are similar to historic explorers. They are brave, curious people who are at the cutting edge of their field of interest. They are very unique individuals. One major difference is that women are an important part of ocean science research in modern times. For example, one of the scientists shown in your Web Quest is the only woman certified to pilot the deep sea submersible known as the *Alvin*. Find her name and describe what type of science she does?
Dr. Cindy Lee Van Dover studies Marine Chemistry

6) Often our first inspiration to be curious and to explore comes from our parents and our teachers. Which explorer's elementary teacher inspired him by making him read *A Half Mile Down*, by William Beebe, a book about the first deep dive? Have you read this book?
Dr. Peter Rona I have/have not read *A Half Mile Down*

Teacher Answer Key

Bonus: List other explorers who were inspired by parents and/or teachers. Some are:
Dr. Fred Grassle
Dr. Mary Scranton
Dr. Joan Bernhard

7) How do you think that exploring the deep sea is similar to exploring outer space? Answers will vary. Some include:
Humans would need special equipment to survive and explore there.
Humans know very little about both places.
Humans get very excited about the prospect of finding life in both places.

8) Which explorer studies biodiversity and believes that extreme environments (such as those in the deep sea) may give us insight into life on other planets?
Dr. Joan Bernhard

9) There is a big world waiting for you to explore it, and the technology to do so gets better every day. Yesterday's discoveries are today's necessities. Which explorer hopes that new compounds from the deep sea will be used in the future to treat diseases?
Dr. Fred Grassle

10) As we learn more about the vastness of the planet we inhabit, we realize how little we know about the creatures and plants that share it with us. Which scientist studies the relationship between food supply and egg production in deep-water invertebrates?
Dr. Kevin Eckelbarger

11) Another group of creatures that shares the Earth with us are beautiful single celled, shelled protozoans. Name these creatures and the explorer who studies them.
The creatures are known as Foraminifera.
They are studied by Dr. Barun Sen Gupta.

12) On the back of this data sheet, document your time of exploration on the Deep Sea Explorer Web Quest by drawing something that represents your favorite part of the site. Label your drawing and tell why this part of the site was interesting to you.
Enjoy your students' drawings and celebrate the diversity of their interests.

Congratulations, Explorers!
You have successfully navigated the Deep Sea Explorer Web Quest!

Student Handout

Part II: Individual Explorers Reflections Sheet

1) Reflect and write about differences and similarities between explorers of the past and modern day explorers. What types of hardships do both have in common?

Some Similarities: _____

_____

_____

_____

Some Differences: _____

_____

_____

_____

2) Name some places that have been explored in modern times.

_____

_____

_____

_____

3) Name places that were explored during the early history of humans.

_____

_____

_____

_____

4) Describe a place that you have explored. What was unique about it that you think another visitor to that site would not have noticed?

_____

_____

_____

_____

5) Name and describe a place that you would like to explore. What do you think you would find there? Why?

_____

_____

_____

_____

Student Handout

6) Why is it important to document your explorations? What is your favorite way to remember your own adventures?

7) On the space provided, list a few of your science and exploration role models (alive or historic) and why they inspire you. On a sheet of notebook paper or on the computer, compose a letter to one of your science and exploration role models. Write something you would want them to know about you and why you consider them an inspiration.

Section 2

Mapping the Ocean Floor: Bathymetry

Why Bathymetry?

Exploring the ocean starts with getting some idea of what the bottom topography is like. Thanks to satellites and a variety of measuring stations—both fixed and drifting, we have a pretty good idea of the surface of the sea, but have seen only bits of the bottom. Ship and submersible time for ocean exploration are expensive. Expeditions need to be carefully planned in order to produce the maximum amount of information in the least amount of time. For that to happen, scientists need to have a general idea of where interesting features might be located and then develop site information for those areas. Detailed maps are rare for areas other than shallow, near shore areas. Towing a remotely operated vehicle (ROV) or diving in a manned submersible without a clear understanding of the bottom topography risks losing the equipment or even losing human life. Consequently, mapping the sea floor—bathymetry—is an important part of many OE expeditions. With good maps, the researchers can focus their time and energy.

GPS and Computers

Global Positioning System (GPS) data are combined with the input from latest bottom-topography technology available, including ship-based swath mapping systems, side-scan sonar, and seismic reflection, as well as submersible and ROV dives to reveal exciting new details about the geology and the flora and fauna of the ocean. Computers with digital acquisition systems process masses of data and create three-dimensional views of the ocean bottom. The OE web site includes many of these maps, enabling students to visualize the structure

of interesting underwater features such as seamounts, canyons and mid-ocean ridges.

What We Can Learn from Mapping

Surprisingly fine scale details are evident in observations of near shore depths. Sea stacks, beaches, sea cliffs, lagoons, shore faces, wave cut platforms, and sand ripples, all formed about twenty thousand years ago when the accumulation of ice on land lowered the ocean level, show up clearly. Future exploration and mapping may reveal more about climate and the geological and biological conditions of periods of lowered sea level, as well as information on the indigenous people who lived along that ancient shore.

Farther from shore, swath mapping systems, side-scan sonar, seismic reflection, and exploration by submersible and ROVs reveal details about underwater volcanic rifts in the Pacific Ocean, seamounts in the Pacific and the Atlantic, submarine canyons off US shores and deep vents and cold water seeps in many sites.

Classroom Activities on Mapping in this Section

The following three exercises give students an introduction to the techniques used to create maps of the underwater world—bathymetric maps. Of particular content relevance are the *Mission Plan* and *Mapping the Unknown* from Hudson Canyon 2002, as well as several of the seamount expeditions from the OE CD or web site.

- *A Watered Down Topographic Map* from Submarine Ring of Fire 2002
- *Mapping the Canyon* on Deep East 2001 and Hudson Canyon 2002
- *Mapping Deep-sea Habitats* from Northwest Hawaiian Islands Exploration 2002

Where to Find More Activities on Mapping

Mapping exercises in the OE 2001-2002 database on the OE CD or web site include:

- *Come on Down* from Galapagos Rift and Deep East 2001
- *An Ocean of Weather* in Islands in the Stream 2002

- *Finding the Way* from Deep East 2001
- *At the Edge of the Continent* in Islands in the Stream 2002
- *Mapping Seamounts in the Gulf of Alaska* from Exploring Alaska's Seamounts 2002

Lesson Plan 2

A Watered-down Topographic Map

Focus Questions

How can a two-dimensional map be created showing the three-dimensional nature of a landform?

What are topographic maps and bathymetric charts?

Learning Objectives

Students will create a bathymetric map of a model underwater feature.

Students will interpret a simple topographic or bathymetric map.

Students will explain the difference between topographic and bathymetric maps.

Students will create models of some of the undersea geologic features studied in ocean explorations.

Materials Per Group Of Four Students

- ❒ A square quart plastic food storage container at least 7 cm deep
- ❒ 500-700 ml of water in measuring cup or bottle
- ❒ Small plastic funnel
- ❒ 10 cm plastic ruler (can be made by photocopying a ruler repeatedly on an overhead acetate)
- ❒ Overhead projector acetate cut to fit food container top
- ❒ Felt tip waterproof marker
- ❒ 12 inches of masking tape
- ❒ Scissors
- ❒ Two sticks of modeling clay – two colors
- ❒ Student Handouts

Audio/visual Equipment

- ❒ Overhead projector

Teaching Time

Two 45-minute periods

Seating Arrangement

Cooperative groups of up to four students

Key Words

Topographic
Bathymetric
Contour line
Contour interval
Relief
Elevation
Depth
Submarine canyon
Seamount
Ridge/bank
Rift/mid-ocean ridge
Continental shelf

Background Information

This activity serves two purposes: it introduces your students to contour maps—both bathymetric and topographic—and it introduces them to the geologic features that many explorers study. Bathymetric mapping is a major part of many of the OE expeditions since our understanding of the ocean floor starts with knowing what it looks like. We do not know much at this point.

Topographic maps are tools used by anyone in need of knowing his/her position on Earth in relation to surrounding surface features. A topographic

map is a two-dimensional map portraying three-dimensional landforms. Geologists, field biologists, and hikers are just a few who routinely use topographic maps.

Bathymetric maps (also called charts) are topographic maps of the bottom features of a lake, bay or ocean. They are very similar to topographic maps in their terminology and interpretation. The primary difference is that bathymetric maps show depth below sea level while topographic maps show elevation above sea level. Another difference is the limited data available to create a bathymetric map when compared to a topographic map.

The skill needed to see two dimensions on a map and visualize three dimensions can be a difficult for students. Interpreting familiar topographic maps provides practice in this skill. This exercise will build an understanding of the relationship between a two-dimensional representation and a three-dimensional landform.

Both topographic and bathymetric maps use contour lines to show elevation or depth. Contour lines are imaginary lines connecting points of the same elevation or depth. A contour interval is the predetermined difference between any two contour lines. A contour interval of 100 feet means that the slope of the land or sea bottom has risen or declined by 100 feet between two contour lines. A map that shows very close contour lines means the land is very steep. A map that has wide spacing between contour lines has a gentle slope. The smaller the contour interval, the more capable a map is of depicting finer features and details of the land. A contour interval of 100 feet will only pick up details of features larger than 100 feet. It also means that a seamount could be 99 feet higher in elevation than the map depicts.

Because one cannot usually easily see beneath the water, the difference between what is mapped and the reality of what actually exists is greater on bathymetric maps. With the advent of new, more sophisticated ocean floor sensing technology, bathymetric maps are becoming much more detailed, revealing new information about ocean geology.

Learning Procedure

1. Distribute the plastic food storage containers and sticks of clay to each group, along with a card describing an underwater feature (these same features also occur on dry land). Each group should read the card and build a clay model to match the description written on the card. The model may not extend above the top of the container. For ease of construction, they may assemble them on the desk and then install them in the container. Allow them to consult the OE web site or CD or oceanography texts if they need help visualizing the descriptions.

2. Challenge the students to create a two-dimensional map of their three-dimensional underwater feature that would visually interpret it for other groups of students.

3. Help them think this through as a group. Draw a large circular shape on the board. Ask the students what they think the drawing represents. Guide the answers, if necessary, toward maps of landforms, such as a pond, an island, a race track circuit, and so on. Could it be the base of an underwater mountain? Draw a side view of an undulating mountain directly below and matching the horizontal margins of the circle. Tell the students the two drawings represent the same thing, but from a different perspective. Ask the students again what they think the circular shape and the new side view of the circular shape represents. A mountain should be one of the obvious answers. How can we combine the two dimensions of the circle with the third dimension—height—in the second drawing on a flat map?

4. Hand out the *Student Handouts* and ask them to follow the instructions. When the equipment is

ready, have the students check with you to make sure they set up correctly. Depending on your students' abilities you may have all setups complete and proceed as a class through drawing of the contour line. Some classes will take off and do this very well on their own. Having completed the first contour line, have the class add water to the first centimeter mark on the ruler, reminding them to take care when pouring the water into the funnel. Remind them about accuracy in measurement also. Once they draw the second contour line they may work at their own speed.

5. When the "maps" are completed, introduce the terms topographic and bathymetric maps and discuss contour lines to make sure the concept is clear.

6. Have the students remove the water from their models and display the models with the maps. Pass around a model and challenge the students to pick the map that represents it from the maps displayed on the overhead projector.

7. During this oral assessment of understanding, show an overhead projection which is 180 degrees opposite in perspective to the view the students have of the respective feature. This not only tests the students understanding of topography with respect to the orientation but also reinforces the value of compass directions on maps.

8. Have students use the Ocean Exploration CD or web site to find and list the expeditions that explore each of the geologic features listed here: ridge/bank, submarine canyon, seamount or mid-ocean ridge/rift. Have them finds maps and/or illustrations of the features in this exercise, print them out, label them and put them up in the bulletin board. Also look for bathymetric maps that show the same features.

The BRIDGE Connection

www.vims.edu/bridge

The "Me" Connection

Have you ever been lost? What is it that helps you find your way? A familiar landmark is what most people need to find. A topographic map is all about finding landmarks even if you have never seen the landmark before.

Connections To Other Subjects

Mathematics, Geography

Evaluation

Teacher reviews maps created by students for accuracy and understanding. Teacher performs summative assessment by showing mapped objects and topographic map representations for class to relate to each another. Teacher performs formative assessment test questioning on key terms and topographic/bathymetric interpretations.

Extensions

Have students find landmarks and important features on a topographic map of their own area. "Topo" maps are sold at places that sell hiking and camping gear. Take a topographic map on the next field trip. Have students locate where they are on the map, what elevation they are at, and what distance they are from a prominent landmark.

National Science Education Standards

Content Standard A – Science as Inquiry
- Ability necessary to do scientific inquiry

Content Standard D – Earth and Space Science
- Structure of the Earth system

Content Standard E – Science and Technology
- Abilities of technological design

Content Standard G – History and Nature of Science
- Nature of science

Activity developed by Bob Pearson, Eddyville School, Philomath, Oregon

Student Handout

Read ALL of the instructions first!

Materials:

- Model in quart plastic container: follow the instructions on the Underwater Feature cards to build the clay model in a square plastic food storage box using modeling clay
- Measuring cup or liter beaker of water
- Plastic funnel
- Centimeter ruler
- Overhead projector acetate
- Waterproof felt tip marker
- Masking tape
- Scissors

Procedure:

Read these instructions carefully. They contain new terms you will need for the Student Analysis Worksheet.

1. Build and install your model underwater feature in your plastic container.

2. Place the centimeter ruler inside the container against a side wall near a corner. Make sure that the highest number mark is at the bottom. Use the tape to attach the centimeter ruler to the container side, taking care not to make the measurement lines unreadable.

3. Cut the overhead acetate to a size that completely covers the container. On one corner of the acetate, cut away enough material so that the funnel spout can just fit through.

4. Tape the acetate to the top of the container. Attach the tape only at a few edges of the overhead and not completely across the container opening. You will need to remove the acetate later so use only enough tape to hold it firmly.

5. Insert the funnel into the opening and tape it so it is securely in place.

6. Check your setup for approval by your teacher.

7. Draw a line on the acetate that correlates with the place the object meets the bottom of the container.

Student Handout

8. Take the beaker of water and carefully add water through the funnel until the water level rises to the one centimeter mark on the ruler.

9. View the model by placing your eyes directly above it, looking downward. Focus on the outline of where the model and the water meet. Using the felt tip pen, very carefully draw this outline on the acetate. Label it with the cm shown at that depth on the ruler. The line that you draw is called a "contour line."

10. Add another centimeter of water to 2 cm in depth. Again, look directly downward at the object. Focus on where the object and water line meet. Draw this contour line in the same way you drew the first one, following the line where the water meets the object. You now have two contour lines which represent a one-half centimeter change in depth. Label it from the ruler measurement.

11. Continue adding water at centimeter intervals and drawing the contour lines at each centimeter rise until the model is completely covered with water. You have created a bathymetric map of the model.

Note: If you have a feature with high relief like a tall seamount, use 1 cm intervals. If you have a flat feature like a bank, use 0.5 cm intervals.

Student Handout

Underwater Feature Cards

Seamount

Volcanoes occur in the ocean too. If they build high enough above the ocean floor, they may form islands. The islands may weigh so much they eventually sink into the Earth's crust. Or they may not ever break the surface of the water. Either way, they may become seamounts—mountains under the ocean. Use your clay to make a volcano-shaped model mountain that is 6 cm high and not wide enough at the base to touch the sides of the plastic container.

Ridge/Bank

Hard bottom features may rise above the continental shelf. Since many organisms need a hard surface to attach and grow, ridges or banks may be unusually rich areas. They may be large or small and may be quite irregular in shape. Use your clay to make a low mound that ranges from 0.5 to 2 cm high, covers about two thirds of the container bottom and has an irregular shape.

Submarine Canyon

Along the edges of the North American continent, the sea floor is shallow—forming an underwater plain that is very wide in some places and less so in others. Where rivers empty into the sea, canyons were cut into this plain when sea level was much lower during the Ice Ages. As sea level rose, the canyons became flooded. Use your clay to make a shallow sloping platform 4 cm high filling two sides of the container with the third side diagonal across the middle—the continental shelf. From the middle to the other two sides, create a slope down to a clay bottom that is 0.5 cm. Use a tool (dissecting needle or pencil) to cut a canyon that starts at the highest point in the corner between the two high sides and gradually gets deeper as it crosses the shelf. At the slope it should reach all the way to the bottom.

Mid-Oceanic Ridge/Rift

Make a flat bottom of clay about 1 cm deep from one color of clay. Make a thin rope about 1 cm in diameter of the same clay, rolling it in your hands. Lay a strip of the rope across the middle of the clay floor in the model ocean container. It should be about 1 cm higher than the floor. Use the second color of clay to make two flat sheets a little less than ½ the area of the container floor. Place one sheet down each side of the central "ridge" coming up to the middle but not touching so that the clay below shows through the middle. If the lower layer is red, you can think of it as glowing volcanic magma that flows up through the rift in the Earth's crust. In cross-section, there will be a small valley at the top of the ridge.

Lesson Plan 3

Mapping the Canyon

Focus
Bathymetry of Hudson Canyon

Focus Question
What are bathymetric and topographic maps, and what are the differences between them?

Learning Objectives
Students will compare and contrast a topographic map and a bathymetric map.

Students will investigate the ways in which bathymetric maps are made.

Students will interpret a bathymetric map.

Materials for Each Group
Part I:
- ❒ 1 Hudson Canyon Bathymetry map transparency from http://www.photolib.noaa.gov/ships/ship3201.htm
- ❒ 1 local topographic map
- ❒ 1 USGS Fact Sheet on Sea Floor Mapping from http://pubs.usgs.gov/fs/fs039-02/fs039-02.html

Part II:
- ❒ 1 local topographic map per group
- ❒ 1 Hudson Canyon Bathymetry map per group
- ❒ Hudson Canyon Bathymetry map transparency
- ❒ *Contour Analysis Worksheet*

Part III:
Internet access

Audio/visual Equipment
Overhead Projector

Teaching Time
Two 45-minute periods

Seating Arrangement
Cooperative groups of four

Key Words
Topography
Bathymetry
Map
Multi-beam sonar
Canyon
Contour lines
Sonar
Side-scan sonar
GLORIA
Echo sounder

Background Information
A map is a flat model of all or part of Earth's surface drawn to a specific scale. A map is a model of the real world. The better maps communicate information, the more effective they are as a model.

Topographic maps show elevation of landforms above sea level. Bathymetric maps show depths of landforms below sea level. The topographic elevations and the bathymetric depths are shown with contour lines. A contour line is a line on a map representing a corresponding imaginary line on the surface of the land or bottom of the sea that has the same elevation or depth along its entire length.

Since the ocean floor is not visible to us, it is difficult to map. Scientists use various techniques to gather data for a bathymetric map. In the early 1800s,

mariners recorded depths of shallow water features with a weighted line. Then in 1854, a depth-sounding device was attached to the line instead of the weight. This made determining when the line hit the bottom of the ocean easier. However, measuring a small section of shallow ocean still took hours or days and was restricted to shallow depths.

The difficulty and technical limitations meant mapping the sea floor took place much later than the production of good maps of dry land. Much of the ocean remains unmapped, even today. During World War II, when submarine warfare was the highly effective against Allied shipping, sonar (sound navigation ranging) was developed. Active sonar devices use returning echo times to measure distance to the object that is being studied.

Using sonar, scientists were able to map ocean trenches, ridges, plains, and submerged islands, creating more accurate ocean floor maps. Today, scientists are working on advances that make sonar more accurate, including a side-scan sonar device called GLORIA (Geologic Long-Range Inclined Asdic). Sidescan sonar is towed behind a vessel and is able to scan the depth along the sides of the vessel as well as the depth directly below it. GLORIA is making detailed maps of the continental margin along the North American coasts. Another sonar advance is multi-beam sonar. By emitting signals of different frequencies, multi-beam sonar produces a detailed three-dimensional map of the sea floor.

Even with new advances in bathymetric mapping, only a limited portion of the vast sea floor has actually been mapped. Consequently, sea floor mapping is an important part of Ocean Exploration expeditions.

Learning Procedure

See Resources for web sites and sources of maps.

Part I:

1. Introduce topographic maps and bathymetric maps.
2. Hand out USGS Fact Sheet on Sea Floor mapping for them to read and study.

Part II:

1. Use the following materials to answer the worksheet questions: a local topographic map, the Hudson Canyon bathymetry map, and the *Contour Analysis Worksheets*.

Part III:

1. Have student groups research and give presentations on the different techniques used to collect depth data for bathymetric mapping. Topics could include:
   a. Echo sounder
   b. Seismic reflection profiles
   c. Multi-beam sonar
   d. Weighted wires
   e. Sonar
   f. GLORIA
   g. World War II and sonar

The BRIDGE Connection

http://woodshole.er.usgs.gov/epubs/openfiles/ofr98-616/titlepage.html

Connection To Other Subjects

Mathematics, English/Language Arts

Evaluations

Have students write a paragraph summarizing what they learned about the bathymetry of the Hudson Canyon.

Teacher review of each student's *Contour Analysis Worksheet*

Teacher review of presentations given by students on the various techniques used to map the bottom of the ocean floor

Extensions

Ask students to write a short essay comparing the Grand Canyon to the Hudson Canyon.

Make a clay model of the Hudson Canyon.

Ask students to identify all of the deep-sea canyons found along the Atlantic Coast.

Visit the Ocean Exploration Web Site at www.oceanexplorer.noaa.gov

Visit the National Marine Sanctuaries web page for a GIS fly-through of the Channel Islands National Marine Sanctuary at http://www.cinms.nos.noaa.gov/

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National Science Education Standards

Content Standard A – Science as Inquiry
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard D – Earth and Space Science
- Structure of the Earth system

Content Standard E – Science and Technology
- Abilities of technological design
- Understandings about science and technology

Content Standard F – Science in Personal and Social Perspectives
- Science and technology in society

Content Standard G – History and Nature of Science
- Nature of science
- History of science

Activity developed by Tanya Podchaski, Bernards High School, Bernardsville, New Jersey

Student Handout

Contour Analysis Worksheet

1. Collect the following materials from your teacher:
   a. 1 local topographic map
   b. 1 bathymetric map of Hudson Canyon

2. What is the scale on the topographic map?

3. What is the scale on the bathymetric map?

4. Why do you think the scales are so different?

5. What is the contour interval on the topographic map?

6. What is the contour internal on the bathymetric map?

7. What do the two contour intervals indicate?

8. What do the colors represent on a topographic map?

9. What do the colors represent on a bathymetric map?

10. Why do these color schemes differ?

Student Handout

11. What is the highest feature on the topographic map? What is its elevation?

12. What are the latitude and longitude coordinates of this feature?

13. Locate Hudson Canyon on the bathymetric map. What is the depth of the deepest part?

14. What are the latitude and longitude coordinates of the Hudson Canyon?

15. Why is it important for the submarine *Alvin* to know the bathymetry of Hudson Canyon?

16. Write a two-paragraph summary comparing and contrasting topographic maps to bathymetric maps.

Lesson Plan 4

Mapping Deep-sea Features

Focus
Bathymetric mapping of deep-sea habitats

Focus Question
How can deep-sea areas be mapped to facilitate exploration with a manned submersible?

Learning Objectives
Students will create a two-dimensional contour map from actual bathymetric survey data.

Students will create a three-dimensional model of the landform on the underwater contour map they created.

Materials
- ❒ Copies of *Loihi Submarine Volcano Bathymetric Data* for each student group
- ❒ *Bathymetric Data Reduction Sheet* enlarged to 11″ x 14 ″ for each student group
- ❒ 8 different colored makers, crayons or pencils in color range from purple to red; use in order of their appearance in the color spectrum
- ❒ *Bathymetric Data Reduction Sheet* enlarged for bulletin board (make as large as possible)
- ❒ Scissors for each group
- ❒ Colored modeling clay rolled into flat sheets – at least two colors
- ❒ 8 dissecting needles

Audio/Visual Materials
None

Teaching Time
Two 45-minute class periods

Seating Arrangement
Eight groups

Key Words
Seamount
Bathymetry
Transducer
Backscatter
Contour lines
False color

Background Information
This activity focuses on how bathymetric maps are created from multi-beam bathymetric data. Students will construct a three-dimensional model of the Loihi submarine volcano from bathymetric maps they make using real data. The model seamount will help visualize the translation of a two-dimensional model (a map) into three-dimensional model.

A chain of small islands and atolls stretches for more than 1,000 nautical miles northwest of the main Hawaiian Islands. While scientists have studied shallow portions of the area for many years, almost nothing is known about deeper ocean habitats below the range of SCUBA divers. Only a few explorations have been made with deep-diving submersibles and remotely operated vehicles (ROVs). These brief excursions led to the discovery of new species and species previously unreported in Hawaiian waters.

A major constraint to exploration of deepwater regions around the Northwestern Hawaiian Islands is the absence of accurate maps. In fact, recent expeditions found that some islands are not where

they are supposed to be according to official nautical charts. Since time in submersibles is limited and expensive, every dive is carefully planned to ensure that the submersible goes to places of scientific interest. Good bathymetric maps are essential to good planning.

Scientists aboard the University of Hawaii's research vessel *Kilo Moana* used multi-beam swath bathymetry to create detailed pictures of the underwater topography around the Northwestern Hawaiian Islands. Multi-beam swath bathymetry, also called high-resolution multi-beam mapping, uses a transducer —a combination microphone/loudspeaker —on the ship's hull to send out sound pulses in a fan-shaped pattern below the ship. It records sound reflected from the sea floor through receivers focused at different angles on either side of the ship. This system collects high-resolution water depth data, distinguishing differences of less than one meter. It also measures back scatter—the amount of sound energy returned from the sea floor—which identifies different materials such as rock, sand, or mud on the sea floor.

The multi-beam system, coupled with a global positioning system (GPS), pinpoints sea-floor locations within one meter. Data are collected in digital form for computer analysis which produces maps, three dimensional models, and even fly-by videos simulating a trip through the area in a submersible.

Bathymetric maps are the most common output. Points with the same depth are connected by lines, showing mountains and valleys as a series of concentric, irregular closed curves. Lines that appear close together indicate steep slopes while lines that are farther apart indicate more gentle slope.

Learning Procedure

1. Introduce the location of the Northwestern Hawaiian Islands and point out some features that make this area interesting to scientists. Discuss the need for accurate maps in planning deep-sea diving expeditions. Discuss the general concept of multi-beam swath bathymetry. You may need to review the basic idea of topographic/bathymetric maps if students have not completed a previous activity using them.

2. Distribute copies of *Loihi Volcano Bathymetric Data* and an enlarged *Bathymetric Data Reduction Sheet* to each group. Tell the students that the bathymetric data are part of a real data set that was produced by a research vessel, using multi-beam bathymetry. Be sure students understand that each data point represents the depth of water below the research vessel when the vessel was at the location of the grid coordinates. If you wish to, relate the grid to the actual location. The lower left corner of grid cell 1,1 is latitude 18° 45'N, longitude 155° 20'W. Each grid cell is one minute of latitude or longitude. The students may assume that the depth reading was taken at the center of each grid cell, but they will color the entire cell as if it were in the depth range.

3. Assign each group a data range of 500 m (for example, 4600 – 4100 m) and a color. The maps they make are going to have 500 m contour lines. An example of the possible assigned color appears next to each below.
   Data Range:
   5000-4600 m - purple
   4500-4100m - blue violet
   4000-3600m - blue
   3500-3100m - blue green
   3000-2600m - green
   2500-2100m - yellow
   2000-1600m - orange
   1500-1100m - red

4. Each group will find ALL the recorded depths within its data range and color the entire square the assigned color for that depth. For example, if group 1 has 5000-4600 m and has been assigned purple, it will color the squares everywhere that there is a depth in the assigned range.

On the *Bathymetric Data Reduction Sheet* the square at row 1, column 4 would be purple.

5. Have the students translate their colors onto a single larger grid map on a bulletin board so that all colors are displayed. They have created a false color map showing depth with the purple deepest and the red most shallow. What is the object measured shaped like? Do they think they could draw it? Since digital imagining is common, ask students what would be needed to make this map more accurate. Better resolution would be achieved with more data points—more pixels and smaller ones.

6. Have each group use scissors to cut around the shape each group colored on the outside edges only. Each group will cut out their color and all shallower colors inside its color. Where a depth was skipped (sharp drop) go between the two colors on either side of the group's color.

7. Place the cut out shapes on a rolled out piece of modeling clay big enough to trace the outline of the contour and about 1/2-in thick. Use a dissecting needle to cut the clay to the shape of the grid. If you have several clay colors, alternate them for contrast.

8. Starting with the deepest contour (purple), lay the clay layers on top of each other in the orientation of the map to assemble a three-dimensional representation of the two-dimensional map. Now can they visualize its shape? This is a model of the Loihi Submarine Volcano.

9. Discuss the fact that a map is a model for a real place. The students have created two models of the same space. Which do they prefer? Using computers, bathymetric maps can be converted into three-dimensional pictures of spaces underwater.

10. Using the model the students produced, ask them to discuss the advantages of various sites on the volcano for diving missions. Integrate information on currents and sediment deposition. Flat regions are more likely to accumulate sediment, creating different habitats than steep places. On the other hand, steep areas have greater depth range within a short distance, so these are better places to study how depth influences the distribution of various species. Identify dive sites that are likely to offer a variety of habitats within a short distance. These offer good opportunities for getting the most benefit from limited diving time.

11. Have the students compare their models with the bathymetric image of the Loihi volcano at http://www.oar.noaa.gov/spotlite/archive/spot_loihi.html. This image provides much more detail than the students' topographic maps because it includes thousands of data points. This detailed mapping is only possible with computer analysis.

The BRIDGE Connection

www.vims.edu/BRIDGE/pacific.html

The "Me" Connection

Have students write a first-hand account of an exploratory mission to the Loihi volcano, referring to topographic features revealed by their model.

Connections to Other Subjects

English/Language Arts, Mathematics

Evaluation

Have students write a description of the Loihi volcano based on their model, including geographic directions: north, south, east, and west, as well as latitude and longitude, topography such as steepness, and depth. Ask them to discuss the utility of two-dimensional vs. three-dimensional bathymetric maps in writing their descriptions.

Extensions

Have students visit http://oceanexplorer.noaa.gov to study real deep-sea mapping in the Northwestern Hawaiian Islands.

Resources

http://oceanexplorer.noaa.gov – Northwestern Hawaiian Islands Expedition documentaries and discoveries.

http://geopubs.wr.usgs.gov/fact-sheet/fs013-00/ – Fact sheet on multi-beam mapping

http://www.oar.noaa.gov/spotlite/archive/spot_loihi.html – Short article on the Loihi volcano

http://www.soest.hawaii.edu/GG/HCV/loihi.html – More extensive web site with information on Loihi and other volcanoes in Hawaii

http://newton.physics.wwu.edu:8082/jstewart/scied/earth.html – Earth science education resources

http://www.sciencegems.com/earth2.html – Science education resources

http://www-sci.lib.uci.edu/HSG/Ref.html – References on just about everything

National Science Education Standards

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard D: Earth and Space Science

- Structure of the Earth system

Activity developed by Mel Goodwin, PhD, The Harmony Project, Charleston, SC

Student Handout

Loihi Submarine Volcano Bathymetric Data

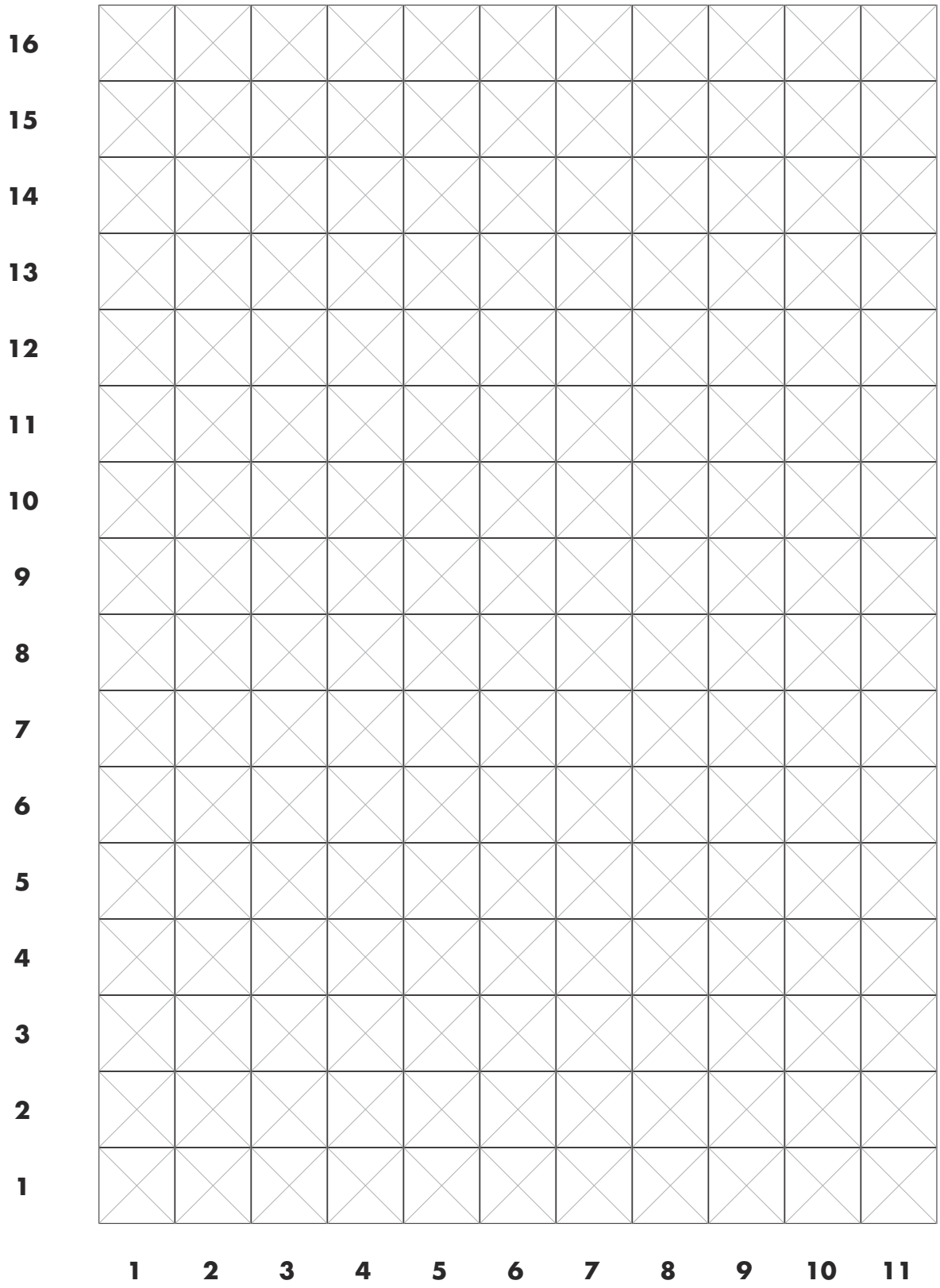
Grid Cell (row, column)	Depth (m)	Grid Cell (row, column)	Depth (m)	Grid Cell (row, column)	Depth (m)	Grid Cell (row, column)	Depth (m)
1,1	no data	3,12	1900	6,8	1800	9,4	3400
1,2	no data	3,13	2000	6,9	1600	9,5	3900
1,3	no data	3,14	2100	6,10	1300	9,6	4000
1,4	4600	3,15	2200	6,11	1200	9,7	3800
1,5	4400	4,1	no data	6,12	1700	9,8	3700
1,6	4400	4,2	no data	6,13	2000	9,9	3600
1,7	4000	4,3	4400	6,14	2200	9,10	3800
1,8	3800	4,4	3800	6,15	2000	9,11	3600
1,9	3600	4,5	3500	7,1	4500	9,12	3500
1,10	3300	4,6	3200	7,2	4400	9,13	3400
1,11	2700	4,7	2800	7,3	4000	9,14	3300
1,12	2400	4,8	2800	7,4	3800	9,15	3200
1,13	2500	4,9	2300	7,5	3000	10,1	4500
1,14	2600	4,10	1800	7,6	2400	10,2	4200
1,15	2800	4,11	1400	7,7	2400	10,3	4200
2,1	no data	4,12	1500	7,8	2300	10,4	4700
2,2	no data	4,13	1600	7,9	2300	10,5 - 10,15	no data
2,3	no data	4,14	1800	7,10	2500	11,1	4700
2,4	4200	4,15	1900	7,11	2500	11,2	4500
2,5	4100	5,1	no data	7,12	2700	11,3	4700
2,6	4100	5,2	no data	7,13	2900	11,4 - 11,15	no data
2,7	3900	5,3	4600	7,14	3000		
2,8	3400	5,4	4000	7,15	2500		
2,9	3200	5,5	3400	8,1	4500		
2,10	2800	5,6	2900	8,2	4000		
2,11	2400	5,7	2300	8,3	3600		
2,12	2200	5,8	1800	8,4	3100		
2,13	2300	5,9	1600	8,5	3000		
2,14	2300	5,10	1000	8,6	3200		
2,15	2400	5,11	1100	8,7	3200		
3, 1	no data	5,12	1200	8,8	3100		
3,2	no data	5,13	1400	8,9	3000		
3,3	no data	5,14	1600	8,10	3100		
3,4	4000	5,15	1800	8,11	3100		
3,5	3800	6,1	no data	8,12	3200		
3,6	3800	6,2	no data	8,13	3200		
3,7	3700	6,3	4500	8,14	3200		
3,8	3300	6,4	4000	8,15	2800		
3,9	2800	6,5	3400	9,1	4400		
3,10	2400	6,6	2700	9,2	4000		
3,11	2000	6,7	2000	9,3	3600		

Use Colored Pencils, Markers or Crayons for Data Ranges:

5000-4600 m - purple
4500-4100m - blue violet
4000-3600m - blue
3500-3100m - blue green
3000-2600m - green
2500-2100m - yellow
2000-1600m - orange
1500-1100m - red

Student Handout

Bathymetric Data Reduction Sheet



Section 3
Currents

Currents Are an Important Consideration

Each time a submersible goes down on an Ocean Exploration expedition, currents are an important consideration. If it is tethered, as are ROVs, not only will the current tug at the ROV, but it will also pull at the entire length of the tether. An autonomous submersible may be forced into a position from which it cannot free itself with its relatively weak thrusters, endangering lives as well as equipment. Additionally, the surface currents may be very different than currents at depth.

Surface currents are generated largely by wind. Their patterns are determined by wind direction, Coriolis forces from the Earth's rotation, and the position of landforms that interact with the currents. Surface wind-driven currents generate upwelling currents in conjunction with landforms, creating deepwater currents.

Currents may also be generated by density differences in water masses caused by temperature and salinity variations. These currents move water masses through the deep ocean—taking nutrients, oxygen and temperature with them.

Occasional events also trigger serious currents. Huge storms move water masses. Underwater earthquakes may trigger devastating tsunamis. Both move masses of water inland when they reach shallow water and coastlines. Earthquakes may also trigger rapid downslope movement of water-saturated sediments, creating turbidity currents strong enough to snap submarine

communication cables. Bottom currents scour and sort sediments, thus affecting what kind of bottom develops in an area—hard or soft, fine grained or coarse. Bottom substrate determines what kinds of communities may develop there.

Understanding Currents Is Critical to the Success of Ocean Exploration Expeditions

Finally, when a current that is moving over a broad area is forced into a confined space, it may become very strong. On the ocean floor, water masses forced through narrow openings in a ridge system or flowing around a seamount may create currents that are far greater than in the surrounding water—affecting both the distribution and abundance of organisms as well as the scientists and their equipment seeking to study them. Consequently, understanding currents and their patterns at a site is critical to the success of an Ocean Exploration expedition. There are three excellent current activities on the OE CD. One is modified and presented here, but you may wish to look at all three:

Where to Find More Activities on Currents

- *Current Events* in the Arctic Ocean Exploration 2002 examines density driven currents
- *In Gyre Straits* from Islands in the Stream 2002 looks at forces that create a gyre off of the Gulf Stream
- *Currents: Bad for Divers; Good for Corals* in the Northwest Hawaiian Islands Exploration 2002 examines the interaction between landforms and currents; it has been modified for this publication as it has general application to the OE expeditions.

Lesson Plan 5

Speeding Up: Deep Currents and Landforms

Focus
Deep-sea currents

Focus Question
How are deep-sea currents affected by submarine topography?

Learning Objectives
Students will examine the general effects of topography on deepwater ocean current speed.

Students will examine and discuss how speed affects the ability of a current to transport sediment or sand.

Students will apply information from the demonstrations to the problem of working in underwater submersibles around undersea landforms.

Materials
- ❒ Plastic flower window box (light-colored or spray painted white inside - about 30cm wide by 1m long by 20cm deep
- ❒ Sink with small diameter hose attached to faucet or 5-gallon capacity container with a siphon and flow-control clamp
- ❒ Rubber or plastic tubing about 1/2-in in diameter
- ❒ Cork or rubber stopper same size a hole in box
- ❒ Drill bit and drill with diameter that matches the tubing
- ❒ Silicone aquarium cement
- ❒ Large plastic eye dropper or pipette
- ❒ Two adjustable hose clamps
- ❒ Dye solution: 20 drops food coloring or India ink in 250 ml water
- ❒ Two or three blocks of modeling clay per student group
- ❒ Mixed sand (collected from several locations on a beach or builders' sand from builders supply store, about 150 ml per group

Teaching Time
Two 45-minute class periods

Seating Arrangement
Groups of four to six students

Key Words
Seamount
Mid-Atlantic ridge
Submarine canyon
Reef
Bank
Currents

Background Information
This activity focuses on topographic effects on deepwater currents and on how these currents may affect bottom characteristics that in turn influence species composition of an area. They may also affect the scientists studying an area. During the Ocean Exploration expedition to the Northwest Hawaiian Islands on September 22, 2002, the deep-diving submersible Pisces IV was pinned against an underwater cliff by a strong current 1,465 ft below the surface. After some tense moments, the submersible's pilot was able to break free (read more at http://oceanexplorer.noaa.gov/explorations/02hawaii/logs/sep22/sep22.html). Scientists believe that these strong currents may have an important role in shaping the deep-sea habitat around the Northwestern Hawaiian Islands.

Underwater currents shape both the bottom characteristics by sorting sediments and scouring hard bottom. The species composition of an area is determined in part by these features.

While surface currents are directly influenced by the frictional drag of wind moving over the ocean surface, purely wind-driven currents do not penetrate much below 100 m. In deeper water, currents are driven by pressure gradients which are a function of density and water depth. Changes in seawater density are caused by changes in salinity and/or temperature. Although it seems as if water depth in a given location is uniform, this is not always true. Even without wind, the sea's surface is not absolutely flat, but rather has broad mounds and valleys. Even small pressure gradients cause water to flow from regions of high pressure to low pressure, resulting in barotropic currents. These currents are relatively slow-moving in the open ocean, but can be significantly accelerated near the bottom or around solid objects, like seamounts, ridges or submarine canyons.

Learning Procedure

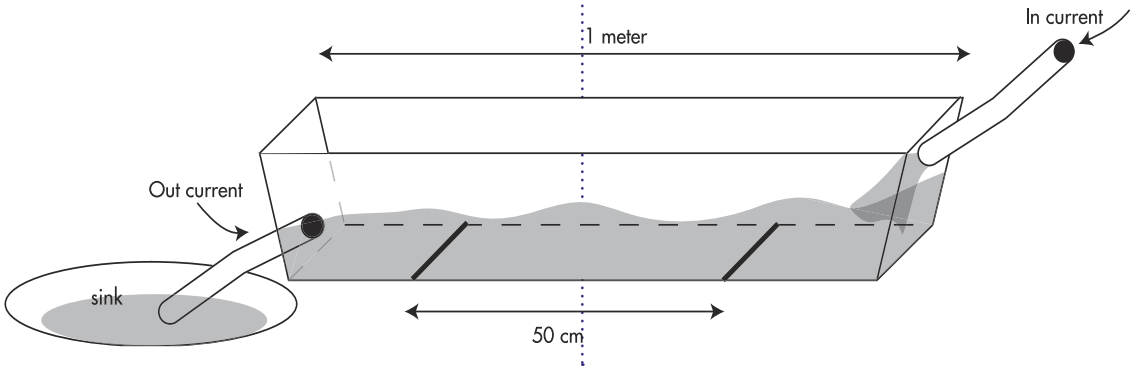
1. Build the current chute by filling the bottom holes in the window box if there are any. Drill holes on the vertical ends as shown below. They should be the same diameter as the tubing on the sink faucet or siphon. Insert the faucet tubing in the high end and seal. Add tubing to the low end and set it over the sink to catch the overflow. Attach hose clamps to each tube. Use a waterproof marker to make a 50 cm current racecourse in the center of the box, marking the front and back ends. See illustration for design. It is a bit time consuming to make this, but it can be used repeatedly. Modeling clay does not perform well when repeatedly soaked, but can be used more than once if handled carefully and not left in water very long.

2. With students, review the major forces that drive ocean currents discussed in the introduction above. Be sure students distinguish between currents that are largely wind-driven (less than 100 m deep) and those that result from pressure gradients due to differential density and/or depth. Students may read the log entries of September 22 (web address above) to get a sense of the force of deepsea currents.

3. How do scientists study currents in the lab? Ask for ideas. They actually build test tanks that simulate conditions in the ocean and study waves and currents in models of the real world. Display your test tank.

4. Review the undersea features that were introduced in Section 2 of this curriculum: Seamounts, Mid-Atlantic Ridges, Banks, and Submarine Canyons. Challenge your students to make models of these features to test in your underwater current testing box. Assign each group one of the five geologic features listed above. Explain that they will be

Current Chute



making observations on the effects of these features on current flow. These should be designed as follows, using modeling clay:

a. **Bank #1**: a flat round surface, like a pancake, about 10 cm diameter and 2 cm high.
b. **Bank #2 or Reef**: a low rounded form like half of a hardboiled egg about 10 cm long, 5 cm at its highest point and 5 cm at its widest point; rocky outcrops are referred to as reefs by mariners.
c. **Seamount**: a cone-shaped mountain that is 6-8 cm high and 10 cm across at the base.
d. **Mid-Atlantic Ridge**: a ridge of clay that spans the entire width of the test tank that is 6 cm high, 6 cm wide and as long as the tank is wide; cut two notches in the ridge—one 5 cm deep and the other 2 cm deep.
e. **Submarine Canyon**: collect spare clay from other groups and make a platform that fills the box from side to side in the middle and is about 5-6 cm high; carve a canyon in it with the shallow end on the side with the incoming current and the deepest end all the way to the bottom of the test tank on the outflow end; there many be twists in the canyon if desired.

5. To study the effects of the models on current flows:
   a. Set up the tank at the sink and test its function before class; empty it.
   b. Place a model in the test tank nearer the inflow end with object just touching the upstream start of the 50-cm range markings.
   a. Fill the window box about 3/4 full of water. Adjust the clamp on the siphon tubing so that water is flowing into one end at about 500 ml per minute.
   c. Adjust the outflow to match input when the box is ¾ full.
   d. Fill a pipette or long eye dropper about half full with dye solution. Being careful not to squeeze the rubber bulb, place the tip of the pipette just above the model surface at the end of the 50-cm mark. Gently squeeze a small amount of dye solution out of the pipette, and measure the time required for the dye plume to reach the other end of the 50-cm interval mark. Repeat this procedure by placing the tip of the pipette at the end of the model nearest the inflow from the siphon. Repeat these steps twice more, and calculate the average flow rate in cm per second.
   e. Repeat for each model.

6. Then test the model for current effect on sediment before switching to the next model. Pour about 50 ml of mixed sand into the top end of the test tank and record observations.

7. Increase the flow rate to about 1,000 ml per minute and repeat sediment test. Record student observations.

8. Clean test tank and repeat with the next model.

9. Have groups present their results. Lead a discussion to analyze these results. Students should have observed that current flow is increased around steep objects or objects that confine the water flow to a narrow passage. This flow acceleration can cause large, slow flowing water masses to become extremely strong and rapid currents. Students should also have observed that smaller particles of sand tend to be carried farther by currents than larger particles and that when speed of the current increases, the particle-carrying capacity of the current also increases.

10. What happened to sediment landing on the models? It was scoured by the current where currents moved fastest. What characteristics would be required of organisms growing on these sites? Species that are sediment aversive, species that have strong attachments, species that depend on currents to bring food—all might grow here. How might current influence on the distribution and sorting of sediments by particle size affect species composition of a soft bottom area?

The BRIDGE Connection

www.vims.edu/bridge.html

The "Me" Connection

Tell students to imagine that they are visitors to one of the uninhabited Northwestern Hawaiian Islands. Have them write a short essay on what signs they might look for in potential swimming areas that could indicate the presence of dangerously-strong currents.

Connections To Other Subjects

English/Language Arts, Physics, Biology, Mathematics

Evaluation

Develop a grading rubric that includes skill in laboratory observations and participation in discussions. You may wish to have students prepare individual written analyses prior to group discussion.

Extensions

Visit http://topex-www.jpl.nasa.gov/ for lots of information, links, and activities related to sea surface monitoring by satellites, El Niño, and other oceanography topics.

Resources

http://oceanexplorer.noaa.gov – the Northwestern Hawaiian Islands Expedition documentaries and discoveries are posted.

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

- Motion and forces

Content Standard D: Earth and Space Science

- Energy in the Earth system

Activity developed by Mel Goodwin, PhD, The Harmony Project, Charleston, SC

Section 4
Ocean Geologic Features

This introduction summarizes ocean geology as it relates to the Ocean Exploration expeditions. It is not a comprehensive examination of all aspects of ocean earth sciences. It starts with features of the continental shelf associated with passive margins—those that are less tectonically active—and includes both hard and soft bottoms. The introduction goes on to look at the common features among tectonically-active margins, hotspots and sea floor spreading regions that create particularly interesting ecosystems and geologic features.

Major Ocean Features: Continental Margin and Deep Sea

Two major ocean features are shallow continental margins and the deep sea. Sea level changes through time have exposed and submerged the upper portion of continental margins, called the continental shelf. Continental shelves of the world vary greatly in their width from a few kilometers to a hundred or more, but are relatively shallow in depth. Most extend offshore to water depths of 100 to 200 m. Just beyond the shelf, the sea floor slope is much steeper. This is the continental slope. At the base of the slope lies the continental rise, which is less steep and quite broad in places. The shelf, slope and rise together make up the entire continental margin. Many continental margins have steep-walled submarine canyons cutting through them. Some canyons may have formed during lowered sea levels as rivers ran out across the shelf, cutting into it. Submarine canyons are also channels for turbidity currents—water that carries sediment down slope—and continues the erosion that formed the canyon.

Passive Margin Processes

Continental margins may be geologically active or passive. Active margins occur along tectonic plate boundaries where earthquakes and/or volcanoes are common. Passive margins are not associated with plate boundaries, experiencing little volcanism and relatively fewer earthquakes. The Atlantic Ocean's continental shelf is a passive margin so the Ocean Exploration Hudson Canyon, Deep East and Islands in the Stream expeditions focused on features of passive margins.

Shelves and Sediment

The shelf is generally a broad, gently slopping platform that extends from the shoreline to the continental slope. It has thick accumulations of both coarse and fine-grained sediments. Since fine particles remain suspended in the water column longer than larger or denser particles, finer and lighter particles are carried farther, often to the edge of the shelf, before they settle. Consequently, slope and deep-sea sediments tend to be finer grained.

The continental slope is an abrupt drop. Sediments on the steep slope are largely soft mud. The slope flattens at the bottom where sediment slides pile up, forming the continental rise. Its thick sediment accumulations have fallen from the continental shelf—down the slope, sometimes quite abruptly.

Submarine Canyons

Submarine canyons cut into the shelf. They usually have v-shaped profiles, steep walls, rock outcrops, flat floors, strong currents, and deep-sea sediments fans at their base. Most are on the upper, steeper part of the slope. They run perpendicular to the shelf, across the continental shelf and slope. Generally submarine canyons are associated with major rivers.

Turbidity Currents

Turbidity currents form deep-sea sediment fans at the base of the slope. Fine sediments suspended by currents cause water to become murky or turbid. Turbid water is more dense and sinks. Turbidity currents—down-slope movements of sediment-laden water—continuously

erode many submarine canyons. Some turbidity currents are quite dense and abrupt in forming. These currents are set into motion when sand and mud on the continental shelf are loosened, perhaps by sudden melting of gas hydrates, by collapse of an overly steep slope, or by an earthquake. The sediment mixes with water to form a dense suspension, flowing like an avalanche down-slope, eroding and accumulating more sediment. Turbidity currents are likely contributors to submarine canyon growth. As they lose momentum, they deposit sediment as deep-sea fans at the canyon's lower end.

These deposits, called turbidites, are characterized by decreasing sediment size from the bottom to the top of a flow—forming graded bedding. As sediments settle, coarser, heavier particles settle out first, followed by finer sand and then clay.

Some 78% of the world's ocean sediments are in these three zones of the continental shelf. They are thickest along passive continental margins like the East and Gulf Coasts and less so along active margins such as the western U. S. coastline.

Sediment Characteristics

Sediment is classified either by grain size or its source. From smallest to largest, the particle sizes are clay, silt, sand, and gravel. Classified by origin, they are:

- *lithogenic* – coming from land by erosion of rocks,
- *biogenic* – derived from hard parts of organisms, usually calcium carbonate or silica,
- *authigenic* – precipitated by chemical or biochemical reactions in the water,
- *volcanogenic* – particles ejected from volcanoes,
- *cosmogenic* – grains that originate in outer space.

Sediment composition at a site depends on several factors. Under high energy conditions, such as waves or strong currents, fine grains stay in suspension or are re-suspended whereas coarse grains might settle out. Where currents scour the sediment most effectively, underlying

rock is exposed, and is referred to as hard bottom. Lower energy sites have finer grain because there is not enough energy to transport coarse material to the site. The shape of the grains also tells us something. Generally, the more rounded the grains, the older the sediment. They have been tumbled and rolled around for a long time. Younger coarse material may be rounded if it is in a high energy zone. Sediment bottom environments are referred to as soft bottom. The characteristics of the sediment determine which species of organisms occupy the site.

Proximity to land also determines sea floor sediment composition. The continental shelf is relatively shallow and close to land, receiving more lithogenic sediment from rivers and wind-blown dust. The deep sea has some lithogenic sediments carried by strong currents, but its sediment is largely biogenic—the hard parts of organisms living near the surface that settle to the bottom when the organisms die.

Cold Water Seeps and Gas Hydrates

Gas hydrate is an ice-like substance that forms in deep sea sediments when gas molecules, primarily methane, are trapped in a lattice of water molecules, forming a stable solid at temperatures above 0°C and pressures above 1 atmosphere. Gas hydrate deposits along ocean margins are estimated to exceed known petroleum reserves by about a factor of three. There is at least twice as much carbon locked up in hydrates as in all other fossil fuels on the Earth. There is commercial interest in mining methane from hydrates on the part of a number of countries.

Hydrates influence ocean carbon cycling, global climate change, and coastal sediment stability. Localized meltdowns have caused massive continental slope failure. They are an important geological hazard for shelf oil and gas production. Massive hydrate dissolution events, releasing vast amounts of the greenhouse gas methane, are possible causes of some of the abrupt climate changes seen in the geologic record.

There are vast hydrate deposits below 1,000 meters along the US East Coast. The gas hydrate beds leak gases into the water, forming cold seeps on the ocean floor. This hydrocarbon seepage is common on continental margins around the world. Chemosynthetic communities similar to those found at hydrothermal vents form at cold seeps, using hydrocarbons or hydrogen sulfide for carbon and energy. Seep tube worms, mussels, and clams form 2 m high bushes over kilometer-sized beds. Most seeps are also characterized by high microbial productivity.

Seep faunas vary in species and abundance, depending on the type and amount of seepage. Some species live exclusively with a particular form of hydrocarbon such as the hydrate ice worms. Others like the bacterium *Beggiatoa* are common at a variety of kinds of seeps. Seep communities are ecologically valuable as sources of food and refuge for an array of species. They may also be economically important as markers of underlying oil and gas reserves. Perhaps even more interesting, they are potential sources of new commercially-valuable bacteria. For all these reasons, Ocean Exploration expeditions may target cold water seeps.

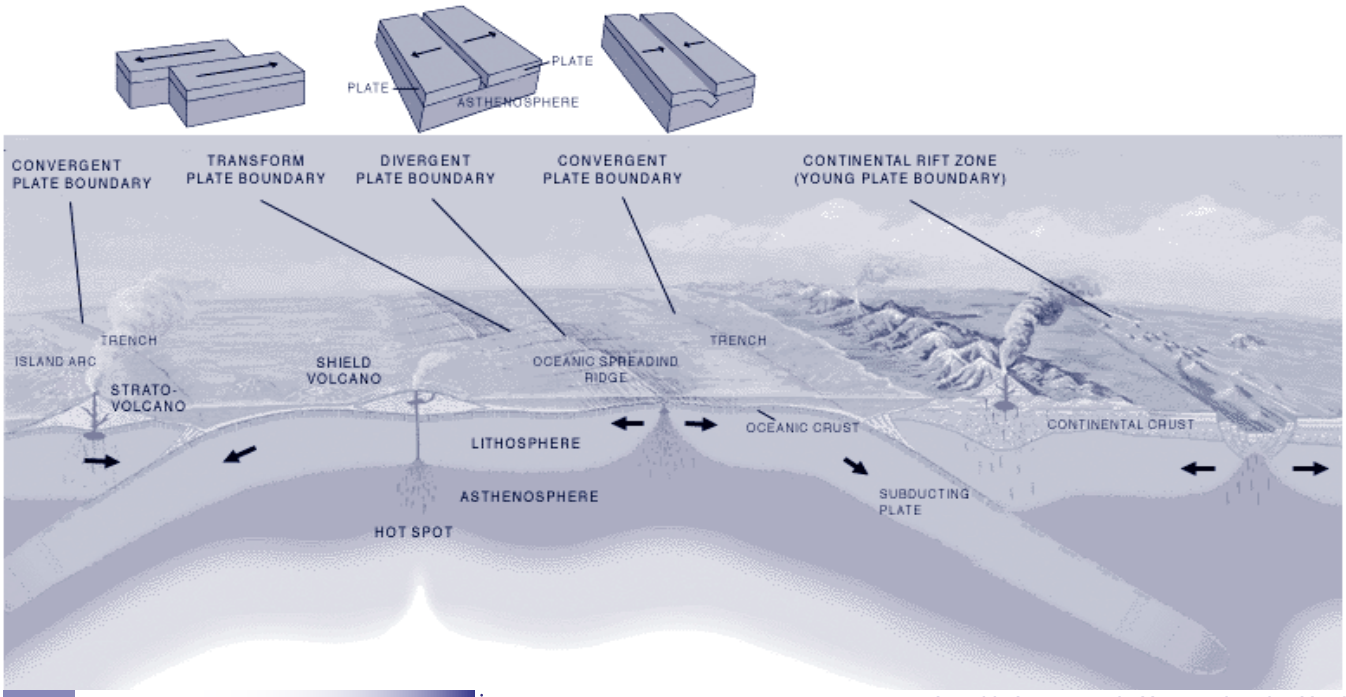
Active Margin Process

The outer shell of the Earth, the lithosphere, has about a dozen large plates of rock called tectonic plates. Each moves several centimeters per year relative to adjacent plates. The plates that make up the lithosphere move on a hot flowing mantle layer called the asthenosphere, which is several hundred kilometers thick. Heat within the asthenosphere creates convection currents (similar to the currents that can be seen if food coloring is added to a heated container of water). These convection currents cause the tectonic plates to move. Plates move in several ways in relation to each other.

Transform Plate Boundaries

Plates slide horizontally past each other at transform plate boundaries. Friction may lock plates temporarily as they try to move past each other, creating huge stress

Main Types of Plate Boundaries



Source: http://pubs.usgs.gov/publications/text/Vigil.html

in the boundary. If the force becomes too great, the plates may move abruptly, creating earthquakes. Places where breaks occur are called faults. A well-known transform plate boundary is California's San Andreas Fault.

Divergent Plate Boundaries

Where tectonic plates move away from each other, divergent plate boundaries form. Here magma—molten rock—rises from deep within the Earth and erupts, forming new crust in the lithosphere. Most divergent plate boundaries are underwater. Iceland is an exception. The boundaries form submarine mountain ranges called oceanic spreading ridges or rifts. These underwater ridges may be substantial—as much as 2,000 to 3,000 m high. They form the longest mountain chain in the world. As new oceanic crust forms at the ridges, older crust is progressively moved farther and farther from the ridge, creeping along at a rate of a few centimeters per year. As the new oceanic crust moves away from the ridge, it cools and contracts, decreasing the ridge height.

Deep Hydrothermal Vents

Hydrothermal vents form at ridges. Ocean water percolates down into rock fractures and encounters rising magma. Super-heated water, gases, and minerals escape from deep within the Earth. These vents provide the raw materials for communities whose primary producers are chemosynthetic bacteria—both endosymbiotic and free-living—enabling rich assemblages of organisms to live in deep water, far from sunlight.

Convergent Plate Boundaries

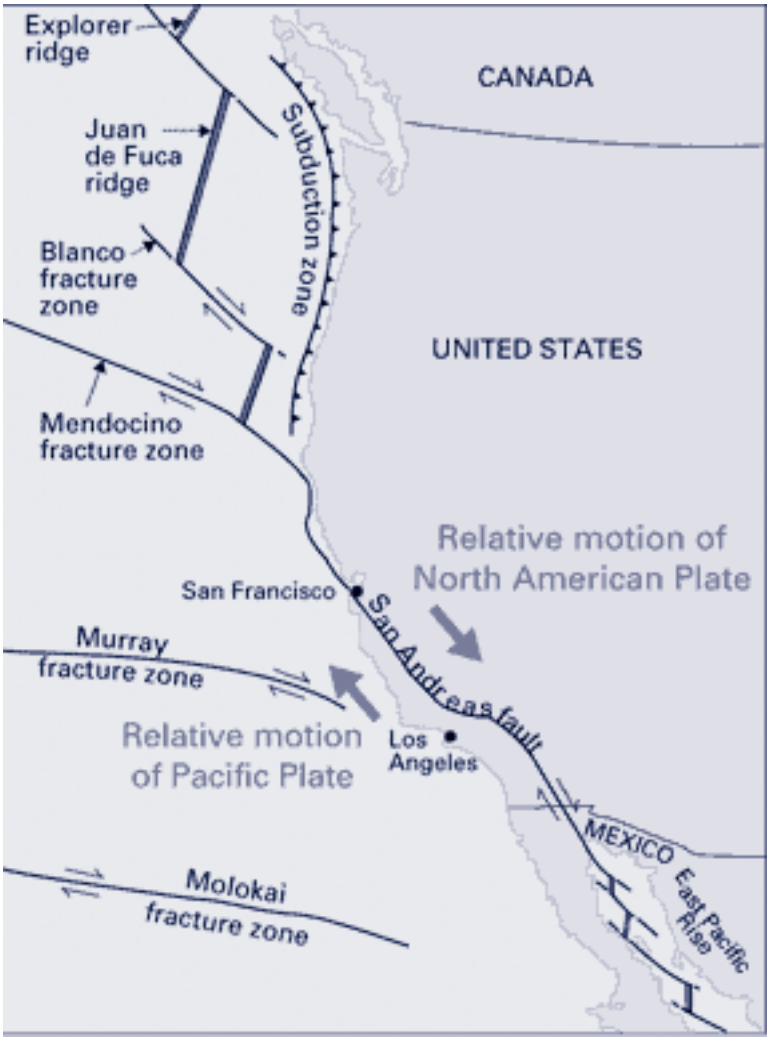
Yet another plate boundary is convergent. Here tectonic plates are pushed together. Usually one plate moves under the other—it is subducted. Deep trenches often form where one tectonic plate is being pushed beneath a second plate. Volcanic activity and earthquakes are common. As the sinking plate moves deeper into the mantle, the overlying mantle partially melts, forming new magma. It rises, erupting as a volcano. Island arcs produced by volcanic activity often form along a convergent boundary.

Many of the Ocean Exploration expeditions focus on active margins. The 2002 Submarine Ring of Fire Expedition investigated the formation of new ocean crust on the edge of the Juan de Fuca tectonic plate off the coast of western North America. This comparatively small tectonic plate has a divergent boundary with the Pacific plate as well as a convergent boundary with the North American plate, making it a microcosm of the large plate dynamics. The Mt. St. Helen eruption in 1980 was a result of the subduction of the Juan de Fuca plate beneath the North American plate. The divergent boundary is an active spreading center that is organized along three ridges: Gorda Ridge, Juan de Fuca Ridge, and Explorer Ridge.

Hotspots

Volcanoes also form at hotspots, thought to be pipelines to magma reservoirs in the upper Earth's mantle. The Hawaiian Islands are the result of volcanic activity associated with a hotspot that appears to penetrate the Pacific plate. The Pacific tectonic plate moves over the asthenosphere to the northwest at 5 to 10 cm per year.

As it moves over the hotspot, magma periodically erupts, forming volcanoes that become islands.



source: http://pubs.usgs.gov/publications/text/understanding.html#anchor15039288

Where to Find More Activities on Ocean Geologic Features

There are seven activities in this section that use inquiry-based experiences to introduce your students to some of the earth science discussed above. There are a number of Ocean Exploration Expedition Activities from 2001 and 2002 exploration on the OE CD and web site. Their topics appear below:

Sediments

- *Let's Bet on Sediments* from Deep East 2001 and Hudson Canyon 2002

- *Mud is Mud … Or Is It?* from Islands in the Stream 2002
- *An Underwater Sediment Slide?* see Hudson Canyon 2002

Cold Water Seeps/Methane Hydrates

- *It's a Gas!* in Deep East 2001 and Hudson Canyon 2002

Plate Tectonics

- *The Biggest Plates on Earth* from Submarine Ring of Fire 2002

Hotspots, Volcanoes and Plate Movement

- *Volcanoes, Plates and Chains* in Exploring Alaska's Seamounts 2002
- *History's Thermometers* from Exploring Alaska's Seamounts 2002
- *Mystery of the Alaskan Seamounts* in Exploring Alaska's Seamounts 2002
- *Roots of the Hawaiian Hotspot* from Northwest Hawaiian Islands Exploration 2001
- *Islands, Reefs and a Hotspot* in Northwest Hawaiian Islands Exploration 2001

Mid-ocean Ridges, Rifts and Hydrothermal Vents

- *The Galapagos Spreading Center* in Galapagos Rift Expedition 2002
- *AdVENTurous Findings on the Deep Sea Floor* from Galapagos Rift Expedition 2002
- *Yo-Yos, Tow-Yos and pH, Oh My!* from Galapagos Rift Expedition 2002
- *Mystery of the Megaplume* in Submarine Ring of Fire 2002

Lesson Plan 6

Let's Bet on Sediments

Focus
Sediment settling characteristics and shelf bottom composition

Focus Question
Is sediment size related to the time the sediment is suspended in water? If so, how?

Learning Objectives
Students will investigate and analyze patterns of sedimentation in the Hudson Canyon.

Students will observe that heavier particles sink faster than finer particles so bottom type is related to distance from the sediment source.

Students will infer that a passive continental margin is not as geologically quiet as previously thought.

Teaching Time:
Two 45-minute periods

Materials
Part I: Teacher
- ❒ Exploring Ocean Frontiers: Hudson Canyon transparency

Part II: for each group of 4
- ❒ 3 pint jars with lids, e.g. Snapple bottles, mayonnaise jars or canning jars
- ❒ 1/4 cup of each of the 3 sizes of sediments – small gravel, sand and silt
- ❒ Water to fill the 3 jars
- ❒ *Sediment Analysis Worksheets* for each student
- ❒ Stopwatch
- ❒ Magnifying glass
- ❒ Plastic spoon

Part III: Teacher Demonstration
- ❒ 10 gallon aquarium
- ❒ 1/2 cup of each of the 3 sediments used above
- ❒ Water - enough to fill the aquarium
- ❒ Hair dryer or aquarium filter

Audio/visual Equipment
- ❒ Overhead Projector

Teaching Time
One 45-minute period

Seating Arrangement
Cooperative groups of four

Key Words
Turbidites
Sedimentation
Sediments
North American plate
Suspension
Deep-sea fans
Active continental margin
Passive continental margin
Topography
Turbid
Turbidity currents
Shelf break
Continental shelf
Continental slope
Continental rise
Submarine canyon
Graded bedding
Avalanche

Background Information

Review information in Section 4 of this Curriculum on sediments and passive margins.

Learning Procedure

Part I Discussion

Using the *Exploring Ocean Frontiers: Hudson Canyon* overhead, discuss the features of a passive continental margin. Introduce submarine canyons and the location of Hudson Canyon. Challenge the students to test sediments for settling rates and other features related to continental shelf and submarine canyon geology.

Part II Activity

1. Have student groups gather the materials listed above for Part II.

2. Ask the students to predict which sediment type will reach the bottom the fastest and which the slowest on the *Sediment Analysis Worksheet.*

3. Working independently in their groups, have the students observe and analyze the three sediment types using the *Sediment Analysis Worksheet.*

4. Lead a discussion of results—did they predict correctly? Did they all get the same results?

Part III Demonstration Extension

1. While the students are working on Part II, set up a 10-gallon aquarium in front of class.

2. Fill it with water.

3. When they have finished discussing Part II, you, THE TEACHER ONLY, turn a hair dryer on and use it to produce surface currents in the aquarium (alternately use an aquarium filter to produce currents). SAFETY PRECAUTION: DO NOT DROP HAIR DRYER INTO AQUARIUM. A PERSON COULD GET ELECTROCUTED!

4. While the class is watching, pour all three sediment samples into the aquarium, starting with the most coarse.

5. Observe how the water currents affect the types of sediment.

6. Discuss with the class why the Hudson Canyon has fine sediment deposits on and around it and not coarse sediments. Use this demonstration as evidence.

7. Discuss turbidity currents and how they form deep-sea fans.

The BRIDGE Connection

www.hudsonvoice.com
http://bromide.ocean.washington.edu/oc540/lec01-16/
www.abdn.ac.uk/geology/profiles/turbidites/homepage/modern_c.html

Connection To Other Subjects

Mathematics, English/Language Arts

Evaluation

Students will write a paragraph summarizing what they learned about turbidity currents and the sedimentation.

The teacher will review each student's *Sediment Analysis Worksheet.*

Extensions

Ask students to research slumping and underwater avalanches.

Ask students to investigate the various sources of sedimentation caused by human activity.

Ask students to identify all of the deep-sea canyons found along the Atlantic Coast.

Visit the Ocean Explorer Web Site at
www.oceanexplorer.noaa.gov

Visit the National Marine Sanctuaries web page for a GIS fly-through of the Channel Islands National Marine Sanctuary at http://www.cinms.nos.noaa.gov/

National Science Education Standards

Content Standard A – Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B – Physical Science

- Motions and forces

Content Standard D – Earth and Space Science

- Structure of the Earth system
- Earth's History

Content Standard F – Science in Personal and Social Perspectives

- Natural Hazards

Content Standard G – History and Nature of Science

- Nature of science
- History of science

Activity developed by Tanya Podchaski, Bernards High School, Bernardsville, New Jersey

Student Handout

Sediment Analysis Worksheet

Part I:

1. Collect materials:
   3 jars filled with water
   3 1/4 cup sediment samples
   1 plastic spoon

2. Set jars filled with water aside.

3. Analyze the three sediment samples.

4. Sketch each of the three sediment samples and indicate scale in the boxes below:

Sample 1	Sample 2	Sample 3

5. Use your magnifying glass to look at the three samples.
   a. Does each of your samples have smooth edges or rough edges?
   Sample 1: _____
   Sample 2: _____
   Sample 3: _____

   b. Are each of your samples the same color throughout or are they made up of various colors?
   Sample 1: _____
   Sample 2: _____
   Sample 3: _____

6. If you were to drop each of these samples into water, which one would fall to the bottom the fastest? The slowest?

   _____
   _____
   _____

Student Handout

7. Using your jars, add one spoonful of each sediment to each jar and record the time it takes the entire sediment sample to reach the bottom, using the watch. Settling time may take as much as 24 hours.

   Jar 1 with Sample 1: _____ seconds
   Jar 2 with Sample 2: _____ seconds
   Jar 3 with Sample 3: _____ seconds

8. Using the observations from above, predict what would happen if you added all three samples at once to the large jar.

   _____
   _____
   _____

9. Using one jar add 2 spoonfuls of each of the other sediment samples. Then tighten the lid on the jar. Shake the jar to make a sediment-laden suspension and observe what happens with all the sediments. Sketch your observations below.

10. Based on your observations above, explain what graded bedding means.

   _____
   _____
   _____

Part II Demonstration Extension:

1. Looking at the aquarium in the front of the room, predict which sediment sample each type of current—surface and/or turbidity—would move.

   _____
   _____
   _____
   _____
   _____
   _____
   _____
   _____

Student Handout

2. Write a short essay comparing an underwater turbidity current avalanche to a snow avalanche found in the mountains.

Lesson Plan 7

Mud is Mud...Or is It?

Focus
Comparing and analyzing deep-sea sediments

Focus Question
What are some sources of variation in deep-sea sediments and how do they differ?

Learning Objectives
Students will compare and contrast similar items.

Students will use computers to find information.

Students will identify variables affecting deep-sea habitats and organisms.

Students will use different scales, comparing sizes of items shown at different scales.

Materials
❒ Computer with Internet access
❒ One *Sediment Comparison Worksheet* per student

Audio/visual Materials
❒ Overhead projector

Teaching Time
45-minute period

Seating Arrangement
Groups of 2 to 3 students

Key Words
Sediment
Lithogenic
Biogenic
Eddie
Continental shelf
Plateau
Upwelling
Gulf Stream
Scarp

Background Information
In this activity students will study photographs of actual sediments from the southeastern United States' continental shelf. These enlarged photos enable the students to measure grain size and to observe actual structure of the grains. Students will be challenged by the need to keep scale in mind as they do their analysis. Soft bottom sediments determine the species composition of organisms that live in and on them. Where they are scoured away revealing hard bottom, totally different species become established.

Sediment can be classified either by grain size or mode of formation. From smallest to largest, the particle sizes are clay, silt, sand, and gravel. Using origin, sediments can be classified as:

lithogenic: from land by erosion of rocks,
biogenic: from hard parts of marine organisms made of calcium carbonate or silica,
authigenic: precipitates from chemical or biochemical reactions in the water,
volcanogenic: material ejected from volcanoes, including ash,
cosmogenic: grains that originate in outer space.

Sediment composition is also influence by waves and currents. They sort by grain size and density as well as wearing down rough edges over time. Proximity to land also helps determine the sediment composition. Since the shelf is close to land, it has

more lithogenic sediment. Most deep-sea sediments are largely the hard parts of surface-water organisms that settle to the bottom.

The sediment pictures used for this activity came from the Savannah Scarp and the Charleston Bump. The Savannah Scarp is a series of rocky ridges and outcrops where Gulf Stream currents have diverted sediments away from the underlying rock, forming a rocky reef. It is at about 55 m (180 ft) with a steep drop to 70 m (250 ft) or more. Along this drop large rocks, ridges, ledges, caves, and overhangs provide spectacular habitat for a diverse abundance of organisms.

The Savannah Scarp sediment samples come from 61m (200 ft) deep about 60 miles offshore. Here the Savannah Scarp is limestone rock which probably originated as loose grains of calcium carbonate sediment or oolitic sands that became cemented together during the lower sea level of the last Ice Age, approximately 18,000 yrs ago.

The Charleston Bump rises above the relatively flat Blake Plateau beyond the edge of the continental shelf in the South Atlantic Bight. From over 700 m (2,300 ft), the bottom rises to a shallow scarp at 375m (1,230 ft). From there, the bottom plunges in a series of steep scarps with rocky cliffs, overhangs and caves. The Charleston Bump deflects the flow of the Gulf Stream. Its warm current is pushed offshore by the Bump, producing eddies that are important fish habitats. In these eddies mixing and upwelling bring nutrient-rich, deep water to the surface, enhancing plankton production which supports a diverse assemblage of zooplankton and fish. The Charleston Bump sediment sample came from about 100 mi. offshore from a depth of about 490 m (1,600 ft).

Learning Procedure

1. The sediment sample photos are at http://oceanica.cofc.edu/samplematerial/images.htm. Students should open the page twice so that they can have Bump sediment on one window and Scarp sediment on the other for easy comparison.

2. Once at the page, they can choose Bump or Scarp sediment by clicking the appropriate button. They can then enlarge the images by clicking on them.

3. The *Sediment Comparison Worksheet* refers to Figures 1-6. These figure numbers are just for this activity and DO NOT match the image numbers on the web page. Use the key on the *Sediment Comparison Worksheet*.

4. Working independently, have the students complete the worksheet.

5. If you need to use an overhead, make overheads of the figures for each question on the *Sediment Comparison Worksheet* and use them to take the students through the worksheet. For example: Question 1 refers to Figures 1 and 2. Put them both on one overhead so they are next to each other and easily compared.

The BRIDGE Connection

www.chariho.k12.ri.us/curriculum/MISmart/ocean/sands.htm

The "ME" Connection

(See Extension #2) Have the students describe what organisms can best survive in the soil in their backyard versus the organisms that may live in the other habitat from which they gathered soil.

Connections To Other Subjects

Oceanography, Geology

Evaluation

Completed *Sediment Comparison Worksheets*

Extemsions

Go to http://oceanica.cofc.edu/samplematerial/samples.htm and request actual samples of the sediment from the Charleston Bump and the Savannah Scarp. (They

are FREE!!). Using the samples, go back to the same web page and have your students go through the activity available on the web page.

Have students gather soil samples from two very different habitats (e.g., a beach and their backyard). Modify the worksheet, using many of the same questions, to suit the samples they have collected.

Resources

http://oceanexplorer.noaa.gov/explorations/islands01/background
http://oceanexplorer.noaa.gov/explorations/islands01/log

"A Profile of Savannah Scarp", NOAA Ocean Exploration Web Site (2001) George R. Sedberry, Senior Marine Scientist, Marine Resources Research Institute, South Carolina Department of Natural Resources

"A Profile of the Charleston Bump", from NOAA Ocean Exploration Web Site (2001) George R. Sedberry, Senior Marine Scientist, Marine Resources Research Institute, South Carolina Department of Natural Resources

"Getting to the Bottom of a Rocky Rubble Reef", from NOAA Ocean Exploration Web site (2001) Dr. Leslie R. Sautter, Dept. of Geology and Environmental Sciences, College of Charleston, Charleston, SC

National Science Education Standards

Content Standard A – Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard D – Earth and Space Science

- The origin and evolution of the Earth system

Activity developed by Rachel McEvers, College of Charleston
All figures courtesy of Project Oceanica

Teacher Answer Key

Sediment Comparison Worksheet

If you are doing this activity on the web refer to the following key for the proper images:

Figure 1 = Bump Image #4
Figure 2 = Scarp Image #7
Figure 3 = Bump Image #1
Figure 4 = Scarp Image #5
Figure 5 = Bump Image #15
Figure 6 = Scarp Image #3

1. What are the two main ways to classify sediment?
   By particle size and basis of formation.
2. What is the difference between biogenic and lithogenic sediment?
   Biogenic sediment is composed of the skeletal remains of microscopic organisms and fragments of coral. Lithogenic sediment is derived from the weathering and erosion of rocks on land and is composed of mostly rock fragments.
3. Figure 1 was taken from the Charleston Bump. Figure 2 was taken from the Savannah Scarp. How would you classify each of them in terms of their basis of origin—their primary composition?
   The Bump sediment is primarily biogenic and the scarp sediment is primarily lithogenic.
4. Give two reasons why the samples might be so different in composition.
   The Scarp is much closer to land than the Bump (60 mi offshore vs. 100 mi.) and, therefore, receives more eroded rock from rivers and wind-blown debris. The Scarp is much shallower than the Bump. The Gulf Stream runs past the Bump making it a very high energy area, thus preventing fine particles from settling out.
5. Figure 3 is from the Bump. Figure 4 is from the Scarp. Using the 3-mm scale bar in each figure, determine which of these samples has the larger grain size. What do you think is the main reason for this?.
   The Bump has larger grains due to the high energy environment of the Gulf Stream.
6. Low-energy conditions tend to have what size sediment grains?
   Fine
7. Using Figures 5 (Bump) and 6 (Scarp) as well as all the previous figures, describe any similarities in the two sediments.
   They should be able to find many of the same organisms or "grains" in each of the two samples.Grain shape in both is mixed. There are rounded coral and rock pieces and angular shell fragments in both.
8. What can grain shape tell us about sediment?
   It can tell us about the age (young or old, not specific years) of the sediment. It can tell us about the energy conditions where the sediment was collected.
9. Again using all of the figures, what are some other differences you notice?
   The color of the two sediments is different. The Scarp sediment is a very dark, almost a greenish color, whereas the Bump sediment is a light to medium brown.

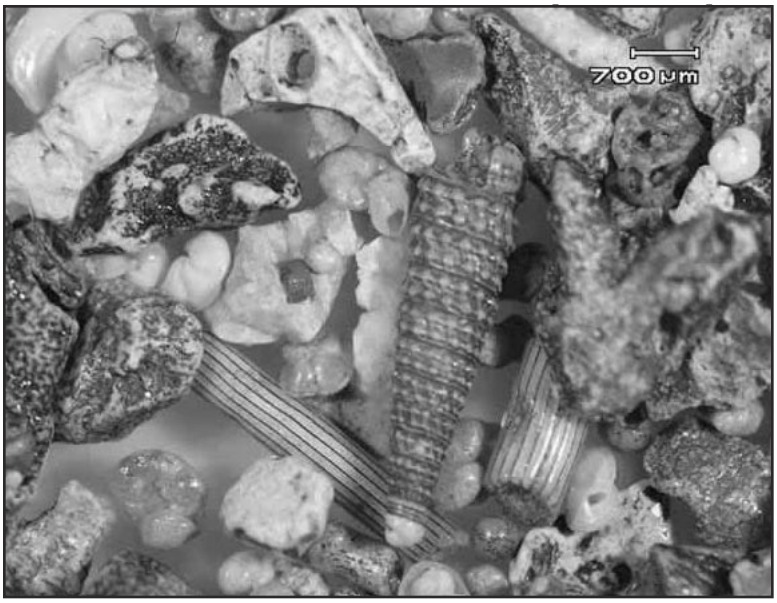


Figure 1

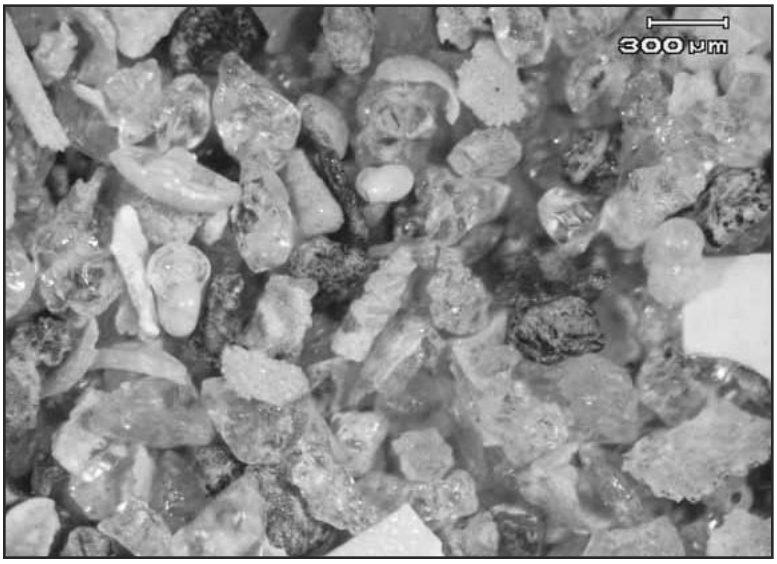


Figure 2

Figure 3

Figure 4

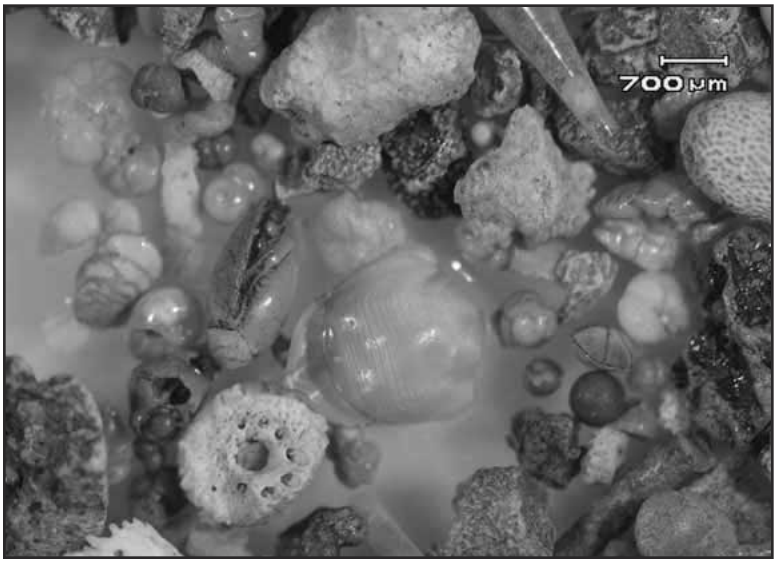


Figure 5

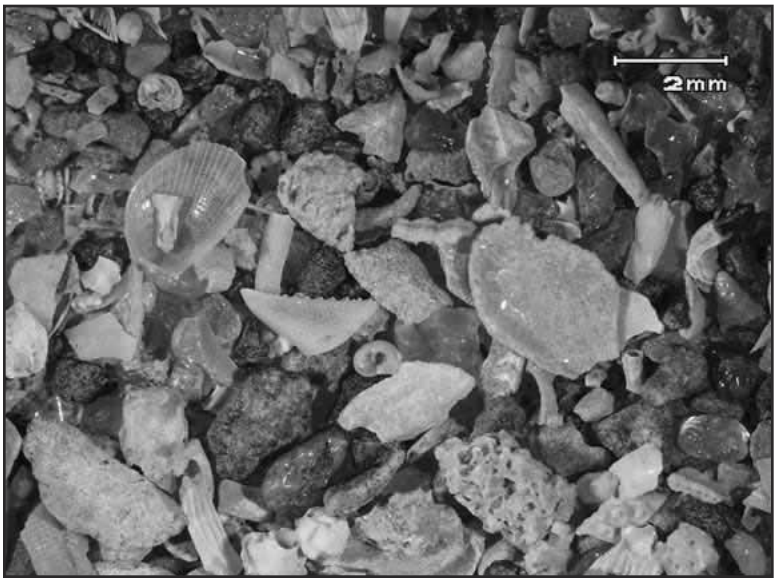


Figure 6

Student Handout

Sediment Comparison Worksheet

If you are doing this activity on the web refer to the following key for the proper images:

Figure 1 = Bump Image #4
Figure 2 = Scarp Image #7
Figure 3 = Bump Image #1
Figure 4 = Scarp Image #5
Figure 5 = Bump Image #15
Figure 6 = Scarp Image #3

1. What are the two main ways to classify sediment?

2. What is the difference between biogenic and lithogenic sediment?

3. Figure 1 was taken from the Charleston Bump. Figure 2 was taken from the Savannah Scarp. How would you classify each of them in terms of their basis of origin (i.e., what is the primary composition of each?)

4. Give two reasons why the samples might be so different in composition.

Student Handout

5. Figure 3 is from the Bump. Figure 4 is from the Scarp. Using the 3-mm scale bar in each figure, determine which of these samples has the larger grain size. What do you think is the main reason for this?

6. Low-energy conditions tend to have what size sediment grains?

7. Using Figures 5 (Bump) and 6 (Scarp) as well as all the previous figures, describe any similarities in the two sediments.

8. What can grain shape tell us about sediment?

9. Again using all of the figures, what are some other differences you notice?

Lesson Plan 8

The Biggest Plates on Earth

Focus
Plate tectonics

Focus Question
How do tectonic plates move, what are some consequences of this motion, and how do magnetic anomalies document the motion at spreading centers?

Learning Objectives
Students will describe the motion of tectonic plates and differentiate between three typical boundary types between tectonic plates.

Students will infer what type of boundary exists between two tectonic plates, given information on earthquakes and volcanism in the vicinity of the boundary.

Students will infer the direction of motion between two tectonic plates given information on magnetic anomalies surrounding the spreading ridge between the plates.

Materials
❒ One copy each per student group - *Pacific Basin Tectonic Plates* and *Magnetic Anomalies on the Juan de Fuca Plate*

Audio/visual Equipment
❒ Overhead transparency of cross section illustrating the main types of plate boundaries (download from U.S. Geological Survey web site: http://pubs.usgs.gov/publications/text/Vigil.html)
❒ Overhead transparency of map illustrating the Ring of Fire (from U.S. Geological Survey web site: http://pubs.usgs.gov/publications/text/fire.html)
❒ Overhead projector

Teaching Time
Two or three 45-minute class periods

Seating Arrangement
Groups of two to four students

Key Words
Basalt
Ring of Fire
Asthenosphere
Lithosphere
Magma
Fault
Transform boundary
Convergent boundary
Divergent boundary
Subduction
Magnetic anomaly
Tectonic plate
Spreading center

Background Information
This lesson is divided into two parts. First, students will infer whether plate boundaries associated with the Pacific Ring of Fire are divergent, convergent, or transform based on information about earthquakes and volcanic activity in the vicinity of the boundaries. In the second part, students will use magnetic anomaly data to draw inferences about the spreading center system on the divergent boundary of the Juan de Fuca plate.

Measurements of magnetic variations on the ocean floor have provided critical evidence for theories of continental drift and plate tectonics. When magma erupts along oceanic spreading ridges, it has high mineral content, including magnetic minerals, such as iron and magnetite that align with the Earth's magnetic field like compass needles. As the magma cools to form solid rock (basalt), particles of magnetite become immobilized, providing a record of the position of the Earth's magnetic field when the magma was extruded.

The Earth's magnetic field reverses at irregular intervals of an average of 400,000 years. The alignment of magnetic particles in the crust that was formed during periods of reversal is opposite to that of particles produced when the Earth's magnetic field is oriented similarly to the present. Scientists have found that the intensity of the Earth's magnetic field varies around spreading centers. In some locations it is stronger than normal, in other locations it is weaker. These variations, called magnetic anomalies, are the result of magnetic minerals in the basalt rocks. If the minerals' alignment was "locked" into the rocks when the Earth's magnetic field was similar to its present magnetic field, then the magnetism of the minerals is added to the Earth's magnetic field. Thus the total magnetic intensity is greater than normal and is called a positive magnetic anomaly. On the other hand, if the minerals' alignment occurred when the Earth's magnetic field was opposite to the present, then the magnetism of the minerals is opposite the Earth's current magnetic field. The total magnetic intensity is less than normal when measured above this negative magnetic anomaly.

When positive and negative magnetic anomalies are measured on either side of an oceanic spreading center, they form a zebra-striped pattern with the stripes running parallel to the spreading center ridge. Scientists have reconstructed the history of magnetic reversals for the past 4 million years using a dating technique based on isotopes of potassium and argon (see http://oceanexplorer.noaa.gov/explorations/02alaska/background/edu/media/mapping7_8.pdf.) They have calculated the age of the magnetic anomaly stripes and the rate at which tectonic plates are moving away from the spreading centers.

Learning Procedure

1. Review plate tectonics and continental drift. Be sure students understand the idea of convergent, divergent, and transform boundaries, as well as the types of earthquakes and volcanic activity associated with each kind of boundary: strong earthquakes and explosive volcanoes at convergent boundaries; slow-flowing volcanoes, weaker earthquakes at divergent boundaries; strong earthquakes and rare volcanoes at transform boundaries. You may want to use materials from "This Dynamic Earth" and/or "This Dynamic Planet" (see Resources section), but do not give away the answers to the predictive exercise on the Pacific Basin Tectonic Plates.

2. Distribute copies of the *Pacific Basin Tectonic Plates*. Using the overhead of the Ring of Fire (see materials list) have each group decide what type of boundary exists at the indicated sites, based on the direction of plate movement. Tabulate each group's results, and lead a discussion of the reasoning behind their conclusions. If you want to use this exercise for evaluation, collect the worksheets before discussion.

3. Explain the origins of magnetic anomalies, and draw the students' attention to the area around the Juan de Fuca plate. Do not give too much detail on the plate; just talk about where it is in relation to the United States and Canada. Be sure the students realize that the small size of the plate brings convergent and divergent boundaries relatively close together. The fact that subduction at the convergent boundary with the North American plate caused the Mount St. Helen's eruption should spark students' interest.

4. Distribute copies of *Magnetic Anomalies on the Juan de Fuca Plate* to each student or student group. Have each group discuss the handout, and write its conclusions about the location of the spreading site on the ridge on the worksheet. Lead a discussion of the reasoning behind these conclusions. Students should infer that the magnetic anomalies occur on either side of a divergent plate boundary between the Juan de Fuca and Pacific plates with the youngest rocks closest to the spreading center at the boundary of the two plates. How do they account for the interruption in the continuity of the anomaly stripes? There is a transverse fault across the ridge.

The BRIDGE Connection

www.vims.edu/bridge/geology.html

The "ME" Connection

Have students write a first-hand account of a visit to a plate boundary, describing where the boundary occurs and what conditions are found there.

Connection To Other Subjects

English/Language Arts, Geography

Evaluation

Both worksheets may be used to evaluate students' understanding of the concepts presented. Alternatively or additionally, students may be asked to define key words, and/or identify the type of boundaries and expected conditions at the junctions of other tectonic plates.

Extensions

Have students visit http://oceanexplorer.noaa.gov to study the Ring of Fire Expedition discoveries.

Resources

http://oceanexplorer.noaa.gov – The Ring of Fire expedition documentaries and discoveries

http://pubs.usgs.gov/publications/text/dynamic.html#anchor19309449 – On-line version of "This Dynamic Earth," a thorough publication of the U.S. Geological Survey on plate tectonics written for a non-technical audience

http://pubs.usgs.gov/pdf/planet.html – "This Dynamic Planet," map and explanatory text showing Earth's physiographic features, plate movements, and locations of volcanoes, earthquakes, and impact craters

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

- Transfer of energy

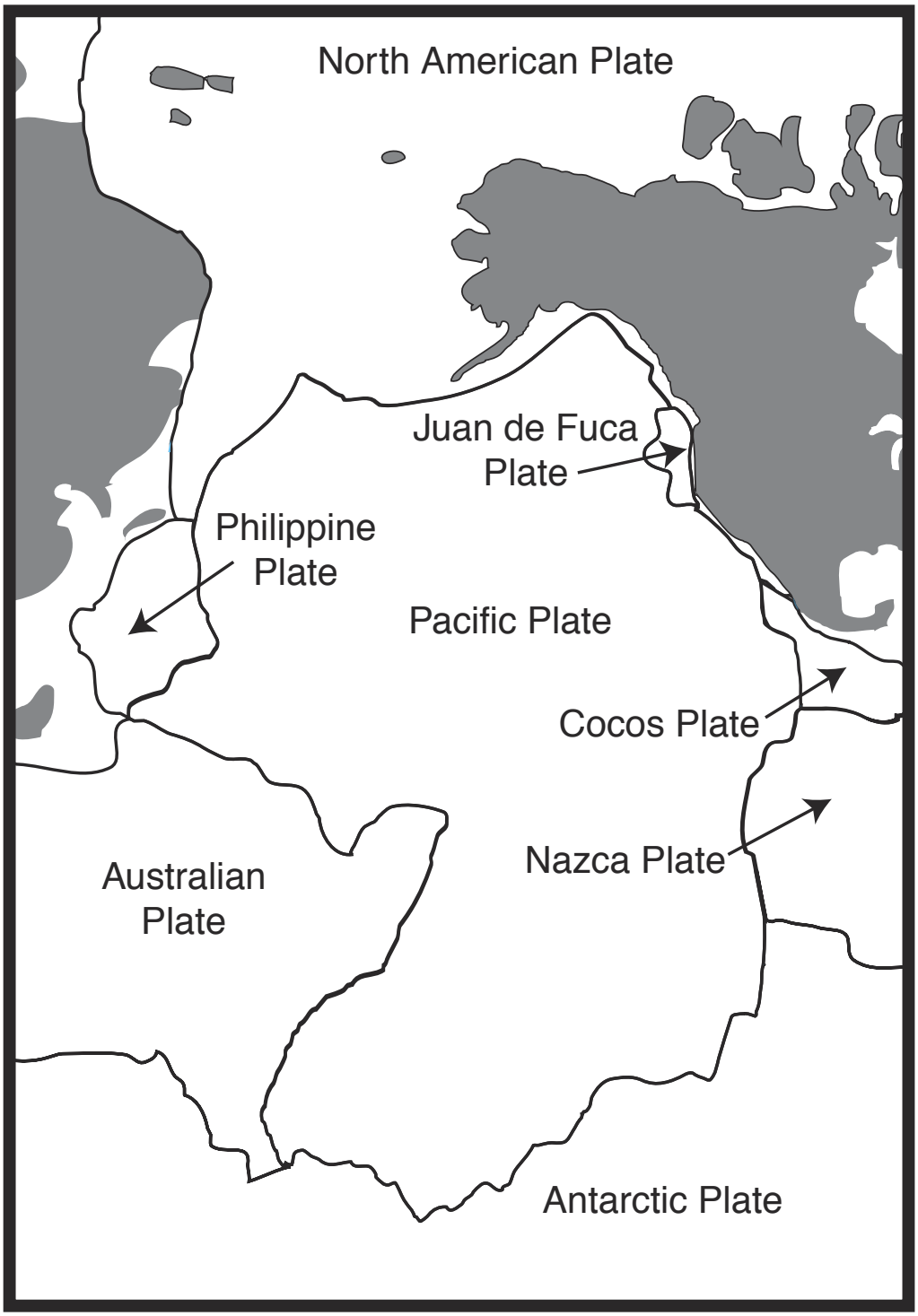
Content Standard D: Earth and Space Science

- Structure of the Earth system

Activity developed by Mel Goodwin, PhD, The Harmony Project, Charleston, SC

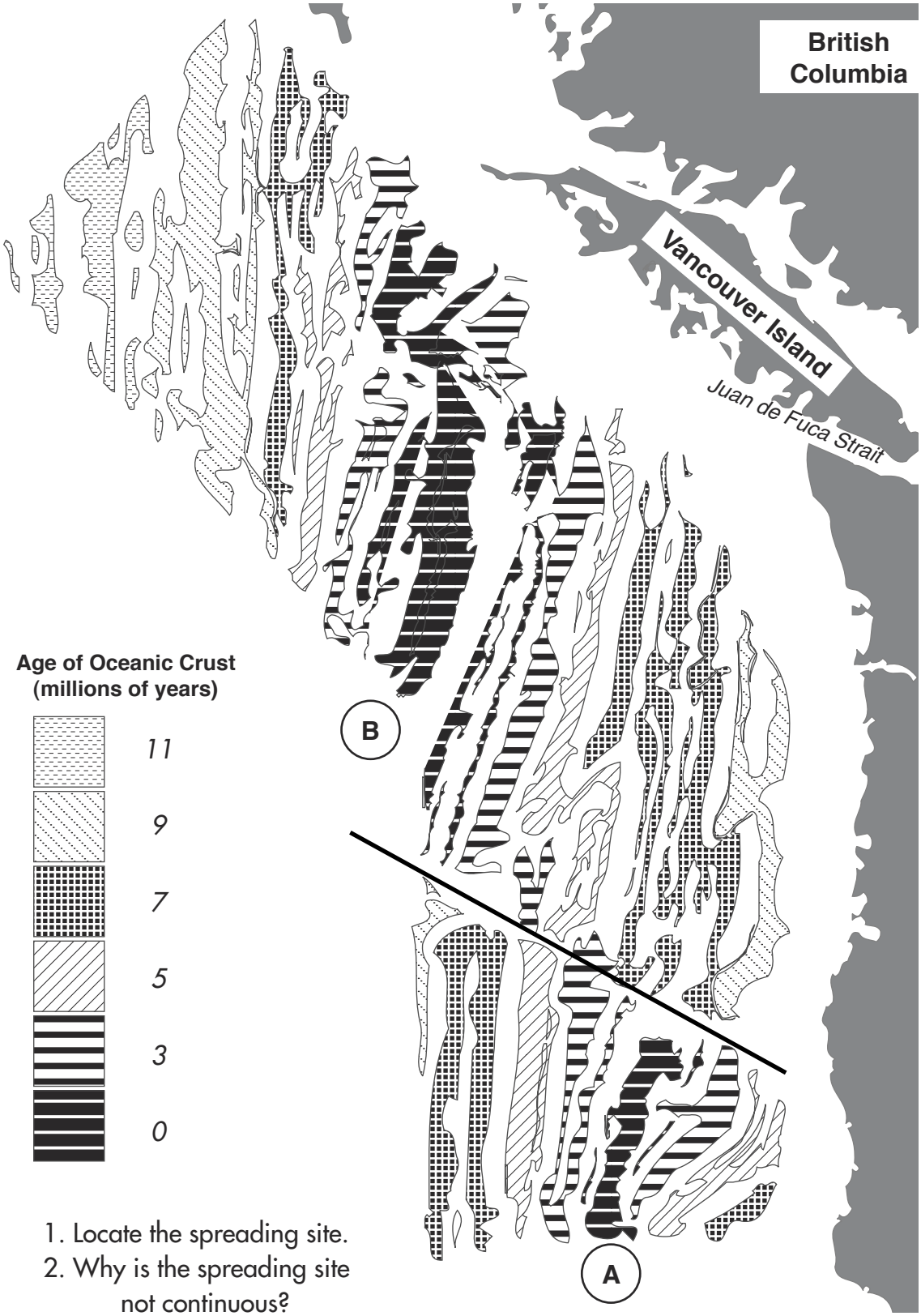
Student Handout

Tectonic Plates Bordering the Pacific Basin



Student Handout

Magnetic Anomalies on the Juan de Fuca Plate



1. Locate the spreading site.
2. Why is the spreading site not continuous?

Source: http://pubs.usgs.gov/publications/text/dynamic.html#anchor19309449

Lesson Plan 9

The Galapagos Spreading Center

Focus
Mid-Ocean Ridges

Focus Question
How does new ocean floor form?

Learning Objectives
Students will model sea floor spreading, using the Galapagos Spreading Center system as an example.

Students will describe the processes that create new sea floor at a mid-ocean ridge.

Materials
For each student:
- ❒ Copy of *Map of the Galapagos Spreading Center*
- ❒ Copy of the *Galapagos Spreading Center Student Worksheet*

For the teacher:
- ❒ Physiographic map of the Pacific Ocean with sea floor features if available
- ❒ Overhead transparency of Figure 1
- ❒ Map of the *Galapagos Spreading Center*
- ❒ Scissors
- ❒ Paper copy of Figure 1, cut in two along the ridge segments and transform fault
- ❒ Red overhead transparency pen
- ❒ Overhead transparency with large area colored red

Audio/Visual Materials
- ❒ Overhead projector

Teaching Time
20 minutes

Seating Arrangement
Individuals or in groups of 2

Key Words
Ridge
Basalt
Fissure
Sea floor spreading
Tensional forces
Transform fault
Divergent
Molten
Translational
Plate
Magma
Extrude
Lithosphere
Hydrothermal vent
Convergent

Background Information
In many areas, the Earth's tectonic plates are being pulled apart by tensional forces. Enormous elongate cracks, or fissures, in the lithosphere allow molten rock from deep within the Earth to rise and escape as lava. If a fissure occurs in oceanic lithosphere, the lava erupts under water, cooling very rapidly. The solid rock that is formed (called basalt) is oriented in elongate bands parallel to the fissure. Repeated events of tensional forces and extruded fissure lava continually add material to the plates being pulled apart. As a result, divergent boundaries produce new lithosphere, and lithospheric plates grow. Ridges form in regions of extensive and repeated fissure eruptions. Often these underwater ridges have substantial height—as much as 2,000

to 3,000 meters. They are regarded as the longest mountain chains in the world. As new oceanic crust forms at the ridges, older crust is progressively moved farther and farther from the ridge, creeping along at a rate of a few centimeters per year. This process is referred to as sea floor spreading. Hence, divergent boundaries are referred to as spreading boundaries. As the new oceanic crust rock moves away from the heated ridge, it cools and contracts, decreasing the ridge height on its flanks.

Recent use of undersea submersibles provides a window to view the mid-ocean ridges. Scientists have actually watched new ocean floor being produced as red-hot lava extrudes from active fissures, instantly hardening in the cold 2°C bottom water. Hydrothermal vents form on ridges where superheated water, gases, and minerals escape from deep within the Earth.

Sea floor spreading not only forms ocean ridges, but over millions of years creates entire ocean basins. The modern oceans were formed by the divergence of two plates creating new oceanic crust in between. Sea floor maps reveal a crooked, but continuous mountain chain that divides the Atlantic Ocean, known as the Mid-Atlantic Ridge. Like the seams of a baseball, the ridge system continues around the globe, connecting with the Indian Ocean ridge system. Eventually the "seam" travels across the southern Pacific and appears to end as it runs into Central America.

Learning Procedure

1. Prepare the Spreading Center Overhead Model:
   a. Cut a paper copy of Figure 1 along the Galapagos Spreading Center of ridge segments and a transform fault.
   b. Reassemble the figure with a piece of tape on the "ridge" to hold the two pieces together, but able to be removed during the demonstration.
   c. Put the red-colored overhead transparency under the paper.

Classroom Procedure

1. Give each student or group a paper copy of Figure 1, the *Galapagos Spreading Center*. Have them locate the ridge segments, the transform fault, and the Galapagos Islands. Lead a discussion of these sea floor features using the overhead of Figure 1.

2. Compare Figure 1 to a large scale sea floor map to see where the Galapagos Spreading Center is located relative to the rest of the Pacific Ocean. What plates lie to the north and south of the spreading center? (the Cocos Plate to the north, the Nazca Plate to the south.)

3. Using the overhead projector and the overhead model prepared in advance, demonstrate how magma extrudes at the ridge. Place the red overhead transparency and cut and taped paper copy of Figure 1 on the overhead projector. The paper blocks the light. The shadow represents the oceanic sea floor crust.

4. Remove the tape carefully so that the "fissure" does not open.

5. Describe how tensional forces in nearly opposite directions to the north and to the south of the Galapagos Spreading Center have, over time, caused fracturing of the oceanic crust. Fissures—or elongate breaks in the crust—have formed and the oceanic crust has diverged or moved away from the fissures. The double lines on Figure 1 represent two ridge segments that began as fissures.

6. At this point, pull the parts away from each other about an inch, revealing the underlying red transparency "glowing" as though it were molten (or melted) rock.

7. Ask students what the red represents—magma or molten rock—and to suggest what happens to the magma when the overlying pressure of the

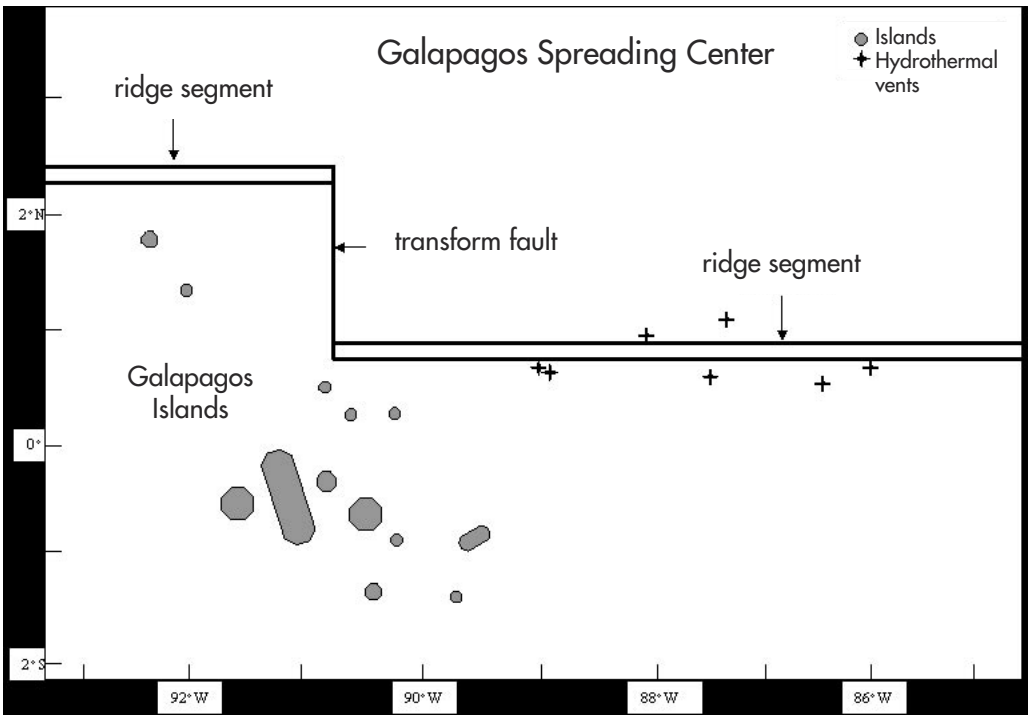


Figure 1. Schematic of the Galapagos Spreading Center. Ridge segments are shown as double lines, whereas a transform fault is shown as a single line. The Cocos Plate lies to the north of the ridge system, and the Nazca Plate lies to the south.

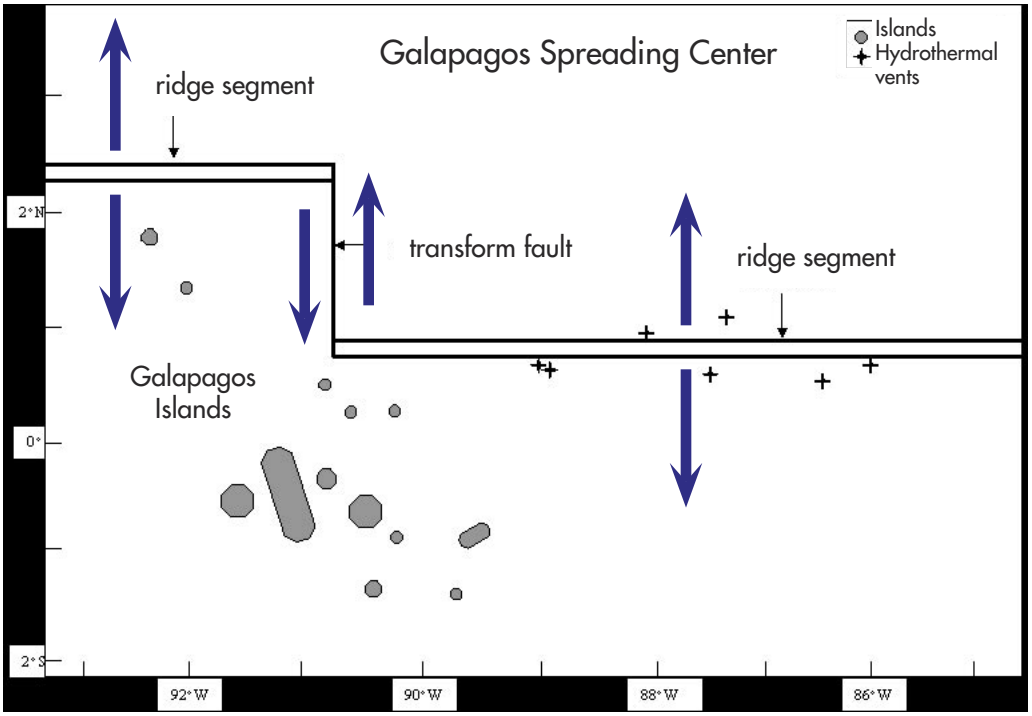


Figure 2. Schematic of the Galapagos Spreading Center with arrows on each side of ridge segments and transform fault, indicating relative motion of the Cocos plate (north) and Nazca Plate (south).

oceanic crust is released. Remind them that the seawater is about 2°C. The magma rises with the release of pressure as the two plates diverge. It solidifies quickly in the cold ocean water and forms new sea floor. This new sea floor is a long band of rock that has solidified between two bands of older rock.

8. Repeat the overhead model demonstration with the Figure 1 transparency, asking the students to focus on the type of motion observed at the transform fault (single line, north-south), across the two ridge segments.

9. Students should draw arrows on their paper copy of Figure 1 to illustrate the direction of relative motion on either side of each ridge segment and on either side of the transform fault. Their figure should have arrows like those on Figure 2.

10. Have students note the locations of potential hydrothermal vents - areas where superheated water, gases, and minerals are released from beneath the oceanic crust. Ask students why hydrothermal vents are so closely associated with ridge systems. Hydrothermal vents form where high temperatures and fractured Earth enable hot water, minerals, and gases to escape from the sea floor. The ridges are fractures in the crust.

The BRIDGE Connection

http://educate.si.edu/lessons/currkits/ocean/secrets/essay.html
http://www.vims.edu/bridge/technology.html

The "Me" Connection

Have students find out which plate they live on and what kind of activity is currently occurring along the boundaries of that plate near their home or near a city of their choice.

Connections to Other Subjects

Geography, Technology, and Mathematics

Evaluation

Use the *Galapagos Spreading Center Student Worksheet*. Students may either complete this individually or in groups, sharing their answers with the class as a whole. Explanations for the teacher are in italics, in parentheses, below.

1. Summarize, in a paragraph, how new sea floor is formed at a divergent ridge. *(See above.)*

2. Summarize, in a paragraph, the differences in motion of the two plates at ridge segments as compared to motion at the transform fault. *(Along ridge segments, the motion is divergent, in opposite directions, moving apart, and the direction of motion is perpendicular to the trend of the ridge segment; along transform faults and transform plate boundaries, motion is translational, meaning that the plates slide past one another and the direction of motion is parallel to the transform fault line.)*

3. Where would you expect to find the most earthquakes in the region depicted in Figure 1? Explain your answer. *(The greatest amount of friction would occur along the transform fault/ transform plate boundary, as the two plates are sliding past each other. Therefore, one would expect the highest frequency of earthquakes to occur here.)*

4. Why do you think oceanographers selected the sites indicated on Figure 1 as potential hydrothermal vent sites? Why might vents be concentrated along a mid-ocean ridge? *(Hydrothermal vents occur where tremendous heat and pressure are released from the Earth's crust. Areas with significant fracturing and an underlying magma chamber would be potential sites for such vents. Mid-ocean ridges are formed by rising magma.)*

5. At the ridge segments, motion is:
   a) divergent

b) convergent
c) translational
d) in the same direction
(answer a is correct)

6. At the fracture between the two ridge segments the motion is:
   a) divergent
   b) convergent
   c) translational
   d) in the same direction
   (answer c is correct)

7. Would you expect to find earthquakes anywhere in this modeled ocean? Why or why not? If so, where? *(Because plates of solid lithosphere are in motion, tremendous friction occurs and energy, in the form of earthquakes, is released throughout the divergent plate boundary system. Most earthquakes occur along the transform faults, as plates slide past each other.)*

Extensions

Have your students visit http://oceanexplorer@noaa.gov and www.divediscover.whoi.edu to read about the Galapagos Rift Expedition discoveries.

What is the origin of the Galapagos Islands? Research the composition of the Galapagos Islands. Are they made of coral, sand, or volcanic material? Infer how they may have formed, based on what you have learned from this activity.

Resources

http://oceanexplorer@noaa.gov and www.divediscover.whoi.edu - Galapagos Rift Expedition documentaries and discoveries.

http://volcano.und.nodak.edu/vwdocs/vwlessons/volcano_ types/spread.htm

http://newport.pmel.noaa.gov/~chadwick/galapagos.html

National Science Education Standards

Content Standard A - Science as Inquiry

- Formulate and revise scientific explanations and models using logic and evidence.
- Understandings about scientific inquiry

Content Standard D - Earth and Space Science

- Energy in the Earth system
- The origin and evolution of the Earth system

Activity developed by Rachel McEvers, College of Charleston and Leslie Sautter, PhD, College of Charleston

Student Handout

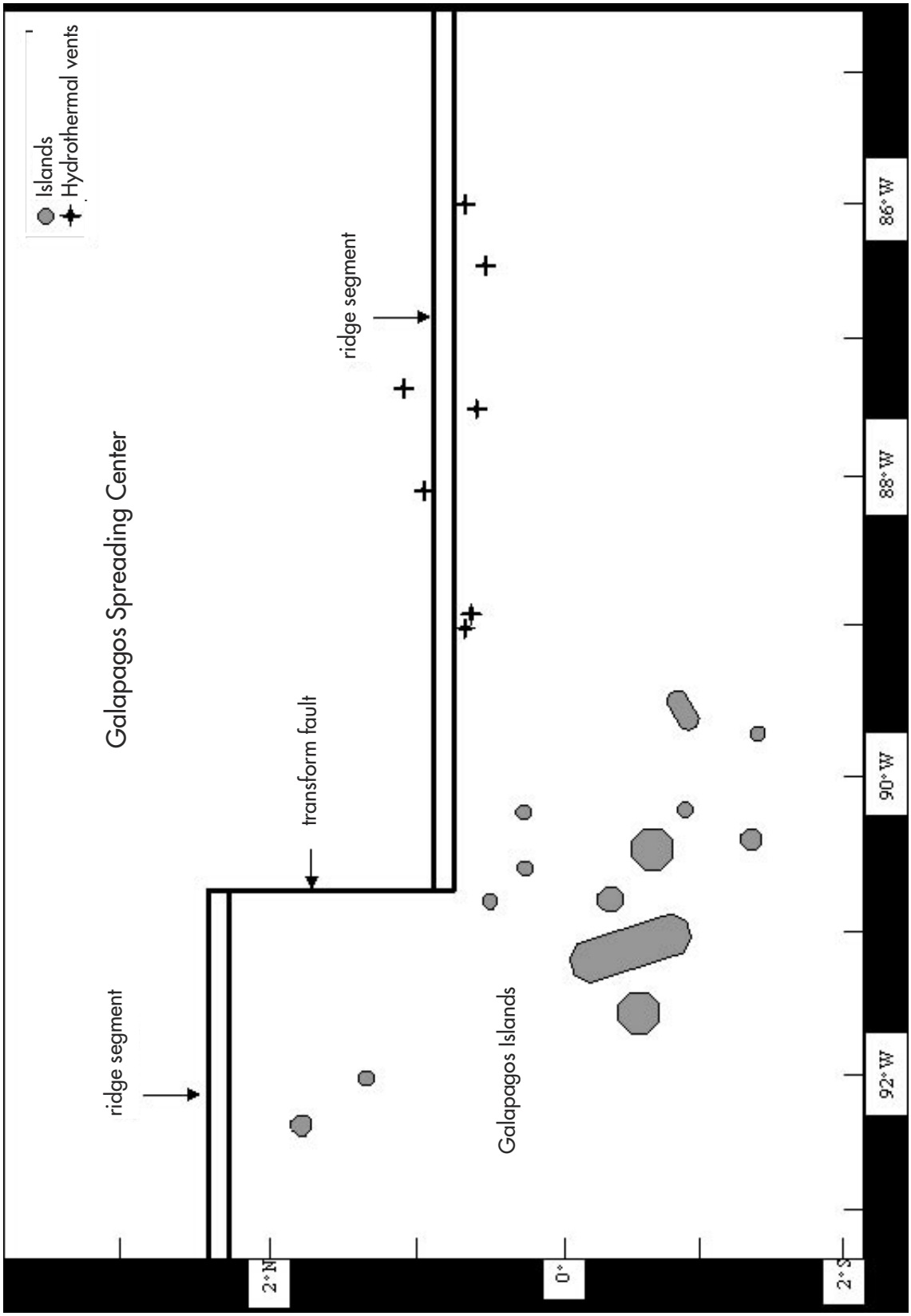


Figure 1. Schematic of the Galapagos Spreading Center. Ridge segments are shown as double lines at A and C, whereas a transform fault is shown as a single line at B.

Galapagos Spreading Center Student Work Sheet

1. Summarize, in a paragraph, how new sea floor is formed at a divergent ridge.

2. Summarize, in a paragraph, the differences in motion of the two plates at ridge segments as compared to motion at the transform fault.

3. Where would you expect to find the most earthquakes in the region depicted in Figure 1? Explain your answer.

4. Why do you think oceanographers selected the sites indicated on Figure 1 as potential hydrothermal vent sites? Why might vents be concentrated along a mid-ocean ridge?

5. At the ridge segments, motion is:
   a) divergent b) convergent c) translational d) in the same direction
6. At the fracture between the two ridge segments the motion is:
   a) divergent b) convergent c) translational d) in the same direction
7. Would you expect to find earthquakes anywhere in this modeled ocean? Why or why not? If so, where?

Lesson Plan 10

AdVENTurous Findings on the Deep Sea Floor

Focus
Vent development along the Galapagos Rift

Focus Question
How do hydrothermal vents form and build structures?

Learning Objectives
Students will observe formation of precipitates in a model hydrothermal vent.

Students will compare the model hydrothermal vent with an actual hydrothermal vent on the Galapagos Rift.

Materials
Part I—For each group:
- ❒ Several pictures of hydrothermal vents downloaded from the NeMo Explorer web site at http://www.pmel.noaa.gov/vents/nemo/explorer.html and www.divediscover.whoi.edu
- ❒ One *Make Your Own Deep-sea Vent!* instruction page
- ❒ Large clear plastic or glass container, about 1 gallon
- ❒ Small bottle, 8 oz or less
- ❒ 5 drops of red food coloring
- ❒ 1m piece of cotton string
- ❒ Cold tap or ice water to fill large container
- ❒ Hot water about 80 degrees C to fill the small bottle.

Part II—For each group:
- ❒ 50 ml water
- ❒ 5 ml calcium chloride (Damp Rid, used to remove moisture from closets is widely available or salt used to melt ice from walks in winter)
- ❒ 5 ml baking soda
- ❒ 8 oz clear plastic cup

Teaching Time
One or two periods 45 minute periods

Seating Arrangement
Groups of 3 or 4 students

Key Words
Hydrothermal vent
Magma
Precipitate
Chemical reaction
Continental plates
Geysers
Rift
Mantle
Molten

Background Information
Rifts and hydrothermal vents are examples of how energy transfer affects solids and liquids. Rifts occur on the ocean floor where drifting continental plates are separating. The rift creates an opening in the crust. The cold deep ocean water comes in contact with materials rising from the Earth's mantle at temperatures of 1000 degrees as molten rock. When the continental plates separate, mantle magma rises into the gap in the crust. When molten rock comes in contact with cold ocean water, at 2 degrees Celsius, the magma's heat energy is transferred to the water. The magma cools, forming new solid rock sea floor crust.

Hydrothermal deep vents are underwater hot springs, but they differ from the geysers and hot springs associated with volcanic areas on land. Ocean water seeps down to the hot mantle through cracks in the thin ocean crust. As is comes in contact with mantle magma, heat energy is transferred to the water, and it becomes superheated. When released to the sea, the heated water is less dense than the cold ocean water, so it rises. High deep sea pressure keeps the heated water from boiling. Great pressure also speeds up chemical reactions. Deep hydrothermal vents form superheated plumes of water that are laced with minerals. These minerals give the hot water plumes color. They also help build the vent structure and feed the vent organisms. In contact with cold water, the dissolved minerals precipitate out and settle. They aggregate to form structures that resemble chimneys around the vent.

Learning Procedure

Part I

1. Using the Background Information, discuss what hydrothermal vents are and where they are found. Distribute hydrothermal vent pictures downloaded from the NeMo Explorer website: http://www.pmel.noaa.gov/vents/nemo/explorer.html and www.divediscover.whoi.edu

2. Challenge your students to experiment with several aspects of deep vent physical science by modeling the release of hot water in cold water and the formation of a precipitate from minerals in solution.

3. Distribute copies of *Make Your Own Deep-sea Vent*. Ask the students: "How can you model the action of the heated water rising from the cracks of hydrothermal vents as it mixes with the surrounding cold water?"

4. Provide the materials listed in Part I and let the student groups work independently, following the instructions.

5. Ask the students what each part of their model represents in a deep vent. What can they conclude about the movement of water around a deep vent?

Part II

1. Provide the student groups with the materials listed under Part II.

2. Ask them to observe the calcium chloride and baking soda separately, recording their observations.

3. Put the calcium chloride and baking soda into the 8 oz. cup and continue to make and record observations. Are there any changes when the solids are combined?

4. Add the water to the solids. What happens? Make sure they understand that they are watching a chemical reaction. The bubbles are carbon dioxide gas given off during this reaction.

5. Do you see anything developing in the bottom of the cup? Students should describe seeing a white substance. Explain that the white substance is calcium carbonate. Because it formed from two chemicals in solution and settled out of solution, it is called a precipitate. A similar process causes hydrothermal vent chimneys to form around deep-sea vents. Heated minerals dissolved in hot water released from the vent come in contact with cooler water. As this water loses its heat to the cold deep seawater, minerals precipitate and settle. They form structures that resemble chimneys with the hydrothermal vent geyser in the middle. Thus, the transfer of energy between magma and water creates new ocean floor structures.

The BRIDGE Connection

http://www.vims.edu/bridge/vents.html Go to this site for a BRIDGE Ocean AdVENTure on hydrothermal vents.

The "Me" Connection

Have the students explore possible uses by humans for the precipitates found around a hydrothermal vent site.

Connections to Other Subjects

English/Language Arts

Evaluation

Written responses in a science notebook may be evaluated for understanding how precipitates and vent chimneys are formed, if students record these findings individually.

Extensions

Have your students visit http://oceanexplorer@noaa.gov and www.divediscover.whoi.edu for Galapagos Rift Expedition discoveries.

Resources

http://oceanexplorer@noaa.gov and www.divediscover.whoi.edu

http://www.pmel.noaa.gov/vents/nemo/explorer.html - A wealth of information on hydrothermal vents

http://pubs.usgs.gov/publications/text/exploring.html "Exploring the deep ocean floor: Hot springs and strange creatures"

http://seawifs.gsfc.nasa.gov/OCEAN_PLANET/HTML/ps_vents.html "Creatures of the Thermal Vents"

National Science Education Standards

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard B: Physical Science

- Properties and changes of properties in matter

Content Standard D: Earth and Space Science

- Structures of the Earth system
- Earth's history

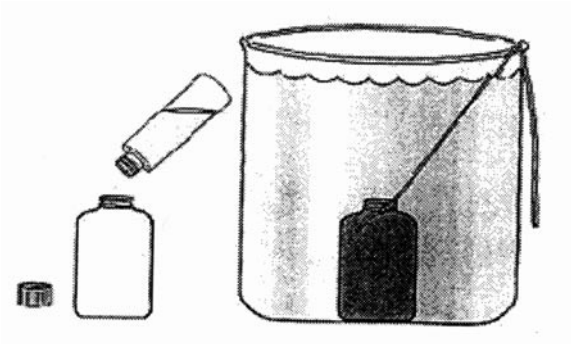
Activity developed by Barbara Eager, Springfield Elementary School, Charleston County School District

Student Handout

Make Your Own Deep-Sea Vent!

Materials:
1 large glass container
1 small bottle
Food coloring
A piece of string
Hot and cold water

Directions:
1. Fill the large glass container with very cold water.
2. Tie one end of the piece of string around the neck of the small bottle.
3. Fill the small bottle with hot water and add a few drops of food coloring.
4. Keeping the small bottle upright, carefully lower it into the glass container until it rests on the bottom.
5. Watch what happens!



Permission to use this activity granted by:
New England Aquarium
Central Wharf
Boston, MA 02110
617.973.5200
http://www.neaq.org/scilearn/kids/seavent.html

Lesson Plan 11

Volcanoes, Plates, Seamounts and Island Chains

Focus
Role of volcanism in the formation of chains of islands and seamounts

Focus Question
How do volcanic hotspots in the Earth's crust and the movement of tectonic plates form island chains?

Learning Objectives
Students will describe the processes that form seamount and island chains.

Students will describe tectonic plate movement and types of volcanic activity associated with these movements.

Students will describe how a combination of hotspot activity and tectonic plate movement produces the arrangement of seamounts observed in the Axial-Cobb-Eikelberg-Patton chain of Alaska.

Materials
- ❒ Framed window screen with outline map of the Gulf of Alaska
- ❒ Small can of Great Stuff (from hardware store)
- ❒ Plastic gloves
- ❒ Newspapers
- ❒ Overhead transparency Gulf of Alaska Seamounts
- ❒ Overhead transparency of Patton seamount 3-D bathymetric model downloaded from http://ridge.coas.oregonstate.edu/rkeller/seamounts.html

Audio/visual Materials
- ❒ Overhead projector
- ❒ Optional computer video of simulated fly-around of the Patton Seamount; download from http://ridge.coas.oregonstate.edu/rkeller/Fly_around.mov

Teaching Time
One class period

Seating Arrangement
Classroom style or in cooperative groups

Key Words
Basalt
Rift
Subduction
Hotspot
Seamount
Magma

Background Information
This exercise combines a teacher-led demonstration with students working with actual data. Both address the sources of seamounts. It assumes students have learned about plate tectonics.

Seamounts (also called guyots) are undersea mountains rising above the ocean floor to heights as great as 3,000 m (10,000 ft) or more. Compared to the surrounding ocean waters, seamounts have high biological productivity and provide habitats for a variety of organisms. There are also seamounts that break the surface of the water forming islands. Numerous seamounts have been discovered worldwide. Many of these seamounts occur in long chains that parallel the west coast of the U.S. and Canada. One of the longest chains, known as the Axial-Cobb-Eikelberg-Patton chain, was studied in the Ocean Exploration Expedition Exploring Alaska's Seamounts. The OE Northwest Hawaiian

Islands Exploration as well as other OE expeditions focused on seamounts and island chains because of their geological and biological interests.

What formed these underwater mountains and islands, and why are they arranged in chains? Seamounts and island chains are probably the products of underwater volcanoes. These volcanoes may have several origins.

First, in places where tectonic plates collide, one plate descends beneath the other in a process called subduction. This generates high temperatures and pressures that lead to explosive volcanic eruptions such as Mount St. Helens' eruption caused by subduction of the Juan de Fuca plate beneath the North American plate. What produced the seamounts in the Alaskan Axial-Cobb-Eikelberg-Patton chain along this junction of two plates? One hypothesis is that they were formed over the Cobb Hotspot, which is currently located off the coast of Oregon near the ridge between the Juan de Fuca and Pacific tectonic plates. As the Pacific plate moved laterally, different parts of the Pacific plate were over the Cobb Hotspot through time. Volcanoes produced by the hotspot are aligned in the same direction as the plate moves.

Volcanoes also form at hotspots not associated with subduction—natural breaks in the Earth's crust that are pipelines releasing magma from the Earth's mantle. As the tectonic plate moves over the hotspot, volcanoes form in a chain along the direction of the plate movement. The Hawaiian Islands form this kind of chain on the Pacific plate.

The volcanoes may be sufficiently active to break the surface of the ocean, forming an island. The island may be so heavy that it eventually sinks —forming a seamount or the volcano may never be active enough to break the surface.

Learning Procedure

1. Make or purchase the framed window screen and Great Stuff. See directions. Draw the map on the screen.

2. Discuss with students the origins of seamounts described above. You may use the overheads and video to illustrate your teaching. You may need to review the concept of plate tectonics. Be sure to distinguish the volcanic activity at spreading ridges—typically a slow ooze of lava—from volcanoes near areas of subduction zones or hotspots—both of which can be quite active.

3. Demonstrate how periodic volcanic eruptions at a hotspot and the movement of a tectonic plate over that hotspot can produce a seamount chain similar to that found in the Gulf of Alaska. Let two students hold the framed screen above the can of Great Stuff which you should control. Position the can so that the starting point is near the 41 Ma mark. Great Stuff is sticky! Wear cheap plastic gloves and work over newspapers. Have the students move the screen very slowly in the direction indicated by the Plate Movement arrow. As the screen moves, gently release a small squirt of Great Stuff to produce a small mound on top of the screen—practice this in advance to get a feel for the trigger! Make a mound at the 41 Ma, 38 Ma, 9 Ma, and 0 Ma marks.

4. Use the Gulf of Alaska Seamounts overhead transparency to show that the framed screen is a model for the edge of the Pacific plate with the four mounds of Great Stuff representing the Patton, Murray, Warwick, and Axial Seamounts. What is the can of Great Stuff? The Cobb Hotspot.

5. Ask the students how long they think this took to happen? Put the age data on the board. What does Ma mean? Millions years. If the Axial Seamount has an age of 0, where is it located? Over the hotspot. It is still being formed.

The BRIDGE Connection

www.vims.edu/bridge/geology.html

The "ME" Connection

Have students write a first-hand account of an exploratory dive to investigate formation of the Axial Seamount. You may want to have them do library or internet research to back up their report.

Connections To Other Subjects

English/Language Arts, Geography, Mathematics

Evaluation

Have students write a newspaper style report about events happening on the Juan de Fuca Ridge. Tell them it is OK to include events that are happening slowly (such as tectonic plate movement) as well as events happening more quickly (such as volcanic eruptions). Their reports should include subduction beneath the North American plate (and possibly associated volcanic activity), sea floor spreading, and events associated with the Cobb Hotspot (such as formation of the Axial Seamount).

Extensions

Have students visit http://oceanexplorer.noaa.gov to check out Exploring Alaska's Seamounts and the Northwest Hawaiian Islands Exploration as well as more recent seamount expeditions.

Get out a world map and ask the students to look for other island chains. Then search for information on their geological origins on the Internet.

Resources

http://ridge.coas.oregonstate.edu/rkeller/seamounts.html - Background on seamount exploration and research in the Gulf of Alaska

http://volcano.und.nodak.edu/vwdocs/vwlessons.atg.html - Teacher's guide on plate tectonics, hotspots, and volcanoes

http://newton.physics.wwu.edu:8082/jstewart/scied/earth.html - Earth science education resources

http://www.sciencegems.com/earth2.html - Science education resources

http://earth.leeds.ac.uk/dynamic earth - Background on plate tectonics

http://www-sci.lib.uci.edu/HSG/Ref.html - References on just about everything

National Science Education Standards

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard D: Earth and Space Science

- Structure of the Earth system

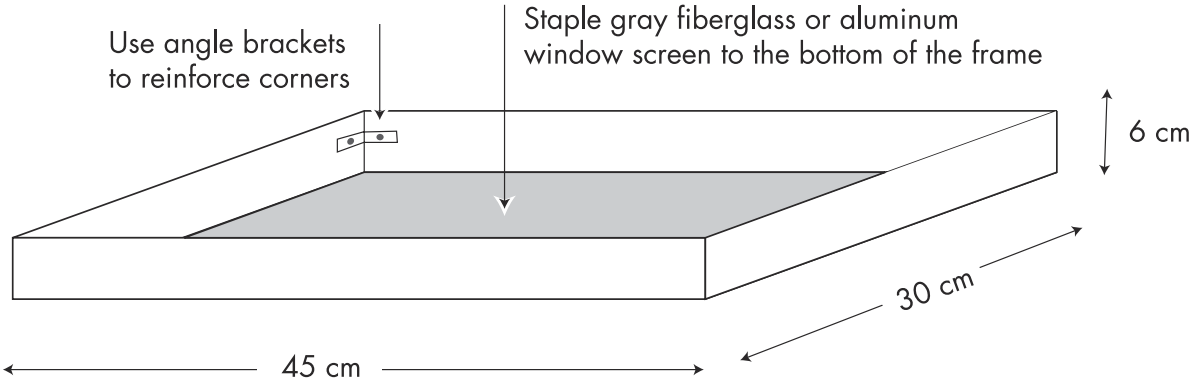
Activity developed by Mel Goodwin, PhD, The Harmony Project, Charleston, SC

Teacher Demonstration

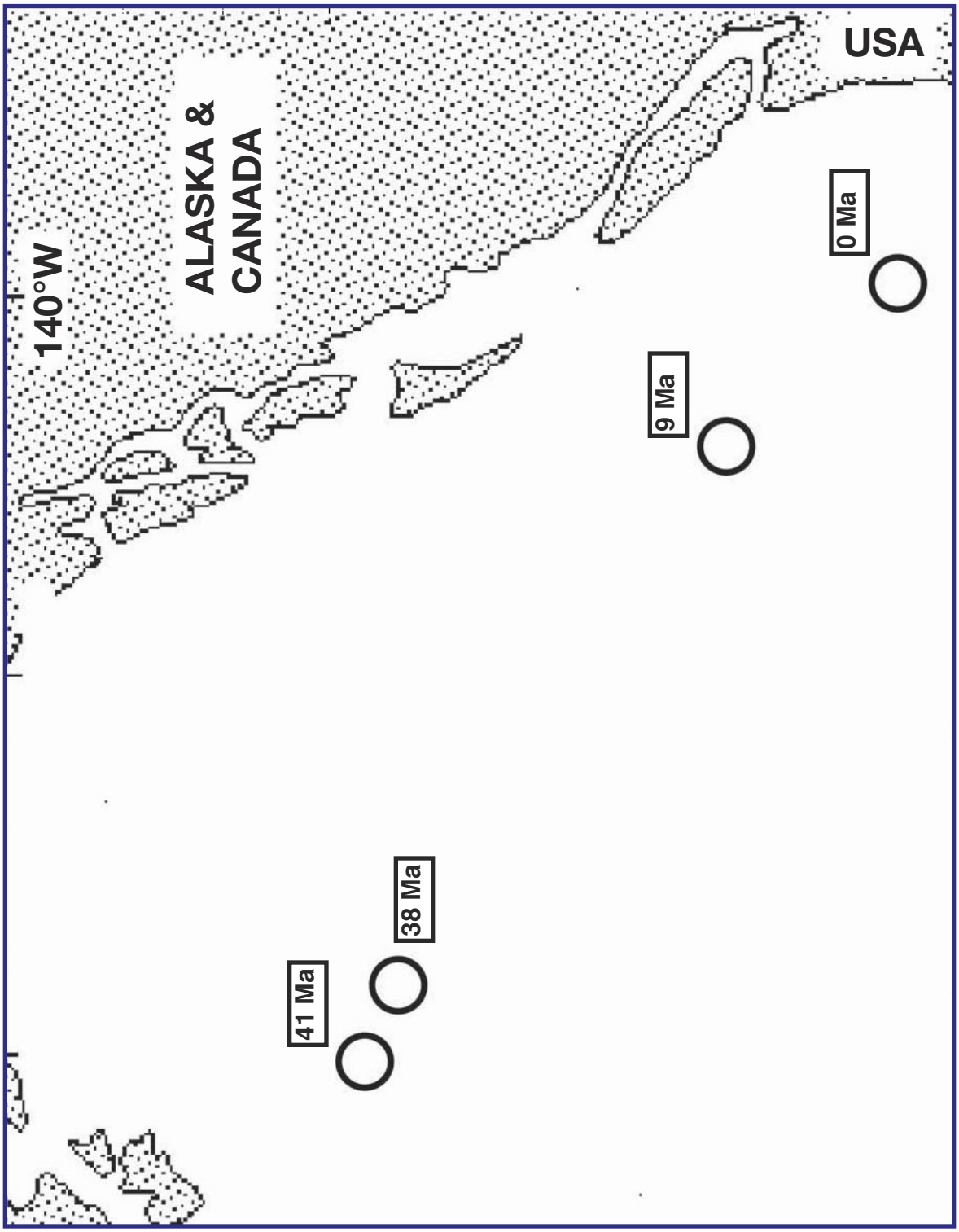
Making a Hotspot

1. You will need a piece of window screen that is at least 11″ x 17 ″ in a frame. You may get it by doing any one of the following:
   a. Buy an aluminum-framed replacement window screen, already put together at a hardware or home store.
   b. Buy a cheap picture frame and a piece of window screen and staple the screen to the frame.
   c. Make a sturdy frame from 1″ x 3″ pine lumber. Fasten corners with glue and screws, reinforce with angle brackets in corners. Staple gray fiberglass or aluminum window screen to bottom of frame (see illustration).

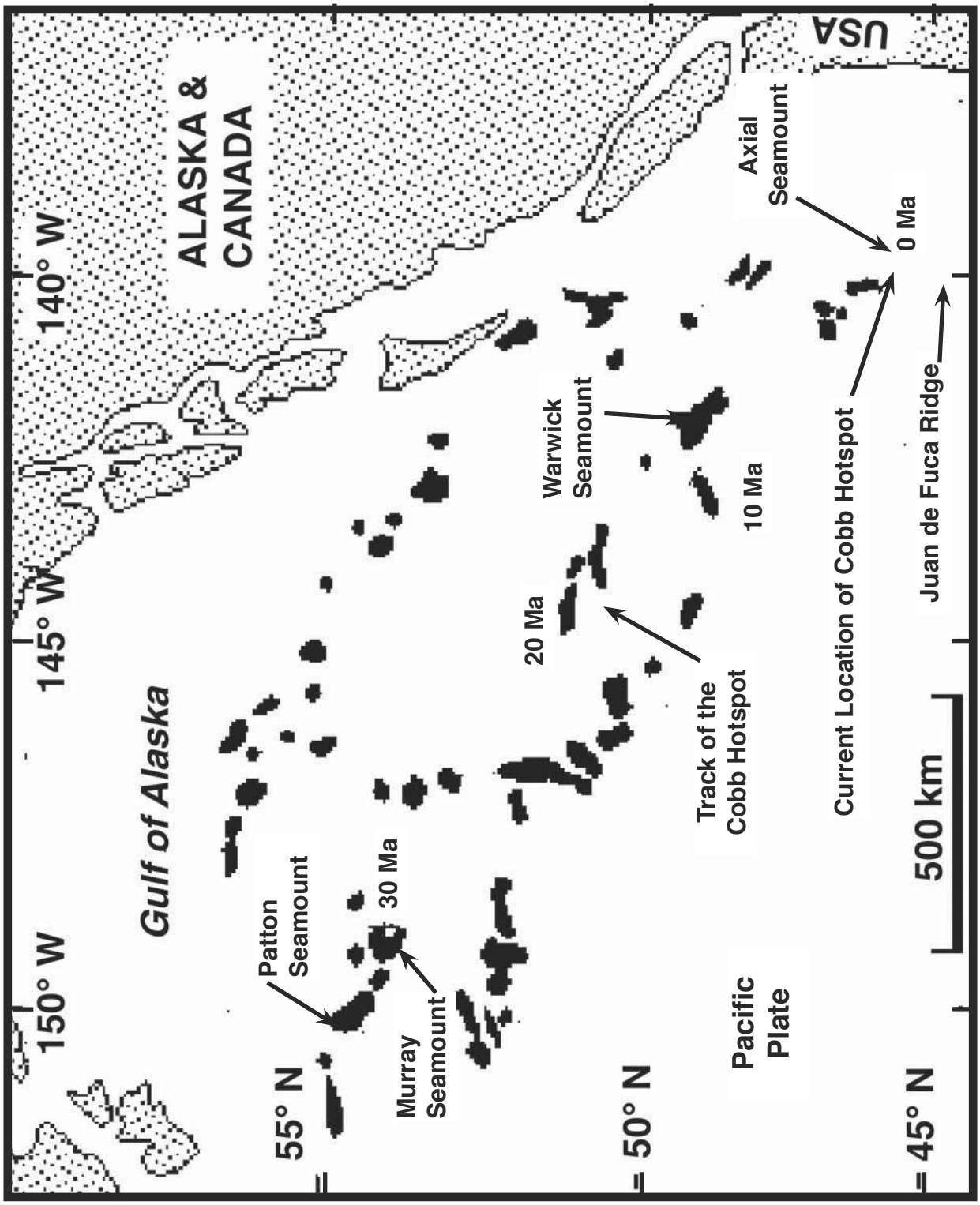
2. Enlarge the outline map of the Gulf of Alaska to 11″ x 17″ on a photocopier, place under the screen and trace the map onto screen with a permanent black marking pen.



Map for use with framed screen and Great Stuff (enlarge it to fit on an 11 x 17 sheet)



Gulf of Alaska Seamounts Map (for overhead)



http://ridge.coas.oregonstate.edu/rkeller/seamounts.html
College of Oceanic and Atmospheric Sciences, Oregon State University

Lesson Plan 12

Islands, Reefs and Hotspots

Focus
Formation of the island chains through hotspots and plate movement

Focus Question
What geological processes produced the island chain of Hawaii?

Learning Objectives
Students will map and describe the stages of Hawaiian Island formation.

Students will describe how hotspot activity and tectonic plate movement produced the seamounts of the Hawaiian archipelago.

Materials
For each student:
- ❒ Copy of *Central Pacific Map Grid* and *Location and Age of Some Islands in the Hawaii Archipelago*

For the teacher:
- ❒ Diagram of the Hawaiian Archipelago downloaded from http://www.soest.hawaii.edu/GGHCV/haw_formation.html
- ❒ Brief description of selected islands (http://www.hawaiireef.noaa.gov/maps/maps.html is a useful source for this information)

Audio/visual Materials
- ❒ None

Teaching Time
One or two 45-minute class periods

Seating Arrangement
Groups of four students

Key Words
Archipelago
Tectonic plate
Mantle
Asthenosphere
Lithosphere
Magma
Subduction
Hotspots
Caldera
Erosion

Background Information
This activity examines a specific example of plate tectonic movement and hotspot activity currently forming an island chain: the Hawaiian archipelago. Students will learn about the stages in the formation and degradations of hotspot islands.

The Hawaiian archipelago has arisen from a series of volcanic eruptions starting more than 80 million years ago with the Hawaiian hotspot, thought of as a pipeline to magma in the upper Earth's mantle. It is presently located near the Big Island of Hawaii at the southeastern end of the archipelago. The Pacific tectonic plate moves over the asthenosphere toward the northwest at a rate of 5 to 10 cm per year. As it moves over the hotspot, magma periodically erupts, creating volcanoes that grow to become islands. The oldest island is Kure at the northwestern end of the archipelago. The youngest is the Big Island of Hawaii at the southeastern end. Loihi, just east of the Big Island, is the newest volcano in the chain

and may eventually form another island. As the Pacific plate moves to the northwest and the island is carried away from the hotspot, the crust cools and subsides. At the same time, erosion gradually reduces the island which eventually sinks below the ocean surface. Northwest of Kure, the Emperor Seamounts are the submerged remnants of islands even older than Kure.

Scientists recognize eight stages of growth and erosion of the Hawaiian archipelago islands:

1. **The deep submarine stage** begins with submarine eruptions, which eventually reach the ocean surface. Loihi is in this stage.

2. **The shallow submarine stage** features an above-water crater, which spouts lava from rifts on the side of the cone.

3. **The subaerial shield-building stage** begins with collapse of the volcano summit, forming a caldera. The volcano continues to emit lava from the summit and from rifts in the side of the cone. Mauna Loa and Kilauea are in this stage.

4. **The post-caldera stage**, in which lava fills and overflows the caldera, forming a rounded summit. While overall volcanic activity may slow down, significant lava flow still continues: (the Kohala Mountains, Mauna Kea, and Hualalai as well as Haleakala are in this stage.

5. **The erosional stage**, in which lava is no longer being added, and the volcanic cone is attacked by erosion from the ocean and rainfall. A sea bluff, deep valleys and sharp ridges are characteristic features. Kauai, Oahu, and portions of all the major Hawaiian Islands are in this stage.

6. **The reef growth stage** occurs as volcanic mountains are eroded to rocks that barely break the ocean's surface. The volcanic island is slowly sinking, but coral growth keep paces with the sinking so that the rocks are fringed with a coral reef. French Frigate Shoals is in this stage.

7. **The post-erosional eruption stage** is marked by minor renewal of volcanism with a few small cones or lava flows. Portions of West Maui are in this stage.

8. **The atoll stage** occurs as the rocks erode or sink below sea level so that only the coral reef remains at the surface. Pearl and Hermes Reefs and Kure are in this stage.

Learning Procedure

1. This activity should follow Volcanoes, Plates, Seamounts and Island Chains. Ask the students to locate the Hawaiian Islands on a world or Pacific Ocean map. Challenge them to figure out how they were formed based on what they learned in the above activity.

2. Distribute copies of the *Central Pacific Map Grid* and *Location and Age of Some Islands in the Hawaii Archipelago* to each group. Working independently or in pairs, have the students plot the location of each island on the Map Grid, then label each island with its name and age. You may need to review the concept of the latitude and longitude coordinate system prior to plotting.

3. Have the students discuss with their partner or group what they think accounts for the observed ages and locations of the islands. Each student should write a paragraph describing the process he/she thinks was responsible. Then hold a class discussion in which the above information is addressed.

4. Having done a previous hotspot exercise, they should get part of the idea, but may not remember erosion. Show the students the Hawaiian Archipelago diagram. Discuss why the older islands (to the left of the diagram) have different profiles from those on the right side of the diagram. Stu-

dents should recognize that islands near or below the sea surface are older than those that have conspicuous mountains, and infer that erosion is a probable reason for this. Students should also recognize that volcanic activity subsides as an island is carried away from the hotspot by motion of the Pacific plate. The three currently active volcanoes in Hawaii are Kilauea, Mauna Loa, and Loihi—all relatively close to the Hawaiian hotspot.

4. Have students infer the direction of motion of the Pacific plate, and calculate its approximate velocity. You may need to help students deal with large numbers and decimal places. The basic calculation is velocity = distance ÷ time, which in the case of Midway is 2,432 km ÷ 27,700,000 yr = 0.0000877 km/yr = 0.0877 m/yr = 8.77 cm/yr; the same calculation for Nihoa is 780 km ÷ 7,200,000 yr = 10.8 cm/yr

5. Describe the stages of volcanic island formation. Have the students identify islands that are examples of each stage as you list and describe the stages.

The BRIDGE Connection

www.vims.edu/bridge/pacific.html

The "Me" Connection

Have students write a travel brochure encouraging tourists to visit to one island, describing the physical conditions as well as plant and animal life that they encounter.

Connections to Other Subjects

English/Language Arts, Geography, Biology

Evaluation

Develop a grading rubric that includes calculations of Pacific plate movement, quality of the paragraph written and participation in discussion.

Extensions

Visit http://explorers.bishopmuseum.org/nwhi/geoact.shtml for others activities relevant to the Northwestern Hawaiian Islands.

Resources

http://oceanexplorer.noaa.gov – See the Northwestern Hawaiian Islands Expedition documentaries and discoveries posted there.

http://www.soest.hawaii.edu/GGHCV/haw_formation.html – Hawaii Center for Volcanology web site about the formation of the Hawaiian Islands

http://www.hawaiireef.noaa.gov/maps/maps.html – Information about the Northwestern Hawaiian Islands region

National Science Education Standards

Content Standard A: Science As Inquiry
- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

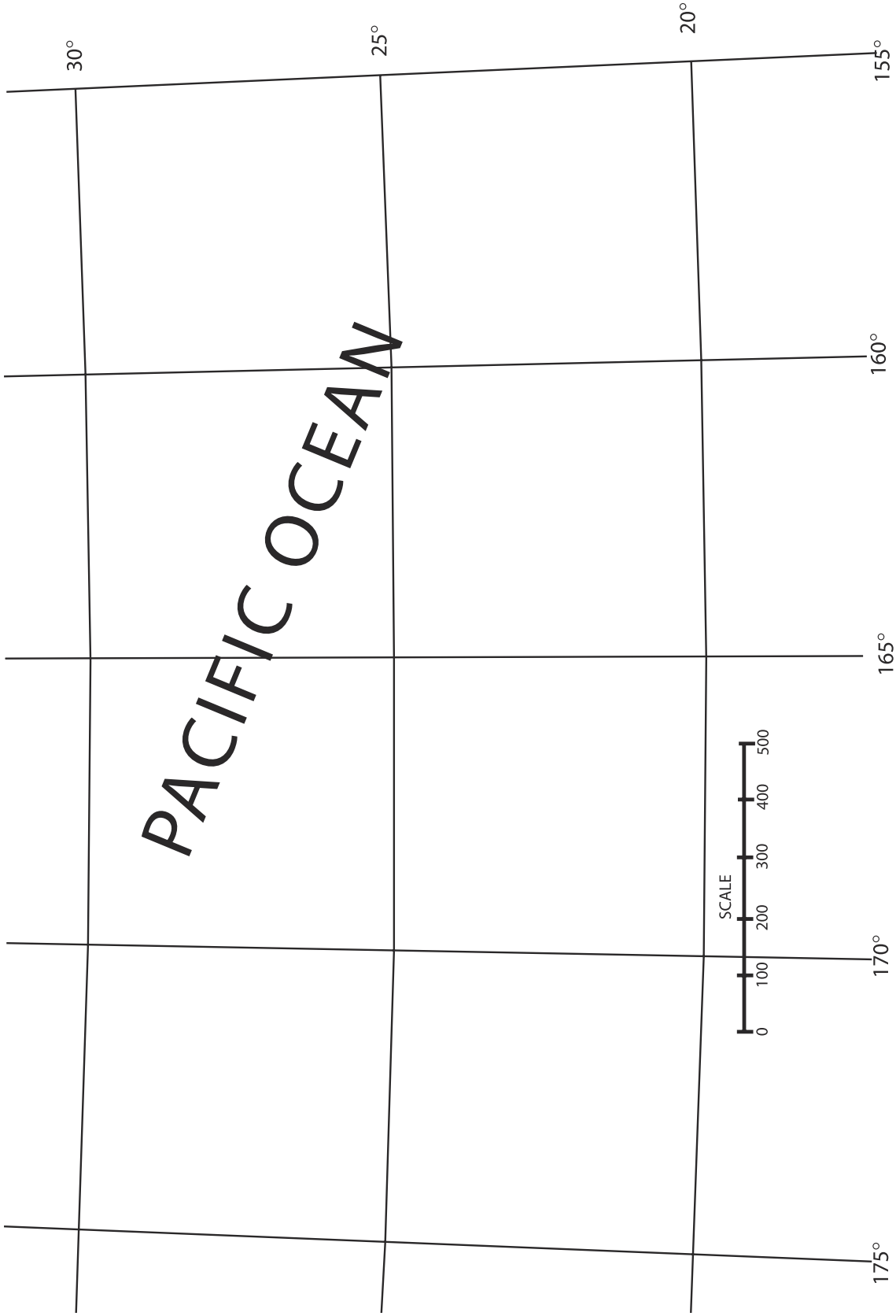
Content Standard B: Physical Science
- Transfer of energy

Content Standard C: Earth and Space Science
- Structure of the Earth system
- Earth's history

Activity developed by Mel Goodwin, PhD, The Harmony Project, Charleston, SC

Student Handout

Central Pacific Map Grid



Student Handout

Location and Age of Some Islands in the Hawaii Archipelago

(from http://www.soest.hawaii.edu/GGHCV/haw_formation.html)

Volcano/Island Name	Distance from Kilauea (km)	Age (million years)	Location (latitude, longitude) (approximate)
Kilauea (Hawaii)	0	0-0.4	19.3°N, 155.4°W
Mauna Kea (Hawaii)	54	0.375	19.9°N, 155.4°W
Haleakala (Maui)	182	0.75	20.9°N, 156.2°W
Kahoolawe	185	1.03	20.7°N, 156.5°W
West Maui	221	1.32	21.0°N, 156.7°W
Lanai	226	1.28	21.0°N, 156.9°W
West Molokai	280	1.90	21.2°N, 157.2°W
Waianae (Oahu)	374	3.7	21.6°N, 158.1°W
Kauai	519	5.1	22.2°N, 159.5°W
Niihau	565	4.89	22.0°N, 160.2°W
Nihoa	780	7.2	23.1°N, 161.8°W
Necker	1,058	10.3	23.6°N, 164.6°W
Gardner Pinnacles	1,435	12.3	25.0°N, 168.0°W
Laysan	1,818	19.9	25.7°N, 171.7°W
Pearl & Hermes Reef	2,281	20.6	28.0°N, 175.6°W
Midway	2,432	27.7	28.3°N, 177.0°W

Section 5

Ocean Zones

Ocean Zones

The Ocean Geologic Features section introduced you to the bottom of the ocean—the benthic regions, examining sediments, vents, rocky reefs, seamounts and other features of the bottom. The majority of Ocean Exploration expeditions have a benthic focus—submersibles and ROVs are most useful where features concentrate geologic and biologic interest. But there are also different kinds of places with different physical characteristics within the water. ROVs and submersibles have to pass through these zones on their way down and up again, giving scientists access to direct observations of these zones as well. The vertical dimension of an aquatic system is called the water column. The most obvious physical characteristics that vary with location in the water column are:

- pressure
- light
- temperature
- oxygen
- mineral nutrients

If you combined all of the world's ocean basins and stirred them together, the average water temperature would be 4 degree Celsius, the average depth would be about 14,000 feet, and the average available light would be zero. But the oceans are not averaged. The distribution of oxygen and mineral nutrients varies greatly, also. The spatial variation in these physical characteristics determines which kinds of organisms live where and have selected for an interesting suite of adaptations.

Temperature

Surface temperatures may range from warm tropical water at 30°C to an ice-covered surface in the polar regions. Since cold water is most dense at 4 degrees C, it sinks in cold regions. Cold water at the poles drops to the bottom and moves across the ocean floor, forming layers of cold water in the deep ocean. Cold water has a high saturation value for oxygen, so the cold, deep water carries dissolved oxygen with it to the ocean floor.

Oxygen

Oxygen at the surface is frequently high in the ocean, and the deep sea has abundant oxygen in its cold water. A layer in between, in the mid-water or mesopelagic region, at around 500 m may be low in oxygen. This oxygen minimum layer creates interesting problems for mid-water species that are solved by both behavioral and biochemical adaptations to low oxygen.

Mineral Nutrients

Nitrogen is generally the limiting mineral nutrient for primary production in the oceans, although iron is also limiting in some oceans. When organisms die, they sink and take their minerals with them to the bottom where the minerals are released by decomposers. Consequently, cold deep ocean water is often much higher in essential mineral nutrients than surface waters where primary production depletes them. Where ocean currents, climate and geography force deep water to the surface, primary production increases dramatically with the introduction of higher levels of mineral nutrients. This production supports entire food chains. This upwelling is caused by both geographic and climatic factors. It produces areas in the ocean where the fisheries are particularly rich, and thus, are of high interest to humans.

Pressure

As organisms with gas-filled spaces upon which we depend—lungs—we tend to focus on pressure as a big deal for aquatic organisms. With each 10 m of seawater, another atmosphere of pressure is added. For example, at 100 m one would experience 1 atm of air pressure and 10 atm of water pressure for a total of 11 atm. At

deep-sea depths, the pressure is unimaginable, yet many creatures have no problem living there. Since most living things are largely water and water is incompressible, organisms lacking gas-filled spaces like lungs or swim bladders are less affected by pressure than we imagine. Some ocean species perform vertical migrations of 1,000 m each day, experiencing a 100 atm range of pressures with no harmful effects.

Most organisms with gas-filled spaces would be crushed by the same pressures. Humans do relatively shallow dives by breathing air at a pressure equivalent to the surrounding water pressure using SCUBA gear. Nitrogen and oxygen both cause cognitive problems for divers saturated at depth. Returning to the surface rapidly results in gases coming out of solution in the blood, causing crippling or death. Exotic mixes of gases allow deeper dives, but still expose humans to problems with blood gases because blood is saturated with these gases at the ambient levels. Instruments put into the ocean must be protected from seawater under great pressure. They are generally sealed in very strong containers. Humans also seal themselves in containers—submersibles that keep the internal pressure the same as on land—1 atm—so that they may go very deep and return to the surface without breathing air at increased pressures.

Deep-sea pressures do affect chemical reaction rates somewhat, speeding up reactions. Organisms adapted to these pressures may experience metabolic problems when brought to the surface for study.

Light and the Zones

The bulk of the oceans are deep-sea habitats with no light. The importance of light in the seas is reflected by the description of the ocean's vertical zones (zones of the water column) in terms of how much light they have. The ocean is generally divided into three named zones. The zones' depth ranges vary with location. The terms epipelagic, mesopelagic and bathypelagic are most com-

monly used when referring to organisms and their adaptations to vertical ocean zones.

Photic or Epipelagic Zone

The upper 200 m of the ocean is termed the photic zone. Sunlight penetrates sufficiently to support the growth of phytoplankton and/or macro algae. Limits to primary production are often low mineral nutrient levels since minerals are consumed by producers that die and sink, removing them from the surface waters. Minerals must be replaced by re-circulation of deeper ocean water or run-off from land. Ocean primary production is largely restricted to the epipelagic zone. Organisms in the zones below are dependent on what food drifts down from above, ranging from tiny clumps of bacteria and dead algae to occasional bonanzas like a dead whale.

Mid-water or Mesopelagic Zone

The area between 200 m and 1,000 m is also called the "twilight" zone in popular sources. Light intensity is severely reduced with increasing depth so light penetration is minimal. When one looks up toward the surface with dark adapted eyes, enough light can be seen so that organisms living here have adaptations that help obscure their outline against the surface. About 20% of the surface primary production is transferred to the mesopelagic zone. Consequently, the density or biomass of its occupants is lower than at the surface, and mesopelagic organisms have an interesting variety of mechanisms that help them find food as well as avoid being a meal for another species.

Bathypelagic or Aphotic Zone

Sunlight does not penetrate this eternal darkness. Popular sources sometimes refer to this as the midnight zone. About 5% of the primary production from the surface makes it to the bottom. Less food means lower biomass. Occasionally large items like dead sharks or whales arrive, but generally food is scarce.

Light In Water

As you travel from surface waters to deeper waters, the quality of light also varies with depth. Sunlight produc-

es a visible spectrum of the colors: red, orange, yellow, green, blue and violet. These colors combined together appear white. Red light is the longest wavelength and has the least energy in the visible spectrum. Violet light has the shortest wavelength with the highest energy. Wavelength decreases and energy increases from red to violet across the spectrum in the order listed above. The visible spectrum has two critical functions—it enables organisms to see and it provides the energy for most primary production.

Water absorbs light. It does so differentially. The longer the wavelength, the lower the energy and the faster that wavelength is absorbed. Thus red light disappears higher in the water column and blue penetrates deepest. The exception to the rule is violet light. Although it has the shortest wavelength and the highest energy, violet is scattered by particles in the water.

Objects that are not transparent or translucent either absorb or reflect most of the spectrum striking them. A red fish in white light reflects red wavelengths and absorbs other colors. Likewise, grass reflects green light and absorbs other colors. White objects are seen as white because they reflect all light in the visible spectrum. Black objects absorb all colors.

Organisms that live in water use light, colors and vision for many things: to find prey, to hide from predators, and to find mates. For example, a red fish swimming at the ocean surface looks red because there is red light in shallow water. In 100 m of water, that same fish is difficult to see, appearing black. There is no red light to reflect at that depth, and the fish absorbs all other wavelengths. In the mesopelagic zone, many species are black or red. At depth, these organisms are virtually invisible unless they are silhouetted against the distant surface viewed from below.

Seeing Thngs Clearly

Since blue travels best through water, there has been selection for blue among animals wishing to be seen. Since there is no ambient light, mid- and deepwater organisms for whom being seen is an advantage, tend to produce blue light in light organs. Done by biochemical means, bioluminescence is relatively common among deep-sea fishes and other organisms. Bioluminescence has evolved in many different species, suggesting its value to deep-sea species. Several OE expeditions included studies of bioluminescence. Some suggested adaptive values for bioluminescence include:

Counter-illumination Many animals that move up and down in the mesopelagic zone have light-producing organs on their underside. They increase the light level underneath themselves as they move up into shallower water where they are silhouetted against the sky and dim it as they descend to deeper water. A fish using counter-illumination blends in with the lighter waters above when viewed from a predator below. This is similar to countershading in which open water photic zone animals have light undersides and dark backs. Shining tubeshoulders and bristlemouths have ventral light organs.

Attracting a mate Many organisms have species-specific light patterns and in some, these patterns are specific by sex. This is a great way to get a date in the dark! Anglerfish and lanternfish both are thought to produce light to attract a mate.

Attracting prey Some organisms have lighted body parts that appear to attract prey. Gulper eels have a light at the end of their tail that is believed to attract prey to its humongous mouth.

Escape or startling tactic Some organisms appear to use light to temporarily distract or divert predators. Some produce shining clouds of light in the water. Others drop bioluminescent body parts that the predator may follow.

Some deepwater shrimp "vomit" bioluminescent clouds, while some copepods emit bioluminescent clouds from their posterior ends.

Lights for Ocean Exploration

Lack of ambient light is an issue for ocean explorers. Humans have to take lights with them in order to see and to shoot film or video. Video data collection has proven very useful as video is highly adaptable to low light, and the recording systems are much less expensive than film. Look for evidence of use of underwater lights as you explore the OE CD expedition stories on the CD or web site.

Classroom Activities about Light in this Section

The activities *All that Glitters…* and *Light at the Bottom of the Deep, Dark Ocean?* from the Ocean Exploration expedition Islands in the Stream 2002 follow.

Where to Find More Activities about Ocean Zones and Light in the Ocean

Other OE education activities that coordinate with this section can be found on the OE CD. They are:

- *Fishy Deep-sea Designs* from the OE Hudson Canyon 2002
- *What's Bright Red and Invisible?* also from the Hudson Canyon 2002 OE expedition
- *Blinded by the Light!* from 2002 OE Islands in the Stream expedition
- *Lights in the Deep* from the OE expedition to the Northwestern Hawaiian Islands

Lesson Plan 13

All That Glitters...

Focus
Light in the deep sea

Focus Question
What happens to light in the ocean? How do deep-sea creatures compensate for lack of light?

Learning Objectives
Students will experiment with a model of what happens to light and colors as one descends into the ocean.

Students will describe at least two adaptations to low or no ambient light on the part of deep-sea organisms.

Materials
For the teacher:
- ❒ 3″ x 5″ card with 1-in slit cut in middle
- ❒ 35 mm slide projector
- ❒ Prism
- ❒ Glow stick (from dive shops, fishing tackle or sporting goods store)
- ❒ Optional: vial of ostracods from Carolina Biological Catalog: GR-20-3430; $32.80

Per student pair:
- ❒ Deep Sea Dive Goggles (one blue transparent report cover per viewer)
- ❒ One red, orange, yellow, green, blue and black (dark brown) M&Ms per pair
- ❒ Sheet of black construction paper

Audio/visual Equipment
- ❒ Slide projector
- ❒ Movie screen or white wall
- ❒ Internet access for students

Teaching Time
One 45-min period

Seating Arrangement
Pairs

Key Words
Photic
Aphotic
Mesopelagic
Bathypelagic
Twilight zone
Midnight zone
Bioluminescence
Spectrum
Wavelength
Reflect
Absorb

Background Information
This activity allows students to explore the nature of light, ask what happens to light as it passes through the ocean and speculate on how deep-sea animals deal with living in the dark.

During the 2002 South Atlantic Bight Expedition, Islands in the Stream, two scientists from the Harbor Branch Oceanographic Institution, Dr. Tamara Frank and Dr. Edith Widder, studied vision and bioluminescence in the deep sea. Of particular interest were animals with large eyes that live on the sea floor in the aphotic zone. Many animals that swim in open water (pelagic) in the mesopelagic or twilight zone have large eyes relative to their body

size. Large eyes capture what little light is available. As depth increases below the mesopelagic, eye size in many organisms decreases. For example, two species of bristlemouths, *Gonostoma denudatum*, a midwater fish, and *Gonostoma bathyphilum*, a deeper water fish, have different eye sizes. The midwater species has much larger eyes. The deep water species has much smaller eyes—the result you would expect if eyes had no value in the total absence of light. However, an enigma exists. Many animals living on the deep-sea floor sea have huge eyes! One possible value of vision where there is no ambient light is that some deep-sea organisms make their own light—they are bioluminescent.

Learning Procedure

Teacher Prep

1. Cut a thin slit, just a few millimeters wide and about an inch long, in the card.

2. Place card over the light source, creating a thin beam of white light.

3. Place prism in beam of light and practice rotating prism to project the colors of the spectrum on the movie screen or white wall.

4. Cut each blue report cover lengthwise into four strips roughly two inches wide and 12 inches long, making 8 strips.

5. Staple the eight strips together, using two staples, along one short edge to make one set of Deep Sea Dive Goggles. Use a hole punch to make a hole through all the plastic on each end. The plastic will form a fan with one end stapled and the other loose.

6. Separate M&Ms by colors so that each student pair has one of each: black (dark brown), red, orange, yellow, green and blue.

Learning Procedure

1. Ask your students to tell you what they know about light. Dim the lights and project a visible spectrum on the wall. Have the students write down the colors they observe in the order they see them in the spectrum. Review colors, absorption and reflection.

2. Tape a small piece of a blue report cover over the light source. Ask students to note what color is projected (blue). Make sure that students understand that the blue report cover blocks part of the spectrum by absorbing colors of light other than blue.

3. Challenge the students to observe what the underwater world looks like by using Deep Sea Dive Goggles. Pass out black construction paper, Deep Sea Diving Goggles, and M&M sets to each pair of students.

4. Explain that the black piece of paper represents the darkness of the deep sea. Spread the M&Ms on the black paper.

5. Bend 7 layers of report covers back and observe the colors of the M&Ms through one layer. Then add a layer and observe. Repeat with each layer, simulating what it looks like to go deeper into the ocean. What happened with each color? The blue report covers enable them to see how colors appear in deeper water. The blue covers filter out other colors just as water absorbs them. Students should observe that the color black disappears first, followed by red, then orange, and yellow.

6. If they were fish wishing to hide in the mesopelagic twilight zone, what colors would be the best camouflage? Black and then red.

7. Introduce bioluminescence using the glow stick. Demonstrate "turning it on"—shaking it makes it brighter as you are mixing the chemicals that produce light when they react. Ask the students for their experiences with bioluminescence: fireflies are the most common among eastern US students.

Black light posters are fluorescence—a very different process. Observe the glow stick with the goggles on. How might deep-sea species use the light they make? Discuss counter-illumination, finding a mate, finding prey, attracting prey and startling predators by blinding them. What color would be the most effective for bioluminescence —blue as it penetrates water most easily.

8. You may wish to go into detail about the chemical nature of bioluminescence if your students have sufficient foundation. If you have the ostracods, place three to five in your palm. Add two drops of water and crush the dried animals using a finger. Show your palm; a bright blue results. When you crush the dried animals, two chemicals mix to create blue light.

9. Visit the South Atlantic Bight OE expedition on the web or the OE CD and see what the scientists were studying about bioluminescence.

The BRIDGE Connection

Go to the BRIDGE web site at http://www.vims.edu/bridge/ Under the Navigation side bar click on Human Activities to learn more about the technology used to study deep sea environments.

The "Me" Connection

If you were to become a SCUBA diver, what color wetsuit would wear to become less visible to fishes (like sharks)? Your wetsuit choices include yellow, orange, red, green and blue.

Connection To Other Subjects

Chemistry, Physics

Evaluation

Provide students with the following hypothetical newspaper article. Ask them to explain why the journalist's hypothesis regarding the brown cloud was wrong.

"Yesterday I was SCUBA diving with a young woman in eighty feet of water just off the coast of South Carolina. The woman was studying the abundance of fish on an offshore rocky reef when she became tangled in some clear, nylon fishing line. Fortunately she was carrying a dive knife and was able to cut herself free. However, in the process she cut a five-inch gash across her left calf. I saw a brown cloud of something in the water around her leg. I thought it might be blood, but knew it couldn't be since it wasn't red. An octopus must have come by and released some ink or some other substance to camouflage itself."

Extensions

Over the next week, have students conduct independent research on any of the following animals:

- anglerfish
- bristlemouth
- fangtooth
- filetail catshark
- sixgill shark
- giant ostracod
- giant red mysid
- gulper eel
- hatchetfish
- lanternfish
- eelpout
- blackdragon
- hagfish
- viperfish
- shining tubeshoulder
- snipe eel
- spiny king crab
- ratfish
- squat lobster
- snailfish
- midwater shrimp (*Sergestes* sp.)

Descriptions of these animals can be found on the Monterey Bay Aquarium's web site http://www.mbayaq.org/efc/living_species/ Although this site displays animals in the Pacific, they share many characteristics with the Atlantic species. Students

should include a physical description of the animal, noting the animal's eye size relative to the overall size, whether or not the animal can bioluminescence, and at what depth(s) it lives.

For an art project, use glow in the dark paint and construction paper to recreate deep sea animals, in 3-D, that bioluminesce. Hang them from the classroom ceiling and shut off the lights. *The Bioluminescence Coloring Book*, by Edith Widder, Harbor Branch Oceanographic Institution. ISBN 0-9659686-0-X is a good source of information.

Resources

http://www.mbayaq.org/efc/living_species/

http://www.mbari.org/

http://www.biolum.org

http://www.bioscience-explained.org/EN1.1/features.html

http://www.pbs.org/wgbh/nova/abyss/

http://oceanlink.island.net/oinfo/deepsea/deepsea.html

http://www.marine.whoi.edu/ships/alvin/alvin.htm

http://www.ocean.udel.edu/deepsea

http://www.whoi.edu/WHOI/VideoGallery/vent.html

National Science Education Stanadards

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard C: Life Science

- Structure and function in living systems
- Populations and ecosystems

Content Standard D: Earth and Space Science

- Structure of the Earth system

Activity developed by Stacia Fletcher, South Carolina Aquarium

Lesson Plan 14

Light at the Bottom of the Deep, Dark Ocean?

Focus
Feeding adaptations of some deepwater organisms

Focus Question
What are some adaptations that might help deep-sea fishes to find food in the dark deep ocean?

Learning Objectives
Students will experience the impact of bioluminescence on finding food and becoming prey in the deep ocean.

Students will be able to describe the positive and negative values of being able to produce light.

Materials
For the class:
- ❒ Long table in open space that can be made dark; push several tables together, pull down shades and turn off lights; cover table with black paper
- ❒ Bag or two of Skittles candy

For each student:
- ❒ Deep Sea Dive Goggles from All That Glitters; use hole punched at each end and tie 18-inch strings (or use paper clips and very long rubber bands) in holes so they may be worn hands free as a mask
- ❒ Flashlight
- ❒ Student worksheet
- ❒ Snack-size plastic bags

Audio/visual Equipment
None

Teaching Time
Two 45-minute periods

Seating Arrangement
Students take turns in large groups depending on size of the table and number of flashlights

Key Words
Adaptation
Camouflage
Photic zone
Aphotic zone
Bioluminescence

Background Information
This exercise should be preceded by *All that Glitters….* It uses some of the same equipment and assumes that the students have an understanding of light, light in the ocean and bioluminescence. The students should have already worked with colors in the ocean.

Deep-sea fish use color to help hide—they may be camouflaged. Red is good camouflage since red light disappears in shallow water. Black is also useful in the dark. In this exercise students will apply what they have learned about color.

Finding food in the deep sea may be aided by use of bioluminescence—fish may have light organs that illuminate the surrounding water, revealing prey. On the other hand, when a fish lights up looking for prey, it exposes itself to predation by a larger fish. Bioluminescence is an adaptation to life in the deep sea. It may be useful for communication among members of a species, for attracting a mate, it may illuminate prey or attract prey, and it is used for counter-illumination to obscure its outline against the lighter surface.

In this exercise, students will be deep-sea fish with light organs that are used to illuminate prey so that they can eat them. They may also eat what they can find in the dark. The teacher will be the large predatory gulper eel.

Learning Procedure

1. The day before this exercise, remind the students of what they learned in *All that Glitters…* about light and color in the deep ocean. Suggest that they dress in clothing that would make good camouflage in the deep sea for the next class. Red or black would be best, with long sleeves and good coverage, but do not tell them this—leave it up to them. Students wishing to go to extremes might choose to bring a face covering ski mask. For this activity they will be modeling the behavior of deep-sea fish that feed using bioluminescence.

2. To do this exercise, select the first set of students, give them flashlights, plastic bags and goggles. Spread Skittles thinly on the black paper on the tabletop and tell them this is their food. They must find it in the dark, wearing the goggles. They are fish living in deep water where there is very little light. They may use the flashlight, their bioluminescent organ, to look for food, but whenever it is on, you may tag them because they are visible to a predator—you. When you tag them, a gulper eel has eaten them. They may only use one hand to collect food—using their thumbs and forefingers to pick up one item at a time and place it in their bag. Students not playing will watch to make sure the rules are followed. Anyone being rowdy loses.

3. With goggles in place, dim the lights and let the students begin feeding. If they can see the prey, they may feed without the light, but the light will illuminate almost invisible items. Play until you have tagged about 1/2 of the students. Repeat with another group. The students may keep their bags when tagged. They just have to stop eating.

4. Have the students evaluate the contents of their bags for colors selected. Add up all the Skittles eaten by color versus those left on the table by color.

5. Allow all students time for reflection by having each student fill out the Student Worksheet. Then have a class discussion about the questions.

The BRIDGE Connection

www.vims.edu/bridge/biology.html

The "Me" Connection

Research the characteristics of deep-sea fishes verses surface-water fishes with regard to vision and bioluminescence. Compare with human vision and eyes as well as our sources of illumination.

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Connection To Other Subjects

Physical Science, Chemistry

Evaluation

Student Worksheets may be collected for assessment; classroom participation in activity and discussion.

Extensions

Have students visit http://oceanexplorer.noaa.gov to check out the 2002 Islands in the Stream Ocean Exploration.

Research the chemistry of bioluminescence and its distribution among different kinds of organisms. Which species make their own light and which have mutualistic symbionts that produce the light for them.

Write a paragraph about how you felt as a deep-sea animal that uses bioluminescence.

Resources

www.biolum.org – Information about bioluminescence

http://www.bioscience-explained.org/EN1.1/features.html – An ar-

ticle written by Dr. Edith A. Widder, Harbor Branch Oceanographic Institution

http://www.sciencegems.com/earth2html

http://www.sci.lib.uci.edu/HSG/Ref.html

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

- Diversity and adaptations of organisms
- Interdependence of organisms
- Behavior of organisms

Content Standard D: Earth and Space Science

- Structure of the Earth system

Activity developed by Margaret Spigner, West Ashley High School, Charleston, SC

Student Handout

1. What color clothing did you choose to wear to class? Why did you select these items? Were they effective? What evidence do you have for this conclusion?

2. Did you do anything special to cover your face, hair or other parts that might show up well? If so, what? Did it work well and why?

3. How well were you able to see the prey with your flashlight off? On? Did the colors make a difference in your ability to see a prey item?

4. When you used the flashlight, did you develop a strategy that decreased your chances of being eaten by the gulper eel? What did you do to avoid becoming prey?

5. Did you benefit from another's flash of light? How?

6. Did the colors of the prey influence those items eaten? If so, in what way?

Section 6

Ocean Primary Production

Photosynthesis

Every ecosystem requires an input of energy. The source varies with the system. In the majority of ocean ecosystems the source of energy is sunlight that drives photosynthesis done by micro- (phytoplankton) or macro- (seaweeds) algae, green plants, or photosynthetic blue-green or purple bacteria. These organisms produce ecosystem food that supports the food chain, hence they are referred to as primary producers. The balanced equation for photosynthesis that is correct, but seldom used, is $6CO_2 + 12H_2O = C_6H_{12}O_6 + 6H_2O + 6O_2$. Water appears on both sides of the equation because the water molecule is split, and new water molecules are made in the process. When the correct equation for photosynthesis is used, it is easier to see the similarities with chemosynthesis in which water is also a product.

Systems Lacking Primary Producers

There are some ecosystems that depend on primary production from other ecosystems. Many streams have few primary producers and are dependent on the leaves from surrounding forests as a source of food that supports the stream food chain. Snow fields in the high mountains and sand dunes in the desert depend on food blown in from areas that support primary production. The oceans below the photic zone are a vast space, largely dependent on food from photosynthetic primary producers living in the sunlit waters above. Food sinks to the bottom in the form of dead organisms and bacteria. It is as small as marine snow—tiny clumps of bacteria and decomposing microalgae—and as large as an occasional bonanza—a dead whale.

Chemosynthesis

Ocean exploration has brought to light new ecosystems, dependent on chemosynthetic bacteria which produce food from CO_2 (and sometimes water) using energy from the metabolism of inorganic materials found around them. Chemosynthesis was already well known in terrestrial systems. Nitrifying and anaerobic denitrifying bacteria as well as sulfur-fixing and anaerobic sulfur-reducing bacteria all use energy sources other than the sun. These bacteria had been studied in terrestrial and shallow water systems, but finding entire large ecosystems in the deep sea dependent on chemosynthetic bacteria using sulfur and methane as substrates opened major new areas of research. The discovery of hydrothermal vents and coldwater methane seeps has given us a new vision of primary production in the deep sea.

Hydrothermal Vent Systems

Hydrothermal vents—hot springs associated with spreading ridges on the sea floor—support exotic chemical-based ecosystems. The thriving communities associated with these vents shocked the scientific world when humans first observed a vent on the deep ocean floor in 1977. These vent ecosystems depend on microbes that use chemical energy available in the minerals from the hot spring water. Since they depend upon chemicals for energy instead of the sun, these autotrophic vent-dwelling microbes are called chemoautotrophs. Sulfur in the form of hydrogen sulfide is an energy rich, but toxic molecule. Bacteria that use hydrogen sulfide as an energy source are important to most vent food chains. They exist as both free-living organisms and as mutualistic symbionts within animals. The equation for chemosynthesis based on hydrogen sulfide is $6CO_2 + 24H_2S + 6O_2 = C_6H_{12}O_6 + 24S + 18H_2O$. The vent food chain supported by chemosynthetic bacteria includes shrimp, tubeworms, clams, fish, crabs, and octopi. These animals are well adapted to the extreme vent environment—complete darkness, water temperatures ranging from the 2°C of the surrounding seawater to 400°C at the vent, hundreds of atmospheres of pressure, and high concentrations of sulfides and other toxic chemicals.

The irony is that once scientists knew what to look for, they went to other well-known ecosystems that were rich in hydrogen sulfides, such as salt marshes, and found the same mutualistic association of chemosynthetic bacteria and animals that had stunned them in the deep vents. No one had ever thought to look for them, but they were there all along.

Both photosynthesis and chemosynthesis require an energy source and use carbon dioxide as a source of carbon to synthesize sugars and new water molecules. Photosynthesis gives off oxygen gas as a by-product, while chemosynthesis produces a wide variety of by-products, depending on what chemical substrate is used. The sugars produced provide both metabolic energy and substrate for synthesis of other biochemical molecules.

Hydrothermal vents have a number of kinds of lithotrophic (chemical-eating) bacteria associated with them in addition to those that use hydrogen sulfide since hydrothermal vents release many inorganic compounds to the surrounding seawater. Not all hydrothermal vents are the same. The very hot vents are called black smokers because some of the minerals released precipitate out as a black cloud in the surrounding colder water. They have high flow rates and very hot water, in addition to the variety of chemicals released. Other vents have cooler temperatures and different chemicals. The Lost City Hydrothermal Field near the Mid-Atlantic Ridge emits fluids at 40 to 75 degrees C and builds carbonate towers up to 60 m high.

Lithotrophic bacteria isolated from deep hydrothermal vents include those that oxidize hydrogen sulfide as well as nitrifying, hydrogen oxidizing, and iron and manganese-oxidizing bacteria. Methylotrophic bacteria that use methane as an energy source also occur there. Those that use hydrogen sulfide are the most studied, in part because they are symbionts in the giant tubeworms.

Many of the free-living lithotrophic bacteria form mats around the vent and are grazed upon directly by animals, so they also contribute to primary production around a deep vent.

Cold Seeps

Cold water seeps form above methane hydrate deposits. Communities develop around methane seeps that depend on the energy from hydrogen sulfide and methane captured by bacteria. Dense huge thickets of organisms surround the seeps. Animals from the nearby ocean may come and feed here as well as those that live only in the seep ecosystem.

Where to Find More Activities on Ocean Primary Productivity

This section includes several activities related directly to primary production in the ocean—both by photosynthesis and chemosynthesis. Additional exercises found on the OE web site or OE CD include:

- *Message in the Bottles* from the 2002 Arctic Ocean Exploration
- *Rock Eaters* of the Gulf of Alaska in Exploring Alaska's Seamounts 2002
- *From the Gulf of Mexico to the Moons of Jupiter* in the 2002 Gulf of Mexico expedition
- *Candy Chemosynthesis* in Submarine Ring of Fire 2002
- *It's a Gas* from Deep East 2001 and Hudson Canyon 2002

Lesson Plan 15

Being Productive in the Arctic Ocean

Focus
Primary productivity and limiting factors

Focus Question
What factors limit primary productivity in the Arctic Ocean?

Learning Objectives
Students will identify the major factors that limit primary productivity in the Arctic Ocean and will describe how these factors exert limiting effects.

Students will infer which factors are limiting in a data set of potentially limiting factors and primary productivity.

Materials
- ❒ Five sets of *Sample Data Cards* – one for each student group
- ❒ One *Data Summary Sheet* for each group

Audio/visual Equipment
- ❒ None

Teaching Time
One or two 45-minute class periods

Seating Arrangement
Five groups

Key Words
Pelagic
Benthic
Zooplankton
Primary productivity
Phytoplankton
PAR
Chlorophyll a

Background Information
This activity focuses on primary productivity in the pelagic realm of the Arctic Ocean. Primary productivity refers to the amount of organic matter, usually expressed as grams of carbon per square meter per day, produced by organisms that make food from simple inorganic substances using energy from sunlight to conduct photosynthesis or the chemical reactions of chemosynthesis. Primary productivity in the Arctic Ocean is largely due to photosynthesis carried out by microscopic drifting algae called phytoplankton. Photosynthesis requires photosynthetic organisms, light, carbon dioxide, water, and mineral nutrients. Lack of any one of these may limit photosynthesis or primary production. Which factors limit primary production in the Arctic Ocean? How much primary production actually occurs? This activity uses data from a scientific paper: Smith, Jr., W. O. 1995. Primary productivity and new production in the Northeast Water (Greenland) Polynya during summer 1992. *Journal of Geophysical Research* 100: 4357-4370. It enables your students to examine the factors that limit primary production using real data.

The Arctic Ocean is the smallest of the world's four ocean basins. It is not easily explored as it is almost entirely covered with ice for eight months of the year, a drifting polar ice pack covers the central and western portions year-round, and sea temperature seldom rises above 0°C. Organisms living in the water column between the ocean surface and the bottom, largely phytoplankton, conduct most

of the primary production in the pelagic water. Melting sea ice allows increased light to enter the sea. Algae grow rapidly since the sun shines for 24 hours a day during the summer. Through photosynthesis, these phytoplankton provide energy for a variety of drifting animals (zooplankton) that include crustaceans and jellyfish. Zooplankton provide food for larger pelagic animals including fishes, squids, seals, and whales. When pelagic organisms of any size die, they settle to the ocean bottom as detritus and become the energy source for benthic organisms, including sponges, bivalves, crustaceans, polychaete worms, sea anemones, bryozoans, tunicates, and ascidians. These animals are food for bottom-feeding fishes, whales, and seals.

Learning Procedure

1. Review the background information on the Arctic Ocean with your students. Emphasize that the sea ice, pelagic and benthic communities are connected in the food chain and that photosynthesis by microscopic algae (phytoplankton) provides the energy for all the other organisms in these realms. Use the OE CD or web site for information on the Arctic Ocean. You may mention that a few marine systems, such as those in the vicinity of hydrothermal vents or cold water seeps, are not dependent on photosynthesis for energy, but rely on chemosynthesis instead. Check the OE CD or the web site at http://oceanexplorer.noaa.gov/explorations/02galapagos/galapagos.html and http://oceanexplorer.noaa.gov/explorations/02fire/welcome.html for information on these systems. If necessary, review the basic concepts of photosynthesis. Be sure students understand that photosynthesis is limited by whichever of the essential components is in limited supply.

2. Students have data on Arctic Ocean primary productivity and measurements of the factors that may limit production. Ten data sets will be examined, representing samples that were taken at 10 different times of the year. As each sample is examined, students are asked to explain the results in terms of what factors seem to be limiting primary productivity.

3. Distribute the five sets of sample data cards to the student groups. One group should receive the Ice Cover cards, a second group should receive the Chlorophyll a cards, a third group should receive the PAR cards, a fourth group should receive the Nitrate cards, and the fifth group should receive the Primary Productivity cards. Each set should contain one card for each of the 10 sampling days.

4. Briefly discuss the meaning of each set of cards:
   - Ice Cover cards show the percent of the sea surface that is covered with ice.
   - PAR cards list the amount of photosynthetically active radiation - the amount of sunlight that is usable for photosynthesis - as a percentage of the maximum radiation that occurs during the year.
   - Chlorophyll a cards show the amount of chlorophyll a - a measure of the photosynthetic-capable algae present in the surface seawater.
   - Nitrate cards list the amount of nitrogen-containing mineral nutrients present such as nitrate or ammonia.
   - Primary Productivity cards show the amount of organic matter produced through photosynthesis at the sea surface.

5. Working with the class as a whole, have each group take turns reading its cards for Sample Day #1. List the readings on the Blank Data Summary Sheet. When each group has read their cards, discuss the results. Repeat this process for two more days. Then have the students fill in the sheet and decide as a group what the limiting factor for each of the days from #4 to #10 is that limits primary production. Then discuss their thoughts as a class.
   - Sample Day #1: This is a fairly high rate of Primary Productivity. Students should note that there is no ice to block sunlight and PAR is fairly high. The significance of Chlorophyll a and Nitrate concentrations will become apparent as other days are examined.

- Sample Day #2: 50% of the sea surface is covered with ice which limits Primary Productivity to less than half the value on Sample Day #1, even though the PAR and Nitrate levels are higher and there are only slightly fewer algae as indicated by Chlorophyll a than on Sample Day #1. Reduction of sunlight by sea ice is a major limiting factor for primary productivity in the Arctic Ocean.
- Sample Day #3: Primary Productivity again is much lower than on Sample Day #1. A combination of ice cover and reduced PAR —perhaps a cloudy day—are probably responsible, since Nitrate and Chlorophyll a levels are similar to previous days.
- Sample Day #4: Primary Productivity is low and the obvious cause is the greatly reduced level of Nitrate.
- Sample Day #5: Everything seems favorable, but Primary Productivity is low. The students may notice that PAR is nearly 100% and may wonder whether there is such a thing as too much light. In the Arctic Ocean, photosynthetic algae can be adapted to rather low light conditions. It is possible for photosynthesis to be inhibited if these algae are exposed to too much light.
- Sample Day #6: Low Primary Productivity again; extensive ice cover is the likely cause.
- Sample Day #7: Time for inferences! When would you expect ice to cover 100% of the sea surface? Winter, of course! So, PAR would be zero because night lasts 24 hours in the polar winter. We would expect Chlorophyll a and Primary Productivity to be pretty close to zero as well.
- Sample Day #8: Reviewing the preceding data sets, students should notice that Nitrate does not appear to limit Primary Productivity except when it is in very limited supply. Since Primary Productivity is relatively high and there is 30% ice cover, students could reasonably infer that Nitrate is not limiting in this case, so it could be any of the previous levels except 0.2.
- Sample Day #9: Low PAR is the key here. It is probably early winter, so students might conclude ice cover is probably fairly high (above 70%) and Primary Productivity is probably quite low.
- Sample Day #10: Since all other factors seem pretty favorable, yet Primary Productivity is low, students should suspect that Nitrate levels are low enough to be limiting.

6. Have students write individual summaries of factors that limit Primary Productivity in the Arctic Ocean.

The BRIDGE Connection

www.vims.edu/bridge/polar.html
www.vims.edu/bridge/plankton.html

The "Me" Connection

Have students write a short essay or prepare a brief oral presentation on how knowledge of primary productivity in the Arctic Ocean might benefit them personally, and/or why they think this knowledge is (or is not) important. Ask students to share their thoughts with the class. If they like whales, they have a good connection.

Connection To Other Subjects

English/Language Arts, Mathematics

Evaluation

Have students write their own interpretations of Sample Days #6 – 10 before these are discussed in class.

Extensions

Have students use the OE CD or visit http://oceanexplorer.noaa.gov to learn about the deep Arctic Ocean and to find out what organisms researchers actually find in the three realms.

Have students research primary productivity in temperate and/or tropical ocean waters and compare these data with primary productivity in the Arctic Ocean.

Resources

http://oceanexplorer.noaa.gov – the Arctic Ocean Expedition daily documentaries and discoveries

http://www.sciencegems.com/earth2.html – Science education resources

http://www-sci.lib.uci.edu/HSG/Ref.html – References on just about everything

http://photoscience.la.asu.edu/photosyn/education/learn.html – Links to many sites and activities about photosynthesis

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

Content Standard C: Life Science

- Interdependence of organisms

Content Standard D: Earth and Space Science

- Energy in the Earth system

Activity developed by Mel Goodwin, PhD, The Harmony Project, Charleston, SC

Student Handout

ICE COVER DATA

Sample Day #1

Ice Cover = 0%

ICE COVER DATA

Sample Day #2

Ice Cover = 50%

ICE COVER DATA

Sample Day #3

Ice Cover = 50%

ICE COVER DATA

Sample Day #4

Ice Cover = 10%

ICE COVER DATA

Sample Day #5

Ice Cover = 0%

ICE COVER DATA

Sample Day #6

Ice Cover = 70%

ICE COVER DATA

Sample Day #7

Ice Cover = 100%

ICE COVER DATA

Sample Day #8

Ice Cover = 30%

ICE COVER DATA

Sample Day #9

Ice Cover = GUESS!

ICE COVER DATA

Sample Day #10

Ice Cover = 15%

Student Handout

PHOTOSYNTHETICALLY ACTIVE RADIATION DATA

Sample Day #1

PAR = 75% of maximum

PHOTOSYNTHETICALLY ACTIVE RADIATION DATA

Sample Day #2

PAR = 78% of maximum

PHOTOSYNTHETICALLY ACTIVE RADIATION DATA

Sample Day #3

PAR = 45% of maximum

PHOTOSYNTHETICALLY ACTIVE RADIATION DATA

Sample Day #4

PAR = 76% of maximum

PHOTOSYNTHETICALLY ACTIVE RADIATION DATA

Sample Day #5

PAR = 98% of maximum

PHOTOSYNTHETICALLY ACTIVE RADIATION DATA

Sample Day #6

PAR = 79% of maximum

PHOTOSYNTHETICALLY ACTIVE RADIATION DATA

Sample Day #7

PAR = GUESS!

PHOTOSYNTHETICALLY ACTIVE RADIATION DATA

Sample Day #8

PAR = 82% of maximum

PHOTOSYNTHETICALLY ACTIVE RADIATION DATA

Sample Day #9

PAR = 10% of maximum

PHOTOSYNTHETICALLY ACTIVE RADIATION DATA

Sample Day #10

PAR = 79% of maximum

Student Handout

CHLOROPHYLL a DATA

Sample Day #1

Chlorophyll a = 87 µg/l

CHLOROPHYLL a DATA

Sample Day #2

Chlorophyll a = 76 µg/l

CHLOROPHYLL a DATA

Sample Day #3

Chlorophyll a = 73 µg/l

CHLOROPHYLL a DATA

Sample Day #4

Chlorophyll a = 82 µg/l

CHLOROPHYLL a DATA

Sample Day #5

Chlorophyll a = 85 µg/l

CHLOROPHYLL a DATA

Sample Day #6

Chlorophyll a = 71 µg/l

CHLOROPHYLL a DATA

Sample Day #7

Chlorophyll a = GUESS!

CHLOROPHYLL a DATA

Sample Day #8

Chlorophyll a = 76 µg/l

CHLOROPHYLL a DATA

Sample Day #9

Chlorophyll a = 5 µg/l

CHLOROPHYLL a DATA

Sample Day #10

Chlorophyll a = 73 µg/l

Student Handout

NITRATE DATA

Sample Day #1

Nitrate = 6.2 µmol/l

NITRATE DATA

Sample Day #2

Nitrate = 8.4 µmol/l

NITRATE DATA

Sample Day #3

Nitrate = 11.3 µmol/l

NITRATE DATA

Sample Day #4

Nitrate = 0.2 µmol/l

NITRATE DATA

Sample Day #5

Nitrate = 7.1 µmol/l

NITRATE DATA

Sample Day #6

Nitrate = 6.7 µmol/l

NITRATE DATA

Sample Day #7

Nitrate = 5.2 µmol/l

NITRATE DATA

Sample Day #8

Nitrate = GUESS!

NITRATE DATA

Sample Day #9

Nitrate = 7.6 µmol/l

NITRATE DATA

Sample Day #10

Nitrate = GUESS!

Student Handout

PRIMARY PRODUCTIVITY DATA

Sample Day #1

Surface Primary Productivity = 9.3 mg C/m^2/day

PRIMARY PRODUCTIVITY DATA

Sample Day #2

Surface Primary Productivity = 4.3 mg C/m^2/day

PRIMARY PRODUCTIVITY DATA

Sample Day #3

Surface Primary Productivity = 5.1 mg C/m^2/day

PRIMARY PRODUCTIVITY DATA

Sample Day #4

Surface Primary Productivity = 3.4 mg C/m^2/day

PRIMARY PRODUCTIVITY DATA

Sample Day #5

Surface Primary Productivity = 4.3 mg C/m^2/day

PRIMARY PRODUCTIVITY DATA

Sample Day #6

Surface Primary Productivity = 3.4 mg C/m^2/day

PRIMARY PRODUCTIVITY DATA

Sample Day #7

Surface Primary Productivity = GUESS!

PRIMARY PRODUCTIVITY DATA

Sample Day #8

Surface Primary Productivity = 6.5 mg C/m^2/day

PRIMARY PRODUCTIVITY DATA

Sample Day #9

Surface Primary Productivity = GUESS!

PRIMARY PRODUCTIVITY DATA

Sample Day #10

Surface Primary Productivity = 2.6 mg C/m^2/day

Teacher Answer Key

Teacher's Master Data Summary

Sample Day	Ice Cover (% of surface)	PAR* (% of maximum)	Chlorophyll a (µg/l)	Nitrate (µmol/l)	Primary Productivity (mg C/m²/day)
1	0	75	87	6.2	9.3
2	50	78	76	8.4	4.3
3	20	45	73	11.3	5.1
4	10	76	82	0.2	3.4
5	0	98	85	7.1	4.3
6	70	79	71	6.7	3.4
7	100	GUESS	GUESS	5.2	GUESS
8	30	82	76	GUESS	6.5
9	GUESS	10	5	7.6	GUESS
10	15	79	73	GUESS	2.6

*photosynthetically active radiation

DATA SUMMARY SHEET

Sample Day	Ice Cover (% of surface)	PAR* (% of maximum)	Chlorophyll a (µg/l)	Nitrate (µmol/l)	Primary Productivity (mg C/m²/day)
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					

*photosynthetically active radiation

Student Handout

Lesson Plan 16

Chemosysthesis for the Classroom

Focus
Chemosynthetic bacteria

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
- ❒ Directions for setting up Winogradsky columns from http://topex- www.jpl.nasa.gov/education/activities
- ❒ Black mud from a local river, lake, or estuary, approximately 500 ml for each student group
- ❒ Water from the same source used to obtain black mud, approximately 3 liters for each student group
- ❒ 500-ml graduated cylinder for each student group
- ❒ Calcium sulfate (plaster of Paris), 80 g for each student group
- ❒ 500-ml jar or beaker
- ❒ Stirring rod
- ❒ Straw (hay) or small pieces of filter paper, 50 g for each student group
- ❒ Sodium bicarbonate (baking soda), 4 g for each student group
- ❒ Crushed multivitamin pill, one for each group
- ❒ Plastic wrap
- ❒ Rubber bands
- ❒ Source of artificial light
- ❒ Tape and markers for labeling graduated cylinders
- ❒ Flashlight with red cellophane over lens
- ❒ Optional: microscopes and materials for making wet mounts

Audio/visual Equipment
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

Key Words
Cold seeps
Methane hydrate ice
Chemosynthesis
Brine pool
Vestimentifera
Trophosome
Succession

Background Information
This activity focuses on chemosynthetic bacteria similar to those that are the base of food webs in

cold seep communities. Black mud from a local water body is incubated in a glass cylinder, called a Winogradsky column, with a source of chemical energy from calcium sulfate and organic material from straw or filter paper. A succession of chemosynthetic bacteria grow over a period of six weeks. This activity was originally developed by the Orange County Marine Institute/San Juan Institute Activity Series and is available on NASA's Jet Propulsion Laboratory Ocean Planet web site at http://topex-www.jpl.nasa.gov/education/activities.

Deep-sea chemosynthetic communities occur where hydrocarbon gases, often methane and hydrogen sulfide and/or oil seep out of sediments. These areas, known as cold seeps, are common along continental margins and, like hydrothermal vents, are home to many unique species. Typical features of the seep communities that have been studied so far include mounds of frozen crystals of methane and water called methane hydrate ice, that are home to polychaete worms. Brine pools, containing water four times saltier than normal seawater, also occur. Researchers often find dead fish floating in the brine pool, apparently killed by the high salinity. Where hydrogen sulfide is present, large tubeworms known as vestimentiferans (formerly classified as belonging to the phylum Pogonophora, but recently Pogonophora and Vestimentifera have been included in the phylum Annelida) grow in clusters of millions of individuals. These unusual animals lack a mouth, stomach, or gut. Instead, they have a large organ called a trophosome, that contains chemosynthetic bacteria. Vestimentiferans have tentacles that extend into the water. The tentacles are bright red due to the presence of hemoglobin that absorbs hydrogen sulfide and oxygen. The hemoglobin transports them to bacteria in the trophosome. These bacteria produce organic molecules that provide nutrition to the tubeworm. A similar symbiotic relationship is found in clams and mussels that have chemosynthetic bacteria living in their gills. Bacteria also live independently from other organisms in large bacterial mats. Coldwater seep communities also include snails, eels, sea stars, crabs, lobsters, isopods, sea cucumbers, and fish which likely use the tubeworms, mussels, and bacterial mats as food.

The Gulf of Mexico has the largest fossil fuel reservoir in the continental U.S. Its geology has been intensively studied for more than 50 years. Yet cold seep communities were only discovered in the Gulf about 20 years ago, and, as of 2001, their biology was examined at only three sites less than 20 km apart.

Learning Procedure

1. Lead a discussion of deep-sea chemosynthetic communities. Contrast chemosynthesis with photosynthesis. In both processes, organisms build sugars from carbon dioxide and a hydrogen source. This process requires energy; photosynthesizers obtain this energy from the sun, while chemosynthesizers obtain energy from chemical reactions. Discuss the variety of chemical reactions that can provide this kind of energy. Contrast hydrothermal vent communities with cold seep communities. Visit http://www.bio.psu.edu/cold_seeps for a virtual tour of a cold seep community.

2. Challenge your students to make their own chemosynthetic communities—closed ecosystems in a bottle. Have them follow the steps given at http://topex-www.jpl.nasa.gov/education/activities to set up two kinds of Winogradsky columns, using locally-collected black mud. Divide the groups in half and assign each group to either the light or the dark half. Cover each column tightly with plastic wrap and secure with rubber bands. One half of the columns will be placed in a darkened area and the other in indirect light—not direct sunlight. Students should observe the light and dark 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 slide disposal, and hand washing following completion of the activity.

3. Have each group present and discuss its results. Students should have observed a series of changes in the mud's appearance in the columns caused by bacterial species succession—that is, as each kind grows, it changes the environment, making it more favorable for other species. They should infer that changes caused by one species, for example, waste product production, create opportunities for other species. Similarly, changes in the chemical composition of the mud, such as formation of hydrogen sulfide, alters the environment in ways that may favor the growth of other bacterial species. The processes they observed in the Winogradsky columns roughly models 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/vents.html

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!.

Connection To Other Subjects

English/Language Arts, Biology, Earth Science

Evaluation

Have students submit records of their observations and their written interpretation of these observations.

Extensions

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.

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

http://www.rps.psu.edu/deep/ – Notes from an expedition exploring deep-sea communities for the origins of life on Earth and extraterrestrial life (http://www.ocean.udel.edu/deepsea/level-2/chemistry/ bacteria.html and http://pubs.usgs.gov/publications/text/dynamic.html#anchor19309449 are useful for this).

Resources

http://oceanexplorer.noaa.gov –Gulf of Mexico Expedition documentaries and discoveries

http://ridge.oce.orst.edu/links/edlinks.html – Links to other deep ocean exploration web sites

http://www-ocean.tamu.edu/education/oceanworld/resources/ – Links to other ocean-related web sites

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

Activity developed by Mel Goodwin, PhD, The Harmony Project, Charleston, SC

Lesson Plan 17

Biochemical Detectives

Focus
Biochemical clues to energy-obtaining strategies

Focus Question
How can researchers determine energy and nutritional strategies used by organisms in cold-seep communities?

Learning Objectives

Students will explain the process of chemosynthesis and its relevance to biological communities near cold seeps.

Students will describe three energy-obtaining strategies used by organisms in cold seep communities.

Students will interpret enzyme activity analyses and $\delta^{13}C$ isotope values and draw inferences from these data about energy-obtaining strategies used by organisms in cold-seep communities.

Materials
- ❒ Flip chart, chalk board, or marker board
- ❒ One copy of *Cold Seep Organism Analysis* results for each student

Audio/visual Equipment
None

Teaching Time
One or two 45-minute class periods

Seating Arrangement
Groups of four students

Key Words
Cold seeps
Methane hydrate ice
Chemosynthesis
Brine pool
Vestimentifera
Tophosome
Detritus
Isotope analysis
$\delta^{13}C$
Enzyme analysis

Background Information
In this activity, students use biochemical analyses of organisms from cold seep communities as a basis for drawing inferences about the energy-obtaining strategies used by these organisms. The teacher introduces coldwater seeps and some of the biochemistry associated with organisms at seeps. Then the students examine real data and draw conclusions from them. This activity assumes the students have a foundation in both chemistry and biology and understand basic physiology. Teachers and students should visit the OE Gulf of Mexico 2002 web site or OE CD and read the *Introduction* plus *Communities* and *Tubeworms* as preparation for this activity.

Coldwater seeps are areas where hydrocarbon gases, generally methane, as well as hydrogen sulfide and/or oil seep out of sediments. They commonly occur along continental margins and, like hydrothermal vents, are home to many species not found anywhere else. Typical features of communities currently known include mounds of frozen crystals of methane and water called methane hydrate ice, occupied by ice worms. Brine pools of

water four times saltier than normal seawater have also been found. Researchers often find dead fish floating in the brine pool, apparently killed by high salinity. As with hydrothermal vents, chemosynthetic bacteria form the base of the food web in cold seep communities. These bacteria exist in thick bacterial mats or may live symbiotically in mutually beneficial association with other organisms.

One conspicuous association is that of chemosynthetic bacteria and large vestimentiferan tubeworms formerly classified within the Phylum Pogonophora. (Recently Pogonophora and Vestimentifera have been placed in the Phylum Annelida). Pogonophora means "beard bearing" and refers to the one or more tentacles at the anterior end. Vestimentiferan tentacles are bright red because they contain hemoglobin, the same molecule that makes our blood cells red. Vestimentiferans can grow more than 10 feet long, occur in huge clusters and are estimated to live to over 200 years. They lack a mouth, stomach, and gut. Instead, they have a large organ called a trophosome that holds chemosynthetic bacteria. Hemoglobin in the tubeworms' blood transports hydrogen sulfide and oxygen to bacteria living in the trophosome. The bacteria produce organic molecules that provide nutrition to the tubeworm. Similar relationships are found in clams and mussels that have chemosynthetic bacteria living in their gills. Other seep organisms use tubeworms, mussels, and bacterial mats as food. These include snails, eels, sea stars, crabs, isopods, sea cucumbers, and fish. As the seep community ages, species composition changes. The area becomes less suitable for the unique species and other organisms are able to forage there.

This activity focuses on different energy-obtaining strategies studied in cold seep organisms. There are two methods of obtaining energy (food) in the deep sea. One is to feed on organic material that derives from photosynthetic organisms living in the upper water column. In bottom dwelling communities, this organic material is present primarily as detritus—bits of dead algal and animal material along with decomposing bacteria settling to the bottom. Some organic material originates from pelagic organisms that move vertically through the water column.

The second source of food and energy is chemosynthesis. The chemosynthetic energy source is a variety of chemicals. In cold seep communities methane and hydrogen sulfide appear to be the primary sources. Chemosynthesis also requires a source of dissolved carbon—CO_2 in seawater or from hydrocarbons from the seep.

The source of carbon and energy used by species gives important clues about food webs and community structure. Researchers use measurements of carbon isotope ratios to determine carbon sources. The amount of the stable carbon isotope ^{13}C varies, depending upon the source of the energy and carbon used in fixing the carbon in organic molecules. Isotope content is compared with a standard. The results are expressed as delta values, abbreviated d(x) in parts-per-thousand (‰; also called parts per mille). Scientists have found that $\delta^{13}C$ of carbon in photosynthetically-derived detritus is -18 to -20‰; $\delta^{13}C$ in carbon derived from seawater is -0‰; $\delta^{13}C$ in carbon from organisms that feed on methane is -40‰ or lower. $\delta^{13}C$ in carbon from organisms that depend upon sulfur as an energy source is between -30 and - 40‰.

Scientists also study energy-obtaining strategies using biochemical studies of cold-seep community organisms. The enzymes adenosine triphosphate sulfurylase (ATPS), adenosine-5 phosphosulfate reductase (APR), and sulfide oxidase (SuO) are common in organisms that use sulfur, while ribulose-bisphosphate carboxylase (RuBP) is more abundant in autotrophic organisms, and methanol dehydrogenase (MeD) is found in organisms that use methanol as an energy source.

Learning Procedure

1. Lead a discussion of deep-sea chemosynthetic communities with an emphasis on cold seeps.

Contrast chemosynthesis with photosynthesis. Discuss the variety of chemical reactions that can provide energy for chemosynthesis. Visit http://www.bio.psu.edu/cold_seeps for a virtual tour of a cold seep community. Have the students access the Gulf of Mexico 2002 OE web site or CD.

2. Review the various energy-obtaining options available to cold-seep organisms. Briefly discuss the use of $\delta^{13}C$ isotope analysis and enzyme analysis for obtaining clues about specific energy-obtaining strategies. Have the students work with you to construct a chart showing what the presence of certain enzymes or $\delta^{13}C$ values tells researchers about the probable source of energy and carbon.

3. Distribute *Cold-Seep Organism Analysis Results* sheets. These are results of actual biochemical studies on gill tissues of bivalves and trophosome tissues of vestimentiferans. These tissues are used because they are the sites of energy-producing activity within the organisms. Students should plot the Bivalve $\delta^{13}C$ Analysis data as histograms and draw inferences about the energy-obtaining strategy used by clams versus mussels at cold seeps. The Enzyme and $\delta^{13}C$ Analysis data can be averaged and compared among organisms and inferences made about the energy-obtaining strategy used by each organism.

4. Have groups present their results and summarize these on a flip chart, chalkboard, or marker board. Lead a discussion of these results. Students who examined $\delta^{13}C$ isotope data for bivalves should recognize three distinct groups: mussels with $\delta^{13}C$ values of -40 or more, suggesting a methane-based strategy; clams with $\delta^{13}C$ values of - 20 to -40, suggesting a sulfur-based strategy; and clams with $\delta^{13}C$ values of -14 to - 20, suggesting a heterotrophic strategy—filter-feeding algae or algal detritus. Students who examined data from the vestimentiferan *Lamellibrachia* sp. and the clam *Pseudomilthia* sp. should recognize that the enzyme activity and $\delta^{13}C$ values suggest a sulfur-based strategy, probably involving bacterial symbionts. Similarly, results for the unidentified mussel suggest a methane-based strategy.

The BRIDGE Connection

www.vims.edu/bridge/vents.html

The "Me" Connection

Have students write a short essay on their personal strategy for obtaining energy, and how their strategy might involve some form of chemosynthesis. What chemical energy source(s) would their chemosynthetic strategy utilize?

Connection To Other Subjects

English/Language Arts, Biology, Earth Science

Evaluation

Have students prepare individual written statements of their conclusions prior to oral presentations. Create a grading rubric that includes the group (oral) and individual (written) components.

Extensions

Have students find biological information and pictures of the organisms they investigated in this exercise using web sources.

Resources

http://oceanexplorer.noaa.gov – Gulf of Mexico Expedition 2002 documentaries and discoveries

http://www.bio.psu.edu/People/Faculty?Fisher/thome.htm – Web site for the principal investigator on the Gulf of Mexico 2002 Expedition

http://www.rps.psu.edu/deep/ – Notes from another expedition exploring deep-sea communities

http://www.ridge.oce.orst.edu/links/edlinks.html – Links to other deep ocean exploration web sites

http://www-ocean.tamu.edu/education/oceanworld/resources/ – Links to other ocean-related web sites

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

Activity developed by Mel Goodwin, PhD, The Harmony Project, Charleston, SC

Student Handout

Cold Seep Organism Analysis Results
Bivalve $\delta^{13}C$ Analysis

Animal	$\delta^{13}C$ (‰)	Animal	$\delta^{13}C$ (‰)	Animal	$\delta^{13}C$ (‰)
mussel	-56	clam	-18	mussel	-46
clam	-32	clam	-34	clam	-18
mussel	-56	clam	-32	mussel	-46
mussel	-56	clam	-16	mussel	-46
clam	-36	mussel	-50	clam	-16
clam	-32	mussel	-50	mussel	-44
mussel	-52	clam	-30	mussel	-44
mussel	-52	mussel	-50	clam	-16
clam	-32	clam	-34	mussel	-44
clam	-36	clam	-18	mussel	-44
mussel	-52	clam	-36	clam	-38
clam	-34	clam	-32	mussel	-44
clam	-32	mussel	-50	mussel	-44
clam	-18	clam	-36	clam	-16
mussel	-52	mussel	-48	mussel	-44
clam	-36	clam	-30	mussel	-42
mussel	-52	mussel	-48	mussel	-40
clam	-36	clam	-32	clam	-38
clam	-32	clam	-34		
clam	-30	clam	-18		
mussel	-50	mussel	-46		
mussel	-50	clam	-30		
clam	-14	mussel	-46		
clam	-34	clam	-38		
clam	-32	mussel	-46		
mussel	-50	clam	-16		
clam	-18	mussel	-46		
mussel	-50	mussel	-46		
clam	-36	clam	-36		
clam	-16	mussel	-46		
clam	-30	mussel	-46		
clam	-32	clam	-36		
mussel	-50	mussel	-46		
clam	-36	mussel	-46		

Student Handout

Cold Seep Organism Analysis Results
Enzyme and $\delta^{13}C$ Analysis

	Enzyme Activity					$\delta^{13}C$ (‰)
Animal	**RuBP**	**ATPS**	**APR**	**MeD**	**SuO**	
Pseudomilthia sp. (clam)						
sample #1	0.43	12.86	0.83	nd	2.1	-33.5
sample #2	0.41	2.47	0.66	nd	1.94	-33.6
sample #3	0.44	15.43	1.36	nd	2.04	-32.5
Unidentified Mussel						
sample #1	0.011	nd	nd	0.66	0.7	-51.8
sample #2	0.017	nd	nd	0.53	0.75	-52.0
sample #3	0.021	nd	nd	0.4	1.09	-52.6
Lamellibrachia sp. (vestimentiferan)						
sample #1	0.24	4.24	0.70	nd	1.77	-36.6
sample #2	4.03	1.03	nt	nd	3.15	-36.8
sample #3	4.97	0.51	0.78	nd	5.47	-37.4

nd = not detected
nt = not tested

Section 7

Individual Species in the Deep Sea

Organisms That Live in the Deep Sea

There are a number of activities on the Ocean Exploration web site that target the characteristics and adaptations of individual deep ocean species. This curriculum has elected to focus on the most unique—those of the hydrothermal vents and cold methane seeps. This barely scratches the surface with regard to examining ocean biodiversity, but these two communities include many members of common groups of vertebrates and invertebrates such as bony fish and sharks; sea stars, brittle stars and sea cucumbers; amphipods, crabs, isopods, lobsters and shrimp; octopods, mussels and clams; and many kinds of worms. The third exercise used here, *InVENT a Deep-sea Invertebrate*, enables students to explore this wide range of species while the first two focus on the giant tubeworms—the animals that blew scientists' minds on the first deep vent expedition in 1977. These two exercises, *Let's Make a Tubeworm* and *This Old Tubeworm*, include details about the unique biology of these strange worms.

Deepwater Corals Versus Stony Corals

Several of the expeditions (Deep East 2001 and Northwestern Hawaiian Islands 2002 among them) have examined deepwater corals for distribution, abundance, biochemical composition and trawl fishing impact. The term coral needs clarification for most people. Many organisms in the phylum Cnidaria have the word coral as part of their common name. This implies a relationship that does not exist among these species. Most biologists use the term coral to refer to reef-building stony corals that possess endosymbiotic, single-celled dinoflagellate

algae called zooxanthellae within their inner cell layer. These stony corals deposit calcium carbonate skeletons underneath themselves, forming increasingly massive stony structures called coral reefs that may have more than a mile of calcium carbonate beneath them on some slowly sinking Indo-Pacific seamount atolls.

Reefs—Coral or Rocky

The word reef refers to any rocky substrate that rises above the ocean floor. Hence, in a coral reef, the hard substrate is calcium carbonate from coral skeletons and coralline algae. A number of OE activities refer to reef fish and reefs off the southeastern United States well out of the range of reef-building corals. In this case, the reef is rock, and the corals associated with it are deep-water corals and non reef-building stony corals.

Stony Corals

Stony corals are not particularly similar to deepwater corals except for possessing the characters common to all members of the Cnidaria—polyps (or medusae which are upside down free-living polyps) and cnidoblast stinging cells containing nematocysts. Stony corals are restricted to shallow water since their algae require light. Their biology, structure and growth forms differ greatly from that of deepwater corals. Since they are easily and extensively studied with SCUBA, they have not been the focus of any Ocean Exploration expeditions.

Octocorals

Deepwater corals are mostly octocorals, having 8 feather-like tentacles. Many have a skeleton of protein and calcium carbonate spicules that is often tree-like in growth form and flexible. The connections among octocoral polyps are inside this skeleton, and the polyps extend out from it. There are a number of octocoral orders. Shallow water octocorals such as sea fans and sea whips as well as deepwater members occur among these orders. Brightly colored, flexible, branched octocorals are common along temperate beaches after storms. Deepwater octocorals growth attached to hard surfaces forming hard bottom communities that give food and shelter to

large numbers of invertebrates and fishes. Trawl fishing, with nets that drag along the bottom, can destroy this sheltering structure and the homes it provides to the very species the fishers are targeting.

Other Deepwater Corals

There are also deepwater corals that are non-reefbuilding stony corals that produce very modest calcium carbonate skeletons, tropical black corals with horny skeletons and tree-like growth form, and hydrocorals which are hydrozoans that deposit exquisitely beautiful and fragile rigid calcium carbonate skeletons around their colonial polyps.

Bioprospecting

Bioprospecting, searching for potentially useful natural biochemical products that may have medical or other commercial value, targets many lesser-known marine species—bacterial, algal and invertebrate. These biologically-active chemicals were selected for by harsh environments and strong predation. A number of the Ocean Exploration expeditions include scientists who are bioprospecting for new valuable chemical products. If samples taken prove interesting, bench chemists can often synthesize the same compound in the lab for further testing and commercial production.

Classroom Activities in this Section

The activities in this section build on information and exercises done in earlier sections, applying earth and physical science to an understanding about the biology of specific ocean species. You may need to refer to earlier sections for content if you are using these exercises as independent pieces. If you are working your way through the materials in the order presented, your students will have the background needed to perform well on this section.

Where to Find More Activities on Individual Species in the Deep Sea

Ocean Exploration biology activities not included here, but found on the OE web site or CD include:

- *Deep Sea Coral Biodiversity*, *Design a Deep-sea Invertebrate or Vertebrate*, *Coral Mania* and *What's New?*

From Deep East 2001

- *One Tough Worm* from the 2002 Gulf of Mexico expedition
- *Spawn*, *Reproductive Lottery* and *Drifting Downward* from Islands in the Stream 2002
- *Survivors on the Ocean Ridge* from the 2002 Galapagos Rift expedition
- *The Odd Couple* from the Northwestern Hawaiian Islands 2002

Lesson Plan 18

Let's Make a Tubeworm!

Focus
Unique species with a symbiotic relationship in cold-seep communities

Focus Question
How do deep-sea tubeworm adaptations, including a symbiotic relationship with chemosynthetic bacteria, enable the worms to survive?

Learning Objectives
Students will describe the process of chemosynthesis in general terms.

Students will describe the major features of cold seep communities.

Students will define mutualistic symbiosis and give two examples of symbiosis in cold seep communities.

Students will be able to describe the anatomy of vestimentiferans and explain how these organisms obtain their food.

Materials
- ❒ A variety of art supplies, including cardboard tubes (mailing tube or paper towel roll), colored markers, pipe cleaners (to simulate tentacles), modeling clay, paper and glue

Audio/visual Equipment
None

Teaching Time
Two 45-minute class periods and homework

Seating Arrangement
Groups of four students

Key Words
Cold methane seeps
Hydrothermal deep vents
Chemosynthesis
Vestimentifera
Trophosome
Plume
Vestimentum
Trunk
Tube
Opisthosome

Background Information
Hydrogen sulfide is abundant in water erupting from hydrothermal vents as well as from cold methane seeps (see the Ocean Geologic Features section of this Curriculum for details on these geologic features). Bacteria that use the energy in hydrogen sulfide to support their metabolism are referred to as chemosynthetic bacteria. They form the basis of much of the food chain in both deep vents and seeps (see the Ocean Primary Production section for details). They may exist as free-living bacteria in clumps that are grazed upon by a variety of animals. Alternately, chemosynthetic bacteria live inside of animals in a mutualistic symbiotic relationship in which the animals support the existence of the bacteria and the bacteria provide food to the animals. One of the most interesting and unusual mutualistic symbiotic relationships exists between chemosynthetic bacteria and large tubeworms that belong to the group Vestimentifera. These very large worms were one of the most startling

discoveries associated with original exploration of hydrothermal vents and were subsequently found at cold methane seeps. They were originally classified within the phylum Pogonophora. More recently some taxonomists have placed the pogonophorans in the phylum Annelida.

Pogonophora means "beard bearing," and refers to the fact that many species in this phylum have one or more tentacles at their anterior end. Tubeworms living in the vicinity of hydrothermal vents and cold seeps are classified as vestimentiferans. Their tentacles are bright red from hemoglobin—the same molecule that carries oxygen and makes our blood cells red. Vestimentiferans can grow to more than 10 feet long and may live in clusters of millions of individuals. Some live more than 100 years. They do not have a mouth, stomach, or gut. Instead, they have a large organ called a trophosome that contains chemosynthetic bacteria. Hemoglobin in the tubeworm's blood absorbs hydrogen sulfide and oxygen from the water around the tentacles. Then the hemoglobin transports these raw chemicals to bacteria living in the trophosome. These bacteria produce organic molecules that provide nutrition to the tubeworm.

Similar symbiotic relationships are found in clams and mussels that have chemosynthetic bacteria living in their gills. A variety of other organisms are also found in cold seep communities, and probably use tubeworms, clams, mussels, and bacterial mats as sources of food. These organisms include snails, eels, sea stars, crabs, lobsters, isopods, sea cucumbers, and fishes. Specific relationships between these organisms are not well-studied. Likewise, there are whole communities of invertebrates and fish that depend on chemosynthetic bacteria around hydrothermal deep vents.

The Ocean Exploration 2002 Gulf of Mexico Expedition and the Galapagos Rift Expedition of 2002 both explored the unusual anatomy and ecology of vestimentiferans.

Learning Procedure

1. If you have not done so during previous classes, lead a discussion of deep-sea chemosynthetic communities. Contrast chemosynthesis with photosynthesis. In both, organisms build sugars from carbon dioxide and water. This requires energy. Photosynthesizers use energy in sunlight, while chemosynthesizers obtain energy from chemical reactions. Contrast hydrothermal vent communities with cold-seep communities. Visit http://www.bio.psu.edu/cold_seeps for a virtual tour of a cold seep community, including several tubeworm pictures.

2. Challenge the groups of students to produce the most accurate model of a vestimentiferan tubeworm, using Internet sources for information. Students may visit http://www.cham.montefiore.org/links/pbs/wgbh/nova/abyss/life/tubewormsans.html for an illustration of tubeworm anatomy and explanations of what each body part does.

3. Have each student group create a three-dimensional model of a tubeworm from materials you supply or those they find themselves. A portion of the model should be in cut-away form so that internal structures are displayed. The following structures should be included:
   - plume (including red color to indicate hemoglobin)
   - vestimentum
   - trophosome (including symbiotic bacteria)
   - trunk
   - tube
   - opisthosome

4. Have each group prepare a written report that includes:
   - a description of the function of each of the organs or structures listed above;
   - a description of the symbiotic relationship between the tubeworm and chemosynthetic bacteria;

- an explanation of how the tubeworm obtains its food;
- a discussion of how this symbiotic relationship supports other organisms in the cold seep food web and what some of these organisms might be.

5. Have the students compare models during group reports to the class. They might have a secret ballot to determine which is the most accurate. If you have more than one section, have sections vote on another class' models.

The BRIDGE Connection

www.vims.edu/BRIDGE/vents.html

The "Me" Connection

Have students write a short essay on symbiotic relationships that are important in their own lives.

Connection To Other Subjects

English/Language Arts, Earth Science

Evaluation

Models and the accompanying written reports can be evaluated on the basis of the extent to which the required elements are included, the quality of the written discussions and the scientific accuracy of the sites they selected for information.

Extensions

Have students draw a cold seep food web that includes at least six organisms representing primary producers and consumers.

Resources

http://oceanexplorer.noaa.gov – the 2002 Gulf of Mexico Expedition daily documentaries and discoveries.

http://www.bio.psu.edu/People/Faculty/Fisher/fhome.htm – Web site for the principal investigator on the 2002 Gulf of Mexico expedition.

http://www.rps.psu.edu/deep/ – Notes from another expedition exploring deep-sea communities.

http://ridge.oce.orst.edu/links/edlinks.html – Links to other deep ocean exploration web sites

http://www-ocean.tamu.edu/education/oceanworld/resources/ – Links to other ocean-related web sites.

http://www.cham.montefiore.org/links/pbs/wgbh/nova/abyss/life/tubewormsans.html

This activity was based on:

Paull, C.K., B. Hecker, C. Commeau, R.P. Feeman-Lynde, C. Nuemann, W.P. Corso, G. Golubic, J. Hook, E. Sikes, and J. Curray. 1984. Biological communities at Florida Escarpment resemble hydrothermal vent communities. *Science* 226:965-967 – an early report on cold seep communities.

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
- Transfer of energy

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

Content Standard D: Earth and Space Science
- Structure of the Earth system

Activity developed by Mel Goodwin, PhD, The Harmony Project, Charleston, SC

Lesson Plan 19

This Old Tubeworm

Focus

Growth rates and ages of species in cold-seep communities

Focus Question

What are the growth rates and longevity of cold seep organisms?

Learning Objectives

Students will construct a graphic interpretation of age-specific growth from data on incremental growth rates of different sized individuals of the same species.

Students will estimate the age of an individual of a specific size from data on age-specific growth in individuals of the same species.

Materials

❒ A copy of *Lamellibrachia Growth Rate Data Sheet* and *Growth Data Worksheet* for each group

Audio/visual Equipment

None

Teaching Time

One or two 45-minute class periods

Seating Arrangement

Groups of four students

Key Words

Cold methane seeps
Chemosynthesis
Vestimentifera
Trophosome
Growth rates
Longevity

Background Information

This exercise should follow *Let's Make a Tubeworm* and assumes the students have studied tubeworm anatomy and ecology. While there are many similarities between biological communities associated with hydrothermal vents and cold-seeps, there are also some important differences. One of these is that the physical environment of vent communities can change dramatically over a short period of time. Highly acidic water as hot as 400°C may suddenly erupt, accompanied by large amounts of toxic hydrogen sulfide. Vent organisms adapted to this rapidly changing environment often have growth rates that are much higher than those seen among organisms living in other deep-sea communities.

Things are different in cold-seep communities where the slow, steady release of methane and other hydrocarbon compounds provides a much more consistent environment. Yet, some species characteristic of cold-seep communities are quite similar to species found in vent communities. Tubeworms, for example, are abundant in both communities and have similar symbiotic relationships with chemosynthetic bacteria. Tubeworms in vent communities are among the fastest-growing invertebrates on the planet and reach a large size in relatively few years. Do tubeworms in cold seep communities also have rapid growth rates? How old are the largest tubeworms in cold seep communities? These are questions asked by biologists on the 2002 Gulf of Mexico expedition and are the subject of this activity.

Learning Procedure

1. If necessary review deep-sea chemosynthetic communities. Contrast chemosynthesis with photosynthesis. Point out that there are a variety of chemical reactions that can provide energy for chemosynthesis. Visit http://www.bio.psu.edu/cold_seeps for a virtual tour of a cold seep community and http://www.bio.psu.edu/hotvents for a virtual tour of a hydrothermal vent community. Have the tubeworm models in the classroom for reference.

2. Give a *Lamellibrachia* Growth Rate Data Sheet to each group. Explain that these are results taken from studies on vestimentiferans at two cold-seep sites in the Gulf of Mexico. In these studies, the worm's outer tube was marked with a blue stain. After one or more years, stained individuals were collected and new tube growth was measured as the length of the unstained segment of the tube between the stain mark and the end of the worm. Have each group plot growth rate (y-axis) as a function of length of the worm (x-axis). Students should draw a curve that passes through or near as many data points as possible.

3. Discuss the plotted data. These graphs show that the tubeworms' growth rates slowed as the size of the animals increases. This is common among most species of animals.

4. Next students will estimate the age of the largest animals. The researchers did this by fitting a curvilinear regression line to the data, then integrating the growth equation over the interval. An alternative, but less precise, approach can be used to estimate an approximate age. This approach involves breaking an animal's growth history into a series of intervals, determining how long it took to grow through each interval, then adding these individual growth times together to arrive at an approximate age (integration is based on a similar approach for a nearly infinite number of intervals). The curve drawn in Step #2 represents the growth history of an "average" tubeworm, based on growth data from 35 individual tubeworms. This curve will be used to estimate the age of a tubeworm 200 cm long.

5. Distribute one *Growth Data Worksheet* to each group. The first interval to be considered is 0 - 10 cm. Have students use their plots from Step #2 to find the predicted growth rates (in cm per year) at size = 0 cm and size = 10 cm. Tell students to find the average of these two numbers, and assume that this average represents how fast the animal was growing between the sizes of 0 and 10 cm. Now, calculate how long (in years) it would take to grow 10 cm by dividing 10 cm by the average growth rate (cm/yr). Round answers to the nearest tenth of a year and enter the result in the last column of the worksheet. Repeat this process for the remaining intervals (10 - 20 cm, 20 - 30 cm ....190 – 200 cm), finding the average growth rate for the interval, calculating how long it would take the animal to grow that 10 cm, and entering the result in the last column of the worksheet. Add all of the entries in the last column of the worksheet to find the total time required to grow through all intervals from 0 through 200 cm. This sum is the estimated age of a tubeworm whose length is 200 cm.

6. Have each group present its results. Each group will probably be somewhat different due to the need to estimate intermediate points on the graphs. The overall trend, however, should show that a 200 cm tubeworm from the sites studied would be over 200 years old. Discuss these results, asking students whether it is reasonable to suppose that tubeworms could be this old. Why not; after all, how much do we really know about average life expectancy among deep-sea organisms? Ask what factors might contribute to this longevity, such as a very stable environment and absence of many predators or competitors because of extreme conditions to which these animals are uniquely well adapted. Is it likely that other species could also be relatively old, compared to similar

species in other communities? Again, why not, since the factors that might help tubeworms live for a long time could also help other species do the same. Ask students why there should be such a striking difference in growth rates between tubeworms at hydrothermal vents and cold seeps. Vent communities exist in very dynamic conditions, and things may change dramatically at any time. Cold seep communities are based on slow leakage of hydrocarbon materials from beneath the sea floor and probably do not experience much change over very long periods of time.

The BRIDGE Connection

www.vims.edu/bridge/vents.html

The "Me" Connection

Have students write a short essay contrasting life in two communities. The first community exists in a remote valley where weather patterns and local physical conditions combine to produce a very stable and livable climate that remains virtually unchanged from year to year. The other community exists in a region that frequently experiences significant volcanic activity, including eruptions of poisonous gases and superheated air. Students may assume that the first community offers unusually long life-spans to individuals living there, while the second community offers unusually rapid growth and maturation of individuals (couples typically have their first child at the age of 7), as well as the prospect of sudden and unpleasant death at any time.

Connection To Other Subjects

English/Language Arts, Earth Science

Evaluation

Have students prepare individual written interpretations of their results prior to oral presentations in Step #6.

Extensions

Have students investigate growth studies in other ocean communities and develop hypotheses for why growth and longevity vary among these communities.

Resources

http://oceanexplorer.noaa.gov – 2002 the Gulf of Mexico Expedition documentaries and discoveries.

http://www.bio.psu.edu/People/Faculty?Fisher/thome.htm – web site for the principal investigator on the 2002 Gulf of Mexico expedition.

http://www.rps.psu.edu/deep/ – notes from another expedition exploring deep-sea communities.

http://www.ridge.oce.orst.edu/links/edlinks.html – links to other deep ocean exploration web sites

http://www-ocean.tamu.edu/education/oceanworld/resources/ – links to other ocean-related web sites.

Based on papers by:

Paull, C.K., B. Hecker, C. Commeau, R.P. Feeman-Lynde, C. Nuemann, W.P. Corso, G. Golubic, J. Hook, E. Sikes, and J. Curray. 1984. Biological communities at Florida Escarpment resemble hydrothermal vent communities. *Science* 226:965-967 – Early report on cold seep communities.

Bergquist, D. C., F. M. Williams, and C. R. Fisher. 2000. Longevity record for deep-sea invertebrate. *Nature* 403:499-500. – Technical journal article upon which this activity is based.

National Science Education Standards

Content Standard A: Science As Inquiry
- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard B: Physical Science
- Chemical reactions

Content Standard C: Live Science
- Interdependence of organisms

Activity developed by Mel Goodwin, PhD, The Harmony Project, Charleston, SC

Student Handout

Lamellibrachia Growth Rate Data Sheet

Length of Tubeworm (cm)	Growth Rate (cm per year)
5	4.75
10	4.25
10	4.75
10	3.75
20	4.25
20	3.60
20	3.00
30	3.20
30	2.80
40	2.75
40	3.00
50	2.00
50	2.75
50	2.40
60	2.00
70	2.25
70	1.25
80	1.50
90	1.75
90	0.75
100	1.25
110	1.00
120	0.75
130	0.75
130	1.00
130	0.50
150	0.50
150	0.75
150	0.25
170	0.50
170	0.10
180	0.70
180	0.10
200	0.05
200	0.45

Student Handout

Growth Data Worksheet

Growth Interval (cm)	Growth Rate at Beginning of Interval (cm/yr)	Growth Rate at End of Interval (cm/yr)	Average Growth Rate (cm/yr)	Time to Grow 10 cm (yr)
0 – 10				
10 – 20				
20 – 30				
30 – 40				
40 – 50				
50 – 60				
60 – 70				
70 – 80				
80 – 90				
90 – 100				
100 – 110				
110 – 120				
120 – 130				
130 – 140				
140 – 150				
150 – 160				
160 – 170				
170 – 180				
180 – 190				
190 – 200				

TOTAL TIME TO REACH 200 CM _____

Lesson Plan 20

InVENT a Deep-Sea Invertebrate

Focus
Adapations to deep sea conditions

Learning Objectives
Students will design an invertebrate capable of living near deep-sea hydrothermal vents.

Students will describe the unique adaptations that organisms must have in order to survive in the extreme environments of the deep sea.

Materials
- ❒ Reference materials – CDs, invertebrate and vertebrate textbooks, Internet access
- ❒ Colored pencils or markers (one pack per student group)
- ❒ *Animal Adaptation Chart* (one copy per pair of students)
- ❒ Chart paper

Teaching Time
Two 45-minute sessions

Seating Arrangement
Students work in pairs for research

Key Words
Benthic
Adaptations
Hydrothermal vent
Chemosynthesis
Photosynthesis
Carbohydrates
Ecosystems
Tubeworm
Invertebrate
Amphipod
Sessile

Background Information
More than twenty-five years ago, Jack Corliss, Robert Ballard, and other Woods Hole Oceanographic Institution oceanographers first observed a hydrothermal vent system near the Galapagos Islands on the Galapagos Rift. The year was 1977. They amazed the world with the discovery of communities of organisms that were unique. These communities were extremely dense near the vents—a surprise because deepwater benthic communities are usually quite dispersed and have low biomass since things living on the bottom are dependent upon food that falls from above in the photosynthetic zone. The explanation for the high biomass in vent communities came with the discovery that bacterial chemosynthesis was the basis of the food web. Since this initial discovery, numerous other hydrothermal vent systems have been located in the Pacific, Atlantic, and Indian Oceans.

Animals living in hydrothermal vent communities have unique adaptations to a challenging set of environmental conditions. Hydrothermal vents occur where seawater erupts up through the cracks between plates of the Earth. Fresh lava flows are common here. Hydrothermal vents are created by water penetrating into these cracks. Seawater percolates deep into the oceanic crust, super heats, rises and returns to the ocean floor at temperatures as high as 400°C. The surrounding ocean water is about 2°C and is under extreme pressure which prevents the vent water from boiling. Vent water contains dissolved metal ions of iron, magnesium,

copper, and zinc. Hydrogen and hydrogen sulfides are also dissolved in the hot vent plumes, along with metallic ions and metallic salts. The metals precipitate out, forming vent chimneys. Hydrogen sulfides may precipitate within the latticework of the vents. Chemosynthetic bacteria synthesize carbohydrates, using hydrogen sulfides, water and oxygen. They are the primary producers of the vent food chain. They may live as colonies or mats or as endosymbionts within animals. The vent organisms are exposed to extreme temperatures, wide pH ranges, very high pressure, and total darkness.

Like all organisms, vent animals have adaptations that enable them to live and reproduce in this extreme environment. Adaptations are inherited characteristics that help organisms live under specific sets of conditions. Adaptations include physical characteristics such as body shape, anatomical features, ways of moving, feeding mechanisms, protective characteristics, and reproductive strategies. They may also be biochemical such as enzymes adapted to higher than normal temperatures or the ability to metabolize unusual substrates. They may also be behavioral traits.

Scientists have discovered over 300 new species associated with vent communities. Perhaps the most notable are the giant tubeworms, which can reach 6 feet in length—the fastest growing invertebrates known. Other worms, like the Jericho worm, are about the size of a pencil and live in tubes that look like accordions. Organisms adapted to vent living include clams, mussels, and shrimp. Amphipods, small lobsters, sea anemones, fish, and octopi have also been found in these extreme environments. Each time scientists explore a new rift system, they discover new species.

Learning Procedure

1. Ask students to list all of the challenges to living things that occur in the area of a deep hydrothermal vent. You may give them a set time to explore reference materials. Then list these on the board. Some are listed above: pressure, lack of light, primary production carried out by chemosynthetic bacteria, cold surrounding water, superheated vent water, extreme pH, toxic dissolved metals and hydrogen sulfides.

2. Discuss the concept of an adaptation—an inherited, genetically-controlled characteristic that enables an organism to be suited to a specific environment or do something unique. Individuals do not adapt, they inherit their adaptations. The environment selects those individuals with the genetics that most fit their environment to reproduce and pass on those characteristics. Brainstorm with your students about the kinds of adaptations that organisms might need to live in the extreme conditions associated with hydrothermal vent ecosystems. Record these answers on the board.

3. Have each student pair research organisms found in or near hydrothermal vent communities, using available references such as the Internet, encyclopedias, and/or textbooks, including: www.divediscover.whoi.edu

4. Give a copy of the *Animal Adaptation Chart* to each pair. Challenge them to design and draw an invertebrate capable of living in or near a hydrothermal vent ecosystem. Each invertebrate should exhibit adaptations in body form (for both young and adult stages), locomotion, feeding, and protection. The pair should name their "new" organism and designate the taxonomic group to which it belongs.

5. The students may be asked to describe to the class, as they display the drawing, what their organism's body shape is and why it is shaped that way, how it moves, how it feeds, how it protects itself, what its young look like and why they might look the way they do.

The BRIDGE Connection

http://www.vims.edu/bridge/vents.html

The "Me" Connection

Ask students to think about what types of adaptations would be useful to humans if the temperature of the air were to rise such that desert conditions existed everywhere on Earth. Examples might be nocturnal habits, large ears for heat loss, nostrils and lungs that conserved water, etc.

Connection To Other Subjects

Art, English/Language Arts

Evaluation

Charts from each student pair may be evaluated for completeness and student drawings may be evaluated for understanding of adaptations.

Extensions

Have your students visit http://oceanexplorer@noaa.gov and www.divediscover.whoi.edu with a family member to check the latest hydrothermal vent discoveries.

Have students write a story about "A Day in the Life of..." for the animal they designed. They should explain the unique adaptations of the animal within the story.

The student pairs could get together with other student pairs to form a food web that incorporates several of the animals they designed.

Resources

http://oceanexplorer@noaa.gov

www.divediscover.whoi.edu

National Science Education Standards

Life Science Content Standard C:

- Structure and function in living systems
- Reproduction and heredity
- Regulation and behavior
- Populations and ecosystems
- Diversity and adaptations of organisms

Activity adapted from Design a Deep Sea Invertebrate, developed by Robin Sheek and Donna Ouzts, Laing Middle School, Charleston SC

Student Handout

Animal Adaptation Chart

Directions: Use references provided to complete the following chart for your invertebrate.

Draw a picture of your animal:

Describe its body form:

_____

_____

_____

Describe how it moves:

_____

_____

_____

Describe how it feeds:

_____

_____

_____

Describe how it protects itself:

_____

_____

_____

Describe what its young look like:

_____

_____

_____

Lesson Plan 21

Invertebrate Chemists

Focus
Some benthic invertebrates produce pharmacologically-active substances

Focus Question
What groups of marine organisms produce substances that may be helpful in treating human diseases?

Learning Objectives
Students will identify at least three groups of benthic invertebrates that are known to produce pharmacologically-active compounds.

Students will describe why pharmacologically-active compounds derived from benthic invertebrates may be important in treating human diseases.

Students will infer why sessile marine invertebrates appear to be promising sources of new drugs.

Materials
❒ Marker board, blackboard, or overhead projector with transparencies for group discussions

Audio/Visual Materials
None

Teaching Time
One or two 45-minute class periods, plus time for student research

Seating Arrangement
Classroom-style or groups of 2-3 students

Key Words
Cardiovascular disease
Cancer
Arthritis
Natural products
Sponge
Tunicate
Ascidian
Bryozoan
Octocorals
Sessile

Background Information
Advances in medicine have resulted in longer average human life span. As infectious diseases such as polio, tuberculosis, and a host of childhood problems have been largely conquered by vaccination and antibiotics, medical research has focused more on cardiovascular disease and cancer which together account for more than 1.5 million deaths annually. These are much more complex, often occurring later in life and having both genetic and environmental causes. Additionally, one in six Americans have some form of arthritis, and hospitalized patients are increasingly threatened by infections that are resistant to conventional antibiotics. The annual cost of these diseases is high: $285 billion per year for cardiovascular disease; $107 billion per year for cancer; and $65 billion per year for arthritis. The economic value of new drugs that effectively treat these diseases or drug-resistant infectious agents is obvious.

Many drugs in use today originated as natural products. Aspirin, for example, was first isolated

from the willow tree. Morphine is extracted from the opium poppy. Penicillin was discovered from common bread mold. To date, almost all of the drugs derived from natural sources come from terrestrial organisms. But recently, systematic searches for new drugs have shown that marine algae and invertebrates are a rich source of biologically-active chemicals that have antibiotic, anti-cancer, or anti-inflammatory properties. Particularly promising invertebrate groups include sponges, tunicates, ascidians, bryozoans, octocorals, and some molluscs, annelids, and echinoderms.

The list of potential drugs derived from marine invertebrates includes:
Ecteinascidin – Extracted from tunicates; being tested in humans for treatment of breast and ovarian cancers and other solid tumors

Topsentin – Extracted from the sponges *Topsentia genitrix*, *Hexadella* sp., and *Spongosorites* sp.; anti-inflammatory agent

Lasonolide – Extracted from the sponge *Forcepia* sp.; anti-tumor agent

Discodermalide – Extracted from deep-sea sponges belonging to the genus *Discodermia*; anti-tumor agent

Bryostatin – Extracted from the bryozoan *Bugula neritina*; potential treatment for leukemia and melanoma

Pseudopterosins – Extracted from the octocoral (sea whip) *Pseudopterogorgia elisabethae*; anti-inflammatory and analgesic agents that reduce swelling and skin irritation and accelerate wound healing

ω-conotoxin MVIIA – Extracted from the cone snail, *Conus magnus*; potent pain-killer

The 2003 Medicines from the Deep Sea Expedition focused on the discovery of new resources with pharmaceutical potential in the Gulf of Mexico. The expedition collected selected benthic invertebrates from deep-water bottom communities in the Gulf of Mexico (sponges, octocorals, molluscs, annelids, echinoderms, tunicates). These samples provide many months of lab work that starts with identification of the organisms. DNA and RNA samples are taken. Scientists then isolate and culture microorganisms that live in association with deep-sea marine invertebrates; prepare extracts of benthic invertebrates and associated microorganisms, and test these extracts to identify those that may be useful in treatment of cancer, cardiovascular disease, infections, inflammation, and disorders of the central nervous system. These tests are largely done in cell cultures. Chemists isolate unique products from those extracts that show pharmacological potential and determine the structure of these chemicals. This allows further study of the pharmacological properties of active compounds. Perhaps most important, scientists develop methods for the sustainable use of biomedically-important marine resources.

The last objective is particularly important, since many potentially useful drugs are present in very small quantities in the animals that produce these drugs. This makes it impossible to obtain useful amounts of the drugs simply by harvesting large numbers of animals from the sea. Some alternatives in addition to chemical synthesis of specific compounds are aquaculture to produce large numbers of productive species, or culture of the cells that produce the drugs. Natural products chemists have become extremely effective at copying new molecules in the lab which removes dependence on wild populations.

This activity is designed to familiarize students with some of the organisms that produce chemicals that have shown promise for the treatment of human diseases. Perhaps most important, it encourages students to think about the physical characteristics and environmental situations that result in the evolution of biologically-active chemicals in certain groups.

Learning Procedure

1. Ask the students to comment briefly without names on their relatives and friends, perhaps even themselves in relation to the value of finding new drugs for the treatment of cardiovascular disease, cancer, inflammatory diseases, and infections. Make a chart on the board listing each of these categories and ask for student hands indicating who has personal knowledge of someone with that category of disease. Discuss the economic value as well as the value of relief of suffering when a new drug is produced that effectively treats one of these diseases.

2. Briefly introduce the concept of drugs from natural products and describe the potential of marine communities as sources for these drugs. These are the objectives of the 2003 Medicines from the Deep Sea Expedition.

3. Challenge the students to do their own bio-prospecting on the Internet and prepare a written report on a marine benthic invertebrate that produces one or more substances having potential for treating human diseases. Reports should include:
   - description of the organism, with pictures if possible;
   - basic life history information about these organisms (where they live, what they eat)
   - students' inferences about how powerful chemicals might be useful to the organism.

   You may also want to ask students to find out about chemicals produced by their assigned organism that may be useful for treating human diseases.

   Assign each student group one or more of the following groups of organisms:

   sponges
   tunicates
   ascidians
   bryozoans
   octocorals

4. When the reports are done, have students make a brief oral presentation of their research results. Lead a discussion focusing on the role of pharmacologically-active substances to the organisms studied. Lead students to discuss the characteristics of these species that make having biologically-active compounds useful to them: discouraging predators by being distasteful or toxic; preventing faster growing organisms from over growing them by inhibiting the growth of competitors; warding off bacteria, fungi or parasites that cause disease by killing them or inhibiting their growth. Like plants that are a rich terrestrial source of drugs, these invertebrates are largely sessile - they are basically "sitting ducks." Have the students speculate on how each of the above might translate into a useful drug. For example, if two species were competing for space on which to grow, it would be helpful to produce a substance that would attack rapidly-dividing cells of the competing organism. Since cancer cells often divide more rapidly than normal cells, the same substance might have anti-cancer properties.

The BRIDGE Connection

www.vims.edu/bridge/ – Click on "Ocean Science" in the navigation menu to the left, then "Chemistry" for resources on drugs from the sea. Click on "Ecology" then deep sea for resources on deep-sea communities. Click on "Human Activities" then "Technology" then "Biotechnology" for resources on biotechnology.

The "Me" Connection

Have students write a short essay from the viewpoint of a sessile benthic invertebrate, describing the hazards their animal must face in a typical day, and how their animal is adapted to survive these challenges.

Connections to Other Subjects

English/Language Arts; Chemistry

Evaluation

Written and oral reports provide opportunities for evaluation.

Extensions

Log on to http://oceanexplorer.noaa.gov for discoveries from the 2003 Medicines from the Deep Sea Expedition.

Resources

http://oceanica.cofc.edu/activities.htm – Project Oceanica web site, with a variety of resources on ocean exploration topics

http://www.science.fau.edu/drugs.htm – An overview article on drugs from the sea

www.nci.nih.gov – Web site of the National Cancer Institute

http://www.woodrow.org/teachers/bi/1993/ – Background and activities from the 1993 Woodrow Wilson Biology Institute on biotechnology

http://www.denniskunkel.com/ – Web site containing hundreds of images taken with light and electron microscopes

National Science Education Standards

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard C: Life Science

- Structure and function in living systems
- Reproduction and heredity
- Diversity and adaptations of organisms

Content Standard F: Science in Personal and Social Perspectives

- Personal health
- Risks and benefits
- Science and technology in society

Activity developed by Mel Goodwin, Ph.D.
The Harmony Project, Charleston, SC

Section 8

Community Ecology and Sampling

Sampling the Deep Ocean

Just as with the *Challenger* Expedition, modern Ocean Exploration requires complex planning, strong teamwork, and expensive use of ship time and technological equipment. Ocean exploration teams include technical staff that run the ship and keep the equipment functioning as well as scientists from a broad range of disciplines and levels of education and science educators. Each person has an important role, including the cook that feeds a crew working 24 hours a day.

Ecological Activities in this Section

Ship, submersible and ROV time is limited and expensive. When a mission objective includes the study of complex ecological communities like those of seamounts or deep vents, planning and effect use of equipment becomes even more critical. This section examines ecological studies of two biological communities—hydrothermal deep vents and seamounts. They are *Who Promised You a Rose Garden?* and *Biological Communities of Alaska Seamounts*. Each exercise asks questions about the distribution and abundance of species within the community as well as questions about change over time in relation to geological events. In other words, they are classical ecological studies. While doing these activities, your students will not only learn about the organisms within these communities, but also the ecological relationships among them and the impact of physical factors on distribution and abundance—both biotic and abiotic factors.

Sampling Activity in this Section

The third exercise—*Would You Like a Sample?*—is one of many OE activities that seek to model the difficult

problems associated with getting representative samples that provide a true picture of the ocean floor and its inhabitants. The Arctic Ocean Exploration provided data for this exercise. Seasons when scientists can safely work at sea are limited especially in the Arctic. Ships, staff and equipment are expensive. Time underwater for submersibles is limited. ROVs can stay down longer, but still are limited by weather and length of expeditions. Your students will do the same kind of planning ocean scientists do before going on their expedition to study the Arctic benthos. This exercise requires extensive preparation the first time it is done, but then is ready to go for future classes. It is a model based on real species and real communities and challenges the students to design their own expedition.

Ocean Exploration

Ocean science has addressed these issues in recent years by concentrating funding on fixed, permanent arrays of instruments and drifting equipment packages. There are also powered unmanned mini subs that range the seas in a programmed pattern, surfacing periodically to radio back their observations. As useful as these are, nothing beats seeing what is there in person or by driving a ROV in response to images it returns to the ship. NOAA's Ocean Exploration program goes to new sites and enables humans to actually see what is there. It pushes back the ocean frontiers.

Where to Find Other Ecological and Community Activities on the OE Web Site or CD

Other ecological and sampling exercises on the Ocean Exploration web site or the OE CD include:

- *The Sea with No Shores* and *Reef Fish Real Estate* in the South Atlantic Bight from 2002 Islands in the Stream
- *Living with the Heat* from 2002 Submarine Ring of Fire
- *Breaking Away (Or Not..)* from Exploring Alaska's Seamounts 2002
- *Let's Get to the Bottom of the Arctic!*, *Life in the Crystal Palace*, and *Meet the Arctic Benthos* all from the

2002 Arctic Exploration
- *Hawaiian Bowl!* in the Northwest Hawaiian Islands Exploration

Exercises focused more on obtaining samples and designing sampling patterns are:
- *Living in Extreme Environments* from Deep East 2001
- *Designing Tools for Ocean Exploration* from Deep East 2001 and the 2002 Galapagos Rift Exploration
- *What on Earth is That, and How Can I Get One?* from Deep East 2001
- *Submersible Designer* from Galapagos Rift 2002

Lesson Plan 22

Who Promised You a Rose Garden?

Focus
Biological communities associated with hydrothermal vents along the Galapagos Rift

Focus Questions
What are the animals in the communities associated with deep hydrothermal vents?

Are the animals at vents evenly distributed?

Do vent communities change over time?

Learning Objectives
Students will conduct independent research to discover what types of organisms live near hydrothermal vents.

Students will interpret a map of the vent community associated with the Rose Garden at the Galapagos Rift.

Materials
- ❒ Ocean map or overhead showing locations of spreading ridges and the Galapagos rift site pictures of hydrothermal vents and animals from web site http://www.divediscover.whoi.edu
- ❒ One *Student Research Sheet* per student
- ❒ One *Map of the Rose Garden* per group
- ❒ One *Student Inquiry Sheet* per student

Audio/visual Materials
- ❒ National Geographic Video *Dive to the Edge of Creation* if available
- ❒ Internet connection for student use

Teaching Time
Two 45-minute periods

Seating Arrangement
Individually or in groups of four

Key Words
Hydrothermal vent
Galapagos rift
Ocean ridges
Ocean plates
Mutualistic symbiosis
Plume
Distribution
Hydrothermal fluid
Dissolved
pH
Oases
Chemosynthesis
Colonize

Background Information
This activity builds on vent-related exercises and information found in the Ocean Geologic Features, Ocean Primary Production and Individual Species in the Deep Sea sections. The first part involves students in independent research to describe the unique animals that make up a thriving vent community—the Rose Garden. The second section enables students to use their mapping skills to describe some of the discoveries Dr. Hessler and his team of scientists made in 1985 as they explored the Rose Garden. Students should then compare this information with the findings from the 2002 Galapagos Rift Expedition and may also compare the Galapagos communities with those found at other sites at

vents on mid-oceanic ridges in both the Pacific and the Atlantic Oceans.

Deep hydrothermal vents were found by using towed cameras off the Galapagos Islands in 1976. The following year an expedition returned with the submersible *Alvin*, enabling scientists to see newly discovered deepsea structures first hand. One of the best NOVA films ever made, *Dive to the Edge of Creation*, documented this amazing voyage of discovery. Scientists observed aqua-colored plumes of shimmering water rising from the seafloor—the first hydrothermal vents. Water heated inside the Earth's crust to as much as 400°C carries dissolved metals and other chemicals like hydrogen sulfide from deep beneath the ocean floor. This water, with a pH of 3 to 5, was venting from cracks near the mid-oceanic ridge opened by sea floor spreading along the rift.

What really startled scientists were areas around the vents that hosted thriving communities of animals—mini oases—on the relatively barren ocean floor. Since then hydrothermal vent community productivity has been found to rival that of salt marshes and coral reefs—highly productive communities. Bacteria using chemosynthesis thrive on hydrogen sulfide and synthesize sugars using energy from these chemicals. They are the base of the food chain in hydrothermal vent communities. Some of these bacteria are also thermophyllic, or heat loving, and can survive temperatures over 100°C. Many animals living in vent communities host mutualistic bacterial symbionts that synthesize sugars which are shared with their host while the host provides a safe refuge and a supply of substrate for the bacteria.

Scientists named these vent communities of tubeworms and other species. Among these names are "Rose Garden," "Garden of Eden," and "East of Eden." This activity includes student research and use of a map from the Rose Garden produced by Dr. Robert R. Hessler from Scripps Institution of Oceanography at the University of California, San Diego, in 1985.

Dr. Hessler and a scientific team revisited the Rose Garden first studied in 1979 on the Galapagos Rift in 1985. They collected data on the distribution and abundance of animals in this vent area. Their goal was to compare their observations with those made in 1979. Scientists towed a camera system that generated over 2,000 photographs, forming a complete picture of the Rose Garden.

Below are some of the organisms observed at the Rose Garden, so named because the red tubeworms remind scientists of roses in a garden. Since rifts extrude magma periodically, they are both highly dynamic sites, requiring adaptations to constantly changing conditions and excellent sites for invertebrates since they have hard, rocky substrates. Look for adaptations to both in these descriptions.

Giant tubeworms reach lengths of over six feet and grow attached to the substrate. They have a bright red plume filled with red blood at the end of a long white tube. This bright red plume functions as a gill and takes up sulfur, oxygen, and carbon dioxide from the water. They may retreat into their tubes if disturbed. Adults lack mouths, stomachs, and anuses. They have an odd-looking organ that fills most of the tube which houses sulfide-loving bacteria. Tubeworms provide sulfide to the bacteria and, in return, the bacteria produce sugars for the tubeworms in a mutualistic symbiotic relationship.

Giant tubeworms thrive in rapid vent flows. When the flow slows or stops, the giant tubeworms begin to die and are replaced or eaten by other organisms. Tubeworms are among the first animals to colonize a hydrothermal vent area. In 1979, the Rose Garden had tubeworms everywhere. In 1985 they were scarce. The difference is likely due to changes in the vent flow.

Mussels are early colonizers of a new vent site.

They grow in clumps in seafloor cracks. Bacteria in their large, fleshy gills produce sugars from hydrogen sulfide, carbon dioxide and water. These bacteria release sugars to the mussels while the mussels provide refuge to the bacteria. This mutualistic symbiosis benefits both partners. Mussels also filter particulate food from sea water; so if hydrothermal fluid stops flowing, the mussels can survive for a short time.

Mussels attach to hard substrate with strong threads they secrete. They may shoot out the thread and then reel themselves into a new position. Movement allows the mussels to travel short distances to a higher vent flow in the dynamic vent area. Tubeworms are permanently attached. Crabs and shrimp eat mussels. In 1979 and 1985, mussels were abundant at the Rose Garden; in 1985, the mussel population seemed larger throughout the vent area.

Clams colonize hydrothermal vents after mussels become established. They have a big muscular foot that wedges into cracks. The foot also enables them to move. Like mussels, clams depend on the symbiotic bacteria in their gills. Crabs and octopi eat the clams. In 1979, clams were not present in the Rose Garden in large numbers. By 1985, there was a notable increase in the clam population at the Rose Garden.

Anemones are related to jellyfish and corals. They prey on other animals using stinging cells with nematocysts on their tentacles. At the Rose Garden, anemones were abundant in 1979 and in 1985. Anemones typically live farther away from the vent openings than tubeworms, mussels, and clams. Anemones, however, are found closer to vent openings than serpulid worms.

Serpulid worms build curly tubes of calcium carbonate. They are sometimes called featherduster worms because they collect tiny food particles with plume-like tentacles resembling an old-fashioned feather duster at the tube top. When disturbed, they withdraw into the tube. They form dense beds at vent field edges. Compared to tubeworms, mussels, clams, and anemones, serpulid worms live furthest from vent openings at the Rose Garden.

Bacteria are microbes found at hydrothermal vents. They are the primary producers of hydrothermal vent communities. They are chemoautotrophic, using energy from chemicals dissolved in water flowing out of vents to build sugars from carbon dioxide. Bacteria grow everywhere! Some bacteria live inside clams, tubeworms, and mussels in symbiotic relationships with these animals. Different bacterial species are adapted to specific water temperatures and use energy from different chemicals, including hydrogen, hydrogen sulfide, and iron. Scientists are intensely interested in these deepsea bacteria, both for research and for economic reasons. They use genetic techniques to identify new species and study their biochemical metabolism.

These are just a few of the organisms living near hydrothermal vents. Your students will find many more! These may include the squat lobsters, shrimp, octopus, so-called dandelions that are siphonophores related to jellyfish and zoarcid fish. The web sites and articles listed in the Resources section provide information for your students' literature search.

There are many factors that alter vent flow. Faulting at the spreading centers alters the shape and the distribution of the flow. Some new sites open, while others areas may stop flowing altogether. Some flow channels may clog up over time. Flow pattern changes create new vents. Others become extinct. Animals, like the giant tubeworms, that require high vent flow may suffer when vent flow is suddenly reduced. Other animals, like mussels and clams, rely on vent flow to support the bacteria living in their gills, but also filter feed in the absence of vent flow. As your students study the 1985 Rose Garden map, tell them that tubeworms were very abundant in 1979. What would account for fewer tubeworms in 1985?

Learning Procedure

1. Review the physical characteristics of hydrothermal vents, using pictures and maps to support your introduction.

2. Challenge your students to search for information on the animals associated with hydrothermal vents and the sources of food for these animals in this harsh environment. Have each group of students research three or more organisms from the list above that live along hydrothermal vents, using resources listed here. They should record their findings, including specific adaptations, on their *Student Research Sheets*. Give them a week to work independently.

3. The following week, discuss the biology of hydrothermal vents using student information from their searches. Use their pictures and string to create a vent food web on a bulletin board.

4. Lead a discussion of the organisms' adaptations, including a discussion of chemosynthesis as the source of primary production.

5. Give a *Rose Garden Map* to each group of students and review what the map represents and how the data were collected.

6. Provide an *Inquiry Sheet* to each student. If your students work more effectively in groups, then divide the class into teams of four to work together, but each student should write his/her own responses.

7. Provide 20 minutes for your students to complete the *Inquiry Sheet*. Then lead a discussion of their answers.

The BRIDGE Connection

www.vims.edu/bridge - Choose Ecology from the sidebar and go to the Deep Sea Link. There are numerous reviewed links to sites about hydrothermal vents.

The "Me" Connection

Ask students to consider how humans could ever harness and utilize the energy produced at hydrothermal vents.

Connection To Other Subjects

Biology, English/Language Arts

Evaluation

Have students write a "Home Wanted" ad for two hydrothermal vent organisms. Include a picture of the ideal home and a full description of those items the organism would need to find in its new home.

Extensions

Have your students visit http://oceanexplorer@noaa.gov and www.divediscover.whoi.edu for Galapagos Rift Expedition discoveries.

Have students create a 3-D model of a hydrothermal vent area.

Resources

http://oceanexplorer@noaa.gov and www.divediscover.whoi.edu -The 2002 Galapagos Rift Expedition daily documentaries and discoveries. A wealth of resource information is found at both of these sites.

http://www.nationalgeographic.com

http://www.marine.whoi.edu/ships/alvin/alvin.htm

http://www.ocean.udel.edu/deepsea

http://www.life.bio.sunysb.edu/marinebio/hotvent.html

http://amnh.org/nationalcenter/expeditions/blacksmokers

http://www.pbs.org/wgbh/nova/abyss/life/extremes.html

http://www.ocean.washington.edu/people/grads/scottv/exploraquarium/vent/intro.html

http://www.pmel.noaa.gov/vents/home.html

http://seawifs.gsfc.nasa.gov/OCEAN_PLANET/HTML/oceanography_recently_revealed1.html

http://www.whoi.edu/WHOI/VideoGallery/vent.html/

Articles from past issues of *National Geographic Magazine*

Oases of Life in the Cold Abyss, October, 1977
Return to the Oases of the Deep, November, 1979
Light in the Abyss Reveals Life, November, 1994
Rebirth of a Deep-sea Vent, November, 1994
Life at the Bottom, May, 1998
Deep-sea Geysers of the Atlantic, October, 1992
Deep Sea Vents: Science at the Extreme, October, 2000
Rebirth of a Deep-Sea Vent, November, 1994
Deep-Sea Geysers of the Atlantic, October, 1992

Research paper on the Rose Garden

Hessler, Robert R. et. al. 1988. "Temporal change in megafauna at the Rose Garden hydrothermal vent." Deep-Sea Research, Vol. 35(10-11): 1681-1709.

Books

Van Dover, Cindy Lee. 1996. The Octopus's Garden: Hydrothermal Vents and Other Mysteries of the Deep Sea. Perseus Press.

Van Dover, Cindy Lee. 2000. The Ecology of Deep-Sea Hydrothermal Vents. Princeton University Press.

Woodman, Nancy. 1999. Sea-Fari Deep. National Geographic Books.

National Science Education Standards

Content Standard A: Science as Inquiry
- Abilities necessary to do scientific inquiry
- Understandings about scientific inquiry

Content Standard C: Life Science
- Structure and function in living systems
- Populations and ecosystems

Content Standard D: Earth and Space Science
- Structure of the Earth system

Activity developed by Stacia Fletcher, South Carolina Aquarium

Student Handout

Student Research Sheet
Hydrothermal Vent Organisms

Name: _____

Name of Organism: _____

Drawing of Organism:

Description of Organism, including Adaptations for Survival:

_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____
_____

Student Handout

Student Inquiry Sheet

Name: _____

1. What animals did Dr. Hessler find at coordinates C,8?

_____

2. What organisms are most abundant on the northern-most edge of the vent field?

_____

3. Which animals are most abundant on the southern edge of the vent field?

_____

4. Of the animals listed on the key, which do you think were least abundant at the Rose Garden in 1985?

_____

5. Which two animals are found in similar locations?

_____

_____

6. If you were a hungry octopus looking for a mussel to eat, what is one set of coordinates where you could be sure to find a yummy meal?

_____

7. How many meters across, from north to south, is the largest clump of tubeworms?

_____

8. Why do you think the tubeworms can only be found in two small pockets along the hydrothermal vent in 1985 when they were much more abundant in 1979?

_____

_____

9. Why would scientists create a map like the one of the Rose Garden in 1985?

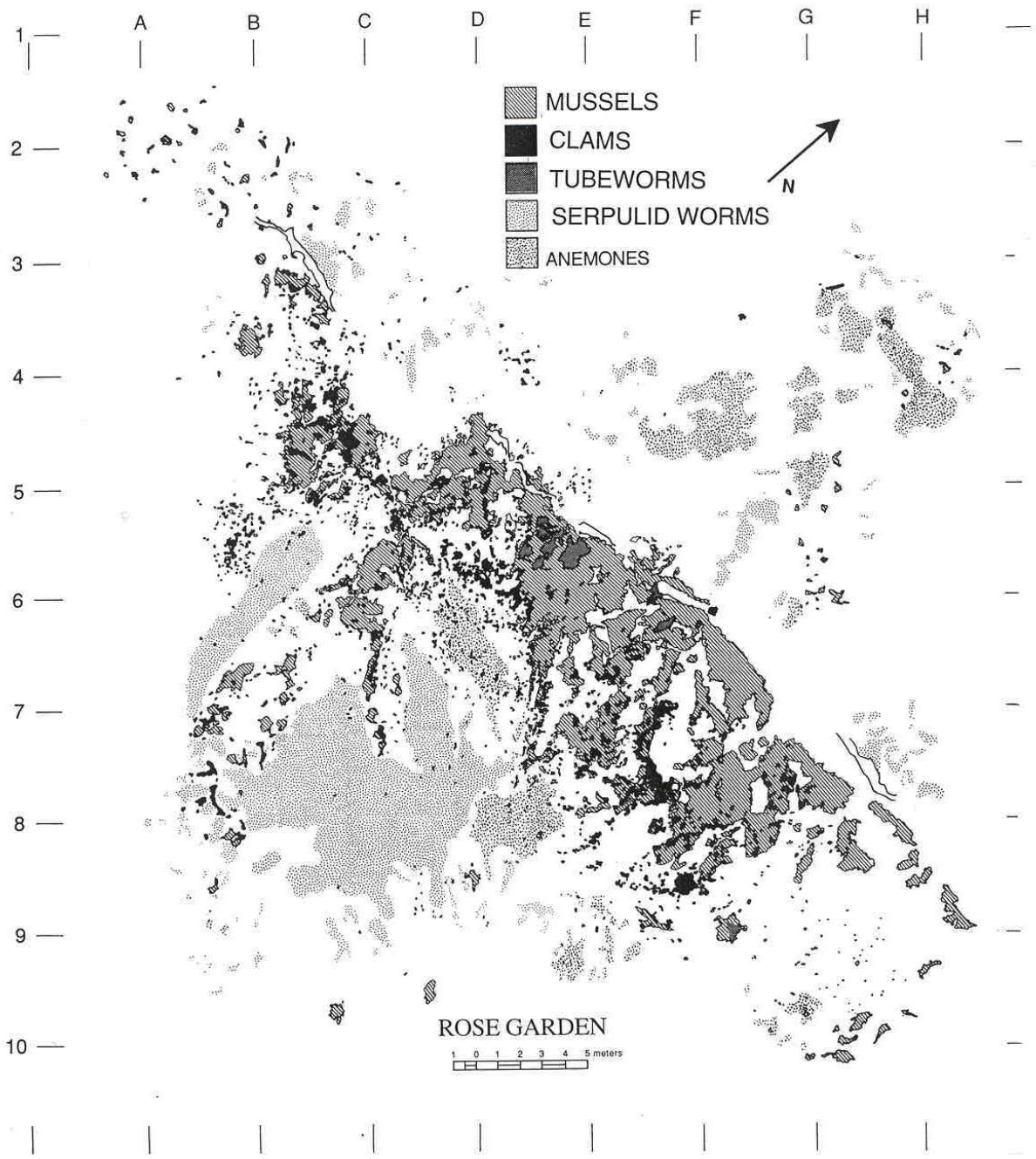
_____

_____

_____

Student Handout

Map of the Rose Garden



Lesson Plan 23

Biological Communities of Alaska Seamounts

Focus
Biological community species composition on seamounts

Focus Question
What is the relationship between distance on a chain of seamounts and the community species composition of each seamount?

Learning Objectives
Students will infer why biological communities on seamounts are likely to contain unique or endemic species.

Students will calculate an index of similarity between two biological communities given species occurrence data.

Students will make inferences about reproductive strategies in species that are endemic to seamounts. Students will explain the implications of endemic species on seamounts to the conservation and potential for the extinction of these species.

Materials
- ❒ One *Seamount Species Checklist* per group
- ❒ One *Gulf of Alaska Seamounts Map* per group
- ❒ One ruler per group

Audio/visual Equipment
None

Teaching Time
One 45-minute period

Seating Arrangement
Groups of two to four students

Key Words
Seamount
Endemic
Extinction
Coefficient of community
Biological community

Background Information
Seamounts or guyots are undersea mountains that rise from the ocean floor, often to heights of 3,000 m (10,000 ft) or more. Compared to the surrounding ocean waters, seamounts have high biological productivity and provide habitats for a variety of plant, animal, and microbial species. Numerous seamounts occur in the Gulf of Alaska. Many exist in long chains that parallel the west coast. One of the longest, the Axial-Cobb-Eikelberg-Patton chain, was intensively studied by the Ocean Exploration 2002 Gulf of Alaska Expedition.

Because seamounts are often isolated from coasts as well as from each other, biologists expect to find new species when they visit unexplored seamounts. In fact, a single research cruise to explore Australian seamounts collected 259 invertebrate species, about a third of which were new to science, many of which probably occur only on seamounts in the region. Seamount communities are easily damaged by commercial trawl fishing that targets these species-rich areas. At the First International Symposium on Deep Sea Corals (August, 2000), scientists warned that more than half of the world's deep-sea coral reefs have been destroyed. Some believe that

destruction of deep-sea corals by bottom trawlers is responsible for the decline of major fisheries, such as cod.

Seamounts in the Gulf of Alaska appear to be relatively undisturbed, but their biological inhabitants have not been thoroughly studied. They may have unique species found nowhere else. Describing biological communities on these seamounts was a major objective of the 2002 Gulf of Alaska Expedition. If they have unique species, what should be done to protect them from extinction? Are the biological communities on seamounts sufficiently similar that protecting one or two seamounts would be sufficient or is every seamount different? How similar are biological communities on Alaskan seamounts? Are they less similar as the distance between seamounts increases?

Learning Procedure

NOTE: This activity uses a hypothetical data set. These are real species that do live on Cobb Seamount, but their presence or absence on other seamounts has not been confirmed. The technique of comparing communities using the coefficient of community will apply to actual data from the Gulf of Alaska Expedition as this information becomes available.

1. Review the origin of seamounts using the Ocean Geologic Features section. Having completed other seamount exercises will improve student understanding of this activity.

2. Review seamount biology. You may let students explore the OE web site or CD to establish background knowledge. Although seamounts have not been extensively explored, expeditions to seamounts report many new species that appear to be endemic to a particular group of seamounts. Ecological studies of islands tells us that any isolated site provides the opportunity for the development of new species due to natural selection, the founder effect and genetic drift. Seamounts are effectively islands, they just have not broken the surface yet. They have all the same characteristics related to recruitment and migration that islands do except that their inhabitants come for other seamounts rather than from adjacent land.

3. The question for your students is whether communities on seamounts that are far apart are less similar that those that are closer together. Does it appear that distance affects settlement rates?

4. Distribute the *Seamount Species Checklist* and *Gulf of Alaska Seamounts Map*. Assign each group one pair of the three seamounts for comparison. Students can calculate the coefficient of community for each pair of seamounts using this formula $C = 2a/(b + c)$, where C is the coefficient of community, a is the number of species in common to both seamounts, b is the total number of species found on one of the seamounts, and c is the total number of species found on the other seamount. Students should also measure the distance between their seamounts.

5. Make a graph on the blackboard plotting the coefficient of community (y axis) against distance between seamounts (x axis). Have students put their results on the graph. The ask them to describe the trend shown by the data: similarity decreases with increasing distance between seamounts. Lead a discussion of what these findings suggest about reproduction in seamount communities and about the implications of these findings to the danger of extinction. Students should recognize that the data suggest that juveniles or larvae of many species are not easily exchanged between seamounts and are either retained near the seamounts where they are produced or do not survive long trips between seamounts. This means that species endemic to particular seamounts are vulnerable to extinction. A relatively localized event could sweep away all individuals of these species, resulting in immediate extinction.

The BRIDGE Connection

www.vims.edu/bridge/biology.html

The "Me" Connection

Have students write a paragraph on why they should care about what happens to biological communities on seamounts or have groups of students debate this question.

Connection To Other Subjects

English/Language Arts, Geography, Mathematics

Evaluation

For individual evaluations, have students prepare written interpretations of the summarized data prior to leading a group discussion.

Extensions

Have students visit http://oceanexplorer.noaa.gov to look at all the seamount explorations, including 2002 Gulf of Alaska and Davidson as well as 2003 New England Seamount Expeditions. Compare findings from each.

Resources

http://oceanexplorer.noaa.gov – 2002 Gulf of Alaska Expedition documentaries and discoveries.

http://www.marine.csiro.au/PressReleasesfolder/98releases/5jun98.html – Information on seamount conservation issues in Tasmania (typical of concerns for seamounts worldwide).

http://www.sciencegems.com/earth2.html – Science education resources

http://www-sci.lib.uci.edu/HSG/Ref.html – References on just about everything

Paper on which this activity was based:

de Forges, B. R., J. A. Koslow, and G. C. B. Poore, 2000. Diversity and endemism of the benthic seamount fauna in the southwest Pacific. *Nature* 405:944-947.

National Science Education Standards

Content Standard A: Science as Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard F: Science in Personal and Social Perspectives

- Populations, resources, and environments

Activity developed by Mel Goodwin, Ph.D., The Harmony Project, Charleston, SC

Student Handout

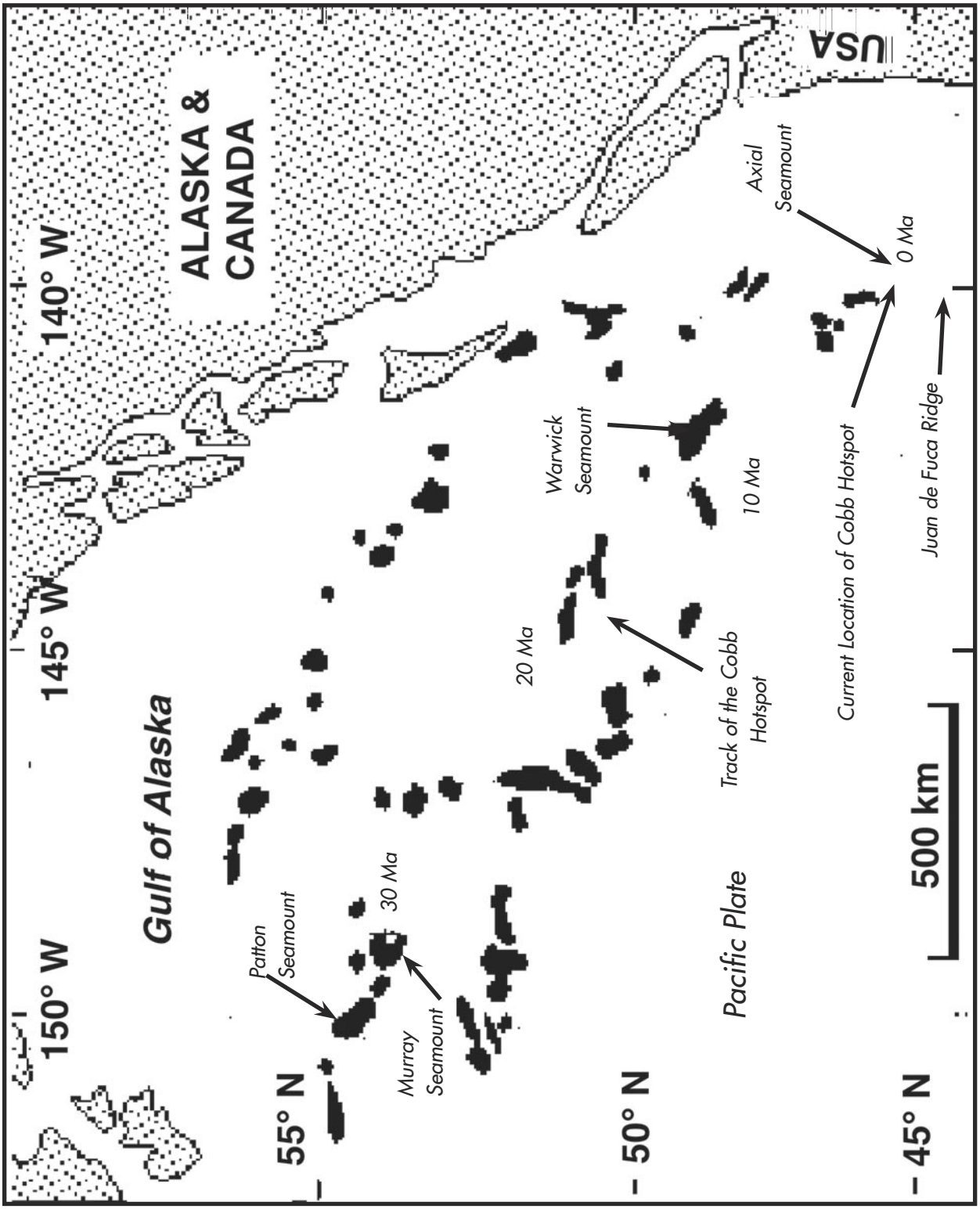
Seamount Species Checklist

(based on Parker and Tunnicliffe, 1994)

Phylum	Class	Species	Found on Seamount		
			Patton	Warwick	Axial
Porifera	Desmospongiae	*Halichrondria panicea*	•		•
Cnidaria	Hydrozoa	*Allopora verrilli*		•	•
	Anthozoa	*Metridium senile*	•		
		Corynactis californica	•	•	•
Annelida	Polychaeta	*Crucigera zygophora*		•	•
		Northria conchylega	•	•	
		Phyllochaetopterus prolifica	•		
		Protula pacifica	•	•	•
		Lumbrineris inflata		•	
Arthropoda	Amphipoda	*Caprella alaskana*	•	•	
		Caprella laeviuscula	•		
		Proboloides sp.	•	•	•
		Micropleustes sp.			•
		Parapleustes sp.	•	•	
		Maera sp.	•	•	
	Isopoda	*Ianiropsis tridens*	•		•
		Munna uniquita	•	•	
		Munna chromatocephala	•	•	
	Tanaidacaea	*Leptochelia* sp.			•
		Paratanais sp.	•	•	
	Malacostraca	*Chorilia longipes*		•	•
		Oregonia gracilis	•	•	
Mollusca	Gastropoda	*Margarites marginatus*		•	•
		Calliostoma annulatum	•	•	
		Calliostoma ligatum		•	•
		Diodora aspera	•		
		Searlisia dira	•	•	•
		Granulina margaritula	•	•	
	Bivalvia	*Crassodoma gigantea*	•	•	•
		Macoma balthica		•	•
		Modiolus modiolus	•	•	
		Petricola pholadiformis	•	•	
Brachiopoda	Articulata	*Platidia hornii*	•		•
Bryozoa	Cyclostomata	*Bicrisia edwardsiana*			•
		Crisia occidentalis	•	•	
		Filicrisia franciscana	•	•	
	Cheilostomata	*Bugula* sp.			•
		Lyrula sp.	•		
Sipuncula		*Phascolosoma agassize*	•		
Echinodermata	Asteroidea	*Pycnopodia helianthiodes*			•
		Crossaster papposus	•	•	
		Henricia sanguinolenta	•	•	
		Henricia leviuscula	•		•
		Leptasterias hexactis	•	•	•
	Crinoidea	*Florometra serratissima*	•		
	Echinoidea	*Strongylocentrotus franciscanus*	•	•	

Student Handout

Student Handout:
Gulf of Alaska Seamount Map



http://ridge.coas.oregonstate.edu/rkeller/seamounts.html
College of Oceanic and Atmospheric Sciences, Oregon State University

Lesson Plan 24

Would You Like a Sample?

Focus
Designing and testing sampling strategies for biological communities

Focus Question
How well do biological samples represent the actual biological communities from which they are taken and how can their accuracy be improved?

Learning Objectives
Students will test the advantages and limitations of several sampling techniques to study biological communities.

Materials
- ❒ One large *Sampling Grid* per group – must use OE CD or web site to download grid pages 7- 26 from *Would You Like a Sample?*, grades 7-8, 2002 Arctic Ocean Exploration and prepare ahead of time
- ❒ One *Sampling Plan Sheet* per student
- ❒ One *Sampling Plan Data Sheet* per student
- ❒ A copy of the *Complete List of All Organisms in the Model Community* on an overhead transparency
- ❒ One copy of a random numbers table per group or pages from an old telephone directory
- ❒ One ream cardstock (110 lb paper)
- ❒ Large roll of invisible tape

Audio/visual Materials
- ❒ Overhead projector to facilitate discussion

Teaching Time
Two 45-minute class periods

Seating Arrangement
Groups of four or five students

Key Words
Transect
Quadrat
Grid
Random

Background Information
This exercise models data similar to that collected on benthic invertebrates on the 2002 Arctic Ocean Expedition. Details about the biology of the three communities studied on this expedition are found on the OE web site or the OE CD. This exercise is not about students learning about the organisms, but rather focuses on how scientists learn what they "know" and what uncertainties exist. It is a bit time-consuming to build the sampling boards, but once they are done, they may be used repeatedly with no prep time.

Ocean exploration is expensive and seasons in which expeditions are safe and possible are restricted. Nowhere is this more true than in the Arctic Ocean. It is almost entirely covered with ice for eight months of the year, a drifting polar ice pack covers the central and western portions year-round, and sea temperature seldom rises above 0°C. All of these problems, plus remote location mean that biologists have to plan their sampling strategies very carefully to get the maximum data in the minimum amount of time with the best possible accuracy. Organisms found in the Benthic Realm of the Arctic Ocean include sponges, bivalves, crustaceans, polychaete worms, sea anemones, bryozoans, tunicates, and ascidians.

Researchers have developed systems for taking samples from a community. They then use these samples to draw conclusions about the community as a whole. There is always a question, though, of how well the samples represent the community. The situation becomes even more complicated when organisms are hidden under rocks or in sediment, or are very small, or very large, or very fast. Scientists used to take grab samples from the bottom with a clam-shell tool somewhat like a steam shovel head. But how do you decide where to make the grabs in the vast space available? New technologies, including remotely operated vehicles (ROVs), underwater video recorders, high resolution digital cameras, and side scan sonar were used by researchers on the Arctic Ocean Expedition to overcome some of the difficulties of sampling biological communities. Despite the new technology, the researchers know that some organisms went undetected.

Learning Procedure

In this activity, students use several common sampling techniques to investigate an unknown biological community. They then compare the strengths and weaknesses of these techniques in giving an accurate impression of the community's organisms.

1. Copy each page of grid cells enough times to make one complete set for each student group. Use heavy card stock copier paper – 110 lb paper works well in modern printers. Cut the margins from each page, leaving all 20 cells in the grid in one sheet. Arrange the sheets from one set face up in the order shown on the *Complete List of All Organisms*. There should be 4 rows of 5 cards. Using invisible tape, tape each row into a long sheet of 5 cards. Turn over and tape the seams on the back as well. These are folded for storage. You will have 4 rows of 5 cards per group. Ideally, this work would be done by parent volunteers under your supervision. Cell labeled "1,1" is in the lower left corner, and the cell labeled "20,20" is in the upper right corner.

2. You may have students research information on the species appearing here before doing this or they may already know a good bit about them.

3. Show the students the grid boards and demonstrate taking a sample by picking a square and recording the species found there. Ecologists seek to describe distribution and abundance of species. Your students are going to do the same thing for this model Arctic Ocean benthic community. How do they decide which ones to turn over?

4. Challenge your students to develop a sampling plan for this benthic community 10,000 feet deep the Arctic Ocean. Side scan sonar indicates that the area is almost completely flat, with no large rocks or other distinct features. Using precision mapping and global positioning equipment, the site has been divided into a grid of 400 squares. Give them the *Sample Plan Sheet* to show this. The plan is to send a ROV to collect video and actual samples, but sampling time is limited. Only 25 grid squares can be sampled from this site.

5. Lead a discussion with the students of how they might arrange their sampling program. One commonly used sampling system is to establish one or more lines, called transects, across the study area and take samples at fixed intervals along the transect line. For visual surveys, these samples are often taken within a square area of fixed size, called a quadrat. In the case of our model community, individual quadrats are represented by the individual grid squares.

   An alternative technique would be to collect randomly-selected samples throughout the community. To apply a random sampling system to the model community, each grid square is assigned a pair of coordinates beginning with 1,1 for the square in the lower left corner and ending with 20,20 for the square in the upper right corner, similar to coordinates on graph paper. Then grid squares to be sampled would be selected using a random number table, taking four at a

time where the choices are 0 to 9. For example, if four numbers in the table were 1,3,0,7, the first square to be sampled would be 13 squares across and seven squares up. Coordinate pairs greater than 20,20 are skipped. A telephone directory can be substituted, using the last digit of each number on a page.

6. Have each student group select a sampling technique and diagram it on the *Sampling Plan Sheet,* selecting 25 squares. Try to have some groups use a random sampling system and others use a transect system.

7. Now hand out the sets of *Sampling Grids*. Have the students lay them out face up to form a large sheet oriented in the same way as the *Complete List of All Organisms*.

8. Hand out the *Sampling Plan Data Sheets*, discuss the abbreviations for the animal names and practice recording data from a grid.

9. Record the quadrat number and check off the species found for each of the 25 quadrats selected on the *Sampling Plan Data Sheet*. Then add up how many times each group was found. This gives some idea of abundance as well as distribution in the grid.

10. Have each group analyze its data to address the three questions listed in Step 11. Make a list of all the species groups found; this answers question (a). Next, tally the number of quadrats in which each group occurred. Classify groups as Abundant if they occurred in more than 50% of the samples, Common if more than 20% but less than 50%, and Rare if in less than 20% of the samples. This answers question (b). Finally, identify species groups that are commonly found together. One way to do this is to make a matrix, listing all species groups in vertical columns, and all species groups in horizontal rows. In each matrix cell, fill in the number of quadrats in which each species group was found with the other groups. This gives an answer to question (c).

	Group A	**Group B**	**Group C**	**Group D**	**etc.**
Group A	20	3	18	12	
Group B		15	5	10	
Group C			23	1	
Group D				14	
etc.					

11. Ask the students to discuss the following questions, using the data they have collected:
    (a) What species groups are present in the model community—did they all get the same answers?
    (b) What was the relative abundance of the groups?
    (c) Which species groups tended to occur together? These associations give clues as to how different species groups may be interacting in the community.

12. Discuss the total number of species found, the relative abundance of each species, and which species appear together in more than three samples. Record these summaries on a marker board, flip chart, or overhead transparency. Lead a discussion comparing the results of the different techniques and speculate about what features of the model community might lead to the results they obtained. Organisms in nature are seldom distributed randomly. They are more often clumped, although territorial species may be over dispersed due to spacing mechanisms.

13. Compare the students' results with the *Complete List of All Organisms in the Model Community*. This sort of list is almost never available in actual research situations, but should show how difficult it is for a single sampling program to detect all of the species in a community. Be sure the students understand that they were able to sample 1/16th

of the entire model community. Coverage with most real sampling programs is much less. How would they use their results to design a follow-up sampling program?

The BRIDGE Connection

www.vims.edu/bridge/polar.html
www.vims.edu/bridge/benthos.html

The "Me" Connection

Have students write a short essay or prepare a brief oral presentation on how knowledge of unexplored biological communities might benefit them personally, and/or why they think this knowledge is (or is not) important. Ask students to share their thoughts with the rest of the class.

Connection To Other Subjects

Mathematics, Earth Science, Physical Science

Evaluation

Individual sampling plans and data summaries prepared by each student group may be collected to assess the thoroughness of their work. Additionally, students may be asked to define key words and/or address discussion points in writing before participating in a group discussion.

Extensions

Have students visit http://oceanexplorer.noaa.gov to see exploration of the deep Arctic Ocean.

Visit http://www.ropos.com to find out about the ROV used on the Arctic Ocean Expedition to explore biological communities.

Have students research species groups and present a brief report describing these groups.

Resources

http://oceanexplorer.noaa.gov – The 2002 Arctic Ocean Expedition documentaries and discoveries.

http://www.sciencegems.com/earth2.html – Science education resources.

http://www-sci.lib.uci.edu/HSG/Ref.html – References on just about everything.

National Science Education Standards

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard C: Life Science

- Populations and ecosystems

Activity developed by Mel Goodwin, PhD, The Harmony Project, Charleston, SC

Student Handout

Complete List of All Organisms in the Model Community

All Quadrats in Columns 1 - 5 Contain: **Sand Dollars Sipunculids**	All Quadrats in Columns 6 - 10 Contain: **Sea Urchins Ascidians**	All Quadrats in Columns 11 - 15 Contain: **Sand Dollars Sipunculids**	All Quadrats in Columns 16 - 20 Contain: **Sea Urchins Ascidians**

All Quadrats in Rows 16 - 20 Contain: **Bivalves**

All Quadrats in Rows 11 - 15 Contain: **Bivalves**

All Quadrats in Rows 6 - 10 Contain: **Tunicates**

All Quadrats in Rows 1 - 5 Contain: **Tunicates**

The 25 quadrats labelled C, D, G, H, and L also contain **Brittle Stars** and **Sea Anemones.**
The 25 quadrats labelled D, H, L and P also contain **Snails.**
The 25 quadrats labelled C, G, K, and O also contain **Isopods.**
The 25 quadrats labelled A, B, E, F, and J also contain **Polyplacophora.**

These contain **Polychaetes** and **Amphipods.**

These contain **Bryozoans** and **Sea Cucumbers.**

These quadrats also contain **Cumaceans.**

These quadrats also contain **Priapulida.**

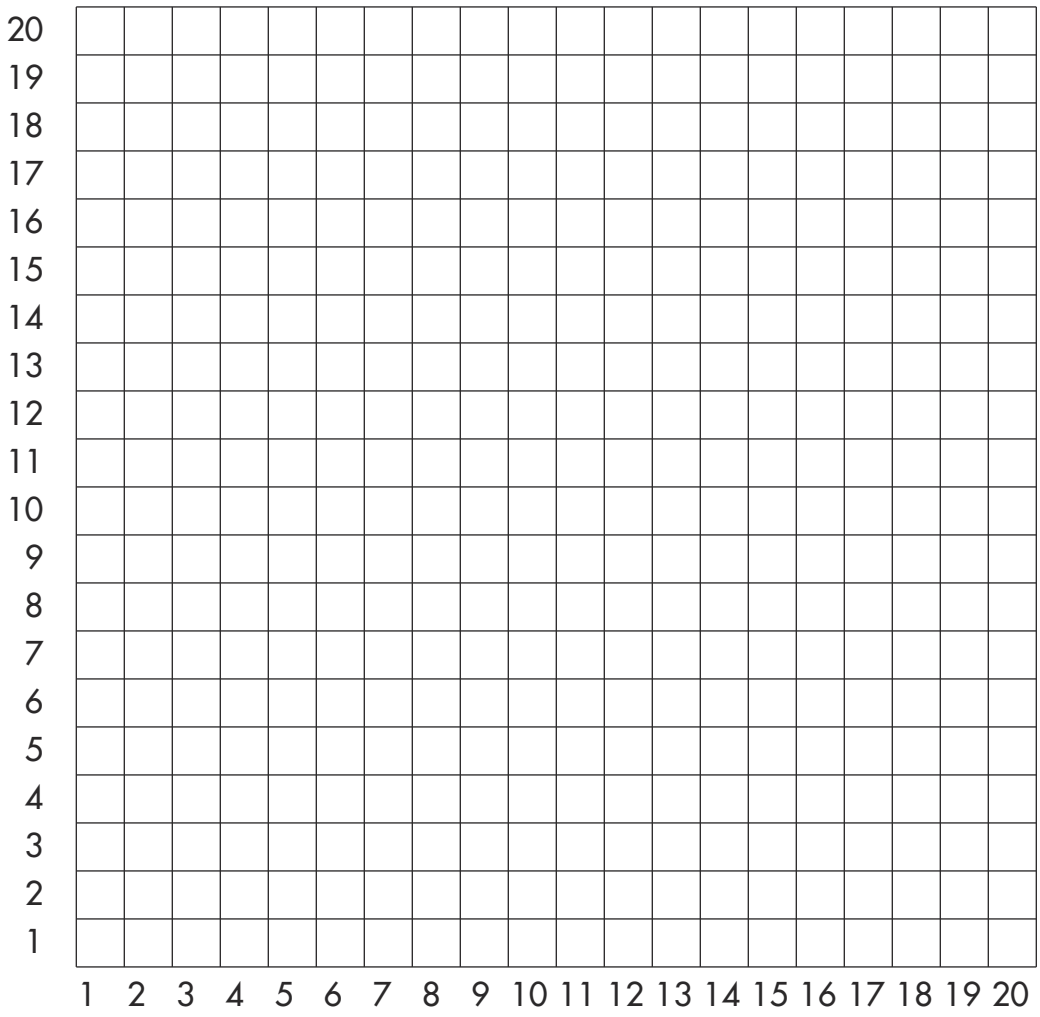
These quadrats also contain **Ectoprocta.**

These quadrats also contain **Nemertine Worms.**

Student Handout

Sampling Plan Sheet

Mark 25 quadrats to be sampled.



Student Handout

Sampling Plan Data Sheet

The columns are labeled with the first letter of each word; if there is one word, the first three letters are used except for POL (polychaetes) and PLP (polyplacophorans)

Quadrat	SD	SIP	SU	ASC	BIV	TUN	BS	SA	SNA	ISO	PLP	PLC	AMP	CUM	ECT	NEM	BR	SC	PR	Total

Section 9

Exploring Potential Human Impacts

Environmental Change

The history of the Earth is a story of change. The Earth and the living things that inhabit it are dynamic systems. Ecologists and geologists alike now recognize that change is a constant process. Sometimes change occurs on a time scale that makes it hard to recognize, taking place over millions of years. We also know that geologic changes may be instantaneous—the eruption of a volcano—or take place over a few thousand years like the end of the last Ice Age that changed our landscape and sea shores dramatically. Human induced change can also be relatively rapid and easily observable to humans. Urbanization, deforestation, desertification, introduction of alien species—all are examples of relatively rapid change caused by human actions. Hardest to study is change that involves both human and natural possible causes like global climate change. We can measure the inexorable increase in the greenhouse gas, carbon dioxide, in the atmosphere due largely to our dependence on fossil fuels, but cannot predict with absolute accuracy what its consequences will be. A meltdown of a major gas hydrate field could release massive amounts of the greenhouse gas, methane. The trigger could be natural or human induced. The impact might be immediate.

NOAA's Ocean Exploration Expeditions

This section focuses on those things over which humans have some control. NOAA's Ocean Exploration program includes both searches for new ocean resources and examination of the impact of past uses. Expeditions to several sites with deepwater corals looked at the results

of trawl fishing. Work on the Hudson Canyon explored possible consequences of years of ocean sewage sludge dumping on the shelf. Trips to the Gulf of Mexico and in the South Atlantic Bight included exploring areas of methane hydrate deposits. The term exploration implies looking forward to new discoveries, but Ocean Exploration also seeks information on ecological changes—both human induced and natural—to explain the past on many expeditions.

Classroom Activities about Environmental Change in this Section

Several expeditions have a bioprospecting component —searching for new and unique biological compounds that may be of value in medicine or industry. The need to preserve unique species while looking for potential useful products is clearly demonstrated in the Ocean Exploration expeditions. *Seals, Corals and Dollars…* examines these issues as well as the management of endangered marine animals dependent on the deepwater coral communities.

Polar Bear Panic! uses long term data sets to ask questions about changes in the extent and thickness of Arctic ice. These are real data taken from published papers. Students practice graphing skills as well as data analysis. While no one is positive about the causes of observed changes, they may well have serious implications for polar bears that hunt and travel on the ice. This activity integrates the biology of a single species with climate change data.

Additional Activities on the OE Web Site or CD

Four additional potential human impact OE exercises found on the OE website or the OE CD are:

- *Down in the Dumps* focuses on ocean dumping from 2001 Deep East.
- *Is there Sewage in My Sample* from the 2002 Hudson Canyon Cruise.
- *Feeling Crabby?* looks at fisheries management from Exploring Alaska's Seamounts 2002.
- *The Puzzle of the Ice Age Americans* examines natu-

ral global climate change as the key to human occupation of the New World due to sea level changes from Submarine Ring of Fire 2002.

Lesson Plan 25

Seals, Corals and Dollars...

Focus
Ecological relationships and resource management of Hawaiian monk seals and precious corals

Focus Question
Do additional actions need to be taken to manage monk seals and precious coral resources in the Northwestern Hawaiian Islands?

Learning Objectives
Students will describe the ecological relationships between Hawaiian monk seals and deep-water precious corals.

Students will explain at least two different viewpoints on how monk seals and precious coral resources might be managed in the Northwestern Hawaiian Islands.

Students will list at least four reasons that Hawaiian monk seals are endangered.

Students will propose a management strategy for monk seals and precious coral resources and explain their rationale for selecting this strategy.

Materials
❒ Internet access or copies of pages from web sites listed in the Learning Procedure

Audio/visual Materials
None

Teaching Time
One 45-minute class period plus time for research and report preparation which may be done as homework

Seating Arrangement
Classroom-style or groups of four students

Key Words
Hawaiian monk seal
Precious coral
Endemic
Indigenous
Alien species
Endangered
Sustainable harvest

Background Information
Deepwater corals and the communities associated with them are the subject of several NOAA Ocean Explorations, including the Northwestern Hawaiian Islands expedition to the chain of small islands and atolls that stretches for more than 1,000 nautical miles (nm) northwest of the main Hawaiian Islands. While scientists have studied shallow portions of the area for many years using SCUBA, little is known about deeper habitats. A few explorations with deep-diving submersibles and remotely-operated vehicles (ROVs) have discovered new species as well as species previously unreported in Hawaiian waters. The possibility of discovering new species has commercial importance as well as scientific interest. Black corals and other precious corals have been harvested under Hawaiian government regulation for local artists who produce jewelry for sale to tourists. The concept is to provide expensive

handcrafted tourist items while supporting local artists. Additionally deepwater corals may be a source of biological products of use to medicine or industry. Bioprospecting for new compounds is a focus of many Ocean Exploration expeditions. See the Individual Species in the Deep Sea section for a discussion.

The Northwestern Hawaiian Islands are home to Hawaiian monk seals—one of two remaining monk seal species. The Caribbean monk seal was declared extinct in 1994. The Northwestern Islands may be an important seal feeding area. Seals appear to feed on fish that live among deep-water coral communities. These corals are also of interest—some because they are commercially valuable for jewelry and others for the unique natural product chemicals they produce. The 2002 Ocean Exploration Expedition to the Northwestern Hawaiian Islands studied the ecological relationships between monk seals and the deep-sea environments of the Northwestern Islands, as well as mapping the previously unexplored deep-sea regions around the islands, investigations of deepwater fishes, and exploration of deepwater habitats.

This activity focuses on management issues posed by an endangered species—the Hawaiian monk seal—that depends to an unknown extent upon deep-water habitats that have commercial value and are being considered for exploitation.

Learning Procedure

1. Introduce the location of the Northwestern Hawaiian Islands and point out some of the features that make this area important.

2. Challenge the student groups to prepare a report based on one of the following web pages containing information about monk seals and/or precious corals. Be sure students note the date their pages were posted!:
   a. http://leahi.kcc.hawaii.edu/~et/wlcurric/seals.html
   b. www.oar.noaa.gov/spotlite/archive/spot_corals.html
   c. www.soest.hawaii.edu/HURL/precious_corals.html
   d. www.planet-hawaii.com/environment/199wtch.htm
   e. http://www.greenhawaii.org/kelly/articles/2001/ Gold.html
   f. http://swfsc.nmfs.noaa.gov/western_pacific_ fishery_ manageme.htm

   Sites (c) and (f) are quite short, but contain links to other sites with more in-depth information.

3. Have each group present its report in the order given above. Lead a discussion of these reports, including the following:
   a. What is the distinction between endemic, indigenous, and alien species?
   b. What are the feeding and habitat preferences of Hawaiian monk seals?
   c. Why are Hawaiian monk seals endangered?
   d. Why are precious corals important? Students should identify commercial importance as well as the role of these corals in natural ecosystems.
   e. What groups have expressed views about the need to manage precious corals, and how do these views differ? Do any of them have a vested interest—that is, they are going to make money on them? Students should distinguish between management objectives directed toward a sustainable harvest of precious corals and bioprospecting and objectives directed toward maintaining the corals as a key habitat element for an endangered species.
   f. What options should be considered in developing management plans for monk seals and precious corals in the Northwestern Hawaiian Islands? Students should recognize that the interests of commercial exploitation and conservation are in potential conflict and that options range from "Do nothing" to "Ban all human interaction with these species." Resource managers generally try to balance desired uses; however, the monk seals are protected by the U.S. Endangered Species Act as well as the Marine Mammal Protection

Act that limit management options.

g. What formal management measures have been taken to address concerns about monk seals and precious corals? Do students believe these measures are sufficient?

The BRIDGE Connection

www.vims.edu/bridge/pacific.html

The "Me" Connection

Have students write a short essay on why endangered species should or should not be protected, and how this might be of personal importance to their own lives.

Ask if any students have traveled in Hawaii and seen monk seals. They are relatively common at the U.S. Fish and Wildlife Service refuge on the north shore of Kawai where they can be viewed through binoculars.

Connection To Other Subjects

English/Language Arts, Social Studies

Evaluation

Develop a grading rubric that includes performance on the group research and report (Step #2) and participation in the overall discussion (Step #3). Alternatively, following the oral reports in Step #3, you may want to have students prepare individual written responses to the questions prior to discussing these questions with the entire class.

Extensions

Visit http://www.radiojerry.com/frigate/ for an "up close and personal" account of life on French Frigate Shoals and encounters with monk seals.

Resources

http://oceanexplorer.noaa.gov – NOAA's Ocean Exploration web site

http://leahi.kcc.hawaii.edu/~et/wlcurric/seals.html – Background information on monk seals

www.oar.noaa.gov/spotlite/archive/spot_corals.html – Article on precious corals

www.soest.hawaii.edu/HURL/precious_corals.html – Article on managing precious corals and monk seals

www.planet-hawaii.com/environment/199wtch.htm – Article on ecological relationship between monk seals and precious corals

http://www.greenhawaii.org/kelly/articles/2001/Gold.html – Article on the "new Hawaiian gold rush"

http://swfsc.nmfs.noaa.gov/western_pacific_fishery_manageme.htm – Press release on management measures adopted by the Western Pacific Fishery Management Council

http://www.radiojerry.com/frigate – Personal account of life on French Frigate Shoals and another perspective on the impact of human activities on local marine life

National Science Education Standards

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard C: Life Science

- Interdependence of organisms

Content Standard F: Science in Personal and Social Perspectives

- Natural resources

Activity developed by Mel Goodwin, PhD, The Harmony Project, Charleston, SC

Lesson Plan 26

Polar Bear Panic!

Focus
Climate change in the Arctic Ocean

Focus Question
What is the potential impact of observed reduction in sea ice in the Arctic Ocean?

Learning Objectives
Students will graphically analyze data on sea ice cover in the Arctic Ocean and recognize a trend in these data.

Students will discuss possible causes for observed trends in Arctic sea ice distribution and infer the potential impact of these trends on biological communities in the Arctic Ocean.

Materials
- ❒ One *Polar Ice Data Sheet* per group
- ❒ Graph paper

Audio/visual Materials
None

Teaching Time
Two 45-minute class periods

Seating Arrangement
Groups of 4

Key Words
Pelagic
Benthic
Sympagic

Background Information
The Arctic Ocean is the smallest of the world's four ocean basins with a total area of about 5.4 million square miles or 14 million square kilometers or roughly 1.5 times the size of the United States. The Arctic Ocean is not explored easily. It is almost covered with ice for eight months of the year, a drifting polar ice pack covers the central and western portions year-round, and sea temperature seldom rises above 0°C.

The Arctic Ocean is bordered by Greenland, Canada, Alaska, Norway, and Russia. The Arctic Ocean has the widest continental shelf of any ocean, extending 750 mi (1,210 km) from the Siberian coast, but also has areas that are quite deep. The average depth is 12,000 ft (3,658 m), and the maximum depth is 17,850 ft (5,441 m). The Chukchi Sea provides a connection with the Pacific Ocean via the Bering Strait, but this connection is very narrow and shallow, so most water exchange is with the Atlantic Ocean via the Greenland Sea. The Arctic Ocean floor is divided by three submarine ridges (Alpha Ridge, Lomonosov Ridge, and the Arctic Mid-Oceanic Ridge), one of which (the Lomonosov Ridge) creates a relatively isolated area known as the Canadian Basin. This area is particularly interesting because its isolation may have resulted in selection for unique life forms. The 2002 Arctic Ocean Exploration expedition studied this isolated area, giving us greater knowledge of the mysteries of this polar frontier.

There are at least three distinct biological communities in the Arctic Ocean. The Sea-Ice Realm includes plants and animals that live on, in, and just under

the ice. Because only 50% of this ice melts in each summer, ice flows exist for many years, reaching a thickness of more than six ft. (2 m). Sea ice is riddled with a network of tunnels, called brine channels, ranging in size from microscopic to more than an inch in diameter. Diatoms and algae live in them, using energy from sunlight for photosynthesis. Bacteria and fungi also inhabit the channels. Together with diatoms and algae, they provide food for flatworms, crustaceans, and other tunnel dwellers. This community is called sympagic, meaning ice-associated. Partial sea ice melting during summer produces ponds on the ice surface that develop their own communities of organisms.

Melting ice releases organisms and nutrients to the ocean below the ice. The ocean's Pelagic Realm includes organisms that live in the water column between the ocean's surface and bottom. Melting ice also increases light entering the sea, allowing rapid algal growth 24 hours a day during the summer. These algae provide energy for zooplankton, drifting animals such as crustaceans and jellyfishes. Zooplankton are food for larger pelagic animals, including fish, squid, seals and whales. Polar bears live on the Sea-Ice Realm, but feed in the Pelagic Realm. They have to have ice on which to move out over the ocean to holes where they feed.

When pelagic organisms die, they settle to the ocean bottom as detritus, becoming food for Benthic Realm invertebrates. Sponges, bivalves, crustaceans, polychaete worms, sea anemones, bryozoans, tunicates, and ascidians are common in Arctic benthic communities. These animals provide energy for bottom-feeding fish, whales, and seals.

Most of our knowledge about Arctic Ocean biological communities comes from studies near the continental shelves. Very little research has been done on the sea ice, pelagic, and benthic realms in deeper water. These areas were the focus of the 2002 Arctic Ocean Expedition. Some scientists believe there is a particular urgency to understanding the Arctic Ocean: the polar ice is shrinking, and no one is sure why. One explanation is that this is part of short-term climate cycles like El Niño that bring warm air and Atlantic Ocean water into the region. Other scientists think increased greenhouse gases in the atmosphere may be causing long-term changes to the Arctic climate that will affect many species, including the polar bears that hunt on the sea ice.

Learning Procedure

In this activity, students analyze data from several sources to look for trends of change in the extent and thickness of Arctic Ocean sea ice. They then are asked to infer what these trends might mean for the Ocean's biological communities.

1. Review the Background Information on the Arctic Ocean and its three known biological realms with your students. Emphasize that the three realms are coupled, and that photosynthesis by microscopic algae, phytoplankton, provides food and energy for other organisms. Have the students prepare a diagram showing the groups of organisms you discuss, and how these groups are linked spatially and in the food chain

2. Distribute *Polar Ice Data Sheets* to each group. Assign one data set to each group. The students should average the numbers in the data set assigned to them. Then they should identify the range—the lowest and the highest numbers. They should plot each year on a graph that has the average as the location of the x-axis. The x-axis will be divided into years. The y-axis extends above and below the average just far enough to include the highest and lowest numbers with a scale that is expanded sufficiently for the students to read it easily. For example, the x-axis on the Northern Sea Ice table would range from 1970 to 1998 and the y-axis would range from a low of about 11.50 to a high of about 13 m sq km. Plotted points will fall around the average.

3. Have each group describe its graph. Copying each groups graph on overhead transparencies

would facilitate discussion and allow different data sets to be compared if the yearly scale is identical for each group. Lead a discussion of the significance of these data. Students should recognize that data from three different sources show a similar trend of declining extent of Arctic sea ice. The fourth source shows that the ice is getting thinner as well. Students should refer to their diagrams of interactions between species and infer what would happen if the Arctic sea ice were to continue to shrink. While it is likely that some species, particularly those that live on the surface of the ice, would be adversely affected and might even disappear, other species might become more abundant. Be sure students realize that the cause of these trends could be natural climate cycles or human-induced greenhouse gas changes, or a combination of both.

For polar bears, loss of ice would be a disaster as they could no longer walk out onto the ice to hunt for seals.

Ask the students what they think should be done; is this a situation that requires urgent action, or should we wait for scientists to do more research into the cause? Are there things that could or should be done regardless of the cause? Is this really a problem, and whose problem is it, anyway? You may wish to have students read "Arctic Life, On Thin Ice" (*Science* 291:424-425, January 19, 2001) as the basis for a more in-depth discussion.

The BRIDGE Connection

www.vims.edu/bridge/polar.html
www.vims.edu/bridge/endangered.html

The "Me" Connection

Have students write an essay on why polar bears are important or are not important to them as individuals.

Connections to Other Subjects

English/Language Arts, Mathematics, Earth Science

Evaluation

Individual graphs prepared by each student group may be collected to assess the thoroughness of their work. Additionally, students may prepare individual written interpretations of the pooled results before participating in a group discussion.

Extensions

Have students visit http://oceanexplorer.noaa.gov for the 2002 exploration of the deep Arctic Ocean, and to find out what organisms live in the three realms.

Have students research the greenhouse effect and global climate change. They may do written or oral reports on the causes, potential impacts, and possible solutions.

Have students do a web search for information on changes in distribution of polar ice in the southern hemisphere. There have been some major changes recently.

Have students research information on polar bears and their biology with emphasis on their time out on the ice. Also consider the difficulty in managing a species that ranges through several countries at the top of the world during their lives.

Resources

http://oceanexplorer.noaa.gov – The 2002 Arctic Ocean Expedition documentaries and discoveries.

http://www.sciencegems.com/earth2.html – Science education resources

http://www-sci.lib.uci.edu/HSG/Ref.html – References on just about everything, including sources for information on invertebrate feeding habits

Vinnikov, K. Y., A. Roboc k, R. J. Stouffer, J. E. Walsh, C. L. Parkinson, D. J. Cavalieri, J. F. B. Mitchell, D. Garrett and V. F. Zakharov, 1999. Global warming and northern hemisphere sea ice extent. *Science* 286:1934-1937 – Scientific journal article on which this activity is based.

Johannessen, L. M., E. V. Shalina, and M. W. Miles. 1999. Satellite evidence for an Arctic sea ice cover in transformation. *Science* 286:1937-1939 – Scientific journal article on which this activity is Based.

Krajick, K. 2001. Arctic life, on thin ice. *Science* 291:424-425. News magazine-style report on the effects of warming in the Arctic.

National Science Education Standards

Content Standard A: Science As Inquiry

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

Content Standard C: Life Science

- Population and ecosystems

Content Standard F: Science in Personal and Social Perspectives

- Populations, resources, and environments

Activity developed by Mel Goodwin, Ph.D., The Harmony Project, Charleston, SC

Student Handout

Polar Bear Ice Data

	Polar Ice Data Sheet #1 Northern Hemisphere Sea Ice (Source: Vinnikov et al., 1999)	Polar Ice Data Sheet #2 Northern Hemisphere Sea Ice (Source: Vinnikov et al., 1999)	Polar Ice Data Sheet #3 Arctic Ocean Multi-Year Sea Ice (Source: Johannessen et al., 1999)
Year	**Sea Ice Extent (million km²)**	**Sea Ice Extent (million km²)**	**Sea Ice Extent (million km²)**
1970	12.85	NA	NA
1971	12.76	NA	NA
1972	12.84	NA	NA
1973	12.41	NA	NA
1974	12.36	NA	NA
1975	12.10	NA	NA
1976	12.61	NA	NA
1977	12.41	NA	NA
1978	12.58	NA	NA
1979	12.37	12.15	4.4
1980	12.42	12.16	4.3
1981	12.24	11.99	4.25
1982	12.62	12.28	3.95
1983	12.48	12.19	4.1
1984	12.19	11.79	4.3
1985	12.28	11.81	4.05
1986	12.27	12.06	4.1
1987	12.54	12.08	4.15
1988	12.59	12.06	4.95
1989	12.37	11.85	4.2
1990	11.72	11.56	4.2
1991	11.85	11.63	3.5
1992	12.27	12.00	3.6
1993	12.08	11.80	3.85
1994	12.15	11.86	3.65
1995	11.62	11.36	3.75
1996	11.95	11.36	3.2
1997	11.89	11.39	4.55
1998	11.91	NA	3.9