2006 Exploring Ancient Coral Gardens

History's Thermometers

(adapted from The Exploring Alaska's Seamounts 2002 Expedition)

Focus
Paleoclimatological proxies

Grade Level
9-12 (Physics)

Focus Question
How can deep-water corals be used to determine long-term patterns of climate change?

Learning Objectives
Students will be able to explain the concept of paleoclimatological proxies.

Students will learn how oxygen isotope ratios are related to water temperature.

Students will be able to interpret data on oxygen isotope ratios to make inferences about climate and climate change in the geologic past.

Materials
❐ Copies of "Oxygen Isotope Ratios in Deep-water Coral Samples," enough for each student or student group

Audio/Visual Materials
None

Teaching Time
One 45-minute class period

Seating Arrangement
Classroom style, or groups of two or three students

Maximum Number of Students
32

Key Words
Paleoclimatological proxy
Isotope
$\delta^{18}O$
Deep-water coral

Background Information
Seamounts are undersea mountains formed by volcanic processes, either as isolated peaks or as chains that may be thousands of miles long with 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 many species of plant, animal, and microbial organisms. Recently, increasing attention is being directed toward deep water coral species found on seamounts. In contrast to shallow-water coral reefs, deep-sea coral communities are virtually unknown to the general public and have received much less scientific study. Yet, deep-water coral ecosystems may have a diversity of species comparable to that of corals reefs in shallow waters. Because many seamount species are endemic (that is, they are found nowhere else), these ecosystems may be a unique feature of seamounts, and are likely to be important for several reasons. First, because of their high biological productivity, these communities are directly associated with important commercial fisheries. Moreover, deep-sea corals have been identified as promising sources for new drugs to treat cancer and other diseases, as well as natu-

ral pesticides and nutritional substances. Recent discoveries suggesting that some corals may be hundreds of years old means that these organisms can provide important records of past climactic conditions in the deep ocean. Apart from these potential benefits, deep-sea corals are part of our world heritage—the environment we hand down from one generation to the next.

Despite their importance, there is growing concern about the impact of human activities on these ecosystems. Commercial fisheries, particularly fisheries that use trawling gear, cause severe damage to seamount habitats. Scientists at the First International Symposium on Deep Sea Corals (August, 2000), warned that more than half of the world's deep-sea coral reefs have been destroyed. Ironically, some scientists believe that destruction of deep-sea corals by bottom trawlers is responsible for the decline of major fisheries such as cod.

In addition to impacts from fisheries, deep-sea coral communities can also be damaged by oil and mineral exploration, ocean dumping, and unregulated collecting. Other impacts may result from efforts to mitigate increasing levels of atmospheric carbon dioxide. One proposed mitigation is to sequester large quantities of the gas in the deep ocean, either by injecting liquid carbon dioxide into deep ocean areas where it would form a stable layer on the sea floor or by dropping torpedo-shaped blocks of solid carbon dioxide through the water column to eventually penetrate deep into benthic sediments. While the actual impacts are not known, some scientists speculate that since coral skeletons are made of calcium carbonate, their growth would probably decrease if more carbon dioxide were dissolved in the ocean.

The Davidson Seamount, located about 75 miles southwest of Monterey, CA, was the first geological feature to be described as a "seamount" in 1933. The now-extinct volcanoes that formed this and other nearby seamounts were different from typical ocean volcanoes. While the typical undersea volcano is steep-sided, with a flat top and a crater, seamounts in the Davidson vicinity are formed of parallel ridges topped by a series of knobs. These observations suggest that the ridges were formed by many small eruptions that occurred 3 to 5 million years apart. Typical undersea volcanoes are formed by more violent eruptions that gush out lava more frequently over several hundred thousand years.

Although it was the first recognized seamount and is relatively near the U.S. coast, the Davidson Seamount is still 99.98% unexplored. In 2002, a NOAA-funded expedition to the Seamount found a wide variety of organisms, including extensive deep-water coral communities. Among many intriguing discoveries were observations of animals that had never been seen live before, as well as indications that some coral species may be several hundred years old (visit http://oceanexplorer.noaa.gov/explorations/02davidson/davidson.html and http://montereybay.noaa.gov/reports/2002/eco/ocean.html for more information about the 2002 Expedition).

The 2006 Exploring Ancient Coral Gardens Expedition is focussed on learning more about deep-sea corals at Davidson Seamount, with four general goals:

- to understand why deep-sea corals live where they do on the seamount;
- to determine the age and growth patterns of the bamboo coral;
- to improve the species list and taxonomy of corals from the seamount; and
- to share the exciting experience with the public through television and the Internet.

Deep-sea corals build their skeletons from calcium and carbonate ions which they extract from sea water. Oxygen and oxygen isotopes contained in the carbonate ions, as well as trace metals that are also incorporated into the corals' skeleton, can be used to determine the temperature of the water when the skeleton was formed. Because some corals on the Davidson Seamount live for several centuries, their skeletons contain a natural record of climate variability. Natural recorders are known as proxies, and include tree rings, fossil pollen, and ice cores in addition to corals.

When studying temperature records in proxies, we are usually interested in the ratio of the rare oxygen isotope, ^{18}O, to the common oxygen isotope, ^{16}O. Because the absolute abundance of an isotope is difficult to measure with sufficient accuracy, the isotope ratios in a sample are compared with those in a standard, and the results are expressed as delta values, abbreviated $\delta(x)$ which is found by subtracting the isotopic ratio of the standard from the isotopic ratio of the sample, dividing the result by the ratio of the standard, and multiplying the 1,000 to give a result in parts-per-thousand (‰; also called "parts-per-mille"). Scientists have found that the ratio of oxygen isotopes in carbonate samples is inversely related to the water temperature at which the carbonates were formed, so high ratios of ^{18}O mean lower temperatures. In the simplest case, a temperature change of 4°C corresponds to a $\delta^{18}O$ of about 1‰.

Ocean temperature changes are known to have significant effects on climate and weather (e.g., El Niño), but these relationships are not generally well-understood. One of the first steps to improving our understanding of these interactions is to document variations that have occurred in the past. Comparing climatic conditions at different times in the past gives important information about rates of climate change. One of the major concerns associated with the prospect of climate change is that this climate change may be happening much more quickly than has been the case in the Earth's past. If this proves to be true, many organisms and living systems may have difficulty adapting to an unusually rapid rate of change.

Learning Procedure

1. To prepare for this lesson, read the introductory essays for the 2006 Exploring Ancient Coral Gardens Expedition at http://oceanexplorer.noaa.gov/explorations/06davidson/welcome.html, and review the NOAA Learning Object on deep-sea coral reefs at http://www.learningdemo.com/noaa/.

2. Lead a brief introductory discussion of the Davidson Seamount and the 2002 and 2006 Ocean Exploration expeditions to the area. You may want to show students some images from the 2002 Expedition Web site (http://oceanexplorer.noaa.gov/explorations/02davidson/davidson.html). Discuss the deep-sea corals that are relatively common on seamounts, and be sure that students realize that these animals produce skeletons from calcium carbonate, and continue to grow and add to these skeletons throughout their lives. Explain the concept of climatological proxies, perhaps drawing an analogy to tree rings. Be certain that students understand the concept of isotopes, and explain that the ratio of oxygen isotopes varies with temperature. When oxygen, in both of its isotopic forms, is precipitated in the coral skeleton as calcium carbonate, a record is formed of the temperature at the time of precipitation. Be sure students understand that a temperature change of 4°C corresponds to a $\delta^{18}O$ of about 1‰.

2. Distribute copies of "Oxygen Isotope Ratios in Deep-water Coral Samples." Have students or student groups plot these ratios as a function of age ($\delta^{18}O$ on the y-axis). Ask students to explain their results. They should recognize that corals 1, 3, and 4 grew during a period in which water temperatures were relatively low (as would be the case during periods of glaciation), while corals 2 and 6 grew in warmer conditions. Coral 5 exhibits significantly different $\delta^{18}O$ in different portions of its skeleton. Have the students examine the data further to determine that the difference in $\delta^{18}O$ between two samples only 3 mm apart on the coral

skeleton indicates that this coral experienced a rapid cooling of about 6°C in the space of less than 5 years. Discuss how this might have happened. Evidence for such an event has been reported, and has been interpreted to be linked to a rapid climate shift, the Younger Dryas cooling event which took place 13,000 to 11,700 years ago. Discuss the significance of rapid versus gradual changes to biological communities.

The Bridge Connection

www.vims.edu/bridge/ – In the "Site Navigation" menu on the left, click on "Ocean Science Topics," then "Atmosphere," then "Global Climate Change" in the menu bar at the top of the page for links to resources about climate change.

The "Me" Connection

Have students write a paragraph on how global climate change would affect their personal lives.

Connections to Other Subjects

English/Language Arts, Chemistry, Mathematics, Biology

Assessment

If individual assessments are desired, have students write their interpretations of the data prior to the group discussion.

Extensions

1. Log on to http://oceanexplorer.noaa.gov to keep up to date with the latest Davidson Seamount Expedition discoveries, and to find out what researchers are learning about deep-water hard-bottom communities.

2. Visit NOAA's Climate Timeline and Paleoclimatology Web sites (http://www.ngdc.noaa.gov/paleo/ctl/index.html and http://www.ncdc.noaa.gov/paleo/primer.html) for more information more information and activities related to paleoclimatology.

Resources

NOAA Learning Objects

http://www.learningdemo.com/noaa/ – Click on the link to "Lesson 3 – Deep-Sea Corals" for an interactive multimedia presentation on deep-sea corals, as well as Learning Activities and additional information on global impacts and deep-sea coral communities.

Other Relevant Lesson Plans from the Ocean Exploration Program

Cool Corals (http://oceanexplorer.noaa.gov/explorations/03edge/background/edu/media/cool.pdf; (7 pages, 476k)

Focus: Biology and ecology of Lophelia corals (Life Science)

Students will describe the basic morphology of *Lophelia* corals and explain the significance of these organisms, interpret preliminary observations on the behavior of *Lophelia* polyps, and infer possible explanations for these observations. Students will also discuss why biological communities associated with *Lophelia* corals are the focus of major worldwide conservation efforts.

What's the Difference? (http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_difference.pdf; (15 pages, 1Mb) (from the Mountains in the Sea 2003 Expedition)

Focus: Identification of biological communities from survey data (Life Science)

Students will be able to calculate a simple similarity coefficient based upon data from biological surveys of different areas, describe similarities between groups of organisms using a dendrogram, and infer conditions that may influence biological communities given information about the groupings of organisms that are found in these communities.

Round and Round (http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_round.pdf; (11 pages, 1Mb) (from the Mountains in the Sea 2003 Expedition)

Focus: Circulation cells in the vicinity of seamounts (Earth Science)

Students will be able to interpret data from a three-dimensional array of current monitors to infer an overall pattern of water circulation, hypothesize what effect an observed water circulation pattern might have on seamount fauna that reproduce by means of floating larvae, and describe the importance of measurements to verify theoretical predictions.

A Tough Neighborhood (http://oceanexplorer.noaa.gov/explorations/03bump/background/edu/media/03cb_toughhood.pdf; (4 pages, 244k) (from The Charleston Bump 2003 Expedition)

Focus: Adaptations of benthic organisms to deep water, hard substrates, and strong currents (Life Science)

Students will be able to describe at least three attributes of the deep ocean physical environment that are radically different from ocean habitats near the sea surface and explain at least three morphological or physiological adaptations that allow organisms to survive in the physical environment of the deep ocean. Students will also be able to identify at least three organisms with adaptations to the deep ocean environment that are found (or may be found) on the Charleston Bump.

Keep It Complex! (http://oceanexplorer.noaa.gov/explorations/03bump/background/edu/media/03cb_complex.pdf; (5 pages, 272k) (from The Charleston Bump 2003 Expedition)

Focus: Effects of habitat complexity on biological diversity (Life Science)

Students will be able to describe the significance of complexity in benthic habitats to organisms that live in these habitats and will describe at least three attributes of benthic habitats that can increase the physical complexity of these habitats. Students will also be able to give examples of organisms that increase the structural complexity of their communities and infer and explain relationships between species diversity and habitat complexity in benthic communities.

Eddies, Gyres, and Drowning Machines (http://oceanexplorer.noaa.gov/explorations/03bump/background/edu/media/03cb_eddies.pdf; (5 pages, 256k) (from The Charleston Bump 2003 Expedition)

Focus: Effects of bottom topography on currents (Physical Science/Earth Science)

Students will be able to describe at least three types of effects that physical obstructions may have on water flowing past the obstructions, explain at least three ways in which current flow can be significant to benthic organisms, and explain how physical obstructions to current flow can create hazardous swimming conditions.

Top to Bottom (http://oceanexplorer.noaa.gov/explorations/05stepstones/background/education/ss_2005_topbottom.pdf; (7 pages, 348k) (from the North Atlantic Stepping Stones 2005 Expedition)

Focus (Earth Science/Life Science) - Impacts of climate change on biological communities of the deep ocean

Students will be able to describe thermohaline circulation, explain how climate change might affect thermohaline circulation, and identify the time scale over which such effects might take place. Students will also be able to explain how warmer temperatures might affect wind-driven surface currents and how these effects might impact biological communities of the deep ocean, and discuss at least three potential impacts on biological communities that might result from carbon dioxide sequestration in the deep ocean.

Designing Tools for Ocean Exploration (http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_designingtools.pdf; (13 pages, 1Mb) (from the Mountains in the Sea 2003 Expedition)

Focus: Ocean Exploration

Students will understand the complexity of ocean exploration; students will understand the technological applications and capabilities required for ocean exploration; students will understand the importance of teamwork in scientific research projects; students will develop abilities necessary to do scientific inquiry.

Living in Extreme Environments (http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_extremeenv.pdf; (12 pages, 1Mb) (from the Mountains in the Sea 2003 Expedition)

Focus: Biological Sampling Methods (Biological Science)

Students will understand the use of four methods commonly used by scientists to sample populations; students will understand how to gather, record, and analyze data from a scientific investigation; students will begin to think about what organisms need in order to survive; students will understand the concept of interdependence of organisms.

Mystery of the Alaskan Seamounts (http://oceanexplorer.noaa.gov/explorations/02alaska/background/edu/media/mystery9_12.pdf; (9 pages, 132k) (from the Exploring Alaska's Seamounts 2002 Expedition)

Focus: Earth Science - Formation of seamounts in the Axial-Cobb-Eikelberg-Patton chain, Gulf of Alaska

Students will be able to describe the processes that form seamounts, learn how isotope ratios can be used to determine the age of volcanic rock, and interpret basalt rock age data from seamounts in the Gulf of Alaska to investigate a hypothesis for the origin of these seamounts.

Are You Related? (http://oceanexplorer.noaa.gov/explorations/05deepcorals/background/edu/media/05deepcorals_related.pdf (11 pages, 465k) (from the Florida Coast Deep Corals 2005 Expedition)

Focus: Molecular genetics of deepwater corals (Life Science)

Students will define "microsatellite markers" and explain how they may be used to identify different populations and species, explain two definitions of "species," and describe processes that result in speciation. Students will also use microsatellite data to make inferences about populations of deep sea corals.

Feeding in the Flow (http://oceanexplorer.noaa.gov/explorations/03bump/background/edu/media/03cbfeedflow.pdf; (6 pages, 268k) (from The Charleston Bump 2003 Expedition)

Focus: Effect of water currents on feeding efficiency in corals (Life Science)

Students will be able to describe at least two ways in which current flow may affect the feeding efficiency of particle-feeding organisms and explain how interactions between current flow and the morphology of a particle-feeding organism may affect the organism's feeding efficiency. Students will also be able to identify at least two environmental factors in addition to current flow that may affect the morphology of reef-building corals.

Gellin (http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_gellin.pdf} (4 pages, 372k) (from the Gulf of Mexico Deep Sea Habitats 2003 Expedition)

Focus: DNA analysis

Students will explain and carry out a simple process for separating DNA from tissue samples, explain and carry out a simple process for separating complex mixtures, and explain the process of restriction enzyme analysis.

Breaking Away (Or Not . . .) (http://oceanexplorer.noaa.gov/explorations/02alaska/background/edu/media/breaking9_12.pdf; (5 pages, 96k) (from the Exploring Alaska's Seamounts 2002 Expedition)

Focus: Life Science - Reproductive/developmental strategies of some benthic seamount species

Students will be able to compare and contrast common reproductive strategies used by benthic invertebrates, describe the most common reproductive strategies among benthic invertebrates on a seamount and explain why these strategies are appropriate to seamount conditions. Students will be able to describe how certain reproductive strategies favor survival of species on seamounts and what changes on seamounts might favor other strategies, and discuss the implications of reproductive strategy to the conservation and protection of seamount communities.

Other Links and Resources

http://www.ngdc.noaa.gov/paleo/ctl/resource.html – The Climate TimeLine's Resource section provides links to sources of information and references, including ideas for further inquiry into climate processes and their human dimension.

http://ethomas.web.wesleyan.edu/ees123/ – very readable lecture notes on isotopes in paleoclimatology

Smith, J. E., M. J. Risk, H. P. Schwarcz, and T. A. McConnaughey, 1997. Rapid climate change in the North Atlantic during the Younger Dryas recorded by deep-sea corals. Nature 386:818-820. –The research paper on which this activity is based

http://oceanexplorer.noaa.gov/explorations/02davidson/davidson.html – Daily logs, photos, video clips, and backgrounds essays on the 2002 Davidson Seamount Expedition

http://montereybay.noaa.gov/reports/2002/eco/ocean.html – Web page from the Monterey Bay National Marine Sanctuary describing the 2002 exploration of the Davidson Seamount

http://www.mbari.org/ghgases/ – Web page from the Monterey Bay Aquarium Research Institute describing MBARI's work on the Ocean Chemistry of Greenhouse Gases, including work on the potential effects of ocean sequestration of carbon dioxide

http://seamounts.edsc.edu/main.html — Seamounts website sponsored by the National Science Foundation

Pickrell, J. 2004. Trawlers Destroying Deep-Sea Reefs, Scientists Say. National Geographic News. http://news.nationalgeographic.com/news/2004/02/0219_040219_seacorals.html

http://www.mcbi.org/Current_Magazine/Current_Magazine.htm – A special issue of Current: the Journal of Marine Education on deep-sea corals.

Morgan, L. E. 2005. What are deep-sea corals? Current 21(4):2-4; available online at http://www.mcbi.org/Current_Magazine/What_are_DSC.pdf

Reed, J. K. and S. W. Ross. 2005. Deep-water reefs off the southeastern U.S.: Recent discoveries and research. Current 21(4): 33-37; available online at http://www.mcbi.org/Current_Magazine/Southeastern_US.pdf

Frame, C. and H. Gillelan. 2005. Threats to deep-sea corals and their conservation in U.S. waters. Current 21(4):46-47; available online at http://www.mcbi.org/Current_Magazine/Threats_Conservation.pdf

Roberts, S. and M. Hirshfield. Deep Sea Corals: Out of sight but no longer out of mind. http://www.oceana.org/uploads/oceana_coral_report.pdf — Background on deep-water coral reefs

http://www.oceanicresearch.org/ – The Oceanic Research Group Web site; lots of photos, but note that they are very explicit about their copyrights; check out "Cnidarians: Simple but Deadly Animals!" by Jonathan Bird, which provides an easy introduction designed for classroom use

http://oceanexplorer.noaa.gov/gallery/livingocean/livingocean_coral.html – Ocean Explorer photograph gallery

http://oceanica.cofc.edu/activities.htm – Project Oceanica Web site, with a variety of resources on ocean exploration topics

National Science Education Standards

Content Standard A: Science As Inquiry

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

Content Standard B: Physical Science

- Structure of atoms

Content Standard F: Science in Personal and Social Perspectives

- Natural and human-induced hazards

Ocean Literacy Essential Principles and Fundamental Concepts

Essential Principle 1.
The Earth has one big ocean with many features.

- *Fundamental Concept b.* An ocean basin's size, shape and features (such as islands, trenches, mid-ocean ridges, rift valleys) vary due to the movement of Earth's lithospheric plates.
- *Fundamental Concept h.* Although the ocean is large, it is finite and resources are limited.

Essential Principle 5.
The ocean supports a great diversity of life and ecosystems.

- *Fundamental Concept c.* Some major groups are found exclusively in the ocean. The diversity of major groups of organisms is much greater in the ocean than on land.
- *Fundamental Concept d.* Ocean biology provides many unique examples of life cycles, adaptations and important relationships among organisms (such as symbiosis, predator-prey dynamics and energy transfer) that do not occur on land.
- *Fundamental Concept e.* The ocean is three-dimensional, offering vast living space and diverse habitats from the surface through the water column to the seafloor. Most of the living space on Earth is in the ocean.
- *Fundamental Concept f.* Ocean habitats are defined by environmental factors. Due to interactions of abiotic factors such as salinity, temperature, oxygen, pH, light, nutrients, pressure, substrate and circulation, ocean life is not evenly distributed temporally or spatially, i.e., it is "patchy." Some regions of the ocean support more diverse and abundant life than anywhere on Earth, while much of the ocean is considered a desert.

Essential Principle 6.
The ocean and humans are inextricably interconnected.

- *Fundamental Concept b.* From the ocean we get foods, medicines, and mineral and energy resources. In addition, it provides jobs, supports our nation's economy, serves as a highway for transportation of goods and people, and plays a role in national security.
- *Fundamental Concept c.* The ocean is a source of inspiration, recreation, rejuvenation and discovery. It is also an important element in the heritage of many cultures.
- *Fundamental Concept e.* Humans affect the ocean in a variety of ways. Laws, regulations and resource management affect what is taken out and put into the ocean. Human development and activity leads to pollution (such as point source, non-point source, and noise pollution) and physical modifications (such as changes to beaches, shores and rivers). In addition, humans have removed most of the large vertebrates from the ocean.
- *Fundamental Concept g.* Everyone is responsible for caring for the ocean. The ocean sustains life on Earth and humans must live in ways that sustain the ocean. Individual and collective actions are needed to effectively manage ocean resources for all.

Essential Principle 7.
The ocean is largely unexplored.

- *Fundamental Concept a.* The ocean is the last and largest unexplored place on Earth—less than 5% of it has been explored. This is the great frontier for the next generation's explorers and researchers, where they will find great opportunities for inquiry and investigation.
- *Fundamental Concept b.* Understanding the ocean is more than a matter of curiosity. Exploration, inquiry and study are required to better understand ocean systems and processes.
- *Fundamental Concept c.* Over the last 40 years, use of ocean resources has increased significantly, therefore the future sustainability of ocean resources depends on our understanding of those resources and their potential and limitations.
- *Fundamental Concept d.* New technologies, sensors and tools are expanding our ability to explore the ocean. Ocean scientists are relying more and more on satellites, drifters, buoys, subsea observatories and unmanned submersibles.
- *Fundamental Concept f.* Ocean exploration is truly interdisciplinary. It requires close collaboration among biologists, chemists, climatologists, computer programmers, engineers, geologists, meteorologists, and physicists, and new ways of thinking.

For More Information

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Student Handout

Oxygen Isotope Ratios in Deep-water Coral Samples

Coral Specimen	$\delta^{18}O$ (‰)	Age (years)
#1, base of coral	3.8	15,140
#1, 50 mm from base	3.9	
#1, 200 mm from base	4.5	
#1, 400 mm from base	4.1	15,550
#2, base of coral	0.8	3,100
#2, 70 mm from base	0.9	
#2, 220 mm from base	1.1	
#2, 450 mm from base	1.0	3,410
#3, base of coral	4.1	15,400
#3, 100 mm from base`	4.3	
#3, 200 mm from base	3.9	
#3, 300 mm from base	4.1	15,695
#4, base of coral	4.5	14,445
#4, 75 mm from base	4.1	
#4, 150 mm from base	3.9	
#4, 300 mm from base	4.0	14,800
#5, base of coral	1.7	13,300
#5, 80 mm from base	1.8	
#5, 85 mm from b ase	3.3	
#5, 100 mm from base	3.6	13,400
#6, base of coral	1.3	6,400
#6, 100 mm from base	1.5	
#6, 155 mm from base	1.6	
#6, 400 mm from base	1.4	6,675