2006 Exploring Ancient Coral Gardens

Climate, Corals and Change

(adapted from the North Atlantic Stepping Stones 2005 Expedition)

Focus
Paleoclimatology

Grade Level
7-8 (Physical Science)

Focus Question
How can scientists obtain clues about past climatic conditions from samples of living organisms or fossils?

Learning Objectives
Students will be able to explain the concept of "paleoclimatological proxies" and describe at least two examples.

Students will be able to describe how oxygen isotope ratios are related to water temperature.

Students will be able to interpret data on oxygen isotope ratios to make inferences about the growth rate of deep-sea corals.

Students will be able to define "forcing factor" and will be able to describe at least three forcing factors for climate change.

Students will be able to discuss at least three potential consequences of a warmer world climate.

Materials
- ❒ Copies of "Oxygen Isotope Ratios in Coral Samples, 1751 – 1995;" one copy for each student

Audio/Visual Materials
- ❒ (Optional) Equipment for viewing downloaded images of the Davidson Seamount

Teaching Time
One or two 45-minute class periods

Seating Arrangement
Classroom style

Maximum Number of Students
30

Key Words
Seamount
Biogeography
Climate change
Forcing factor
Paleoclimatological proxy
Isotope
$\delta^{18}O$

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 natural 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.

Using information about coral growth rates to obtain clues about climate history is an example of "paleoclimatological proxies," which are the remains of something that existed in the past such as pollen grains, tree rings, lake sediments, ice cores, or coral skeletons (for more information about paleoclimatological proxies, see http://www.ngdc.noaa.gov/paleo/ctl/about2.html#proxies).

One of the ways that corals are used as paleoclimatological proxies is to measure the ratio of oxygen isotopes in the coral skeleton. Oxygen occurs in two common, stable isotopes: ^{16}O, which is most common, and ^{18}O which is relatively rare. Corals build their hard skeletons from calcium carbonate ($CaCO^3$), which contains both isotopes of oxygen. The ratio of ^{18}O to ^{16}O in carbonate samples is inversely related to the water temperature at which the carbonates were formed; so high ratios of ^{18}O mean lower water temperatures.

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 ("standard mean ocean water," SMOW), and the results are expressed as delta values, abbreviated δ 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"):

$$\delta^{18}O = \{ [(^{18}O/\ ^{16}O \text{ sample}) - (^{18}O/\ ^{16}O \text{ SMOW})] \div (^{18}O/\ ^{16}O \text{ SMOW})\} \bullet 1000$$

By definition, $\delta^{18}O$ is zero for standard mean ocean water. A value of $\delta^{18}O = -10$ thus means the sample has an $^{18}O/\ ^{16}O$ ratio that is 10‰ less than SMOW.

In this lesson students will examine oxygen isotope data to look for trends and patterns in water temperature over a period of 244 years.

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 corals at http://www.learningdemo.com/noaa/.

2. Lead an 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). Tell students that branching corals are conspicuous features of biological communities on the Davidson Seamount, and that one reason scientists are interested in these corals is that they can be used to obtain evidence of climate changes that may have taken place in this region.

   Be sure students understand the distinction between weather and climate: Weather is the state of atmosphere-ocean-land conditions (hot/cold, wet/dry, calm/stormy, sunny/cloudy) over relatively short periods such as hours or days. Climate is weather patterns over a month, a season, a decade, a century from now or in past time periods. Climate may be thought of as "average weather conditions."

   Lead a brief discussion of students' ideas about climate change, including possible causes for such change, and the potential consequences of these changes to natural systems. Tell students that Earth's climate has changed many times in its 4,500 million-year history, and that processes that cause climate change are called "forcing factors." Major forcing factors include

- astronomical factors such as the tilt of the Earth's axis, rotation of the Moon around the Earth, and variations in the Earth's orbit;
- volcanic activity that alters the chemical composition of the atmosphere;
- biological activity that produces fluctuations in atmospheric carbon dioxide;
- variations in solar output from the sun;
- input of glacial water from large lakes; and
- variations in ocean temperatures such as El Niño

The latter variations are called "oscillations;" in addition to the El Niño Southern Oscillation (ENSO), the North Atlantic Oscillation (NAO) and Pacific Decadal Oscillation (PDO) are also relevant forcing factors. During an ENSO event, for example, surface waters in the Pacific Ocean are unusually warm and may block the upwelling of cold deep-ocean water that normally occurs, particularly along the equator in the eastern half of the Pacific basin. During the 1982-83 El Niño event, interference with upwelling had enormous economic impact on the fishing industries in Ecuador and Peru due to the failed anchovy harvest that occurred when the fish unexpectedly migrated south into Chilean waters. In addition, unusually severe weather hit Hawaii and Tahiti; monsoon rains fell over the central Pacific instead of the western Pacific, leading to droughts and disastrous forest fires in Indonesia and Australia; and winter storms battered southern California, causing widespread flooding across the southern United States.

Briefly review the concept of paleoclimatological proxies and how oxygen isotope ratios in coral skeletons can provide information about temperatures when the skeletons were formed. Be sure students understand that coral skeletons often contain growth rings that are superficially similar to the growth rings of trees, so it is possible to distinguish portions of the skeleton that were formed in successive years. Students should also understand that the outer portion of the skeleton is youngest (since the skeleton is produced by the living coral tissue on the outside of the skeleton).

3. Provide each student group with a copy of "Oxygen Isotope Ratios in Coral Samples, 1751 – 1995." Tell students that they are to examine these data for trends and patterns in the water temperature of the habitat from which these samples were collected.

   Explain that our primary interest is in changes in temperature over time, rather than the actual water temperatures. This means that we can analyze relative water temperature rather than absolute temperature (which can be very difficult to precisely determine). Tell students that scientists have found that if water temperature increases by 1°C, the $\delta^{18}O$ value will decrease by 0.18‰. So the first task is to find the largest $\delta^{18}O$ value. Since all of the values are negative, the largest value will be the one closest to zero. Once students have found the largest $\delta^{18}O$ value (which is -3.11), they should subtract this value from each of the other $\delta^{18}O$ values in the list to find the difference between these values and the smallest value. Next, they should divide each of these differences by -0.18 to find the relative difference in water temperature between these samples.

   So, the calculation for the first row would be:

   $(-3.61) - (-3.11) = -0.50$

   $-0.50 \div -0.18 = 2.78$ °C

   You will probably want to divide the list among the student groups to spread the work load (there are a total of 244 data points). Finally, have each group plot their data on a graph on which the x-axis represents dates from 1751 through 1995, and the y-axis represents the difference in water temperature (which should be a maximum of about 6°C).

4. Ask students to describe the overall pattern of temperature fluctuation during the period 1751 through 1995, and to identify:
   - The year of the minimum temperature;
   - The year of the maximum temperature;
   - The period of time (date range) when relative temperature increases exceeded 5°C; and
   - The period of time (date range) when relative temperature increases were less than 1°C.

   Students should recognize that the data indicate that temperatures normally fluctuate from year to year, as well as over longer time intervals (i.e., the really high temperatures occur at intervals of roughly 20 to 40 years. In addition, there is a progressive trend toward higher temperatures in the last 100 years, and these higher temperatures occur more frequently. So, the maximum temperature occurred in 1974, while the minimum temperature occurred in 1835. Similarly, relative temperature increases exceeded 5°C between 1986 and 1995, and were less than 1°C between 1826 and 1835.

5. These data are consistent with a general warming trend in the world's climate. Lead a brief discussion of some of the potential consequences of global warming. Some of the most profound consequences relate to sea ice, ocean temperature, sea level, and freshwater influx to the oceans.

   Sea ice has a direct relationship to sea level (sea level is lower when there is a lot of sea ice). Increased ocean temperature caused by a warmer climate, means less sea ice and higher sea levels. Disappearance of sea ice in arctic regions may result in extinction of species that depend upon this habitat (such as polar bears). Higher sea levels can increase coastal erosion, destroy coastal habitats, and allow saltwater to intrude into freshwater ecosystems.

   Increased ocean temperature can dramatically alter marine ecosystems, and may result in deadly stress to organisms such as shallow-water corals that live in habitats where temperatures are already near lethal levels. These temperature changes can lead to changes in ocean circulation. For example, such changes in the Atlantic Ocean could alter the flow of the Gulf Stream and cause major air temperature alterations that would result in colder climates in western European countries that are warmed by the Gulf Stream. Warmer temperatures can also increase wind speed and rainfall in hurricanes, increasing the severity of disturbance to coastal ecosystems associated with these storms. At the same time, the impacts of storm surges will be greater because of higher sea levels.

   Changing climates are likely to produce significant changes in runoff and river flows, which will affect the influx of chemicals and sediments to estuaries and coastal waters. Because these ecosystems are important nursery habitats for many species and help protect inland areas from erosion by coastal storms, alterations in freshwater flow are likely to be accompanied by stress to living organisms and human communities that depend upon these systems.

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 brief essay describing three ways in which a warmer global climate might affect them personally, and how information on previous climate change at the New England and Corner Rise Seamount chains could help prepare for these changes.

Connections to Other Subjects

English/Language Arts, Geography, Life Science

Assessment

Student participation in discussions and activities in Steps 2–4 provide opportunities for assessment.

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

Biological Communities of Alaska Seamounts (http://oceanexplorer.noaa.gov/explorations/02alaska/background/edu/media/biocomm7_8.pdf; 5 pages, 108k) (from the Exploring Alaska's Seamounts 2002 Expedition)

Focus: Biological Communities of Alaska Seamounts (Life Science)

Students will be able to infer why biological communities on seamounts are likely to contain unique or endemic species, calculate an index of similarity between two biological communities given species occurrence data, make inferences about reproductive strategies in species that are endemic to seamounts, and explain the implications of endemic species on seamounts to conservation and extinction of these species.

It's OK To Be a Clod (http://oceanexplorer.noaa.gov/explorations/03bump/background/edu/media/03cb_clod.pdf; (5 pages, 252k) (from The Charleston Bump 2003 Expedition)

Focus: Principles of solubility and measurements of water currents (Physical Science/Earth Science)

Students will be able to describe factors that affect the solubility of a chemical substance in seawater and explain how information on the solubility of a substance can be used to measure water currents.

Design a Reef! (http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_aquarium.pdf; (5 pages, 408k) (from the Gulf of Mexico Deep Sea Habitats 2003 Expedition)

Focus: Niches in coral reef ecosystems (Life Science)

Students will compare and contrast coral communities in shallow water and deep water, describe the major functions that organisms must perform in a coral ecosystem, and explain how these functions might be provided in a miniature coral ecosystem. Students will also be able to explain the importance of three physical factors in coral reef ecosystems and infer the fundamental source of energy in a deep-water coral community.

Let's Go to the Video Tape! (http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_letsgo.pdf; (7 pages, 552k) (from the Gulf of Mexico Deep Sea Habitats 2003 Expedition)

Focus: Characteristics of biological communities on deep-water coral habitats (Life Science)

Students will recognize and identify some of the fauna groups found in deep-sea coral communities, infer possible reasons for observed distribution of groups of animals in deep-sea coral communities, and discuss the meaning of "biological diversity." Students will compare and contrast the concepts of "variety" and "relative abundance" as they relate to biological diversity, and given abundance and distribution data of species, will be able to calculate an appropriate numeric indicator that describes the biological diversity of a community.

A Matter of Density (http://oceanexplorer.noaa.gov/explorations/04mountains/background/edu/media/MTS04.density.pdf; (6 pages, 416k) (from the Mountains in the Sea 2004 Expedition)

Focus: Temperature, density, and salinity in the deep sea (Physical Science)

Students will be able to explain the relationship among temperature, salinity, and density; and, given CTD (conductivity, temperature, and density) data, students will be able to calculate density and construct density profiles of a water column. Students will also be able to explain the concept of sigma-t, and explain how density differences may affect the distribution of organisms in a deep-sea environment.

Food Web Mystery (http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_foodweb.pdf; (4 pages, 1Mb) (from the Mountains in the Sea 2003 Expedition)

Focus: Food webs in the vicinity of seamounts (Life Science)

Students will be able to describe typical marine food webs, and explain why food is generally scarce in the deep-ocean environment and discuss reasons that seamounts may be able to support a higher density of biological organisms than would appear to be possible considering food available from primary production at the ocean's surface.

Come on Down! (http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_comedown.pdf; (6 pages, 1Mb) (from the Mountains in the Sea 2003 Expedition)

Focus: Ocean Exploration

Students will research the development and use of research vessels/vehicles used for deep ocean exploration; students will calculate the density of objects by determining the mass and volume; students will construct a device that exhibits neutral buoyancy.

Biodiversity of Deep Sea Corals (http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_deepseacoral.pdf; (3 pages, 1Mb) (from the Mountains in the Sea 2003 Expedition)

Focus: Deep-sea corals

Students will research life found on tropical coral reefs to develop an understanding of the biodiversity of the ecosystem; students will research life found in deep-sea coral beds to develop an understanding of the biodiversity of the ecosystem; students will compare the diversity and adaptations of tropical corals to deep-sea corals.

Treasures in Jeopardy (http://oceanexplorer.noaa.gov/explorations/05deepcorals/background/edu/media/05deepcorals_treasures.pdf; (6 pages, 299k) (from the Florida Coast Deep Corals 2005 Expedition)

Focus: Conservation of deep-sea coral communities (Life Science)

Students will compare and contrast deep-sea coral communities with their shallow-water counterparts and explain at least three benefits associated with deep-sea coral communities. Students will also describe human activities that threaten deep-sea coral communities and describe actions that should be taken to protect resources of deep-sea coral communities.

How Am I Supposed to Eat THAT? (http://oceanexplorer.noaa.gov/explorations/03bump/background/edu/media/03cb_eatthat.pdf; (4 pages, 248k) (from The Charleston Bump 2003 Expedition)

Focus: Feeding adaptations among benthic organisms (Life Science)

Students will be able to describe at least three nutritional strategies used by benthic organisms typical of deep-water coral communities and describe physical adaptations associated with at least three nutritional strategies used by benthic organisms.

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://www.ncdc.noaa.gov/paleo/primer.html – NOAA's Paleoclimatology Web site

Felis, T., J. Pätzold, Y. Loya, M. Fine, A. H. Nawar, and G. Wefer. 2000. A coral oxygen isotope record from the northern Red Sea documenting NAO, ENSO, and North Pacific teleconnections on Middle East climate variability since the year 1750. Paleoceanography, 15, 679-694 – The technical journal article on which this lesson 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 Web site 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
- Understandings about scientific inquiry

Content Standard B: Physical Science

- Properties and changes of properties in matter

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

Content Standard E: Science and Technology

- Understandings about science and technology

Content Standard F: Science in Personal and Social Perspectives

- Populations, resources, and environments
- Natural hazards
- Risks and benefits
- Science and technology in society

Content Standard G: History and Nature of Science

- Nature of science

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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Oxygen Isotope Ratios in Coral Samples, 1751 – 1995

(based on Felis, et al., 2000. Retrieved from NOAA's Paleoclimatology Web site, http://www.ncdc.noaa.gov/paleo/primer.html)

These data are values of $\delta^{18}O$ from a coral core which was collected from a 2.6-m-high coral colony (Porites sp.) in the northern Red Sea at Ras Umm Sidd (27°50.9'N, 34°18.6'E) in the Ras Mohammed National Park near the southern tip of the Sinai Peninsula (Egypt) in November. 1995. Each data value represents calcium carbonate that was deposited in July of the year indicated.

Our primary interest is in changes in temperature over time, so we can analyze relative water temperature; that is, differences between the temperature of each sample and the lowest temperature in the data set. Scientists have found that if water temperature increases by 1°C, the $\delta^{18}O$ value will decrease by 0.18‰.

First task is to find the largest $\delta^{18}O$ value, which corresponds to the lowest temperature.

Next, subtract this value from each of the other $\delta^{18}O$ values in the list to find the difference between these values and the smallest value. Fill in the result in Column 3.

Finally, divide each of these differences by -0.18 to find the relative difference in water temperature (°C) between these samples.

Year	$\delta^{18}O$	$\delta^{18}O$ - minimum $\delta^{18}O$	Column 3 ÷ 0.18 (=°C above minimum)
1751	-3.61	________	________
1752	-3.5	________	________
1753	-3.59	________	________
1754	-3.37	________	________
1755	-3.51	________	________
1756	-3.54	________	________
1757	-3.36	________	________
1758	-3.45	________	________
1759	-3.97	________	________
1760	-3.68	________	________
1761	-3.32	________	________

1762	-3.67	________	________
1763	-3.46	________	________
1764	-3.34	________	________
1765	-3.85	________	________
1766	-3.55	________	________
1767	-3.82	________	________
1768	-3.47	________	________
1769	-3.57	________	________
1770	-3.84	________	________
1771	-3.57	________	________
1772	-3.64	________	________
1773	-3.63	________	________
1774	-3.83	________	________
1775	-3.78	________	________
1776	-3.51	________	________
1777	-3.58	________	________
1778	-3.48	________	________
1779	-3.53	________	________
1780	-3.67	________	________
1781	-3.5	________	________
1782	-3.7	________	________
1783	-3.58	________	________
1784	-3.65	________	________
1785	-3.86	________	________
1786	-3.75	________	________
1787	-3.65	________	________
1788	-3.52	________	________
1789	-3.78	________	________
1790	-3.56	________	________
1791	-3.54	________	________
1792	-4.01	________	________
1793	-3.76	________	________
1794	-3.81	________	________
1795	-3.79	________	________
1796	-3.83	________	________
1797	-3.62	________	________

1798	-3.96	________	________
1799	-3.57	________	________
1800	-3.75	________	________
1801	-3.56	________	________
1802	-3.67	________	________
1803	-3.71	________	________
1804	-3.86	________	________
1805	-3.75	________	________
1806	-3.6	________	________
1807	-3.71	________	________
1808	-3.67	________	________
1809	-3.31	________	________
1810	-3.67	________	________
1811	-3.79	________	________
1812	-3.92	________	________
1813	-3.45	________	________
1814	-3.92	________	________
1815	-3.43	________	________
1816	-3.68	________	________
1817	-3.44	________	________
1818	-3.47	________	________
1819	-3.68	________	________
1820	-3.66	________	________
1821	-3.66	________	________
1822	-3.54	________	________
1823	-3.53	________	________
1824	-3.47	________	________
1825	-3.45	________	________
1826	-3.27	________	________
1827	-3.59	________	________
1828	-3.8	________	________
1829	-3.84	________	________
1830	-3.75	________	________
1831	-3.69	________	________
1832	-3.38	________	________
1833	-3.34	________	________

1834	-3.24	________	________
1835	-3.11	________	________
1836	-3.52	________	________
1837	-3.48	________	________
1838	-3.69	________	________
1839	-3.57	________	________
1840	-3.7	________	________
1841	-3.74	________	________
1842	-3.6	________	________
1843	-3.29	________	________
1844	-3.92	________	________
1845	-3.65	________	________
1846	-3.72	________	________
1847	-3.51	________	________
1848	-3.73	________	________
1849	-3.6	________	________
1850	-3.75	________	________
1851	-3.88	________	________
1852	-3.69	________	________
1853	-3.86	________	________
1854	-3.7	________	________
1855	-3.82	________	________
1856	-3.71	________	________
1857	-3.71	________	________
1858	-3.46	________	________
1859	-3.7	________	________
1860	-3.72	________	________
1861	-3.72	________	________
1862	-3.64	________	________
1863	-3.65	________	________
1864	-3.75	________	________
1865	-3.9	________	________
1866	-3.82	________	________
1867	-3.73	________	________
1868	-3.79	________	________
1869	-4.01	________	________

1870	-3.88	________	________
1871	-3.7	________	________
1872	-3.75	________	________
1873	-3.74	________	________
1874	-3.52	________	________
1875	-3.38	________	________
1876	-3.68	________	________
1877	-3.92	________	________
1878	-3.91	________	________
1879	-3.83	________	________
1880	-3.78	________	________
1881	-3.72	________	________
1882	-3.58	________	________
1883	-3.35	________	________
1884	-3.57	________	________
1885	-3.8	________	________
1886	-3.65	________	________
1887	-3.79	________	________
1888	-3.85	________	________
1889	-3.75	________	________
1890	-3.94	________	________
1891	-3.94	________	________
1892	-3.78	________	________
1893	-3.62	________	________
1894	-3.7	________	________
1895	-3.82	________	________
1896	-4.09	________	________
1897	-3.92	________	________
1898	-3.64	________	________
1899	-3.78	________	________
1900	-3.76	________	________
1901	-3.77	________	________
1902	-3.72	________	________
1903	-3.62	________	________
1904	-3.7	________	________
1905	-3.86	________	________

1906	-3.63	________	________
1907	-3.63	________	________
1908	-3.83	________	________
1909	-3.8	________	________
1910	-3.79	________	________
1911	-3.87	________	________
1912	-3.87	________	________
1913	-3.69	________	________
1914	-3.54	________	________
1915	-3.93	________	________
1916	-3.77	________	________
1917	-3.86	________	________
1918	-3.69	________	________
1919	-3.84	________	________
1920	-3.55	________	________
1921	-3.58	________	________
1922	-3.76	________	________
1923	-3.84	________	________
1924	-3.9	________	________
1925	-3.76	________	________
1926	-3.69	________	________
1927	-3.53	________	________
1928	-3.93	________	________
1929	-3.84	________	________
1930	-3.66	________	________
1931	-3.84	________	________
1932	-4	________	________
1933	-3.81	________	________
1934	-3.88	________	________
1935	-3.9	________	________
1936	-4	________	________
1937	-3.8	________	________
1938	-3.85	________	________
1939	-4.08	________	________
1940	-3.79	________	________
1941	-3.87	________	________

1942	-3.82	________	________
1943	-3.59	________	________
1944	-3.85	________	________
1945	-3.68	________	________
1946	-3.9	________	________
1947	-3.74	________	________
1948	-3.66	________	________
1949	-3.53	________	________
1950	-3.85	________	________
1951	-3.73	________	________
1952	-3.89	________	________
1953	-3.77	________	________
1954	-3.92	________	________
1955	-3.74	________	________
1956	-4.03	________	________
1957	-3.89	________	________
1958	-3.78	________	________
1959	-3.74	________	________
1960	-3.66	________	________
1961	-4.05	________	________
1962	-3.97	________	________
1963	-3.94	________	________
1964	-3.92	________	________
1965	-3.81	________	________
1966	-3.82	________	________
1967	-3.94	________	________
1968	-3.77	________	________
1969	-3.93	________	________
1970	-3.85	________	________
1971	-3.85	________	________
1972	-3.67	________	________
1973	-3.75	________	________
1974	-4.19	________	________
1975	-3.87	________	________
1976	-3.76	________	________
1977	-3.97	________	________

1978	-3.85	________	________
1979	-3.97	________	________
1980	-3.92	________	________
1981	-4.03	________	________
1982	-3.97	________	________
1983	-3.71	________	________
1984	-3.78	________	________
1985	-4.08	________	________
1986	-3.88	________	________
1987	-3.76	________	________
1988	-4.02	________	________
1989	-3.9	________	________
1990	-3.85	________	________
1991	-3.68	________	________
1992	-3.79	________	________
1993	-3.9	________	________
1994	-3.92	________	________
1995	-4.12	________	________