



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
 $\delta^{18}\text{O}$

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 climatic 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”):

$$\delta^{18}\text{O} = \left\{ \left[\frac{^{18}\text{O}}{^{16}\text{O}} \text{ sample} \right] - \left(\frac{^{18}\text{O}}{^{16}\text{O}} \text{ SMOW} \right) \right\} \div \left(\frac{^{18}\text{O}}{^{16}\text{O}} \text{ SMOW} \right) \cdot 1000$$

By definition, $\delta^{18}\text{O}$ is zero for standard mean ocean water. A value of $\delta^{18}\text{O} = -10$ thus means

the sample has an $^{18}\text{O}/^{16}\text{O}$ 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 $\delta^{18}\text{O}$ value will decrease by 0.18‰. So the first task is to find the largest $\delta^{18}\text{O}$ value. Since all of the values are negative, the largest value will be the one closest to zero. Once students have found the largest $\delta^{18}\text{O}$ value (which is -3.11), they should subtract this value from each of the other $\delta^{18}\text{O}$ 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:

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

$$-0.50 \div -0.18 = 2.78 \text{ }^\circ\text{C}$$

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 under-

standing 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 $\delta^{18}\text{O}$ 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 ($27^{\circ}50.9'\text{N}$, $34^{\circ}18.6'\text{E}$) 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 $\delta^{18}\text{O}$ value will decrease by 0.18‰ .

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

Next, subtract this value from each of the other $\delta^{18}\text{O}$ 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 ($^{\circ}\text{C}$) between these samples.

Year	$\delta^{18}\text{O}$	$\delta^{18}\text{O} - \text{minimum } \delta^{18}\text{O}$	Column 3 \div 0.18 (= $^{\circ}\text{C}$ 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	_____	_____