The NOAA Ship *Okeanos Explorer*

NOAA Ship *Okeanos Explorer:* America's Ship for Ocean Exploration. Image credit: NOAA. For more information, see the following Web site: *http://oceanexplorer.noaa.gov/okeanos/welcome.html*

History's Thermometers

(adapted from the 2006 Exploring Ancient Coral Gardens Expedition)

An essential component of the NOAA Office of Ocean Exploration and Research mission is to enhance understanding of science, technology, engineering, and mathematics used in exploring the ocean, and build interest in careers that support ocean-related work. To help fulfill this mission, the Okeanos Explorer *Education Materials Collection is being developed to encourage educators and students to become personally involved with the voyages and discoveries of the* Okeanos Explorer*—America's first Federal ship dedicated to Ocean Exploration. Leader's Guides for Classroom Explorers focus on three themes: "Why Do We Explore?" (reasons for ocean exploration), "How Do We Explore?" (exploration methods), and "What Do We Expect to Find?" (recent discoveries that give us clues about what we may find in Earth's largely unknown ocean). Each Leader's Guide provides background information, links to resources, and an overview of recommended lesson plans on the Ocean Explorer Web site (*http://oceanexplorer.noaa.gov*). An Initial Inquiry Lesson for each of the three themes leads student inquiries that provide an overview of key topics. A series of lessons for each theme guides student investigations that explore these topics in greater depth. In the future additional guides will be added to the Education Materials Collection to support the involvement of citizen scientists.*

This lesson guides student inquiry into the key topic of Climate Change within the "Why Do We Explore?" theme. Optionally, this lesson may be extended to include an inquiry into the concept of proxies using conductivity and salinity as an example.

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 be able to explain 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 *Paleoclimatological Proxies Inquiry Guide* enough for each student or student group
- Copy of a graph of global surface temperature, approximately 1850 - 2005 (e.g., http://www.pewclimate.org/docUploads/images/global-surface-temp-trends.gif)

Audiovisual Materials

- None

Teaching Time

One 45-minute class period

Seating Arrangement

Classroom style, or groups of 2-3 students

Maximum Number of Students

No limit, if students work individually

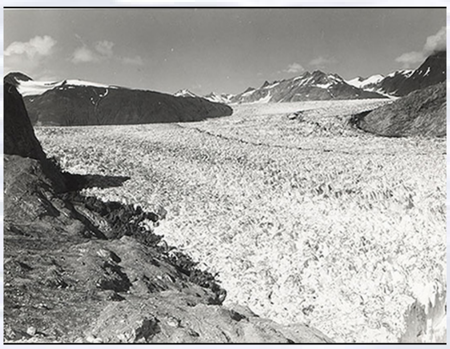
Key Words and Concepts

Paleoclimatological proxy
Isotope
Deep-water coral
Climate change
Fractionation

Background Information

Within the world scientific community there is broad consensus that:

- Earth's climate is undergoing a significant warming trend that is beyond the range of natural variability;
- The major cause of most of the observed warming is rising levels of carbon dioxide;
- The rise in carbon dioxide levels is the result of burning fossil fuels;
- If carbon dioxide levels in the atmosphere continue to rise over the next century the warming will continue; and



The black and white photograph of Muir Glacier was taken on August 13, 1941; the color photograph was taken from the same vantage on August 31, 2004. Between 1941 and 2004 the glacier retreated more than twelve kilometers (seven miles) and thinned by more than 800 meters (875 yards). Ocean water has filled the valley, replacing the ice of Muir Glacier; the end of the glacier has retreated out of the field of view. The glacier's absence reveals scars where glacier ice once scraped high up against the hillside. In 2004, trees and shrubs grew thickly in the foreground, where in 1941 there was only bare rock. Image credit: National Snow and Ice Data Center, W. O. Field, B. F. Molnia.
http://nsidc.org/data/glacier_photo/repeat_photography.html

- The climate change that is expected to result from these conditions represents potential danger to human welfare and the environment.

The consensus on these points is supported by a huge amount of data from many places on Earth. A brief summary of some of the key data is provided in Appendix A; for more details, see references listed under "Other Resources."

Since the late 1800's, average global surface temperatures have increased by about 0.74°C. The word "average" is very important, because some parts of Earth (including the southeastern United States and parts of the North Atlantic) have cooled slightly during this period. The greatest warming has been observed in Eurasia and North America between latitude 40° and 70° N.

Some confusion about the warming trend has recently been generated by assertions that Earth's temperature has been dropping for the last ten years. These statements are based on the fact that 1998 was abnormally hot due to the strongest El Nino event in the last century. The years following 1998 were indeed cooler than 1998, but the long-term trend still shows continued warming. There are many factors that affect global temperatures in a single year, and it is not surprising that one year might be cooler than the preceding year. But the global warming trend is a matter of decades, not just one or two years. The long-term trend is still clear: Seven of the eight warmest years on record have occurred since 2001, and the ten warmest years on record have all occurred since 1995.

Evidence from longer periods also suggests that present temperatures are highly unusual. 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 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. Analyses of over 400 proxies show that the 1990s was the warmest decade of the millennium and the 20th century was the warmest century. The warmest year of the millennium was 1998, and the coldest was probably (but with much greater uncertainty) 1601.

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. Stable isotope ratios of elements such as oxygen, hydrogen, carbon, nitrogen, and sulfur are normally compared to the stable isotope ratios of a standard material of known composition. The results of such comparison measurements are reported as delta (δ) values in parts per thousand (‰). The δ notation signifies difference; in this case the difference in isotope ratios between a standard and a sample. Delta value are abbreviated $\delta^{H}X$, where X is an element and the superscript H is the heavy isotope mass of that element. Delta values are found by subtracting the isotope ratio of the standard from the isotope ratio of the sample, dividing the result by the ratio of the standard, and multiplying by 1,000:

$$[(R_{SA} - R_{ST}) \div R_{ST}] \bullet 1000 = \delta^{H}X‰$$

where R_{SA} is the ratio of heavy/light isotopes in the sample and R_{ST} is the ratio of heavy/light isotopes in the standard. Positive delta values mean that the sample has more of the heavy isotope than the standard, and negative delta values mean that the sample has less of the heavy isotope than the standard. 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‰.

This lesson guides a student inquiry into the interpretation of oxygen isotope data as a climatic proxy.

Learning Procedure

1. To prepare for this lesson:
   - If you have not previously done so, review introductory information on the NOAA Ship *Okeanos Explorer* at http://oceanexplorer.noaa.gov/okeanos/welcome.html. You may also want to consider having students complete some or all of the Initial Inquiry Lesson, *To Boldly Go…* (http://oceanexplorer.noaa.gov/okeanos/edu/leadersguide/media/09toboldlygo.pdf).
   - Review the essay *Paleoclimate and Deep-Sea Corals* (http://oceanexplorer.noaa.gov/explorations/05stepstones/background/paleoclimate/paleoclimate.html) and the Ocean Explorer North Atlantic Stepping Stones 2005 expedition.
   - Review procedures on the *Paleoclimatological Proxies Inquiry Guide*.

2. If you have not previously done so, briefly introduce the NOAA Ship *Okeanos Explorer*, emphasizing that this is the first Federal vessel specifically dedicated to exploring Earth's largely unknown ocean. Lead a discussion of reasons why ocean exploration is important, which should include further understanding of climate change. Show students a graph of global surface temperature trends (e.g., http://www.pewclimate.org/docUploads/images/global-surface-temp-trends.gif), and ask them if they can recognize any trend in the data. Data are variable prior to about 1910, but thereafter there is a distinct trend of increasing temperature. Ask students whether the drop in surface temperature between 1935 and 1945 cancels out the overall trend. Students should realize that year-to-year fluctuations do not negate trends over longer periods of time.

   Point out that reliable temperature measurements are only available for a few hundred years of human history, and the significance of recently observed trends might be more easily determined if temperature data were available for a longer time period. Ask how such data might be obtained. Explain the concept of proxies, perhaps drawing an analogy to tree rings. Briefly discuss deep-sea corals as climatological proxies. Be sure students realize that these animals produce skeletons from calcium carbonate, and continue to grow and add to these skeletons throughout their lives.

   If necessary, review the concept of isotopes and isotope ratios. Explain that the ratio of oxygen isotopes varies with temperature, and 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‰.

3. Distribute copies of *Paleoclimatological Proxies Inquiry Guide*, and have each groups complete the activities described in the *Guide*.

4. Lead a discussion of students' results. The correct $\delta^{18}O$ values are:

Coral Specimen	$\delta^{18}O$
#1, base of coral	3.8
#1, 50 mm from base	3.9
#1, 200 mm from base	4.5
#1, 400 mm from base	4.1
#2, base of coral	0.8
#2, 70 mm from base	0.9
#2, 220 mm from base	1.1
#2, 450 mm from base	1.0
#3, base of coral	4.1
#3, 100 mm from base	4.3
#3, 200 mm from base	3.9
#3, 300 mm from base	4.1
#4, base of coral	4.5
#4, 75 mm from base	4.1
#4, 150 mm from base	3.9
#4, 300 mm from base	4.0
#5, base of coral	1.7
#5, 80 mm from base	1.8
#5, 85 mm from base	3.3
#5, 100 mm from base	3.6
#6, base of coral	1.3
#6, 100 mm from base	1.5
#6, 155 mm from base	1.6
#6, 400 mm from base	1.4

Students 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. Students should recognize that the difference in $\delta^{18}O$ (1.5) between two samples only 5 mm apart on the coral skeleton indicates that this coral experienced a rapid cooling of about 6°C in the space of only 5 years.

Evidence for such a period of rapid cooling has been reported and 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, emphasizing that it is much more difficult for biological organisms to adapt to rapid change. Consequently, extinctions are more likely to occur under rapidly changing conditions.

Encourage students to speculate about possible mechanisms that might account for changing $^{18}O/^{16}O$ ratio in response to temperature. There are numerous processes that contribute to isotope fractionation, ranging from processes that operate at the level of atoms to processes that operate at the level of ecosystems. The most obvious consequence of having one or more extra neutrons is that additional neutrons make atoms physically heavier. In general, light isotopes react faster than heavy isotopes in chemical reactions, and the bonds formed by heavy isotopes tend to be stronger than similar bonds formed by light isotopes. When water evaporates, light isotopes evaporate more readily so the ratio of heavy isotopes is lower in the vapor phase and higher in the liquid phase. At the ecosystem level, fractionation usually involves multiple processes that often are not well-understood. While the correlation between temperature and $\delta^{18}O$ has been repeatedly observed in corals, the exact mechanisms responsible for this fractionation are not fully known, and may vary among different coral species.

The BRIDGE Connection

www.vims.edu/bridge/ – Scroll over “Ocean Science Topics,” then click “Chemistry,” or “Atmosphere” for links to resources about ocean chemistry or climate change.

The “Me” Connection

Have students write a paragraph on how global climate change may affect their own lives over the next 20 to 50 years.

Connections to Other Subjects

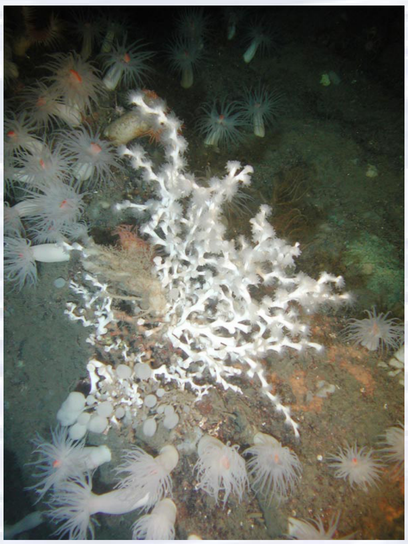
English/Language Arts, Social Sciences, Mathematics

Assessment

Students’ responses to Inquiry Guide questions and class discussions provide opportunities for evaluation.

Extensions

1. Follow events aboard the *Okeanos Explorer* at http://oceanexplorer.noaa.gov/okeanos/welcome.html.



Lophelia pertusa, the bright white coral seen in the midst of a field of anemones and sponges, is one of the primary species of deep-water corals under study. It can occur as an individual colony, like this one, or in vast 'thickets' of many colonies clustered closely together. We are still in the process of learning what type of habitat is needed to support the growth of these corals. Image credit: University of Alabama and NOAA.
http://oceanexplorer.noaa.gov/explorations/03mex/logs/summary/media/lophon_rock.html

2. Have student groups prepare scientific posters about climate change. See Appendix B for information about scientific posters, and "Other Resources" for additional sources of information about climate change.

3. 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 and activities related to paleoclimatology.

Multimedia Discovery Missions

http://www.oceanexplorer.noaa.gov/edu/learning/welcome.html Click on the links to Lessons 3 for interactive multimedia presentations and Learning Activities on Deep-Sea Corals.

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)

In this activity, 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.

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

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

The 2006 Tracking Narwhals in Greenland Expedition used satellite-linked time-depth-temperature recorders to track whale movements, diving behavior, and ocean temperature structure during the fall narwhal migration from north Greenland to Baffin Bay. This information is needed to help understand how Arctic climate change may affect the deep-ocean thermohaline circulation, sometimes known as the "global conveyor belt." Image credit: Mads Peter Heide-Jorgensen. *http://oceanexplorer.noaa.gov/explorations/06arctic/background/hires/male_narwhals_hires.jpg*

deep ocean, and discuss at least three potential impacts on biological communities that might result from carbon dioxide sequestration in the deep ocean.

The Good, the Bad, and the Arctic
http://oceanexplorer.noaa.gov/explorations/06arctic/background/edu/media/goodbad.pdf
(16 pages, 344 kb) (from the 2006 Tracking Narwhals in Greenland Expedition)

Focus: Social, economic and environmental consequences of Arctic climate change (Biology/Earth Science)

In this activity, students will be able to identify and explain at least three lines of evidence that suggest the Arctic climate is changing; identify and discuss at least three social, three economic and three environmental consequences expected as a result of Arctic climate change; identify at least three climate-related issues of concern to Arctic indigenous peoples; and identify at least three ways in which Arctic climate change is likely to affect the rest of the Earth's ecosystems.

Other Resources

The Web links below are provided for informational purposes only. Links outside of Ocean Explorer have been checked at the time of this page's publication, but the linking sites may become outdated or non-operational over time.

http://oceanexplorer.noaa.gov – Web site for NOAA's Ocean Exploration Program

http://celebrating200years.noaa.gov/edufun/book/welcome.html#book – A free printable book for home and school use introduced in 2004 to celebrate the 200th anniversary of NOAA; nearly 200 pages of lessons focusing on the exploration, understanding, and protection of Earth as a whole system

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

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 dimensions

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

http://www.ncdc.noaa.gov/oa/climate/globalwarming.html – "Global Warming Frequently Asked Questions," from NOAA's National Climatic Data Center

http://www.ipcc.ch/ – Home page for the Intergovernmental Panel on Climate Change

http://www.unep.org/climatechange/ – United Nations Environment Programme Climate Change Web page

http://www.epa.gov/climatechange/ – U. S. Environmental Protection Agency Climate Change Web page

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

- Structure of atoms

Content Standard F: Science in Personal and Social Perspectives

- Natural and human-induced hazards

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 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.

Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education setting.
Please send your comments to: oceanexeducation@noaa.gov

For More Information

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Paleoclimatological Proxies Inquiry Guide

Background

A proxy is a person or thing that substitutes for another person or thing. Proxies are often used in scientific investigations when there is a known relationship between two things that makes it possible to measure one to predict the measurement of the other. Tree rings are an example: the number of tree rings is a proxy for the age of the tree, and the distance between rings can be a proxy for climatic conditions during the year when the rings were formed.

Deep-sea corals can be a proxy for water temperature, because these corals build their skeletons from calcium and carbonate ions which they extract from seawater. Carbonate ions (CO_3^{-2}) contain oxygen. Like other elements, oxygen can occur as several different isotopes. Isotopes are atoms with the same number of electrons and protons, but different numbers of neutrons. Different isotopes belong to the same element because they have the same number of electrons, which means that they behave similarly in chemical reactions. But different isotopes of the same element do not behave identically, and there are a variety of chemical and physical processes that can cause one isotope to become more or less concentrated relative to other isotopes. This process is called fractionation.

Oxygen in seawater may occur as the rare oxygen isotope ^{18}O (about 0.20% of all oxygen atoms) or the common oxygen isotope ^{16}O (about 99.76% of all oxygen atoms). You may notice that the percentages do not add to exactly 100.000%; this is because oxygen also occurs as the very rare ^{17}O. Scientists have found that the ratio of the ^{18}O isotope to the ^{16}O isotope in carbonate samples is inversely related to the water temperature at which the carbonates were formed, so higher ratios of $^{18}O/^{16}O$ mean lower temperatures.

Concentrations of isotopes of a specific element are measured in mass spectrometers, which separate molecules according to their mass. The stable isotope ratios of elements such as oxygen, hydrogen, carbon, nitrogen, and sulfur are normally compared to the stable isotope ratios of a standard material of known composition. The results of such comparison measurements are reported as delta (δ) values in parts per thousand (‰). The δ notation signifies difference; in this case the difference in isotope ratios between a standard and a sample. Delta value are abbreviated $\delta^{H}X$, where X is an element and the superscript H is the heavy isotope mass of that element. Delta values are found by subtracting the isotope ratio of the standard from the isotope ratio of the sample, dividing the result by the ratio of the standard, and multiplying by 1,000:

$$[(R_{SA} - R_{ST}) \div R_{ST}] \bullet 1000 = \delta^{H}X‰$$

where R_{SA} is the ratio of heavy/light isotopes in the sample and R_{ST} is the ratio of heavy/light isotopes in the standard.

Paleoclimatological Proxies Inquiry Guide - Page 2

Note that positive delta values mean that the sample has more of the heavy isotope than the standard, and negative delta values mean that the sample has less of the heavy isotope than the standard.

Some deep-sea corals live for several centuries, and the carbonates in their skeletons contain a natural record of climate variability. The oldest part of the coral skeleton is at the base of the coral, where coral growth began after the coral larva settled on a suitable surface.

Analyze

Table 1 on the following page lists $^{18}O/^{16}O$ ratios for calcium carbonate samples taken from the skeletons of six corals. The table also gives ages of the sample taken from the base of each coral skeleton and the sample taken from the tip of each skeleton. The difference in age between these two samples is the maximum age of the coral while it was alive. So, Coral #1 lived for 410 years (15,550 - 15,140).

Calculate $\delta^{18}O$ for each sample, and use the results to help answer the following questions. Assume that a temperature change of 4°C corresponds to a $\delta^{18}O$ of about 1‰.

Paleoclimatological Proxies Inquiry Guide - Page 3

Table 1
Oxygen Isotope Ratios in Deep-water Coral Samples

Coral Specimen	$^{18}O/^{16}O$ Sample	$^{18}O/^{16}O$ Standard	$\delta^{18}O$ ‰	Age (years)
#1, base of coral	0.0020076	0.0020000	____________	15,140
#1, 50 mm from base	0.0020078	0.0020000	____________	
#1, 200 mm from base	0.0020090	0.0020000	____________	
#1, 400 mm from base	0.0020082	0.0020000	____________	15,550
#2, base of coral	0.0020016	0.0020000	____________	3,100
#2, 70 mm from base	0.0020018	0.0020000	____________	
#2, 220 mm from base	0.0020022	0.0020000	____________	
#2, 450 mm from base	0.0020020	0.0020000	____________	3,410
#3, base of coral	0.0020082	0.0020000	____________	15,400
#3, 100 mm from base	0.0020086	0.0020000	____________	
#3, 200 mm from base	0.0020078	0.0020000	____________	
#3, 300 mm from base	0.0020082	0.0020000	____________	15,695
#4, base of coral	0.0020090	0.0020000	____________	14,445
#4, 75 mm from base	0.0020082	0.0020000	____________	
#4, 150 mm from base	0.0020078	0.0020000	____________	
#4, 300 mm from base	0.0020080	0.0020000	____________	14,800
#5, base of coral	0.0020034	0.0020000	____________	13,300
#5, 80 mm from base	0.0020036	0.0020000	____________	
#5, 85 mm from base	0.0020066	0.0020000	____________	
#5, 100 mm from base	0.0020072	0.0020000	____________	13,400
#6, base of coral	0.0020026	0.0020000	____________	6,400
#6, 100 mm from base	0.0020030	0.0020000	____________	
#6, 155 mm from base	0.0020032	0.0020000	____________	
#6, 400 mm from base	0.0020028	0.0020000	____________	6,675

Paleoclimatological Proxies Inquiry Guide - Page 4

Interpret

1. Which corals grew during periods in which water temperatures were relatively low?

2. Which corals grew during periods in which water temperatures were relatively high?

3. Is there evidence that any coral experienced a rapid change in environmental temperature?

4. Is there any evidence that a rapid shift in climate has ever actually taken place? (Hint: Search the name "Dryas")

5. What processes might cause heavy oxygen isotopes (^{18}O) in carbonates to increase as temperature decreases?

Appendix A: Climate Change Review

A Brief Review of Some Key Data Concerning Global Climate Change

Within the world scientific community, there is a broad consensus that:

- Earth's climate is undergoing a significant warming trend that is beyond the range of natural variability;
- The major cause of most of the observed warming is rising levels of carbon dioxide;
- The rise in carbon dioxide levels is the result of burning fossil fuels;
- If carbon dioxide levels in the atmosphere continue to rise over the next century the warming will continue; and
- The climate change that is expected to result from these conditions represents potential danger to human welfare and the environment.

The scientific consensus on these points is supported by a huge amount of data from many places on Earth. Following is a brief review of a few key points.

1. Climate Warming Trend

Since the late 1800's, average global surface temperatures have increased by about 0.74°C. The word "average" is very important, because some parts of Earth (including the southeastern United States and parts of the North Atlantic) have cooled slightly during this period. The greatest warming has been observed in Eurasia and North America between latitude 40° and 70° N.

You may have heard statements such as "Earth's temperature has been dropping for the last ten years." These statements are based on the fact that 1998 was abnormally hot due to the strongest El Nino event in the last century. The years following 1998 were indeed cooler than 1998, but the long-term trend still shows continued warming. There are many factors that affect global temperatures in a single year, and it is not surprising that one year might be cooler than the preceding year. But the global warming trend is a matter of decades, not just one or two years. The long-term trend is still clear: Seven of the eight warmest years on record have occurred since 2001, and the ten warmest years on record have all occurred since 1995.

2. Cause of the Observed Warming

Earth's climate is affected by a number of factors, including changes in Earth's orbit, solar variability, volcanoes, and the greenhouse effect. But the only factor that coincides with the warming trend of the last century is the observed increase in greenhouse gases, particularly carbon dioxide. There is no scientific debate about this: Since the start of the Industrial Revolution, atmospheric carbon dioxide concentrations have increased from 280 parts per million (ppm) to 380 ppm. Today, the global concentration of carbon dioxide is significantly higher than the natural range over the last 650,000 years of 180 – 300 ppm.

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3. Cause of Increasing Atmospheric Carbon Dioxide

There is also no scientific debate about the source of increased atmospheric carbon dioxide. Humans burning fossil fuels release billions of tons of carbon into the atmosphere every year, and the quantity of fuels burned has been increasing for over 150 years (see, for example, http://cdiac.ornl.gov/trends/emis/tre_glob.html).

What about volcanoes? Scientists estimate that volcanoes (including underwater volcanoes) emit 145-255 million tons carbon dioxide into the atmosphere each year. Emissions of carbon dioxide from human activities is estimated at about 30 billion tons per year. So, the amount of carbon dioxide from human activities is more than 100 times greater than the amount of carbon dioxide emitted by volcanoes (http://volcano.oregonstate.edu/education/gases/man.html). Further, if volcanoes had a significant impact, we should see "spikes" on graphs of atmospheric carbon dioxide every time a volcano erupts; but such spikes are not present on these graphs.

What about increases in atmospheric carbon dioxide that happened during pre-human times? It is true that carbon dioxide rose and fell by over 100 ppm at various times in Earth's history, but these rises took place over 5,000 to 20,000 years; the present increase of 100 ppm has happened in only 150 years. Additional evidence implicating human activities comes from isotope analyses of the carbon and oxygen atoms that make up atmospheric carbon dioxide molecules. These analyses show that the oxygen atoms in some of these molecules are much younger than the carbon atoms in the same molecule. Older carbon could only come from fossil fuel deposits, and the only way these deposits could become airborne is through combustion.

4. Effect of Continued Increase in Atmospheric Carbon Dioxide

If atmospheric carbon dioxide concentrations continue to increase, global temperatures are also expected to increase by 2° to 5°C. So, the minimum expected temperature increase under these conditions is nearly three times the increase that has already been observed. The actual increase could be much greater, depending upon the influence of feedbacks. For example, decreasing ice and snow in polar regions means that less solar radiation will be reflected away from Earth's surface. This would result in more radiation being absorbed at the surface, and increased warming.

Warmer temperatures in the Arctic could also trigger another feedback process. Methane hydrates are a type of ice that contains methane molecules surrounded by a cage of frozen water molecules. Most methane

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hydrates are believed to exist in ocean sediments, but some are also found in high latitude soils called permafrost. If these soils become warm enough, methane hydrates could melt and release methane gas to the atmosphere. Since methane is a powerful greenhouse gas, and decomposes to form carbon dioxide, increased atmospheric methane could results in an increased greenhouse effect and additional warming of Earth's climate.

A warmer atmosphere could also mean warmer temperatures in Earth's ocean. Since the solubility of carbon dioxide decreases as temperature rises, warmer temperatures could decrease carbon dioxide absorption by the ocean creating yet another feedback mechanism. Temperature has an opposite effect on the atmosphere's capacity for water vapor: Increased temperature can result in increased atmospheric water vapor. Since water vapor is also a greenhouse gas, additional warming might result from a strengthened greenhouse effect. The latter feedback, however, might be moderated if increased atmospheric water vapor caused an increase in cloud cover that could reduce the amount of solar radiation reaching Earth's surface.

Increasing atmospheric carbon dioxide is also having a serious effect on ocean pH. Each year, the ocean absorbs approximately 25% of the CO_2 added to the atmosphere by human activities. When CO_2 dissolves in seawater, carbonic acid is formed, which raises acidity. Ocean acidity has increased by 30% since the beginning of the Industrial Revolution, causing seawater to become corrosive to the shells and skeletons of many marine organisms as well as affecting the reproduction and physiology of others. See "Off Base" (http://oceanexplorer.noaa.gov/explorations/09lophelia/background/edu/media/09offbase.pdf) for additional discussion and references.

5. Impacts of Expected Climate Change if Trends Continue

The Intergovernmental Panel on Climate Change (the leading provider of scientific advice to global policy makers) has produced a report on some of the impacts that are occurring as a results of climate change as well as impacts that are anticipated if present trends continue (http://www.ipcc.ch/publications_and_data/publications_ipcc_fourth_assessment_report_wg2_report_impacts_adaptation_and_vulnerability.htm). These impacts include:

- Decreased water resources in semi-arid areas such as the Mediterranean Basin, western USA, southern Africa and north-eastern Brazil;
- Decreased availability of fresh water due to sea-level rise;
- Ecosystems such as tundra, boreal forest, mountains, mangroves, salt marshes, coral reefs, and sea-ice are highly vulnerable, and are virtually certain to experience species extinctions and major changes;

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- A global intensification and expansion of wildfires is likely, as temperatures increase and dry spells become more frequent and more persistent;
- Increased risk of coastal flooding in low-lying areas due to sea-level rise and more intense coastal storms;
- Surface ocean pH is very likely to decrease by as much as 0.5 pH units by 2100, and is very likely to impair shell or exoskeleton formation in marine organisms such as corals, crabs, squids, marine snails, clams and oysters.

Resources

http://www.ncdc.noaa.gov/oa/climate/globalwarming.html –
"Global Warming Frequently Asked Questions," from NOAA's National Climatic Data Center

http://www.ipcc.ch/ –
Home page for the Intergovernmental Panel on Climate Change

http://www.unep.org/climatechange/ –
United Nations Environment Programme Climate Change Web page

http://www.epa.gov/climatechange/ –
U. S. Environmental Protection Agency Climate Change Web page

Appendix B: Scientific Posters

Scientific posters are an increasingly popular way to communicate results of scientific research and technical projects. There are a number of reasons for this, including limited time at conferences for traditional "public speaking"-style presentations, better options for interacting one-on-one with people who are really interested in your work, opportunities for viewers to understand the details of your work (even if you aren't present), and having a more relaxed format for those who dislike speaking in public. In addition, posters are more durable that one-time presentations; once they are created they can be used in many different settings, over and over again. For more discussion of pros and cons, as well as examples of good and bad posters, visit

http://www.swarthmore.edu/NatSci/cpurrin1/posteradvice.htm
http://www.ncsu.edu/project/posters/NewSite/
http://www.the-aps.org/careers/careers1/GradProf/gposter.htm

Scientific posters usually contain the same elements as traditional written reports: title, introduction, materials and methods, results, conclusions, literature cited (key citations only!), acknowledgments, and contact points for further information. Good posters do NOT usually have an abstract, though an abstract is often required as part of the submission process and may be included in a printed program.

Another similarity to traditional reports is that the best posters almost always go through several drafts. You should always expect that the first draft of your poster will change significantly before it emerges in final form. Be sure to allow enough time for others to review your first draft and for you to make needed changes.

An important difference (and advantage) that posters have compared to written reports is that posters can be much more flexible in terms of layout and where these elements appear, as long as there is still a clear and logical flow to guide viewers through your presentation. Here are a few more tips for good scientific posters (see the Web sites listed above for many other ideas):

- Posters should be readable from 6 feet away;
- Leave plenty of white space (35% is not too much) – densely packed posters can easily repel potential viewers;
- The top and right columns of your poster are prime areas for vital material, while the bottom edge will receive much less attention;
- Serif fonts (e.g., Times) are easier to read than sans serif fonts (e.g., Helvetica), so use sans serif fonts for titles and headings, and serif fonts for body text (usually no more than two font families on a single poster)
- Text boxes are easiest to read when they are about 40 characters wide