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*

Section 3: Key Topic – Climate Change

History's Thermometers

(adapted from the 2006 Exploring Ancient Coral Gardens Expedition)

Focus
Paleoclimatological proxies

Grade Level
9-12 (Physics/Chemistry/Life Science)

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

Learning Objectives
- Students will explain the concept of paleoclimatological proxies.
- Students will explain how oxygen isotope ratios are related to water temperature.
- Students will interpret data on oxygen isotope ratios to make inferences about climate and climate change in the geologic past.

Materials
- Copies of *Paleoclimatological Proxies Investigation 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
Deepwater coral
Climate change

Ocean Exploration and Research

Background Information

NOTE: Explanations and procedures in this lesson are written at a level appropriate to professional educators. In presenting and discussing this material with students, educators may need to adapt the language and instructional approach to styles that are best suited to specific student groups.

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

- Global warming is unequivocal and primarily human-induced.
- Climate changes are underway in the United States and are projected to grow.
- Widespread climate-related impacts are occurring now and are expected to increase.
- Climate change will stress water resources.
- Crop and livestock production will be increasingly challenged.
- Coastal areas are at increasing risk from sea-level rise and storm surge.
- Risks to human health will increase.
- Climate change will interact with many social and environmental stresses.
- Thresholds will be crossed, leading to large changes in climate and ecosystems.
- Future climate change and its impacts depend on choices made today. (Karl, Melillo, and Peterson, 2009).

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 Diving Deeper (page 21); for more details, see references listed under "Other Resources," page 217.

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.

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 12 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

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 investigation into the interpretation of oxygen isotope data as a climate proxy.

Learning Procedure

1. To prepare for this lesson:
   - 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 lesson, *To Boldly Go…*.
   - 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 Investigation 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 climate 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.

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 the ratio of oxygen isotopes in carbonate samples is inversely related to water temperature when the carbonates were formed, so high ratios of ^{18}O mean lower temperatures; and that a temperature change of 4°C corresponds to a $\delta^{18}O$ of about 1‰.

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

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

Coral Specimen	$\delta^{18}O$	*Coral Specimen*	$\delta^{18}O$
#1, base of coral	3.8	#4, base of coral	4.5
#1, 50 mm from base	3.9	#4, 75 mm from base	4.1
#1, 200 mm from base	4.5	#4, 150 mm from base	3.9
#1, 400 mm from base	4.1	#4, 300 mm from base	4.0
#2, base of coral	0.8	#5, base of coral	1.7
#2, 70 mm from base	0.9	#5, 80 mm from base	1.8
#2, 220 mm from base	1.1	#5, 85 mm from base	3.3
#2, 450 mm from base	1.0	#5, 100 mm from base	3.6
#3, base of coral	4.1	#6, base of coral	1.3
#3, 100 mm from base	4.3	#6, 100 mm from base	1.5
#3, 200 mm from base	3.9	#6, 155 mm from base	1.6
#3, 300 mm from base	4.1	#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 approximately 12,900 to 11,700 years ago. The exact cause (or causes) of the Younger Dryas cooling is not known, but available evidence suggests that an influx of cold, fresh water from melting ice sheets may have been at least partly responsible. This melting began well before the beginning of the Younger Dryas cooling, and freshwater influx is believed to have had an impact on deep ocean circulation. Although coral 5 lived 400 – 500 years before the onset of the Younger Dryas event, this coral was collected from Orphan Knoll in the northwestern Atlantic Ocean at a depth of 1,600 m. It is possible that some of the events involved with conditions accompanying the Younger Dryas event may also have subjected this coral to cooler temperatures before that event actually began.

What Caused the Younger-Dryas Cooling Event?

A recent hypothesis (Firestone *et al.*, 2007) to explain the Younger Dryas cooling event involves a meteor hitting the Earth about 12,900 years ago, sending enough debris (and possibly ash from fires) into the atmosphere to block incoming solar radiation and cause global temperatures to briefly decline. It has also been suggested that the same hypothesis explains the mass extinction of North American megafauna, the end of the Clovis culture of Paleo-Indians in North America, and the creation of elliptical depressions known as the Carolina Bays.

While there are still many unresolved questions, this hypothesis and its associated events can provide a fascinating context for lessons touching on archaeology, astronomy, and the nature of scientific discovery. A lesson plan based on this hypothesis is described by McGarry, Straffon, and Patterson (2012).

References

Firestone, R.B., A. West, J.P. Kennett, L. Becker, T.E. Bunch, Z.S. Revay, P.H. Schultz, T. Belgya, D.J. Kennett, J.M. Erlandson, O.J. Dickenson, A.C. Goodyear, R.S. Harris, G.A. Howard, J.B. Kloosterman, P. Lechler, P.A. Mayewski, J. Montgomery, R. Poreda, T. Darrah, S.S. Que Hee, A.R. Smith, A. Stich, W. Topping, J.H. Wittke, and W.S. Wolbach. 2007. Evidence for an extraterrestrial impact 12,900 years ago that contributed to the megafaunal extinctions and the Younger Dryas cooling. Proceedings of the National Academy of Sciences 104(41): 16016–21.

McGarry, M. A., D. Straffon, and C. Patterson. 2012. Explaining four Earth science enigmas with a new hypothesis. Science Scope 35:35-41. *http://www.nsta.org/publications/browse_journals.aspx?action=issue&id=10.2505/3/ss12_035_07*

Whatever connection may or may not exist with the Younger Dryas cooling, coral 5 provides clear evidence of very rapid climate change. 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 *Invstigation* questions and class discussions provide opportunities for evaluation.

Extensions

1. Follow events aboard the *Okeanos Explorer* at *http://oceanexplorer.noaa.gov/okeanos/welcome.html*.
2. Have student groups prepare scientific posters about climate change. See Page 114 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

(All of the following Lesson Plans are targeted toward Grades 9-12)

Cool Corals (from the 2003 Life on the Edge Expedition)
http://oceanexplorer.noaa.gov/explorations/03edge/background/edu/media/cool.pdf

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

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

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

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

Students will 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 explain how warmer temperatures might affect wind-driven surface currents and how these effects might impact biological communities of the deep ocean, and discuss at least three potential impacts on biological communities that might result from carbon dioxide sequestration in the deep ocean.

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

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

Students will 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

See page 217 for Other Resources.

Next Generation Science Standards

Lesson plans developed for Volume 1 are correlated with *Ocean Literacy Essential Principles and Fundamental Concepts* as indicated in the back of this book. Additionally, a separate online document illustrates individual lesson support for the Performance Expectations and three dimensions of the Next Generation Science Standards and associated Common Core State Standards for Mathematics and for English Language Arts & Literacy. This information is provided to educators as a context or point of departure for addressing particular standards and does not necessarily mean that any lesson fully develops a particular standard, principle or concept. Please see: *http://oceanexplorer.noaa.gov/okeanos/edu/collection/wdwe_ngss.pdf.*

Lophelia pertusa, the bright white coral seen in the midst of a field of anemones and sponges, is one of the primary species of deepwater 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/hirez/lophon_rock_hirez.jpg

Send Us Your Feedback

We value your feedback on this lesson, including how you use it in your formal/informal education settings.
Please send your comments to:
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Acknowledgments

Produced by Mel Goodwin, PhD, Marine Biologist and Science Writer, Charleston, SC for NOAA. Design/layout: Coastal Images Graphic Design, Charleston, SC. If reproducing this lesson, please cite NOAA as the source, and provide the following URL: *http://oceanexplorer.noaa.gov*

Paleoclimatological Proxies Investigation

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 values 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. 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 18O/16O ratios for calcium carbonate samples taken from the skeletons of six corals collected at a depth of 1,600 m from Orphan Knoll in the northwestern Atlantic Ocean. 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‰.

The data for this activity came from: 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.
http://www.nature.com/nature/journal/v386/n6627/abs/386818a0.html

Table 1
Oxygen Isotope Ratios in Deepwater Coral Samples

Coral Specimen	$^{18}O/^{16}O$ Sample	$^{18}O/^{16}O$ Standard	$\delta^{18}O$ ‰	Years Ago	Specimen Age (yrs)
#1, base of coral	0.0020076	0.0020000	________	15,550	
#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	________	15,140	______
#2, base of coral	0.0020016	0.0020000	________	3,410	
#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	________	3,100	______
#3, base of coral	0.0020082	0.0020000	________	15,695	
#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	________	15,400	______
#4, base of coral	0.0020090	0.0020000	________	14,800	
#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	________	14,445	______
#5, base of coral	0.0020034	0.0020000	________	13,400	
#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	________	13,300	______
#6, base of coral	0.0020026	0.0020000	________	6,675	
#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	________	6,400	______

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?

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://colinpurrington.com/tips/academic/posterdesign
http://www.ncsu.edu/project/posters/NewSite/

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

Below: An example of a scientific poster.