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2005 North Atlantic Stepping Stones Expedition

Climate, Corals, and Change

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 New England and Corner Rise Seamount chains

TEACHING TIME
One or two 45-minute class periods

SEATING ARRANGEMENT
Classroom style

MAXIMUM NUMBER OF STUDENTS
30

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

BACKGROUND INFORMATION
Seamounts are undersea mountains formed by volcanic activity. These volcanoes may rise as much as 4,000 m (13,000 ft) from the ocean floor, either as isolated peaks or more often as chains that may be thousands of miles long. One of the best-known seamount chains is the Hawaiian Islands – Emperor Seamount Chain that stretches more than 6,000 km across the Pacific Ocean from Hawaii to near the Aleutian Islands west of Alaska. In the North Atlantic Ocean, the New England and Corner Rise Seamounts

are part of a volcanic chain that extends from Canada to the African tectonic plate.

Seamounts interrupt ocean currents and cause nutrient-rich deep ocean water to flow up and across the seamount surface. As a result, biological productivity is higher around seamounts than in adjacent deep ocean habitats. Seamounts also have many hard surfaces that can serve as attachment points for a variety of bottom-dwelling animals. By providing chains of favorable habitats that extend long distances across ocean basins, seamounts may serve as "stepping stones" that have a major role in dispersing deep-sea organisms. These dispersal processes have a fundamental impact on the biogeography (biological diversity and species composition) of all regions of the ocean environment. While the geology of seamounts has been studied to some extent, investigations of the role of seamounts in the ecology and evolution of deep-sea species are just beginning. The ultimate goal of the 2005 North Atlantic Stepping Stones Expedition is to determine whether seamounts function as "stepping stones" that allow organisms living on hard substrates to disperse among adjacent seamounts and extend their ranges across ocean basins. To achieve this goal, expedition scientists plan to collect video images and samples of living and fossil corals, as well as other animals living on and near the corals, from three sets of seamount peaks in the Corner Rise area and five seamounts in the New England Seamount Chain.

One of the major objectives of the North Atlantic Stepping Stones Expedition is to deduce the climate history of the New England/Corner Rise Seamounts region from fossil material. Scientists often obtain clues about climate history from "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 by measuring 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 d 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 by 1,000 to give a result in parts-per-thousand (‰; also called "parts-per-mille"):

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

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

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

LEARNING PROCEDURE

1. To prepare for this lesson, read the introductory essays for the 2005 North Atlantic Stepping Stones Expedition at http://oceanexplorer.noaa.gov/explorations.05stepstones/welcome.html. You may also want to review information on paleoclimatology at http://www.ngdc.noaa.gov/paleo/ctl/index.html.

Download a map or other visual image that shows the location of the New England and Corner Rise Seamount chains. [http://oceanexplorer.noaa.gov/explorations/05stepstones/background/plan/plan.html]

2. Show students a map or other visual image that shows the location of the New England and Corner Rise Seamount chains. Explain that seamounts are the remains of underwater volcanoes, and that they are islands of productivity compared to the surrounding environment. Briefly describe the 2005 North Atlantic Stepping Stones Expedition, emphasizing that the overall goal is to determine whether these seamounts actually serve as biological "stepping stones," and a major activity to answer this question involves collecting living and fossil specimens from various seamounts in the chain. Tell students that one of the Expedition's major objectives is to determine climate changes that may have taken place in this region, and that fossil organisms will be used as indicators of these changes.

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

   Lead a brief discussion of students' ideas about climate change, including possible causes for such change, and the potential consequences of these changes to natural systems. Tell students that Earth's climate has changed many times in its 4,500 million-year history, and that processes that cause climate change are called "forcing factors." Major forcing factors include
   - astronomical factors such as the tilt of the Earth's axis, rotation of the Moon around the Earth, and variations in the Earth's orbit;
   - volcanic activity that alters the chemical composition of the atmosphere;
   - biological activity that produces fluctuations in atmospheric carbon dioxide;
   - variations in solar output from the sun;
   - input of glacial water from large lakes; and
   - variations in ocean temperatures such as El Niño

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

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

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

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

   So, the calculation for the first row would be:

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

   $-0.50 \div -0.18 = 2.78\ °C$

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

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

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

5. These data are consistent with a general warming trend in the world's climate. Lead a brief discussion of some of the potential consequences of global climate change. 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

http://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

EVALUATION

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

EXTENSIONS

1. Have students visit http://oceanexplorer.noaa.gov/explorations.05stepstones/welcome.html to keep up to date with the latest discoveries by the North Atlantic Stepping Stones Expedition.

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 and activities related to paleoclimatology

3. Check out the following Ocean Explorer lesson plans for more information and activities about seamounts:

   Round and Round (http://oceanexplorer.noaa.gov/explorations/03mountains/background/education/media/mts_round.pdf)

   Volcanoes, Plates, and Chains (http://oceanexplorer.noaa.gov/explorations/02alaska/background/edu/media/volcanoes5_6.pdf)

   How Does Your (Coral) Garden Grow? (http://oceanexplorer.noaa.gov/explorations/03mex/background/edu/media/mexdh_growth.pdf)

RESOURCES

http://oceanexplorer.noaa.gov/explorations.05stepstones/welcome.html – The North Atlantic Stepping Stones Expedition Web site

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.

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

For More Information

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http://oceanexplorer.noaa.gov

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 d18O from a coral core which was collected from a 2.6-m-high coral colony (*Porites* sp.) in the northern Red Sea at Ras Umm Sidd (27°50.9'N, 34°18.6'E) in the Ras Mohammed National Park near the southern tip of the Sinai Peninsula (Egypt) in November. 1995. Each data value represents calcium carbonate that was deposited in July of the year indicated.

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

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

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

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

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

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

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

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

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

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

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

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