MATERIALS

- Laptop computer
- Access to ice core data on Blackboard
- Microscope and samples will be provided by your instructor

BACKGROUND

Paleoclimatology is the study of past climates and involves trying to understand how the environment was different in the past compared to today. Paleoclimatologists are often interested in using geologic records (sediment cores, ice cores, tree rings, fossil chemistry, etc.) to better understand how different variables (temperature, albedo, ocean currents, orogeny, biologic activity, etc.) influenced past changes in global climate so modelers may better predict future climate scenarios. Several obstacles make the reconstruction of past climates very challenging; for example, there are no perfect proxies that can be used to deduce changes in climate-influencing factors, such as albedo, temperature, biologic productivity, greenhouse gases, etc. The best approaches to reconstructing past climates often use multiple proxies. Generally speaking, proxies records preserve some details about a climate feature or process.

In this lab, you will examine real tree core samples collected from the Wabashiki Fish and Wildlife Area (WFWA) to consider the variables that influence the formation of annual tree ring widths and what information might be deduced from studying tree rings. You will also graph ice core data from the Vostok ice core in Antarctica to investigate climate change over the last several hundred thousand years. Finally, you will consider the strengths and weaknesses of the weather data you collected as a class.

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Figure 13-1. *Iceberg in the Southern Ocean*

Climate Proxies

Because our instrumental records only go back to a few hundred years in the best cases, most of what we know about past climate changes over different geologic intervals comes from proxy records. Climate proxies can be biologic (tree rings, corals), found in geologic materials (sediment, soil, or ice), based on chemical tracers (stable isotopes, biomarkers, etc.), or combinations of the above. For example, stable isotopes of oxygen are commonly used in ice cores and marine sediments to evaluate temperatures and ice volume based on the different physical properties of the different oxygen isotopes found in water that behave in a predictable way and are incorporated in precipitation that ultimately become glacial ice and microfossil skeletons that reflect seawater chemistry.

Commonly used proxies include:

- **Oxygen isotopes**—Oxygen has three isotopes, and two occur commonly—^{18}O and ^{16}O. The relative difference in mass between ^{18}O and ^{16}O leads to water of different masses: $H_2{}^{18}O$ and $H_2{}^{16}O$. The masses are different enough that the two different types of water have different physical properties; namely, lighter water will evaporate more readily and heavy water will precipitate more easily. Ultimately, when ice sheets grow, the isotopic composition of entire oceans changes as light water evaporates from the oceans and is stored in ice sheets. When ice sheets melt, the light water is returned to the oceans. The ratio of ^{18}O to ^{16}O (known as $\delta^{18}O$) changes in a predictable way based on temperature and ice volume and is recorded in the carbonate tests and shells of microorganisms living in the oceans. The changes in $\delta^{18}O$ are also recorded in glacial ice recovered as ice cores. Together these different sets of data provide useful information about the amount of water tied up in ice sheets and sea surface and deep ocean temperatures.

- **Hydrogen isotopes**—Hydrogen also has several stable isotopes—^1H, ^2H (deuterium), and ^3H (tritium). The principle of hydrogen isotopes is very similar to that of oxygen isotopes. Commonly, δD is measured in glacial ice and represents local air temperatures.

- **Carbon isotopes**—Carbon isotopes ($\delta^{13}C$) do not tell us anything in particular about temperatures, but they can inform paleoclimatologists about changes in the carbon cycle, for example, changes in carbon reservoirs and exchanges between reservoirs in the terrestrial biosphere compared to the oceans or the influence of CO_2 compared to methane (CH_4).

- **Marine sediments**—In addition to stable isotopes of carbon and oxygen, marine sediments can be analyzed for other aspects of chemistry and biology. For example, chemicals that some phytoplankton secrete can often be preserved in sediments for long periods of time (biomarkers like alkenones). In other cases, the assemblage of fossil organisms can provide information about paleoenvironmental conditions. Marine sediments can also be analyzed to understand paleo-wind direction and ocean current locations, volcanism, paleo-plate motions, ocean productivity, ocean pH, and many other types of information.

- **Ice cores**—In addition to stable isotopes, ice cores also trap gases that represent past atmospheres. Air bubbles get trapped in the glacial ice and once the air bubbles can no longer exchange gas with the atmosphere, they are preserved; for example, the amount of CO_2 or CH_4 at the time the air was sealed off can be determined by analysis of the air bubble. Ice cores also preserve dust that was in the atmosphere and deposited with the glacial ice. In general, when ice sheets expand and grow, there is so much water tied up in the glaciers that continental areas are more arid and therefore, dustier.

- **Coral reefs**—Corals form their skeleton from seawater; therefore, the chemistry of coral skeletons can provide information about seawater chemistry and temperatures. In addition, coral reefs provide detailed information about changes in sea level.

- **Dendrochrononlogy**—Dendrochronology uses tree rings to learn about paleoclimates. Trees normally produce only one ring each year. The size of the ring is an indicator of the environmental conditions that affected the tree's growth during a particular year. Factors such as drought, insect infestation, flood inundation, and competition from nearby trees may cause the tree to grow more slowly, and thus produce narrower rings for one or several years. Other factors such as fire or flooding may cause physical damage to the tree, which forms a scar that gradually gets covered over with new growth, but can still be seen in the tree rings. Tree cores are frequently taken because they do not damage the tree, and because each ring represents a year of growth, the trees can be dated and anomalous rings or sets of rings can be linked to environmental change. Using a method called cross dating (comparing patterns of growth in rings), trees can be dated and environmental changes can be investigated from fossil wood or trees that are no longer living, for example, in cross beams in homes or other structures.

- **Other useful proxies**—Pollen, paleo-lake levels, speleothems, etc.

Using a dissecting microscope view the tree rings of several different tree cores. Look for differences in annual growth and think about what may have led to the differences between rings and between tree cores. All of these cores are from WFWA, so they theoretically should have experienced the same weather and climate. Record your observations.

1. What are two factors that can affect the width of a trees rings? Describe how each of these factors may exert its effect.

2. Sketch one of the tree cores you viewed. Indicate on your sketch any wider or narrower rings and suggest what may have led to the variability.

PART 2: UNDERSTANDING GLOBAL CLIMATE CHANGE USING VOSTOK ICE CORE DATA

Background

Snow that falls in the polar regions of the earth (e.g., Greenland and Antarctica) and at high altitude is preserved within glaciers and ice sheets, resulting in annual layers in the ice, similar to annual layers seen in tree rings. These annual, vertical layers provide scientists with a record of the earth's past climate going back in time hundreds of thousands of years ago.

One such ice core was drilled in East Antarctica at the Soviet station Vostok. The Vostok ice core is very deep and gives scientists a climate record of Earth dating back 800 thousand years. Analyzing methane and carbon dioxide trapped in the air bubbles of the ice core, as well as investigating dust trapped in the annual layers, provides detailed profiles down the length of the core that show such important climate events as glacial (extensive ice sheets) and interglacial stages (when continental ice sheets melted).

How are scientists able to gain such important knowledge about global climate change from the Vostok ice core?

time that the dust was deposited. Different kinds of fallout from the atmosphere, including airborne continental dust and biological material, volcanic debris, sea salts, cosmic particles, and isotopes produced by cosmic radiation, are deposited on the ice sheet surface along with the snow, thus mixing with the snow and also acting as a distinctive barrier between different ice layers. When there is more dust in the ice core, it is often interpreted as a time of increased aridity.

- The composition of bubbles of air trapped in the ice is a measure of the composition of the atmosphere in ancient times. As more and more snow is deposited on the ice cap, pressure increases and actually traps air within the deposited layer. The isotopic composition of water, and in particular the concentration of the heavy isotope of oxygen, ^{18}O, relative to ^{16}O, as well as ^{2}H (deuterium) relative to ^{1}H, is indicative of the temperatures of the environment. During cold periods, the concentration of less volatile $H_2(^{18}O)$ in the ice is lower than during warm periods. The reason for this is that at lower temperature, the moisture has been removed from the atmosphere to a larger degree resulting in an increased depletion of the heavier isotopes.

1 Activity: Interpretation of the Vostok Ice Core Data

1. **Determining age of the core:** Age is calculated in two different ways within an ice core. The ice age is calculated from an analysis of annual layers in the top part of the core and ice flow models are used at deeper depths where overlying pressure compacts the annual layers making them more difficult to count. Gas ages are different than the ice they are encased within. This is because gas is only trapped in the ice at a depth well below the surface where the pores close.

STEP 1: Open the Excel file titled Global Change.xls and save it. Plot both the ice age (x-axis) and the gas age (x-axis) as a function of depth (y-axis) on the same graph.

REMEMBER: The age of the ice core should increase with depth. Use the plots to answer the following questions:

2. What are the depths of the shallowest and deepest data points?

For the rest of the lab, assume that the most shallow ice core measurements represent the environmental conditions in the 18th century before the Industrial Revolution.

3. Does age increase or decrease down the core? Why?

4. Why do the two age curves differ?

5. How much younger is a bubble of gas than the ice that surrounds it at a depth of 250 meters?

6. Is the thickness of an annual layer of ice smallest at the top or bottom of the core? Why?

STEP 2: Next, calculate temperature changes based on the isotopic composition of the ice.

- Insert a blank column into the table to the right of the delta-deuterium column (δD).
- Isotopic ratios are used to model temperature. Calculate the temperature at Vostok based on the following formula describing the relationship between temperature and deuterium concentration:

$$\text{Temperature } (^\circ\text{C}) = -55.5 + (\delta D + 440) / 6$$

- Now plot your calculated temperature vs. ice age.

7. How reliable do you consider this paleoclimate record to be?

8. How long ago did the maximum temperature occur? How long ago did the minimum temperature occur?

STEP 3: Carbon dioxide (CO_2), methane (CH_4), and dust concentrations are very important when interpreting global climate change.

9. Plot CO_2 as a function of gas age.

   - How closely does the plot of CO_2 resemble that of temperature?

10. Now plot CO_2 against temperature.

    - What trends do you notice?

11. Make the same plots for CH_4.

    - Is CO_2 or CH_4 more closely correlated with temperature? Why do you think that is?

12. Now make a plot of dust as a function of ice age. Compare the dust graph to the temperature graph.

    - How well do the changes in dust concentration correlate with the temperature changes?

13. What are the current concentrations for atmospheric CO_2 and CH_4?

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13. What are the current concentrations for atmospheric CO_2 and CH_4?

14. Calculate the changes in CO_2 and CH_4 concentrations between the last glacial maximum and the 18th century, and between the 18th century and today.

- Why were CO_2, CH_4, and dust concentrations different during the glacial time as compared to the 18th century?

PART 3: CLIMATE CHANGE IMPACTS IN YOUR COMMUNITY

Do some additional research and try to find out more about the predicted consequences of climate change near your hometown. List some of the expected impacts of global warming.

HYPOTHESIS ACTIVITY

Given what you have learned so far this semester, form hypotheses to explain the following scenarios:

1. While studying the Vostok ice core, you identify a time interval with extremely elevated atmospheric carbon dioxide.

2. After taking several tree cores, you identify a pattern of three small tree rings followed by one large ring.

3. Your city has identified a pattern of increasingly hot summers, reduced precipitation, and warmer than normal winters over the past 40 years.

4. In those same 40 years, another city has identified increasing torrential storms, flooding, and lower than normal temperatures.