9.1 Discovering Past Climates

Key Terms
paleoclimatologist
ice core
isotope
sedimentary rock
fossil

People have been recording weather data for only a few hundred years. To learn about what Earth's climate was like more than a few centuries ago, scientists must get creative. People who study past climates are called **paleoclimatologists**. These scientists are interested in how Earth's climate system formed and has changed throughout Earth's history.

paleoclimatologist a scientist who studies past climates on Earth

What Tree Rings Reveal About Past Climates

If you want to know what the weather was like 150 years ago, you could get the answer from an old tree. As trees grow, rings of new growth form within the trunk. Tree growth is affected by temperature and rainfall. The amount that a tree grows each season is indicated by the size and colour of the annual rings, which you can see in the cross section of the tree trunk in **Figure 9.1**.

A wide tree ring indicates wet and cool weather, which allows trees to grow rapidly. A thin ring is produced in dry and hot conditions, when tree growth is slower. A dark ring marks growth during late summer, and a light-coloured ring indicates growth during spring. Tree rings can also provide evidence of floods, droughts, insect attacks, and lightning strikes.

Living trees hold records of climate dating back no more than a few hundred years. Tree trunks from archaeological sites allow scientists to determine what climate was like a few thousand years ago.

Figure 9.1 Each cross section of a tree trunk shown here reveals dozens of rings. A tree grows an additional ring every year.

Ice Cores–Records of Past Climates

ice core a long cylinder of ice obtained by drilling into a glacier

One of the most important sources of evidence used by paleoclimatologists lies buried deep in polar and glacial ice. The great ice sheets that cover most of Greenland and Antarctica have built up over hundreds of thousands of winters. Like tree rings, layers of snow and ice accumulate year after year. To uncover evidence of past climate conditions, scientists use a special drill, shown in **Figure 9.2A**, that penetrates deep into the layers to extract long, cylinder-shaped samples called **ice cores**, as shown in **Figure 9.2B**.

The extent of the climate record obtained by drilling depends on the depth of the ice core. The European Project for Ice Coring in Antarctica (EPICA) obtained climate records from Antarctic ice that date back nearly 800 000 years. Drilling was completed in December 2004, reaching a final drilling depth of 3270 m. Data from this project are being compared with data from earlier research on ice cores extracted in Greenland by the Greenland Ice Core Project (GRIP). The comparison of ice from these two sites provides a more complete picture of natural climate variability around the globe than scientists have had before.

Activity 9-2

Analyzing Tree Rings

How can trees tell us about climate? In this activity, you will analyze tree growth rings for evidence of temperature changes and precipitation patterns.

Materials

- ruler
- pencil
- paper or notebook
- tree stump (sawn off) or other cross section of a tree

The rings of a tree represent the growing conditions for each year of the tree's life.

Procedure

1. Find the innermost ring of the tree. This is the oldest ring. Counting the rings from there to the edge of the tree stump gives you the tree's age. How old is your tree?
2. Measure and record the thickness of several rings near the centre and near the outer edge of your tree stump.
3. Record as many distinctive growth patterns or other markings as you can. For example, do you see three thick, dark rings in a row? Or a thin ring, a thin black line representing a forest fire, and a thick, black line?
4. Wash your hands after this activity.

Questions

1. How did the length of the growing seasons change as the tree aged? What was your evidence for this inference?
2. Compare your tree's growth pattern with those of two other students. Do you think the lives of your trees overlapped? Explain your answer.
3. Investigate the climate and major events (such as fires and insects that infest trees) over some of the lifetime of your tree. What relationships can you find between the tree rings and what happened when the tree was growing?

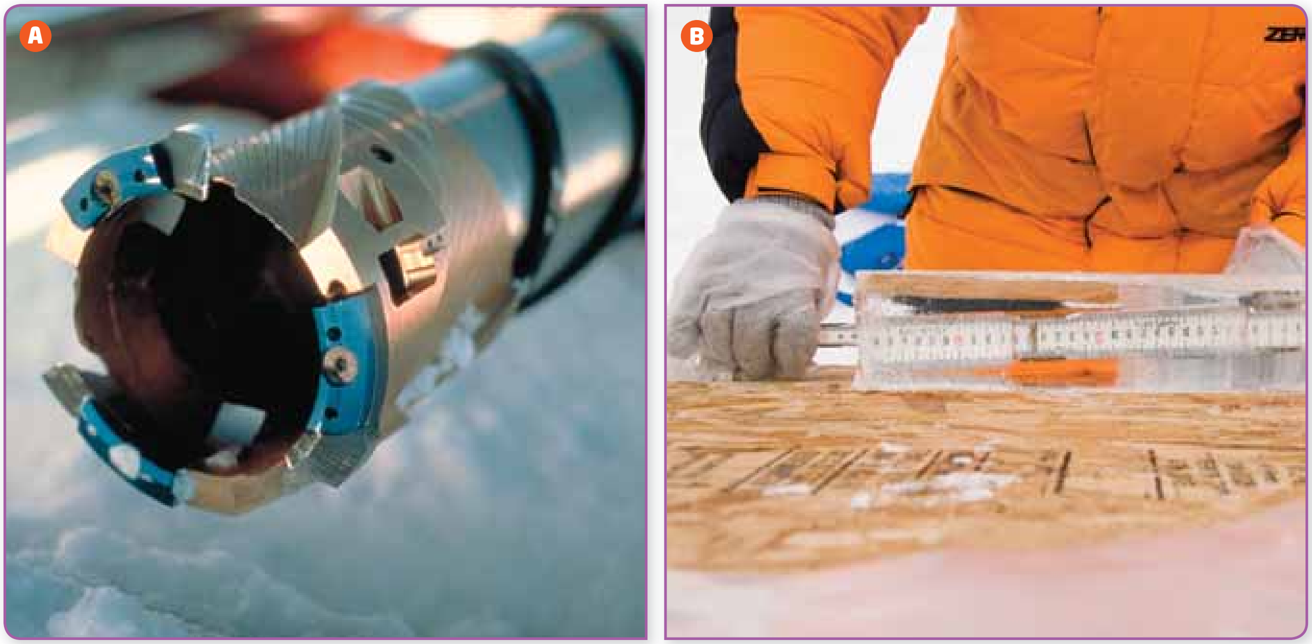


Figure 9.2 Scientists use **A** a special drill to obtain **B** ice cores. A drill can penetrate to a depth of 50 to 70 m in one day. This depth is equivalent to about 200 years of ice build-up.

Evidence of Past Climates Obtained from Ice Cores

The ice that makes up ice cores is deposited annually when the summer melt is not enough to get rid of the previous winter's snow. The formation of glacial ice requires only a few hours of strong sunshine to cause the snow to form an airtight crust, even at –20°C or colder. Ice cores hold four types of clues frozen in time: the types of particles trapped in the ice, the size and shape of ice crystals, the composition of trapped air, and the composition of the water in the ice. Each clue remains trapped as a frozen record, until the ice melts.

1. Dissolved and particulate matter in the ice Dust, ashes, salts, plant pollen, and other matter drifting in the air are brought to Earth's surface when it rains or snows. Frozen samples of these materials give clues about events and conditions, such as volcanic eruptions, meteorite impacts, forest fires, and vegetation cover.

2. Physical characteristics of the ice Ice can occur in many forms—from snowflakes and hail to glaciers and pack ice. In each form, the ice is made up of crystals of frozen water that can vary greatly in size and shape. The physical characteristics of the ice crystals indicate the conditions of temperature and humidity at the time the ice crystals formed.

3. The composition of trapped air bubbles When water freezes, tiny air bubbles in the water may become trapped inside the ice. These pockets of air remain unchanged in the ice, providing time capsules of the atmospheric composition on the day when the ice formed. Analysis of the air locked inside ice cores at different depths gives scientists a record of changes in the atmospheric concentration of greenhouse gases over hundreds of thousands of years.

Suggested Investigation

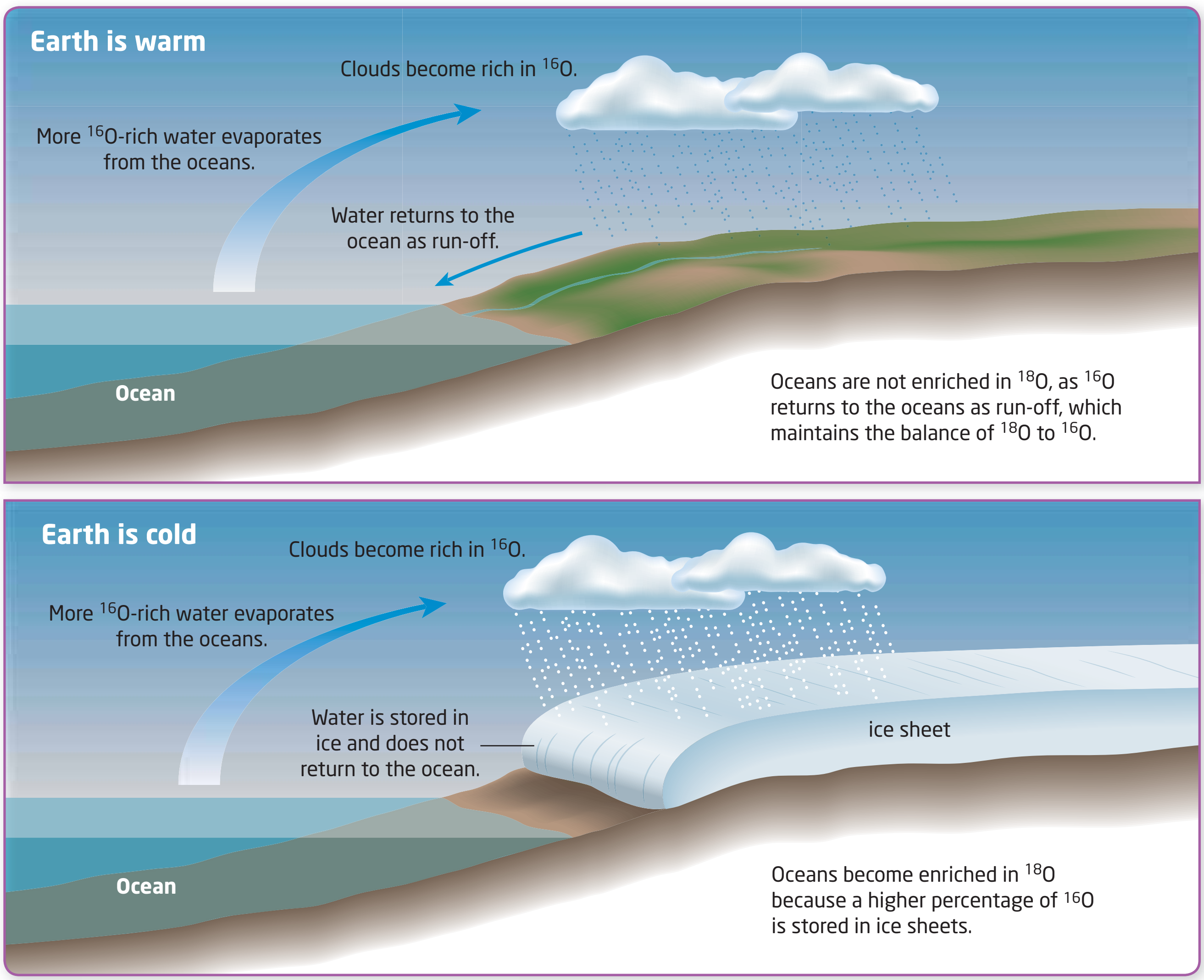
Data Analysis Investigation 9-A, Understanding Ice-Core Data, on page 382

isotope any of two or more forms of an element that have the same number of protons but a different number of neutrons (for example, deuterium is an isotope of hydrogen)

4. The composition of the ice Water (H_2O) contains varying proportions of hydrogen and oxygen isotopes. **Isotopes** are different atoms of a particular element that have the same number of protons but a different number of neutrons. For example, oxygen (O) has three naturally occurring isotopes, oxygen-16 (^{16}O), oxygen-17 (^{17}O), and oxygen-18 (^{18}O). When water contains "heavy" oxygen-18, the molecular weight of the water is heavier than the weight of water that contains oxygen-16. The difference in molecular weight affects the physical properties of the water, including the freezing point. Water that contains oxygen-18 freezes at a higher temperature than water that contains oxygen-16 does. In addition, water that contains oxygen-16 evaporates more quickly than water that contains oxygen-18 does.

The relative concentration of isotopes in different layers of ice indicates the temperature at the time the ice formed. Polar ice that forms when global temperature is high contains a higher percentage of oxygen-18. When global temperature is low, polar ice that forms contains a lower percentage of oxygen-18. This relationship is shown in **Figure 9.3**. Thus, different concentrations of isotopes in different layers of ice allow scientists to reconstruct temperature changes over many years.

Figure 9.3 The amount of different oxygen isotopes in ice layers depends on global temperature changes.



How Scientists Determine Patterns of Past Climate Change

Chemical analyses of ice cores can be used to identify patterns of past climate change. For example, **Figure 9.4** shows carbon dioxide data that were gathered by studying the gas bubbles in ice cores. The data indicate that concentrations of carbon dioxide in the atmosphere have risen and fallen in a series of cycles over the past 650 000 years.

To estimate atmospheric temperatures in the past, scientists measure concentrations of hydrogen and oxygen isotopes in the ice from which the carbon dioxide data were obtained. The ratio of heavy water to light water in an ice core is directly related to temperature. According to the graph, carbon dioxide concentrations and temperatures are closely related. Does this connection prove that rising levels of carbon dioxide cause global warming? Or could global warming be caused by other factors that also lead to increasing concentrations of carbon dioxide? To answer these questions, scientists use computer models to determine how different variables determine different patterns of climate change.

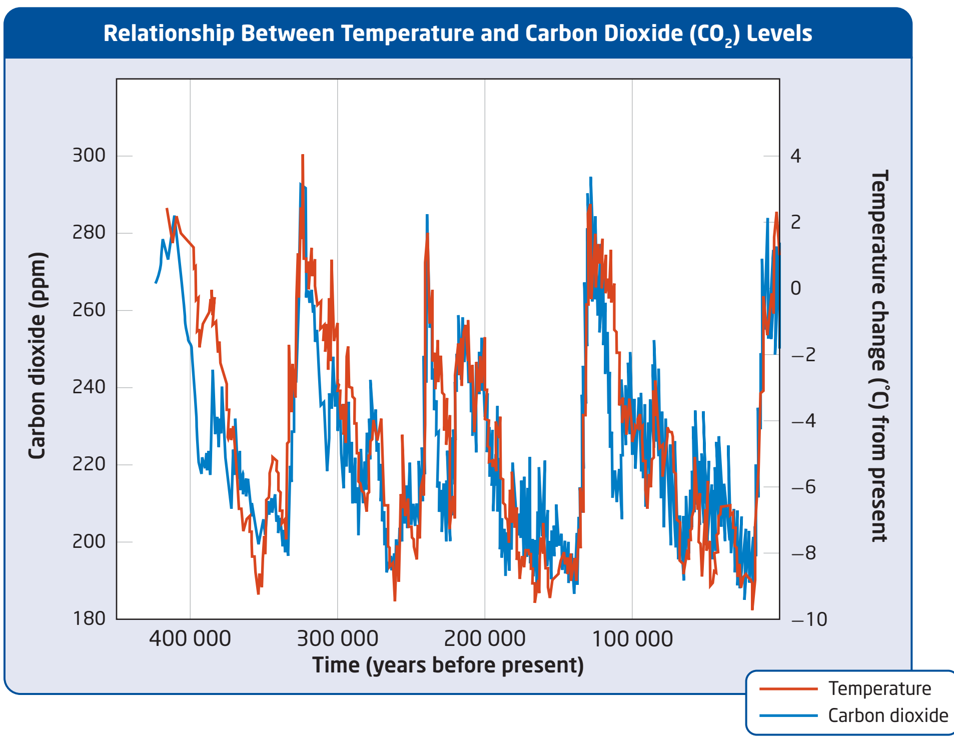


Figure 9.4 Changes in carbon dioxide concentration and temperatures can be graphed based on data from ice cores and sediment cores. The red line represents temperature, and the blue line indicates carbon dioxide levels.

Learning Check

1. How do paleoclimatologists use tree rings to study climate?
2. What four types of evidence do ice cores provide?
3. Based on the evidence provided in **Figure 9.4**, do you think increasing carbon dioxide in the atmosphere causes global warming? Explain your answer.
4. Draw a cause-and-effect map to summarize how oxygen isotopes in ice are related to global temperature.

Evidence of Past Climates from Sedimentary Rock

sedimentary rock a type of rock that is formed by the deposition of sediment

The oldest ice on Earth is less than one million years old. To obtain evidence of climates older than this, paleoclimatologists examine rocks. Every year, billions of tonnes of sediment (fragments of rock) wash from the land and accumulate in thick layers on ocean floors and lake beds. The hard parts of small sea creatures (such as diatoms, algae, and foraminifera) and pollen from flowering plants are preserved in these sediments. Over long periods of time, this deposited material becomes compressed and hardened into **sedimentary rock**, such as that shown in **Figure 9.5**.

Figure 9.5 Sedimentary rock results from the build-up of layers of sediment over long periods of time. Particles in each sedimentary layer hold clues to past climates.

What Sediment Cores from Lakes and Oceans Reveal

A sediment core is shown in **Figure 9.6**. Scientists analyze the composition of the sediments to learn about climate conditions in the past. In some cases, the type of pollen from flowering plants provides a clue about global temperatures by indicating what plants were most common at a certain time in the past. Scientists also study the chemical composition of the microscopic organisms in sediment cores from lakes and oceans. Like ice, the shells of living things contain different isotopes of oxygen. The oxygen isotopes can help paleoclimatologists infer the temperature of the water in which the organisms lived.

Figure 9.6 Scientists study the variations in chemical composition of sediment cores to estimate past climate patterns.

Information from Sedimentary Layers in Glacial Lakes

In some locations, sediment records in lakes reflect regularly repeating annual changes in sediment deposition. Annual sedimentary layers are called *varves*. Sedimentary layers in many glacial lakes provide a record of the seasonal changes in deposition that happen every year. In the summer months, thick deposits of coarse, light-coloured sediments form as meltwater washes sediment into the lakes. In the winter, when little new sediment is entering the lake, fine, dark-coloured sediments settle to the bottom of the lake. This pattern of light and dark layers can be used to measure the amount of sediment and the type of sediment that was deposited each year. In turn, paleoclimatologists can use this information to estimate rainfall and temperature patterns over a long period of time.

Evidence of Past Climates from Fossils and Preserved Organisms

The remains or traces of living things, called **fossils**, also provide valuable clues when paleoclimatologists reconstruct past climates. Fossils form when some part of an organism does not decay after the organism's death. The sediment formed by the remains of micro-organisms can be analyzed to obtain information about the composition of the oceans and atmosphere at the time the organisms lived.

Large fossils are also useful to paleoclimatologists. In some cases, bones, teeth, shells, and other hard parts of living things become fossils. In other cases, whole organisms are trapped in amber or are frozen in ice or permafrost. Even footprints, imprints of leaves, and fossilized dung provide information about the organisms that once lived in a region.

fossil the traces or remains of a once-living organism

What Paleoclimatologists Can Learn by Studying Fossils

The types and abundance of fossilized remains in each rock layer help scientists reconstruct the environment at the time the layer formed—including the climate. Because plants and animals are uniquely adapted to the environments in which they live, studying these fossils gives scientists clues about what environments were like thousands to millions of years ago. For example, alligators and palm trees are adapted to life in tropical regions. If fossils of alligators and palm trees were found on an Arctic island, scientists could infer that those Arctic islands once had a warm climate. An example of this use of fossils is shown in **Figure 9.7**.

Some fossils can provide very specific details about climates. When scientists study a fossilized coral reef, the amount and type of fish fossils tell the scientists much about the temperature and the depth of the water, because different species of fish survive in very specific water depths and temperatures.

Figure 9.7 This fossil is the remains of a fern from Earth's Cretaceous Period, which lasted from 145.5 million years ago to 65.5 million years ago. This type of fern grew in a warm, moist tropical climate that was very different from the ice-covered continent of Antarctica on which this fossil was found.

How Scientists Infer the Rate of Climate Change

The methods described in this section help scientists track climate change. But how long do these changes take to appear, and how long do they last? As you learned in Chapter 7, factors that affect climate act on different time scales. Tectonic plate movement takes millions of years. Orbital changes take several tens of thousands of years. Volcanic activity affects Earth's atmosphere within a day, and the effects can last for several years.

Sedimentary rocks, fossils, and ice cores indicate that climate has changed radically several times throughout Earth's history, as shown in **Figure 9.8**. In some cases, climate change took thousands to millions of years. However, evidence suggests that climate also changed abruptly several times in the past. For example, some ice cores taken from Greenland show increases in average temperature of up to 6°C in a few decades or less.

Scientists are still debating whether climate change is affected more by slow, gradual changes or by sudden, catastrophic changes. This question is at the centre of the controversy about whether humans can cause Earth's climate to change significantly. Recent evidence suggests that the climate shift that caused the last glacial period to end 11 000 years ago may have taken as few as three years to happen, even though the glaciers themselves took thousands of years to melt. A variety of evidence indicates that other ice ages in Earth's history resulted from slow, accumulated changes in the Earth system. However, most climatologists agree that humans are affecting the composition of Earth's atmosphere. This influence may increase or decrease the rate at which climate change progresses.

Sense of *time*

The oldest known sedimentary rock in the world was discovered in 2001 by a team of Canadian scientists on the eastern shore of Hudson Bay in northern Québec. The rock sample is 3.75 billion years old. That rock is about four fifths the age of Earth itself.

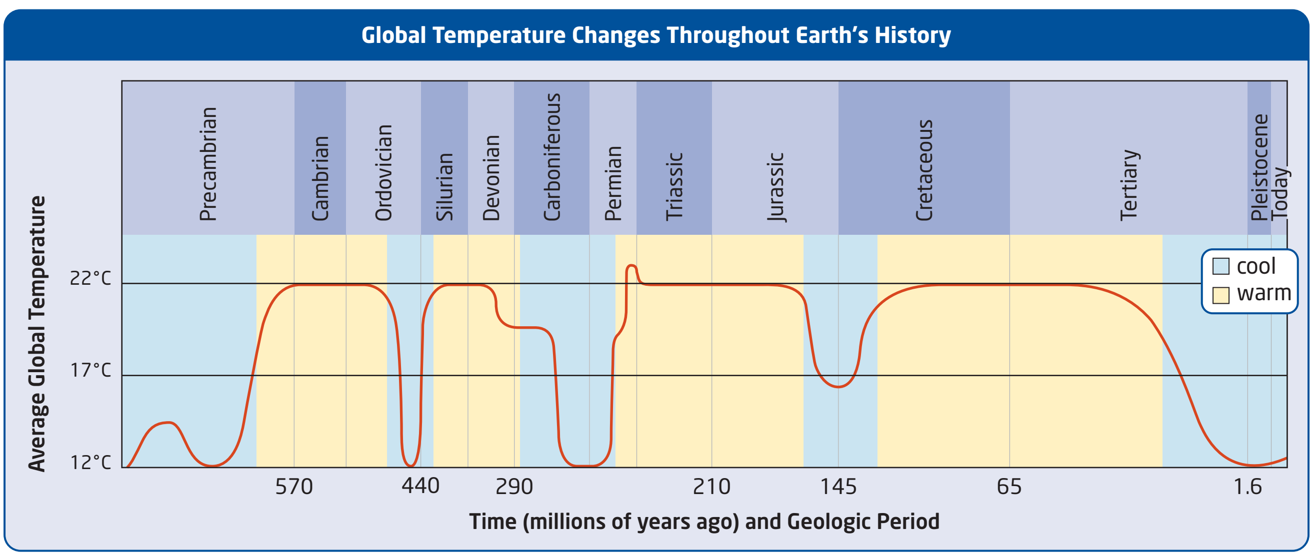


Figure 9.8 Evidence from sedimentary rocks and fossils indicates that before the most recent ice age, Earth experienced several major cooling periods.

Section 9.1 Review

Section Summary

- Paleoclimatologists reconstruct past climates by using the evidence that climate leaves behind in tree rings, ice, sedimentary rock, and fossils.
- Tree rings can provide evidence about growing conditions, such as temperature and precipitation, during the lifetime of the tree.
- Ice cores can provide information about global temperature and the composition of the atmosphere for thousands of years in the past.
- Scientists use chemical analyses of sediment cores from lakes and oceans to reconstruct past conditions of the atmosphere and the hydrosphere.
- Rocks can provide information about the conditions that existed when they formed.
- Fossils are remains of living things. Their distribution and characteristics provide clues about the climate at the time the organisms lived.

Review Questions

K/U **1.** List four sources of evidence about past climates.

K/U **2.** How do particles frozen in polar and glacial ice help paleoclimatologists reconstruct past climates?

K/U **3.** Use the information in **Figure 9.3** to write a brief paragraph that explains how global temperature affects the ratio of oxygen-18 and oxygen-16 in the oceans and in glacial ice.

T/I **4.** The diagram on this page shows a series of varves from a glacial lake. Dark layers indicate the winter deposition and light layers indicate summer deposition. How might you explain the difference in the thickness of layers in years 8 and 9?

T/I **5.** Describe how the methods scientists use to study sediment cores to find out about past climate conditions are similar to the methods they use when studying ice cores.

A **6.** What would finding fossils of tropical fish in sedimentary rock tell you about the climate conditions at the time that the rock formed?

C **7.** Use a Venn diagram to compare information provided from tree rings to information provided from ice-core samples.

K/U **8.** How can scientists produce graphs of atmospheric carbon dioxide levels for thousands of years in the past, when people have only been able to measure these levels for the last few decades?