

Teacher Background Information:

Paleoclimatic Evidence Using Stable Isotopes

It is fortunate for *paleoclimatologists* that about 570 million years ago, marine organisms all over the world began to secrete calcium carbonate (CaCO_3) shells. These shells served as protection against predators and helped enhance the longevity of the species. As it turned out, they were also useful for scientific research. It is possible to use the oxygen molecules in their shells as indicators of past ocean temperatures. The amount of the heavier isotope, ^{18}O , that the organism extracts from the surrounding sea water depends on the temperature of the water; the colder the water the greater the preference for ^{18}O as compared to the lighter, ^{16}O . Past water temperatures can be determined by measuring the $^{18}\text{O}/^{16}\text{O}$ ratio in fossil CaCO_3 skeletons. They are called *isotopic temperatures*.

Paleoclimatologists use an *oxygen isotope ratio index*, $\delta^{18}\text{O}$, which is simply the relative difference between the ratio of $^{18}\text{O}/^{16}\text{O}$ of the water, ice or silicate or carbonate fossil sample and the ratio for today's standard condition. $\delta^{18}\text{O}$ is a small number, typically a few tens of parts per thousand or less. If it is negative, it means that there is relatively less ^{18}O in the sample than for today's standard conditions; the reverse is true if $\delta^{18}\text{O}$ is positive.

There are circumstances that can change the isotopic composition of the water itself, as well as that of the secreted shell. This would confuse interpretation of the $\delta^{18}\text{O}$ values as indicative of specific paleotemperatures. For example, when water evaporates, molecules containing ^{16}O are more readily vaporized, just because it is lighter. Therefore, colder temperatures discriminate against the evaporation of ^{16}O and in favor of the precipitation of ^{18}O molecules. Rain or snow at colder temperatures is generally depleted of ^{18}O ; in part because less ^{18}O is evaporated in the first place from colder water. When glaciers are forming on land, the cold precipitation is depleted in ^{18}O relative to the water in the ocean. As a result, the ocean during an ice age will become "enriched" in ^{18}O because ^{16}O abundant water will be locked up in the glaciers. When ^{18}O in the oceans is positive, it means that the ice volume is large because ^{16}O rich water is tied up in the ice.

At the same time, the snowfall that builds glaciers is poor in ^{18}O . Because colder temperatures cause greater ^{18}O depletion in snowfall, it allows scientists to estimate paleotemperatures by examining the ^{18}O in the fossil ice. Single years of climatic history can be distinguished back over thousands of years by studying the ice layers from places like Greenland and Antarctica. The most intensive study was done on the Greenland ice core by a group headed by the Danish physicist Willi Dansgaard in the 1960's. He characterized various layers representing glacial or interglacial periods by measuring the oxygen isotope ratios of the ice. More ^{18}O in ice relative to ^{16}O indicates an interglacial period. The layers of snow accumulation can be viewed as an absolute chronology, much like the growth rings

of a tree. However, assigning ages to the layers is difficult because seasonal layers of snow in the lower section of an ice sheet merge as they become ice, distorting the year by year chronology. In addition, the ice sheet itself is distorted as it flows out and under its own weight. Ice deep down in the column may have come from a place well upstream and many thousands of years earlier. Dansgaard and his team dated the Greenland ice core back as far as 140,000 years. From 140,000 to 75,000 years ago, they found that ^{18}O was generally abundant in the ice ($\delta^{18}\text{O} = -25\%$), suggesting a warm period. From then until about 10,000 years ago, less ^{18}O ($\delta^{18}\text{O} = -40\%$) suggests an ice age.

Although isotopic chemistry is complicated, and more uncertainties infiltrate $\delta^{18}\text{O}$ interpretations, enough careful experimentation has been done that many scientists are nonetheless fairly confident that the technique works. It is probably the single most important technique for reconstructing the ups and downs of Earth's ancient climates.