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# Stable Isotopes and Climate Change


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## ***Stable Isotopes and Climate Change***

The following description of the role of the study of stable isotopes in water and carbon dioxide molecules when constructing a record of Earth's pattern of climate change is an excerpt from:

*Climate Change and Society* by Raymond S. Bradley & Norman E. Law (2001)  
Nelson Thornes, Cheltenham, UK (ISBN: 0 7487 5823 2)

### **Evidence for Climatic Changes in the Quaternary Period**

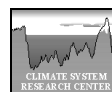
Water in the world ocean has a certain isotopic composition. Isotopes are variations in the atomic mass of an element. In the case of oxygen (which makes up part of the H<sub>2</sub>O molecule) there are 2 important isotopes (O-18 and O-16);

O-18 is the heavier isotope, having more mass (2 more neutrons) in its atomic nucleus. Water molecules may contain both isotopes, but when water evaporates molecules of water containing the heavier isotope do not change from the liquid to the vapour state as easily as those containing the lighter (O-16) isotope.

During ice ages, water is continuously being removed from the oceans and stored on land in the form of snow and ice (whereas during interglacials, most of the water falling on continents returns to the oceans through rivers). The result is that during glacial times, when water molecules are removed from the oceans by evaporation, but not returned (via condensation, and rainfall) the remaining ocean water slowly becomes depleted in molecules with the lighter isotope (or you could say, relatively enriched in water with the heavier isotope). In other words, the growth of ice sheets on land not only caused sea-level to fall, but it also changed the chemical (isotopic) composition of the entire world ocean. We know this was so because tiny organisms known as foraminifera – a form of zooplankton that build a calcareous shell around them – live in many parts of the ocean and the chemistry of the ocean waters in which they live affects the chemical composition of the shells they construct. When the foraminifera die, the hard shell (known as a test) falls to the ocean floor to accumulate as ocean sediment.

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Cores of sediment recovered from the deep oceans provide a record of these organisms going back in time, as successive generations of tests were deposited on those of earlier periods. By analyzing the isotopic composition of the calcium carbonate in these tests, a picture of changing ocean chemistry over time (and hence of ice sheet growth and decay on the continents) can be constructed

The marine isotope record constructed from the chemistry of the tests of foramanifera, only gives us a “big picture” view of the earth’s climate –we see clearly that there have been shifts --- often quite rapid between glacial and interglacial periods on a global scale. But these data do not reveal how climates in particular regions might have varied. For this, studies of other phenomena that might have recorded past climates are needed to build up a geographical picture of climates in the past. These phenomena are termed paleoclimate proxies, meaning they provide a record in their structure of climates in the past. For example, lake sediments may contain pollen grains that were deposited from the vegetation in the local region. Pollen grains are extremely resistant to decay and have a form that differs from one plant type to another. Cores of sediment from lakes can thus give a picture of what vegetation was like in the past. Since vegetation is largely controlled by climate, understanding the changes in past vegetation can be used to infer how climate in a particular location may have changed over time. Pollen grains, in lake sediments and in peat bogs, are thus paleoclimate proxies.

Another example is the study of diatoms -- tiny organisms that secrete a protective cover of silica. In some lakes, the type of diatom living in the water is dependent on its salinity. In a semi-arid environment, if salinity increases due to higher temperatures, and/or less rainfall, the type of diatoms that thrive in the lake will change, and this will be recorded in the lake sediments when the organisms die and fall to the lake floor. Cores of sediment will reveal these shifts in species composition over time, indicating changes in the local climate (in this case in the local hydrology). By studying such sediments in many locations, paleoclimatologists build up a geographical picture of how climates changed in the past.

A remarkably detailed record of past changes in climate has been recovered from ice cores, mainly from Antarctica, Greenland and high mountain ice caps in the Tropics. In such locations, snow that accumulates at high elevations does not melt; it is buried by later snowfall and compressed into ice. As more snow accumulates, the ice is slowly compressed, flowing outwards towards the edge of the ice sheet. By drilling down through the center of the ice sheet, a record of past snowfall events can be recovered. The longest record so far obtained is from East Antarctica, and covers the last 800,000 years. In Greenland, ice cores provide a clear record of approximately the last 120,000 years (almost to the last interglacial) and in the Tropics, an ice core from 6048m on Huascarán in Peru goes back over 25,000 years.

In some areas, such as central Greenland, it is possible to identify annual layers in the ice, enabling a very detailed record to be studied, almost year by year, over the last 40,000 years. The ice from these cores contains an amazing amount of information about past climate. The snow itself contains minute traces

of chemicals washed from the air through which it passed en route to the ice sheet. For example, in Greenland variations in the amount of sodium ions ( $\text{Na}^+$ ) are thought to reflect changes in the extent of sea-ice; when there is a lot of open water nearby, the air picks up salt (sodium chloride) which gets washed out of the air into the snow.

A very prominent variation in the ice between glacial and interglacial periods is the presence of wind-blown dust. During glacial times, the atmosphere was much dustier than today, due to a combination of higher wind speeds, and drier conditions in the continental interiors. Dust from glacial times in ice cores from Antarctica has been chemically identified as coming mainly from Patagonia (Argentina) which was even drier at that time than it is today.

The snow itself in ice cores also provides a direct record of the temperature when the snow formed. Just as the water vapor evaporating from the oceans has slightly less O-18 than the ocean water, so the snow falling from clouds over Greenland and Antarctica must have less O-18 than the original oceanic source. However, as temperatures cool and more water condenses in clouds as snow, the first snow that forms has more O-18 than the vapour from which it condensed. This is because the heavier isotope prefers to be in the water phase (lower energy state); it was for this reason that during the process of evaporation) from the oceans there was a tendency for the O-18 to stay in the liquid form, causing the water vapor to be relatively depleted in O-18 compared to the ocean water. So, as water continues to condense from clouds, the remaining water vapor has less and less of the heavier isotope (O-18) so the snow that is produced also has less O-18. It is as if the air is squeezing the vapor through a sieve that preferentially allows water (snow) with molecules containing the heavy isotope through first. The vapor that is then "left behind" has even fewer molecules of  $\text{H}_2\text{O}-18$ , so the more the air is cooled (for example, by drifting to high latitudes, or to high elevations) the more the snowfall at those locations is "depleted" in O-18.

This change in the relative amounts of the two oxygen isotopes in water molecules ( $\text{H}_2\text{O}-16$  and  $\text{H}_2\text{O}-18$ ) in effect provides a "paleo-thermometer" that records the air temperature when the snow first formed from clouds in the past. Studies have also shown that exactly the same process occurs in the hydrogen isotopes of water. Hydrogen has two "stable" isotopes (H-1 and H-2) and the heavier of these (H-2, also known as deuterium) acts just like the O-18, so measurements of paleotemperature can be based on either oxygen or hydrogen isotopes in the water molecules in ice cores.

Today, the Gulf Stream carries warm salty water towards high latitudes, where it cools and sinks, eventually moving around the global ocean at depth in the manner of a gigantic conveyor belt. This system was displaced during the ice ages, as discussed earlier, so that the warm Gulf Stream did not penetrate very far north. The isotope record in the ice, and changes in ocean sediments at exactly the same time, indicate that there must have been very large and rapid shifts in ocean currents in the North Atlantic, and probably disruptions in the flow of deepwater leaving the Atlantic as well, at many times during glacial times. We don't yet have an explanation for all of these changes, but one clue is provided by layers of coarse sediment found scattered across the North Atlantic, as seen

in cores of sediment recovered from the ocean floor. These layers record times when icebergs from collapsing ice sheets that border the North Atlantic Ocean carried glacial sediments from continental interiors to the oceans. These periods are now known as Heinrich events, after their discoverer. At these times, freshwater from the calving icebergs may have flooded the North Atlantic with low salinity, fairly buoyant water, disrupting the ocean circulation and the formation of deepwater that would have normally occurred when the relatively warm salty waters cooled and sank. So it seems that Heinrich events were one extreme in a whole series of disturbances in the North Atlantic Ocean circulation that occurred during the last glacial period. These changes in circulation then had an impact beyond the North Atlantic, because of the links between ocean and atmospheric circulation there and other parts of the world. Thus, you can see similar features in the Antarctic ice core records, but they are less dramatic than in the Greenland ice. However, rapid climate changes have also been identified in lake sediment records from the Mediterranean region, for example, and even in sites as far away as China, showing that the disturbances to North Atlantic circulation had widespread effects.