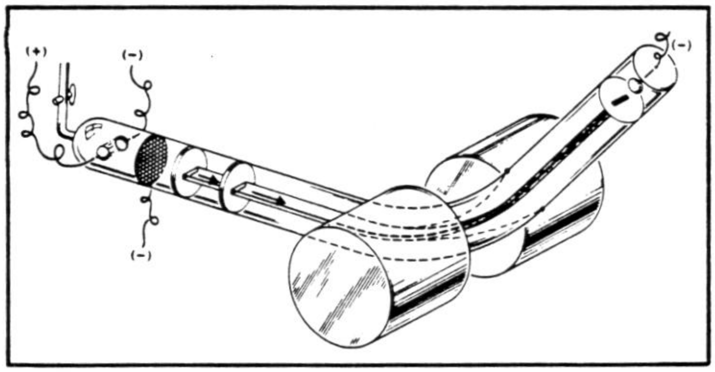
TREES AS ENVIRONMENTAL HISTORIANS

by R.H. Waring

The burial was complete as Mowa packed the last basketful of earth around the lifeless body of her emaciated son. She stood, wiped tears from her eyes, and turned to look at the river valley where her ancestors had built the largest earthen burial mounds in North America. New strains of corn provided her tribe great wealth to barter for copper from the shores of Lake Superior, and for obsidian from the Yellowstone region. Since 1000 AD the cultivation of corn had increased to provide three-quarters of her people's diet. But now, in the year 1225, the rains had failed and parched fields stood brown, framed against the ghostly outline of a leafless forest. For the next century the central part of the continent from the Mississippi Valley to the Allegheny Range would be filled with dust and smoke; her tribe would be scattered and only remnants of her people's culture preserved.



The key to unlocking the secrets hidden in isotope signals is an instrument called the mass spectrometer. The age of organic materials can be determined with fair accuracy back 40,000 years by comparing the extent of disintegration of radioactive carbon to stable carbon atoms. Very small samples of material are burned and pure gases are then injected into the instrument. The pure gases contain two types of atoms: one of common weight and one slightly heavier. The gases are forced, under pressure, down a tube and around a corner. At high speed the ones with higher mass bang against the wall near the start of the turn. The lighter ones strike further down the tube.

Adapted from Brady, Humiston, *General Chemistry 4/E, Principles and Structure*, p. 94, 1986

Archaeologists, working together with other scientists, are now revealing many secrets of prehistoric civilization from chemical clues found in the skeletal remains of primitive people and from the wood of ancient trees. As our present world awakens to the realization that the next generation may experience climatic change more abrupt and more extreme than those that destroyed previous cultures, we search for new techniques to interpret fluctuations in past climates and the environmental change that resulted. To accomplish this, a new technique has been developed to examine the atomic composition of bone, wood, sediment and glacial ice. Then it translates those chemical clues into weather reports of ancient climates to show how they affected past civilizations. The same chemical clues are being deposited today in these materials and may be current harbingers of major changes to our lives in the near future.

The bones of Mowa's ancestors, buried at various layers in the mounds, left a record of generations increasingly dependent on corn. Corn is a subtropical grass with a unique way of incorporating carbon dioxide into plant matter during photosynthesis that differs from other major food plants in Mowa's or her tribe's diet. More precisely, the ratio of the stable isotope of carbon with an atomic weight of 13, relative to that with a weight of 12, is more than double in corn compared to other native food plants. The extent to which the sample of bone collagen becomes enriched in the heavier isotope of carbon provides an accurate record of the tribe's increasing dependence on corn as a staple in their diet.

How do we know that the climate changed around 1200 AD?

Paleobotanists and archaeologists obtain some clues by observing the kinds of plant materials buried in sediments of known age. The age of organic materials can be determined with fair accuracy back 40,000 years by comparing the extent of disintegration of radioactive carbon with an atomic weight of 14, compared to stable carbon atoms with an atomic weight of 12. This is known as carbon 14 dating, often termed radiocarbon dating. Other sets of stable isotopes of carbon, hydrogen and oxygen are found in organic materials in specific ratios determined by climatic conditions the day the material was formed, and these ratios remain constant through time.

The key to unlocking the secrets hidden in isotope signals is an instrument called a mass spectrometer. Very small samples of material are burned and pure gases of carbon dioxide, nitrogen, oxygen, hydrogen or sulfur dioxide are separated and then injected into the instrument.

The pure gases of these elements contain two types of atoms: one of common weight, and one much rarer and slightly heavier in mass. The gases are forced, under pressure, down a tube and around a corner. At high speed the ones with higher mass bang against the wall near the start of the turn. The lighter ones strike further down the tube. By carefully positioning counters at correct places along the tube's wall, it is possible to determine the relative number of strikes of heavy vs. lighter atoms of each element.

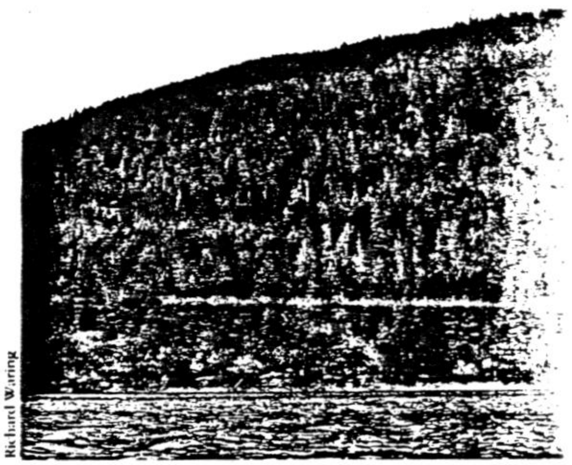
To determine climate conditions during the famine period, we need a piece of undecomposed wood from a prehistoric campfire or buried artifact. On this material, the disintegration of radiocarbon (carbon 14) is measured to determine the approximate age. After that we might analyze for the stable isotope ratios of hydrogen, oxygen and carbon.

The stable isotope ratio of hydrogen 2 to hydrogen 1 in precipitation reflects the average yearly temperature because the air temperature to a large extent determines the hydrogen isotopic composition of precipitation. If warm tropical storms brought rain to the forests and adjacent corn fields in middle America, the temperature of the water would be higher than if snowmelt irrigated the hills and valleys. Indeed, when we look across all of North America, we see that the average isotopic composition of precipitation generally mirrors the average temperature. In northern Canada, we find the lowest fraction of heavy isotopes of hydrogen where most precipitation falls as snow. As the climate warms toward the Gulf Coast, the fraction of heavy isotopes of hydrogen progressively increases in precipitation. During a drought there is little rain, but rain temperatures tend to be warmer and this shows up through an enrichment in the heavier isotope of hydrogen in tree wood cellulose.

The air also holds less moisture during a drought. This lowers the humidity of the air and affects the isotopic ratios of oxygen 18 to oxygen 16 in the cellulose of tree rings. When the humidity is low, more of the lighter isotopes of oxygen escape as a gas during photosynthesis, leaving behind more of the heavy form to be incorporated into the tree's wood.

Of the vast majority of plants that photosynthesize differently than corn, small increases in the stable isotope ratio of carbon 13 to carbon 12 in tree wood cellulose is indicative of stress. The more enriched a sample of wood cellulose is in the heavier isotope, the more closed were the pores in the plant's leaves when photosynthesis occurred (Figure 1). During a drought, lack of water causes leaf pores to close, reducing water loss while also restricting photosynthesis and growth.

Today the "greenhouse" effect of climatic warming, brought about by burning of fossil fuels and release of carbon dioxide and other trace gases, is predicted to be most dramatic at higher latitudes closer to the poles. The reason for this is that the atmosphere near the poles is less buffered against change than elsewhere. It is not as thick nor as well mixed by winds as the atmosphere nearer the equator. Ecologists are now examining the pristine cedar forests of southeastern Alaska to see whether changes



Richard Waring

Researchers, looking for clues to discover why some trees appear to be damaged or dying, use stable isotopes to test climatic change in the history of the forest.

have already occurred. The forests of Alaska yellow cedar are very old and much prized, both culturally and economically. Yet many trees are now dying. Forest pathologists cannot identify the cause; no single disease brings on tree death. Many of the trees started life more than half a millennium ago, but few are reproducing from seed. In many respects, the decline of Alaska yellow cedar exhibits symptoms of stress due to climatic change.

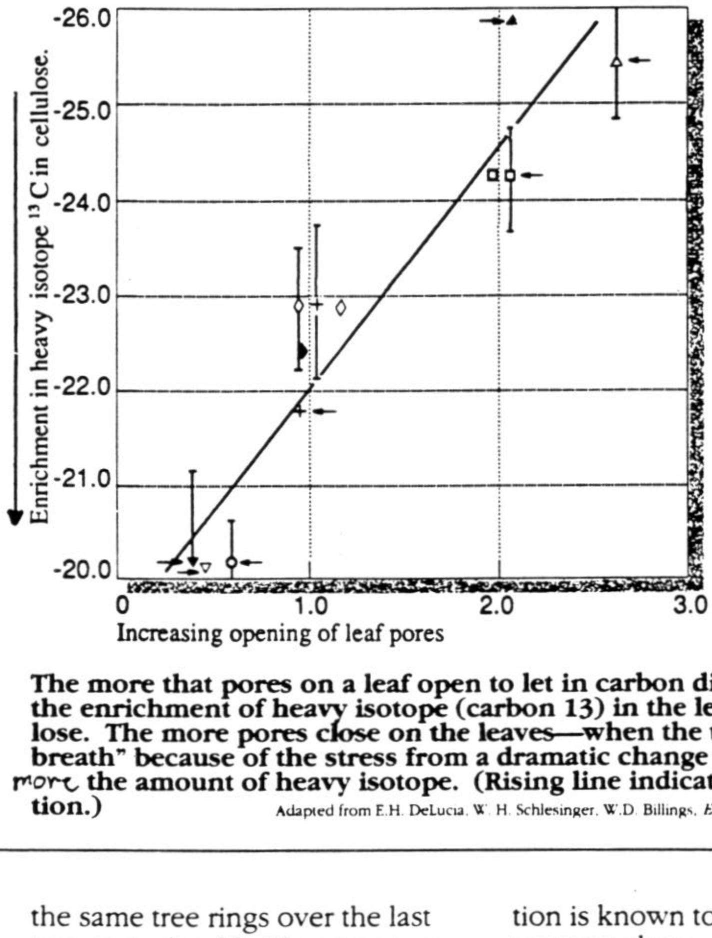
To test the hypothesis that climatic change has caused the cedar in southeastern Alaska to reduce its growth and vigor, ecologists are looking first at the hydrogen isotopic composition in wood cores representing tree rings over the last two centuries. They hope to find evidence of a 2 to 4 degrees Fahrenheit increase in temperature. Such an increase should result in a slight reduction in relative humidity during the growing season. This in turn should be noted by enrichment in the fraction of the heavier isotope of oxygen in the same tree rings over the last two centuries. Maritime tree species such as cedar tend to be very sensitive to lowering air humidity. They should respond to lower humidity by closing the pores in their leaves, causing wood cellulose to show an increasing enrichment in the heavier isotope of carbon 13. Reduced photosynthesis, combined with higher temperatures, would threaten the cedars by forcing them to respire more carbon while acquiring less.

In Europe, as well as downwind from heavily industrialized parts of North America, many forests appear to have been under stress during the last few decades, despite fairly stable climatic conditions at mid-latitudes. Why is this? Acid rain and other forms of air pollution have washed over these forests in increasing waves during this time span and pollution is known to induce leaf pores to close.

Acid rain is composed of sulfur and nitrogen compounds originating from the combustion of fossil fuels or from fertilizers produced from atmospheric nitrogen. The isotopic composition of sulfur and nitrogen from these extraneous sources can differ substantially from those trees normally obtain from weathering of rocks and natural, unfertilized soils. If the hydrogen and oxygen isotopic scribes of weather in tree rings leave no record of major weather changes over the last few decades, but the carbon isotopes indicate that closure of leaf pores is constraining photosynthesis, then we should expect to find some record of changing sulfur and/or nitrogen isotopic ratios in the wood cellulose of more recent tree rings. This kind of signal should increase dramatically in trees close to a major source of pollution, as it is known to in more sensitive plants like mosses.

Forests still stand in North America that were growing before the continent was colonized by Europeans. We have attempted to maintain some ancient forests for their beauty and for the protection they provide other forms of life. In doing so we also protect an irreplaceable wealth of information on past climates, pollution, and other environmental changes that is stored annually by chemical scribes within tree wood cellulose.

Isotope techniques offer the opportunity to tap these wooden data banks. Combined with isotopic analyses of other materials, archaeologists and ecologists may tell us more about how earlier people adapted to the Earth's changing environment. From this legacy we can perhaps also better forecast the future ecological consequences in store for us. **FW**



Trees Under Stress Hold Their Breath. **Changes in climate can sometimes be harmful to trees, so scientists are using stable isotopes to check for evidence of harmful climatic changes in past environments. These same chemical clues are being left in trees today and may be able to tell us of changes in our lives coming in the near future. The graph shows the relative scale of pore openings in leaves of various species of trees growing in different soils.**

The more that pores on a leaf open to let in carbon dioxide, the lower the enrichment of heavy isotope (carbon 13) in the leaf or wood cellulose. The more pores close on the leaves—when the tree "holds its breath" because of the stress from a dramatic change in the climate—the more the amount of heavy isotope. (Rising line indicates isotope depletion.)

Adapted from E.H. DeLucia, W. H. Schlesinger, W.D. Billings, *Ecology*, Vol 69, p. 303-311, 1988.

Richard Waring has been a professor in the College of Forestry at Oregon State University in Corvallis for 25 years. He recently took a leave-of-absence to the Ecosystem Center at Woods Hole, Mass., to learn more about the use of stable isotopes and remote sensing in studies of forest ecosystems.

Figure Reference

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