Concentric clues from growth rings unlock the past

Trees remember, and scientists are learning to ask them about everything from historical dates to earthquakes and volcanic eruptions.

Pueblo dwellings in New Mexico, a 17th-century oil painting and the streets of a medieval Russian city may seem to have little in common, but all are being connected by a new—and unexpected—field of scientific research. That field is the study of the annual growth rings of trees. Tree rings were once of serious concern only to woodcarvers and cabinetmakers, but a combination of individual genius, sophisticated analysis and old-fashioned luck have turned them into tools that can be applied in areas as diverse as anthropology and pollution control.

Carpenters from time immemorial must have known that tree trunks have rings, which give rise to the grain in a piece of wood. We find them mentioned by associates of Aristotle, but Leonardo da Vinci was the first person to suggest that as trees grow, they add a new ring every year. Today, we understand that when spring arrives and vegetation comes alive after the dormancy of winter, the cells just inside the bark of a tree start to divide. They produce large, thin-walled cells that we see as the light-colored material scientists call earlywood. Later in the season, the growth slows down and the cells get smaller and thicker walled. This so-called latewood looks darker and is what makes up the dark rings in a tree trunk. After the late-

Decades of good and not-so-good years are revealed in this cross section of Douglas fir from the Southwest.

wood forms, the tree becomes dormant again for the winter and the whole cycle repeats. The result is that many species carry in their trunks a series of alternating dark and light bands, each pair corresponding to a year's growth. These contrasting bands are most evident in conifers; distinctions between rings are not as pronounced in most temperate deciduous species and are absent in many tropical trees.

Trees are living archives, carrying within their structure a record not only of their age but also of precipitation and temperature for each year in which a ring was formed. The record might also include the marks of forest fires, early frosts and, incorporated into the wood itself, chemical elements the tree removed from its environment. Thus, if we only knew how to unlock its secrets, a tree could tell us a great deal about what was happening in its neighborhood from the time of its beginning. Trees can tell us what was happening before written records became available. They also have a great deal to tell us about our future. The records of past climate that they contain can help us to understand the natural forces that produce our weather, and this, in turn, can help us plan.

Application of the study of tree rings began in the early part of this century with Andrew Ellicott Douglass. Born in Vermont in 1867, Douglass went to Arizona to find a location for a new observatory to be built by his fellow New Englander, Percival Lowell. Beginning in 1901, Douglass made a practice of traveling out to logging camps near Flagstaff to examine the ring patterns in freshly cut tree stumps. He was looking for evidence that the 11-year cycle of sunspots had been recorded in these rings. He didn't immediately find what he was looking for, but he did notice that the tree rings appeared to show the same patterns from one area to another. For example, if freshly cut trees in one logging camp had three wide outer rings preceded by two thin ones, the same pattern would be evident in trees cut down in other camps. One could then reason that this pattern indicated two years with bad conditions, followed by three good years. Douglass noticed that the patterns he found seemed to occur throughout northern Arizona.

Matching sequences from tree to tree

During the first two decades of this century, Douglass continued to study the patterns in tree rings. The technique he used, now known as cross-dating, was based on a simple idea. Suppose you found a particular sequence of growth rings: for example, fat, skinny, fat, fat, skinny, skinny, fat. Suppose further that you found this sequence near the center of a tree that was cut down last winter. You know the outermost ring in the tree was formed in 1984 so, by counting backward

Color photographs by Terrence Moore
along the rings until you come to the sequence, you could figure out when it started. For the sake of argument, let's say that the initial fat ring in our sequence was formed 100 years ago, in 1885.

Now suppose we find the same sequence in the outer rings of an old tree that died long ago. Because we don't know the exact date of the tree's death, we can't just count backward from the outside. We know when our sample sequence started, however, so we can assign a date (in this case 1885) to the first outer ring that matches the similar ring on our initial sample. We could then count inward and establish the approximate year the tree began and count outward to establish the exact year it died (assuming the outer rings are still intact). In the hands of tree-ring scientists, both of these pieces of information are valuable. The pattern in the rings back to the starting date can, with luck, be matched to that in still older trees, extending our knowledge of these patterns further back in time. In this way people working with living and dead bristlecone pines have managed to construct a continuous record of tree rings back to about the year 6700 B.C. At the other end of the scale, the date of the tree's death may be very important if the tree was cut down to be incorporated into a structure, for then the rings allow us to assign a fairly accurate date to the building.

As it happens, reading tree rings to date old structures was the first use to which Douglass put his new knowledge. The pueblo ruins of the American Southwest had long excited the interest of archaeologists. Built by skillful craftsmen, many of them had obviously been occupied for centuries and then, for
reasons unknown, they were abandoned. Dates for the pueblos as early as 2000 B.C. were proposed. Starting in 1916, Douglass began examining wood samples from pueblo ruins, looking at the ring patterns to establish their dates. By 1929 he had succeeded in putting together a relative, or "floating," chronology. He was able to match up ring patterns among various logs in the pueblos, allowing him to say which were early and which late, but none of the pueblo patterns could be assigned calendar dates, as none matched up with those from dated trees. By this time the tree-ring chronology for northern Arizona had been extended back to A.D. 1260, so archaeologists could say that the pueblos were older than that, but nothing more. A gap of unknown length existed between the oldest dated tree ring and the youngest pueblo log.

Then, in 1929, on the third "Beam Expedition," when the archaeologists were getting so desperate they offered a $5 bonus to anyone who found a log with 100 or more rings in it, a laborer uncovered the end of a burned log buried in the ground (p. 50). Douglass quickly recognized the pattern in the outer rings of the log as matching the oldest part of the known tree-ring calendar, and the pattern on the inner part of the log as matching the most recent part of his floating chronology. This single discovery, then, spanned the gap between the known and unknown, proving that the pueblos were inhabited anywhere from the tenth to 13th centuries A.D. before being abandoned.

Following the discovery of the "Rosetta stone" log, the chronology of Pueblo Indian remains throughout the Southwest was quickly worked out. In the wake of this success, Douglass founded the Laboratory of Tree-Ring Research at the University of Arizona, at Tucson, in 1937. The laboratory remains to this day the major world center for this kind of work.

**Complacent trees are harder to read**

Once the usefulness of tree rings had been proved in the Southwest, scientists elsewhere decided to take the methods seriously. It was really a matter of luck that Douglass started his studies in Arizona, where conditions for the growth of trees are often far from ideal. In such a situation, small drops in precipitation or temperature can result in drastically reduced growth for the tree and, consequently, a visibly narrow ring for that year.

In other areas, such as the eastern United States and Europe, tree-ring analysts face a different set of problems. In 1975, with the support of the Climate Dynamics Program of the National Science Foundation, Gordon Jacoby of Columbia University's Lamont-Doherty Geological Observatory founded a tree-ring laboratory that has become a major center for the study of East Coast and northern forests. "Trees in Eastern forests are closer to each other than in the Southwest," he pointed out. "This means that competition between trees is more important here, and this can have a marked effect on the ring growth of an individual tree. Also, in the East the trees are less limited by climate, so there is less variation between rings as the weather changes." In the language of tree-ring scientists, many East Coast trees tend to be less "sensitive," and thus show "complacent" growth.

So great did these difficulties seem in 1975 that, according to Jacoby, some experts despaired of ever establishing reliable tree-ring chronologies in the East. But, since then, many of these difficulties have been overcome, and now chronologies exist for many locations that used to be blanks on the map. Unlike some of their counterparts in the West, however, these chronologies extend back only 300 to 500 years. The oldest trees in the Northeast (hemlocks) do not get much older than that, and trees that die tend to rot in the moister climate, so that their rings are lost quickly.

In places with a long record of advanced civilizations, the use of tree rings can be unexpected and dramatic. For example, the citizens of medieval Novgorod (in northwestern Russia) dealt with the mud in their streets by putting down layers of logs. As each

---

Hydrologist Charles Stockton uses tree-ring analysis to study variations in water supply over the centuries.
layer sank into the mire, it was replaced, until today there are no fewer than 28 streets stacked on top of each other, dating from A.D. 953 to 1462: a tree-ring paradise. In another case, paintings by such Dutch masters as Rembrandt and Rubens were dated by an analysis of the ring patterns in the oak panels backing the paintings.

But if the use of rings to date archaeological objects was the major task in the first half of this century, the analysis of information about past climates and chemical contents of the atmosphere is fast overtaking it in the 1980s. Perhaps nothing illustrates this application of new sorts of science to the tree ring so well as the ongoing calibration of the carbon-14 dating system.

With Methuselah’s help, a 9,000-year record

Bristlecone pines are the oldest living tree. They are found in six states in the Southwest. Gnarled, twisted, stunted, they do not have the grandeur that you might expect to find in an ancient tree, yet the oldest of them, the Methuselah tree, has been adding rings to its trunk for more than 4,600 years. Moreover, in the dry climate of the mountains in which they are found, dead trees remain standing for long periods of time, and even when they fall they do not quickly decay. Using cross-dating between live and dead wood, it is possible to construct a continuous record of tree rings going back almost 9,000 years.

Most of the carbon in living tissues (including your own) is the plain, garden-variety stuff called carbon 12 (the 12 indicates that there is a total of 12 neutrons and protons in the carbon nucleus). Cosmic rays colliding with atoms in the upper atmosphere, however, occasionally produce a mutant version known as carbon 14, which has two additional neutrons in its nucleus. Carbon 14 has the same chemical interactions as ordinary carbon, so a small percentage of the carbon in living tissue will be of this type, with the exact percentage depending on how much carbon 14 is being created at any given time. As soon as the carbon 14 is incorporated, the mutant nuclei begin to decay. The idea is that plants and animals stop adding carbon to their systems when they die, so that from that point on no new carbon 14 is added and the old atoms start to disappear. Provided we know how many carbon-14 atoms were in the environment, then, counting the number left will tell us how much time has elapsed since the organism died.

When this dating scheme was originally proposed, it was assumed that the amount of carbon 14 in the air was always the same as it is today. Based on this assumption, all sorts of organic remains were dated and carbon-14 content became a major tool in archaeology. By the early 1960s, however, problems were develop-
Unscathed remainder of the trunk grew "normally" until tree was cut after formation of the 1981 ring.

ing with the oldest materials analyzed, which dated well into the B.C. era. Carbon-14 dates and dates obtained from historical documents differed, often by hundreds of years.

This was the situation in the late 1960s when C. W. Ferguson at the University of Arizona began attacking the discrepancy with the use of data from bristlecone pines. The idea was that we know the exact year in which the wood in a particular ring was formed, so counting carbon-14 atoms in that ring will tell us how many such atoms there were in the wood at the beginning. It was seen very quickly that the amount of carbon 14 in the atmosphere in the past was not the same as it is today, contrary to the original assumption. More carbon 14 was being created in the past than there is now, so all the original carbon-14 dates had to be moved back. The dates for the three different periods of construction at Stonehenge, for example, have been changed by several hundred years.

What tree rings tell us about climate

All the uses of tree rings we have discussed so far in this article generally go under the name of dendrochronology (from the Greek dendron: tree, and khronos: time). The hot topic in tree-ring research these days is the field of dendroclimatology: the reconstruction of past climates and climatic events from evidence found in tree rings.

This sort of work is much more complicated than dating, because it depends on the differences in widths between rings grown in different years. Given the inherent variability between trees and even within the rings of a single tree, it's much easier to say with certainty that one ring was five years older than another than to assign a precise number to the difference in width between them.

The modern study of dendroclimatology could be said to have been born with the work of biologist Harold Fritts (p. 54) at the University of Arizona in the 1960s. Fritts and his colleagues monitored the growth processes of a small number of trees near Tucson in great detail, covering branches and often entire trees with plastic to determine how much of each atmospheric gas the tree took in and gave off. After a decade of work, they came to a detailed understanding of the processes that lead to the creation of a single ring on a tree.

The growth of a tree ring isn't as simple as it might appear at first. If last year was a particularly good one for tree growth, for example, the root system of the tree might have expanded more than usual, and this will carry over into this year's growth. Similarly, a bad year might slow down the growth for several years in the future, regardless of the weather in those years.
Reading memories of trees in their rings

Sorting out all these effects for a system as complex as a living tree was a monumental task, but once it was done the results had as wide a variety of uses as did the establishing of chronologies.

By gathering data from tree rings around the southwestern United States and comparing this with the weather records of the past 100 years, for example, we can see how the tree rings reflect the climate. Then, going back into the period when there was no weather information recorded, we can deduce what the weather must have been when each particular ring was formed. In this way, Fritts has developed climate maps of the western United States and the northern Pacific (where western weather originates) back to about A.D. 1600.

At first glance, such an exercise might seem academic: Who cares whether 1678 was dry or wet? But Charles Stockton (p. 49), a hydrologist who uses tree-ring analysis to study water supplies, pointed out that this attitude misses an important point. "When we looked at the precipitation data for a period of years, we could see the areas of drought grow and shrink periodically." This visual impression was quickly reinforced by computer studies that showed clear evidence for cyclical droughts in the western United States. The question that concerns dendroclimatologists right now is whether or not the droughts occur in a 22-year cycle, a 19-year cycle or (most likely) some combination of the two. With a tree-ring-derived rainfall record going back more than 300 years, however, they expect to sort out the drought cycle by 1986.

Tree-ring specialists are also getting involved in studying the effects of pollution in a very dramatic way. A group from the University of Arizona, for example, was able to see the effects of a lead smelter in Trail, British Columbia, on tree growth in Washington State. The growth was well below normal when the smelter was turned on, but then rebounded when the smelter was shut down a few years later.

Tree rings also record the explosive eruptions of large volcanoes. When an event like Mount St. Helens happens, large amounts of ash and gases are thrown into the stratosphere (Smithsonian, July 1980). There the dust and gases block out parts of the sunlight that would normally reach the surface. This can lead to

Jacoby explained that as trees grow older, the rings become narrower. This means that it would be very easy to look at a core, see that the rings were getting narrower and conclude that the tree was being adversely affected by acid rain—when the real reason for the narrow rings was the normal aging process. One must also make comparisons with climatic data to rule out other possible causes of growth decline. To find evidence for the effects of acid rain, you have to find retarded growth beyond what you would expect to see in the normal course of affairs. Jacoby does, indeed, see this sort of effect in three of a dozen sites he has sampled around New England, but it is absent in the remaining nine.

In some situations, however, tree rings can be used to document the effects of pollution in a very dramatic way. A group from the University of Arizona, for example, was able to see the effects of a lead smelter in Trail, British Columbia, on tree growth in Washington State. The growth was well below normal when the smelter was turned on, but then rebounded when the smelter was shut down a few years later.

Tree rings also record the explosive eruptions of large volcanoes. When an event like Mount St. Helens happens, large amounts of ash and gases are thrown into the stratosphere (Smithsonian, July 1980). There the dust and gases block out parts of the sunlight that would normally reach the surface. This can lead to

Author James Trefil is a physicist at the University of Virginia. His latest book, Space, Time, Infinity, was published last month by Smithsonian Books.
Dendroclimatologist Harold Fritts uses data from tree rings to chart the historic variations in U.S. weather.

Subfreezing temperatures and leave a characteristic mark called a frost ring on a growing tree. Valmore LaMarche and his coworkers at Arizona recently looked at frost rings in bristlecone pines and found that a number of them seemed to correspond to major volcanic eruptions. The explosion of Tambora in the East Indies, which gave rise to "the year without a summer" in 1816, left frost rings not only on the bristlecone pines, but on trees LaMarche studied in South Africa. One particularly severe set of frost rings occurred in 1626 B.C., and LaMarche suggests that the rings may have been caused by the destruction of the island of Thera (Santorini) in the Aegean Sea by a volcano. This eruption might have given rise to the legend of Atlantis sinking into the sea. LaMarche's date (still disputed by some archaeologists) is by far the most precise that has ever been proposed and agrees with available carbon-14 dates of artifacts that were caught in the eruption.

Another type of transient phenomenon that tree-ring scientists are starting to study seriously is earthquakes. These events can damage a tree by shaking it violently, and the damage can result in narrower rings in subsequent years as the tree heals. Gordon Jacoby of Columbia showed me a core from a ponderosa pine that had grown directly over the San Andreas fault in California. "This was a happy tree until 1857," he said, pointing to a spot where the several atypical narrow rings crowded together. In that year, a major earthquake rocked the Southern California countryside where the tree grew. "If you can rule out wind, fire, disease and climate as the source of this signal, you can use the tree to tell you when the fault was active in the past." With scientists at Caltech, he is starting a study of trees in the neighborhood of his happy pine tree to see if he can supply data from past events that would be useful to people trying to predict the occurrence of earthquakes.

All of these examples illustrate an important point. When we want to study the information stored in trees, we cannot restrict our attention to single geographical areas or even to single countries. The International Project In Dendroclimatology (IPID) is one effort to move tree-ring studies into the international arena. Scientists from many nations have pooled their information in an attempt to reconstruct past climates around the world. Their first goal seems a modest one, but it will be difficult to reach. The group, based in Arizona, wants to find the average yearly temperature in the Northern Hemisphere as far back in time as possible. At the moment, the analysis of the data is well under way.

If they reach their first goal, they might have an important impact on a problem of great public concern: the predicted global heating ("greenhouse effect") resulting from the increased concentrations of carbon dioxide in the atmosphere, an increase caused by the burning of coal and oil during the past few centuries. The IPID data will extend back to A.D. 1700, well before the beginning of the Industrial Revolution, when this burning started. "Without this sort of data base," said LaMarche, "atmospheric scientists may have to monitor temperatures and carbon dioxide for another ten to 20 years before they see unmistakable evidence of warming trends. By then, it may be too late to do anything about it."

The practical significance of such research emphasizes the need for an international effort in tree-ring work. One scientist after another at the Laboratory of Tree-Ring Research talked of "blank spots on the map," and all mentioned that the laboratory brings in foreign scientists for training, then sends them out to set up programs around the world. Perhaps someday we will be able to put together worldwide weather maps based on dendroclimatology similar to those that now exist for the western United States. If so, we will have added important data that is needed to understand how our climate and the living systems that depend on it interact.

Trees remember, and if we are clever enough, we can tap that memory to give us all sorts of useful knowledge about our past—and our future.

Bristlecone pines accumulate growth rings for thousands of years, are history books for scientists.