GENERAL SCIENCE NOTES

CAN TREE RINGS BE USED TO CALIBRATE RADIOCARBON DATES?

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WHAT THIS ARTICLE IS ABOUT

Scientists correct the raw data from radiocarbon dating determinations so as to give what they consider to be a more accurate real-time age. This is necessary because of the uncertainty about the original concentration of carbon-14, which must be assumed to calculate a radiocarbon age. In order to determine what real-time age should be associated with a radiocarbon age, the radiocarbon data are often compared to historical and tree-ring data that are considered to be more reliable indicators of time. Tree-ring data are especially important in the correction process for dates older than 1000 BC. Extensive lists of correlation between radiocarbon data and tree-ring data have been published.

However there is a problem. It appears that the tree-ring chronology that has been established to adjust the raw carbon-14 determinations is a fragile structure. Our oldest living trees appear to be less than five thousand years old. Radiocarbon corrections beyond that are often based on attempts to match the thickness variations of tree rings in old wood samples. If a similar pattern of variation in tree-ring thickness is found in two pieces of wood, the two are assumed to have grown at the same time. By comparing many pieces of wood and combining matches, tree-ring chronologies of over 11,000 years extent have been proposed for use in correcting carbon-14 dates. The reliability of the system is dependent on the correctness of the tree-ring matches, — and here there is considerable uncertainty. Statistical tests show that it is easy to get significant matches of tree-ring patterns at various juxtapositions between samples of wood. More sophisticated statistical tests are being developed to correct for this problem. However, these tests were not used when the original dendrochronological correction scheme for carbon-14 dates was established. It appears that this original scheme is subject to reevaluation.

Using radioactive carbon (carbon-14 — C-14) to determine age is a complex process. The method is based on the slow disintegration of C-14. The less C-14 present in a sample, the older it will date. To determine a date, one must have data concerning:

1. the present content of C-14 in the specimen (determined as the ratio of isotope 14 to isotope 12 — C-14/C-12 —, or as the number of C-14 atom transformations per second per gram of carbon),
2. the rate at which C-14 spontaneously converts to nitrogen (N-14), and
3. the C-14 content — C-14/C-12 ratio — at the beginning of the time period related to the age.

At the best laboratories the C-14/C-12 ratio can be determined to about one-thousandth of the value that characterizes contemporary plants and animals. The most recent determination of the spontaneous C-14 conversion rate indicates that, within an uncertainty of about ± 30 years, in 5715 years half of an initial amount of C-14 will have converted into N-14.[1] At this rate of conversion approximately 57,000 years would be required for the C-14/C-12 ratio to diminish one-thousand-fold. The initial C-14/C-12 ratio is not accessible to experimental determination, and must be assumed. Accordingly, any C-14 age is based on an assumption.

The simplest calibration base for the initial C-14 is the assumption that throughout all past time accessible to C-14 dating, the C-14/C-12 ratio in the active carbon exchange system has been the same as it is at present. With this calibration base a specimen for which the C-14/C-12 ratio is 0.001 times that of corresponding contemporary material has a 57,000 year radiocarbon "age." Radiocarbon ages obtained in this simple, direct way may be classified as "radiocarbon isotope ages."

However, there is good evidence that the proportion of C-14 has varied over time, and a more reliable calibration base is the C-14/C-12 ratio found in artifacts that have a precise and accurate historical (calendric) age. A base established in this manner requires guessing by interpolation for C-14/C-12 ratios that fall between values that have been calibrated by historical dates. Also it is insecure for extrapolation beyond the oldest firmly established historical calibration points.

For older dates the most satisfactory calibration base is the C-14/C-12 ratio of wood that has been dated by dendrochronology.[2] In temperate climates wood cells that are produced in the beginning of the growing season are larger and have thinner walls than the cells produced in the latter part of the growing season. The density difference between early and late growth produces visible features known as tree rings. Variation in the width of these rings results from year-by-year variation in the conditions favorable to growth of a particular portion of a tree.

By assuming that a similar variation in the pattern of ring thickness between samples represents growth during the same period of time, the ring-width patterns of many wood specimens can be combined into a single master dendrochronological sequence that 1) has an average growth-ring width variation pattern for periods of overlapping growth, and 2) extends the time range beyond the time span of any one component. Extension of the time range is accomplished by matching an upper portion of the ring-width sequence in one specimen with the lower portion of another specimen. The Bristlecone Pine master dendrochronological sequence that has been foundational for C-14 calibration has been based on 81 living-wood and 118 dead-wood specimens from the White Mountains of California.[3] This basic pattern for dendrochronological calibration of C-14 age was set by C. W. Ferguson in 1969.[4]

A calibration that falls within a time span that has been established by wood specimens that have been dated by unquestioned historical records (usually by cross-referencing C-14 ages) can be relied on to give a high precision estimate of real time. But because of the uncertainty in matching a wood specimen against a master sequence only on the basis of growth-ring patterns, there is uncertainty regarding the validity of a master tree-ring sequence in a range that has been extrapolated beyond an unquestioned historical reference point.

The magnitude of these uncertainties is indicated by tree-ring study of a Douglas fir log from a Mt. St. Helens pyroclast-flow deposit.[5] I am indebted to R. M. Porter for bringing this study to my attention.[6] The flow that contained this log has been dated by stratigraphy (dating of rock layers) to have occurred within the range AD 1482-1668. The log had 290 growth rings from core to bark. The age of the growth-ring immediately adjacent to the bark is designated as the “bark date.” Segments of 20 or more tree-rings beginning from either edge of this 290-ring sequence were compared for possible match against the Douglas fir master tree-ring sequence.[7]

Computer-calculated coefficients of cross-correlation statistically significant at or beyond the $p=0.001$ level (99.9% confidence) indicated

113 possible bark dates within the range AD 1410-*2240* (projected bark dates that are beyond the present are italicized). Forty-three of these matches were within the bark-date range AD 1483-1668, 23 within the range AD 1669-1771, and 47 within the future range AD *2078-2195*. Matches beyond the limits of the master chronology were made using a partial overlap with the 290-ring log. The AD *2195* date match had a 75 ring overlap with the AD 1980 end of the master-ring sequence. The lowest match, AD 1483, had an 87 ring overlap with the AD 1396 end of the master sequence.

Matches can be evaluated using the Student's-t statistical test of probability. The 113 matches had Student's-t[8] statistical values within the range from 3 to 7, the highest of which was 6.8 for an AD 1647 bark-date match. All these student's-t values suggest a high statistical reliability (99.9% confidence) under the assumptions with which the matches were made. The most secure interpretation of these data indicates tree-ring matches that place bark dates near the midpoints of the six AD ranges 1493-1510, 1642-1664, 1744-1748, 1756-1772, *2078-2098*, *2172-2180*, for which Student's-t values greater than three are clustered.

To see the significance of these data, consider all the dates inverted from AD to BC, and the "bark date" an indication of the beginning rather than the end of a growth sequence. An investigator seeking to extend a tree-ring master chronology that had been developed to 1980 BC might get a match with the last 75 growth rings of a subfossil log containing 290 growth rings. This match could provide a high degree of statistical assurance for incorrectly extending his master chronology to 2195 BC. The investigator might not be aware of a better match possibility with a 1647 BC terminal date (extending growth period 290 years to 1357 BC).

An individual who used C-14 measurements for a guide in assembling a tree-ring sequence, as is often done, would be unlikely to make a single error as great as 215 years (2195-1980), but an accumulation of smaller errors is possible. Or, an investigator with an unknown-aged piece of wood containing 290 growth rings could with a high degree of statistical justification chose any one of 66 matches (113-47) within the previously developed master growth-ring sequence, making his ultimate choice in accord with where he had expected, or wanted, the match to occur.

Special procedures have been developed to reduce such errors. By a mathematical technique for "whitening" a master chronology sequence, i.e., removing the effects of correlated ring-width sequences within the master sequence (repeated patterns of variation — auto-correlation), Yamaguchi[9] was able to eliminate 112 incorrect matches and focus on the AD 1647 bark date. After the whitening process the cross-correlation for the AD 1647 date had a Student's-t value of 5.05 (greater than 99.9% confidence level), and a correlation coefficient of 0.29. (For a correlation coefficient of 1.00 the relative width of *each* of the 290 rings in the log would be exactly the same as the relative width of the corresponding ring in the master chronology.) These results confirmed stratigraphic placement of the volcanic eruption that buried the log within the AD 1482-1686 time range.

Whitening technique was not used in the development of the Bristlecone Pine master dendrochronology that is the standard for calibrating C-14 age. Whitening technique analysis of the various dendrochronology master sequences that were published prior to 1985 indicates that the master sequence developed by Ferguson has unique auto-correlation features, and that its use is definitely questionable.[10]

Matching a 290 growth-ring sub-fossil log to the Pacific Northwest Douglas Fir master growth-ring sequence is an ideal tree-ring dating assignment. If cross-matching is no more certain than in this example, what confidence is justified in the extension of a master tree-ring sequence beyond the range that is constrained by unquestionable historical records, since each stage in the extension of a master chronology is a cross-matching operation? Specifically, what statistical assurance does dendrochronology provide for presuming that C-14 isotope ages relate approximately 1:1 (within 10%) with real time between 500 BC and ~10,000 BC?[11]

ACKNOWLEDGMENTS

I am grateful for contributions to the preparation of this note made by Ariel Roth regarding content, and by Paul Giem and Maurie Evered regarding mathematical concepts.

ENDNOTES

1. CRC. 1994. Handbook of chemistry and physics. 75th ed. Boca Raton, FL: CRC Press, Section 11, p 36.

2. Long A, Kra RS, Devine JM, Stuiver M, editors. 1993. Calibration 1993. Radiocarbon 35(1).

3. LaMarche VC, Jr., Harlan TR 1973. Accuracy of tree ring dating of Bristlecone Pine for calibration of the radiocarbon time scale. Journal of Geophysical Research 78(36):8849-8858.

4. Ferguson CW. 1969. A 7,104-year annual tree ring chronology for bristlecone pine, *Pinus aristata*, from the White Mountains, California. Tree-Ring Bulletin 29(3-4):3-29.

5. Yamaguchi DK.1986. Interpretation of cross correlation between tree-ring series. Tree-Ring Bulletin 46:47-54.

6. Porter RM.1995. Correlating tree rings. Creation Research Society Quarterly 32(3):170-171.

7. See Note 5. Eight-hundred thirty potential bark dates (matches) of a 290-ring log against a 584-ring master sequence.

8. The Student's-t statistic provides an estimate of the degree to which a given set of data is representative, a measure of confidence that the data average represents the true value of the quantity it measures. See a textbook on mathematical statistics.

9. See Note 5.

10. Monserud RA.1986. Time-series analyses of tree-ring chronologies. Forest Science 32(2):349-372. Particularly see p 364.

11. Brown RH. 1994. Compatibility of biblical chronology with C-14 age. Origins 21(2):66-79.