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Journal of the Biblical Creation Trust. 2020, Volume 2, pages 9-15

Dendrochronology: a brief introduction to the problems and opportunities of tree-ring dating

ROBERT M. PORTER

ABSTRACT

The principles of dendrochronology are outlined including how it can be used for dating, either directly or in conjunction with radiocarbon. Dendrochronology has suffered from more than its fair share of errors but, even allowing for these errors, it is currently difficult to match with a 'no-gaps' biblical chronology. Some suggestions are made for further research.

INTRODUCTION

It is well known that in non-tropical climates trees grow by adding rings under the bark, visible as concentric rings if the tree is cut down. New growth in spring normally has large vertical vessels for transporting water and other fluids whereas the summer growth usually has smaller vessels[1] giving a darker appearance, hence the annual ring. The total annual ring can be wide or narrow depending on whether the growing conditions were good or poor, thus giving a pattern of wide and narrow rings back through the years. The width of the ring is particularly affected by climate but also by insect attack and other factors that may be local to a particular tree or group of trees. Oak trees are very consistent at giving one ring per year whereas some other tree species, such as larch, can give several rings in a single year. It is also possible, in a bad year, for some species to miss a ring altogether.

CROSS-MATCHING TREE RINGS TO CONSTRUCT CHRONOLOGIES

With a good supply of dead trees and/or old building timbers, it is possible to match or 'cross date' growth ring patterns from living trees to dead trees far back into the past. *Dendrochronologists* compare the fluctuating ring width patterns visually and by statistics to match the patterns from one timber (or group of timbers) to the next and so build up a long chronology of tree ring width fluctuations, a 'master chronology', to which timbers of unknown date can be compared (Figure 1). It is preferable to have 100 or more rings of overlap to be confident of a correct match between timbers (Baillie 1982, p.84). The rings can be counted and measured where the trunk has been cut but it is also possible to use a hollow drill to take a small 'core' from a living tree or a structural timber.

In the UK master chronologies have been based on

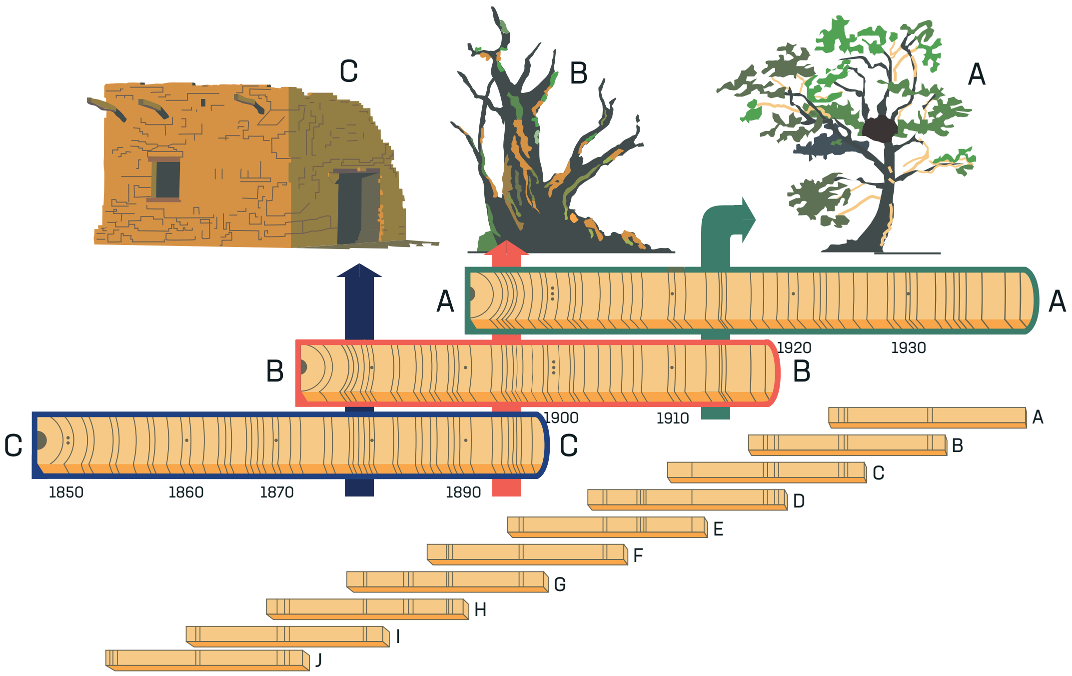

Figure 1. Schematic illustration of the principle of dendrochronology: ring patterns from cores have been taken from a living tree (**A**), a dead tree (**B**) and an archaeological timber (**C**). The ring patterns of these three have been compared and matched up. Further timbers or dead trees (**D–J**) continue the sequence back in time.

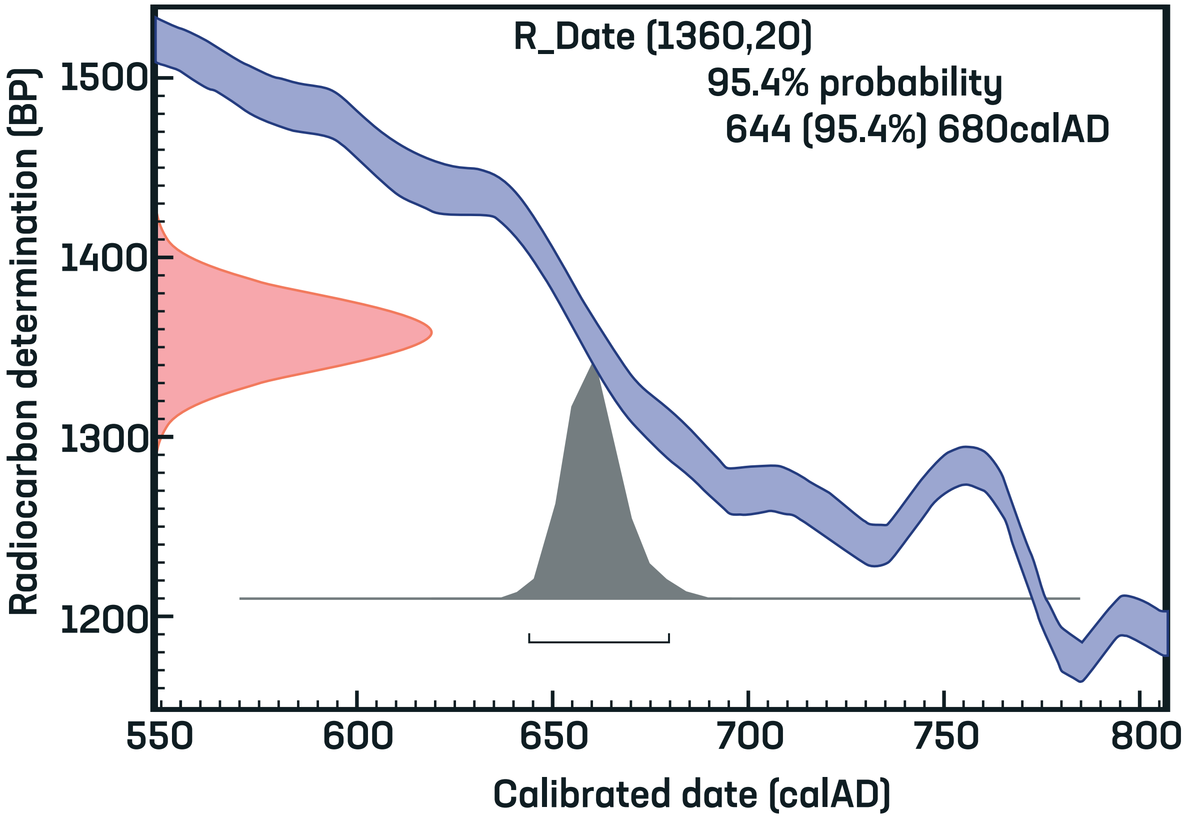

Figure 2. Example of calibration of a carbon date of 1360 +/- 20 years Before Present. The wide blue line shows the calibration curve from about AD 550–800 (the width of the line is due to slight uncertainty in the carbon dating of the tree rings from which the curve was derived). One could imagine drawing a horizontal line from 1360 BP (left axis) across to the curve and then down to the AD axis, giving a result of about AD 660. But, for statisticians, a more complete answer is given by turning the date into a probability distribution (shown in pink) which produces the dark grey distribution with a theoretical 95% certainty of the true date being between AD 644 and 680. Graph produced by the OxCal program of the Oxford Radiocarbon Accelerator Unit (https://c14.arch.ox.ac.uk/oxcal.html).

oak trees and pines. In the AD period, many such oak ring sequences have come from living or dead trees or buildings but, further back, British dendrochronologists have largely relied on 'bog oaks', i.e. oaks that have grown on land that subsequently became waterlogged causing the oaks to fall and become preserved in peat bogs. Such oaks are plentiful in Ireland, and Queens University Belfast has become a major centre for establishing long dendrochronologies. Belfast built up numerous 'local chronologies' from groups of bog oaks and then joined the local chronologies into a continuous one (Baillie 1995, Ch. 2) with almost all years represented by a good number of trees. Dendrochronology can closely date old timbers from ships or buildings and, if there is still bark present, it can give a precise year when a tree was cut down.

USING TREE RINGS TO CALIBRATE RADIOCARBON DATING

A further use, perhaps the main use, to which dendrochronology has been put is calibration of radiocarbon dating. Carbon dating cannot give a true date on its own because the amount of radiocarbon (^{14}C) in the atmosphere has varied over time. An uncalibrated or 'raw' carbon date would be correct if there had been a constant amount of ^{14}C in the atmosphere, but this has not been the case due to variations in cosmic rays and the earth's magnetic field strength, etc. Raw carbon dates are usually expressed as years BP (Before Present, but with 'Present' defined as AD 1950, the approximate time when the method was invented). ^{14}C (atomic weight = 14) is a radioactive isotope of the normal ^{12}C (atomic weight = 12) and is formed in small quantities in the upper atmosphere due to bombardment by cosmic rays, and it spreads around the globe in a few years. ^{14}C is absorbed into plants as part of carbon dioxide; some of the plants get eaten and so it passes into animals and us. After the death of the plant or animal, the ^{14}C slowly decays away with a half-life of 5730 years (i.e. the amount of ^{14}C halves in 5730 years and would halve again in the next 5730 years, etc.). Individual atomic disintegrations of a sample can be estimated for a specified period (beta counting) and the count per gram of sample gives an approximate measure of age. An alternative, more expensive method, AMS (Accelerator Mass Spectrometry), can estimate the individual ^{14}C atoms in a sample and so it can be used on very small samples.

During the atomic bomb tests of the last century, atmospheric ^{14}C levels went very high, and prior to that, burning of old carbon from coal had pushed the atmospheric ^{14}C level low (the ^{14}C in coal has mostly decayed away). For most of the AD period the fluctuations in ^{14}C were fairly small, but going back in time through the BC period there were some large fluctuations and there appears to have been a general trend away from a constant level of ^{14}C in the atmosphere. This would make most BC carbon dates very inaccurate, but the variations can be corrected using tree rings. Samples of rings have been taken from known age trees from long dendrochronologies and carbon dated at intervals of 10 years thus giving a wiggly graph of radiocarbon age versus true age going back for thousands of years. This is the International Calibration Curve of which the latest version is IntCal13.[2] For this graph to be correct, the dendrochronology has to have been done correctly, of course. See Figure 2 for an example of calibrating a carbon date.

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PROBLEMS ARISING WITH TREE-RING DATING

But are the dates derived from the dendrochronology correct? The main queries are due to non-publication and/or non-availability of the evidence (dendrochronology laboratories may share data with each other but are usually reluctant to release it to outsiders), doubts about the statistics used, and occasionally the competence of the dendrochronologist. The main statistical method used is 'Student's *t*-test' which can compare the ring width fluctuations in two trees (or two groups of trees) to see if they follow the same pattern. This is not, strictly speaking, a proper application of the *t*-test because tree ring sequences are not random but each ring partly depends on the previous year or two (the rings are 'serially correlated'). However, dendrochronologists have found the *t*-test useful and they use it with much higher safety factors than would normally be required in a true *t*-test. Nevertheless, the right *t* number for a secure match has been disputed, ranging from about 3.5 to 7 (it can also vary according to the tree species).

NORTH AMERICAN TREE-RING CHRONOLOGIES

Dendrochronology began in the USA and the first long dendrochronology extending back to the BC period was created by Douglass using American giant sequoias (Figure 3) in the early 20th century (McGraw 2001). Sequoias do not always give one ring per annum but they are fairly regular. A century ago, loggers were felling sequoias in large numbers and a few of these very large and long-lived trees had about 3000 rings, presumably representing about 3000 years. Douglass cut strips from across the tree stumps and measured the ring widths – some of the strips are still kept at the University of Arizona. Such long-lived trees avoid the problem of having to match from one tree to another, and they may be suitable for approximately checking the calibration curve back to circa 1000 BC. In fact, some early carbon dating work in the 1960s was done on these trees (Michael and Ralph 1974, particularly their Tree ENT-1 which is Douglass' No. D-22A) but the carbon dating method was still in its early stages and the samples were typically spaced at 50-year intervals. My own attempts to graphically compare these early results to a modern calibration curve did not give a close match but showed consistent offsets over long periods although the general trend was similar. Strangely, a recent attempt to duplicate part of the calibration curve in the second millennium BC also produced a con-

Figure 3. The author beside a 'small' giant sequoia at Basel University gardens. Photograph by Carol Porter.

sistent offset (Pearson et al. 2018, especially Figure 1B).

After the Second World War, dendrochronologists turned their attention to bristlecone pine trees, some of which appeared to have lives even longer than the giant sequoias. However, these are strange trees that grow in hostile conditions at high altitudes in the White Mountains of eastern California (Figure 4). Due to the very poor growing conditions, these trees are unable to maintain a complete ring of bark and so part of the tree trunk dies off leaving a strip of bark up one side or several strips up different parts of the tree, which have to be matched together as if they were separate trees, although with identical growing conditions. It has been argued that bristlecones give approximately one ring per year, which is often the case in the current climate. However, Lammerts (1983; see further below) has shown that bristlecones grown in the laboratory can give more than one ring per year and it may be that, in past climates, at least two rings were appearing each year.

EUROPEAN TREE-RING CHRONOLOGIES

European dendrochronologists tend to use oak trees due to their availability and regular growth of one ring per year. Forest-grown oak trees typically only live for a few centuries, far shorter than the trees used by American dendrochronologists and therefore it is very important to try to ensure correct matching between the numerous trees, both visually using graphs of ring widths and by statistics. Hollstein, a German dendrochronologist, used oak timbers from ancient buildings and old trees preserved in river gravels to create a dendrochronology extending back to the 8th century BC (Hollstein 1980). Hollstein was the only dendrochronologist who ever produced a final publication of a long dendrochronology extending back into the BC period although he did not include data on individual trees. His publication was his undoing because it enabled Belfast University to find an error of 71 years at 550 BC (Pilcher et al. 1984, p.152).

Belfast had been developing its own long dendrochronology back to the fifth millennium BC but had been unable to find timbers to bridge gaps in the first millennium BC. Nevertheless, they thought they knew approximately the dates of their trees because they were partly using radiocarbon dating together with the American bristlecone pine calibration curve. Eventually, Belfast thought they had solved their missing links with trees from elsewhere in the UK and published a three-page article (Pilcher et al. 1984). In 2010, Belfast was forced to release its raw data under the British Freedom of Information Act, and it then became apparent that their dendrochronology had problems at the beginning and end of the first millennium BC (Larsson and Larsson 2012). The Larssons, who identified these problems, have developed sophisticated dendrochronological software that can quickly analyse and link up tree rings from thousands of trees.

Dendrochronologies for the Aegean and Anatolian regions were developed by Kuniholm at Cornell University (Manning and Bruce 2009; pp.xv–xxii for Kuniholm's bibliography). At one time he thought that he was on the point of linking up his AD and BC dendrochronologies but that never quite seemed to happen. He produced parallel dendrochronologies for several tree species, especially juniper which can produce both extra rings and missing rings. However, it gradually became apparent that his work was full of errors, many of them discovered by Manning, his successor at the Cornell University dendrochronology laboratory (Porter 2015, pp.225–227). That leaves primarily German oak dendrochronology (subsequent to Hollstein's work mentioned above) as the basis for the calibration curve in the BC period. This dendrochronology is securely locked away at the Hohenheim branch of the University of Stuttgart by its keeper Dr M. Friedrich. However, there may be hope

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Figure 4. A large bristlecone pine (*Pinus longaeva*) along the Methuselah Trail, Schulman Grove, in the Inyo National Forest, White Mountains, eastern California. Photograph by Dcrjsr / CC BY-SA 3.0.

for release of the data because Friedrich put his name to a multi-authored article, part of which said (perhaps unknown to Friedrich!), 'it is imperative for calibration curve samples that the dendrochronology is well established and fully published. … Raw tree-ring widths of trees sampled for calibration data should be published or logged in a digital archive' (Reimer et al. 2013, p.1934). On the basis of past results, publication of the German dendrochronology can be expected to show errors.

THE CHALLENGE OF TREE-RING DATING FOR YOUNG-AGE CREATIONISM

However, the errors may not be enough to give a post Flood age of about 4500 years (if the Flood was circa 2500 BC) because a number of dendrochronologies, both those used in the calibration curve and others from around the world, now appear to go back between about 5000 and 10,000 years (also, before that, some allowance may be needed for geological periods, depending on where the Flood is placed in the geological column). For example, the Larssons have analysed and confirmed two long pine dendrochronologies, one from Sweden and one from Finland (Larsson and Larsson 2018, but see also Woodmorappe 2018, p.664 for some criticisms). Admittedly, they had to resort to a northern Norwegian dendrochronology to cover a weakness in both Swedish and Finnish chronologies at circa 500 BC (pp.8–9) but, with their more stringent requirements for a correct match, it is difficult to see scope for large shortenings. Certainly dendrochronologists have made mistakes, but could they have made enough mistakes to be out by several thousand years? Bear in mind that the sequences of trees are sometimes roughly confirmed by carbon dates giving the same sequence, which is not entirely a circular argument.

CREATIONIST APPROACHES TO THE CHALLENGE OF TREE-RING CHRONOLOGIES

Nevertheless, let's see what creationist approaches might alleviate our problem.

- The earlier Flood date provided by the Septuagint (circa 3300 BC) would help, but it gives less than a thousand years extra – could the genealogy from Noah to Abraham be lengthened by more than the Septuagint allows?

- The thousands of rings produced by some bristlecone pine trees may be due to multiple rings per year. As already mentioned, although some bristlecone pines have been observed to produce one ring per year under present-day climatic conditions, experiments carried out by a plant breeder showed that bristlecone seedlings produced two rings per year if a summer dry spell was simulated, as may have occurred in the past (Lammerts 1983). More recently, Matthews (2006, especially p.95) has noted that bristlecones living in extreme climatic conditions, high up on the forest borders in the White Mountains of eastern California, have about ten times as many rings as bristlecones living lower down in relatively good growing conditions, and that a former Russian expert on pines suggested that a single cloudburst could have produced a fresh ring. Matthews' article seems convincing for bristlecones, and see also his references to Glock et al. (1960, especially pp.288–289) saying that trees growing at forest outer borders may have multiple annual rings indistinguishable from a normal annual ring and that the multiple rings may match well with other trees from similar growing conditions. Could the same apply to European oaks or pines? Generally, we do not know if these trees grew at extreme forest boundaries where multiple rings might be possible, or in the better growing conditions of mid-forest where multiple rings are unlikely. The European climate regime has changed in the past, from sub-Boreal to sub-Atlantic in the first millennium BC, so this should be an area for research but there does not seem to be any current evidence that sub-Boreal European oaks did or could produce two or more rings per year.

- Woodmorappe (2018) produced a 'disturbance-clustering' hypothesis for bristlecone pines. He suggested that bristlecones may have been repeatedly affected, for example, by their soil material creeping down slope due to an earthquake or erosion. This may have given a repeated low-growth signal in the rings which Woodmorappe attempted to simulate statistically. He took a number of 100-year tree ring sequences from various time periods and imposed on each one a particular set of years of low growth which made the sequences all match despite being from different time periods. However, *if* I have understood him correctly, the set of low-growth years that he imposed gave such a strong statistical signal as to guarantee the apparent matches!

- The RATE project[3] has shown that there are low levels of ^{14}C in coal and other minerals which are therefore thousands of years old, not millions by which time ^{14}C would have long since decayed away completely (Baumgardner 2005 gives a short summary), but that does not obviously help with the tree rings problem. Also, it has been shown that the decay rate of some radioactive substances fluctuates by small amounts (e.g. Jenkins 2009). If we assume greater fluctuations in the past and that they were applicable to ^{14}C, perhaps that could somehow help by giving the same ^{14}C readings for widely different periods (would have to be combined with false matches in the dendrochronology). There have in any case been fluctuations in atmospheric ^{14}C giving historical dates centuries apart for the same carbon date, e.g. 750 BC and 430 BC have almost the same carbon date according to the calibration curve.

PROSPECTS FOR FUTURE CREATIONIST RESEARCH

Dendrochronology, despite the flaws outlined above, is a difficulty which creationists should be aware of. We can be confident that the age of the earth is far closer to 6000 years than 4.5 billion, but at present the dendrochronological evidence is not obviously compatible with a Flood as late as the Bible appears to put it. Sanders (2018, pp.521–523), after reviewing creationist dendrochronological research, suggested further work in the following areas:

1. Biblical studies critically analysing the genealogical and historical texts.
2. Verification of the time increments represented by growth rings.
3. Development of accurate models of global and local ^{14}C flux during the post-Flood recovery period.
4. Geological placement of the Flood / post-Flood boundary and the associated geological and climatic context for the whole period.
5. Complete understanding of ^{14}C contamination in long-lived species.
6. Biogeographic history of the tree species used for dendrochronology calibration curves.

ENDNOTES

1. Sometimes the walls of the cells are thicker (rather than smaller) which gives them a darker appearance in cross-section.
2. See www.radiocarbon.org/IntCal13.htm, Figures S1–S7. About to be superseded by IntCal20.
3. RATE stands for Radioisotopes and the Age of The Earth, and was a joint research initiative of the Institute for Creation Research and the Creation Research Society.

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AUTHOR BIOGRAPHY

Robert M. Porter was formerly a chartered mechanical engineer with BSc(Eng) and MSc, but he took a 'short break' at age 40 to investigate ancient history and archaeology in Old Testament times. That work continues to the present, and has included an MA in middle eastern archaeology.