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Dendrochronology and Other Applications of Tree-ring Studies in Archaeology

Peter Ian Kuniholm

Introduction

Tree-ring dating, as Bryant Bannister said in the 1963 forerunner to this volume, is deceptively simple. Some species of trees add their annual growth increments in two parts: spring wood and then summer wood cells ('early wood' and 'late wood'). These pairs of growth increments, when seen on the end-grain, look like 'rings:' hence the term. When trees in a given climatic region are similarly affected by yearly changes in the climate, their rings can be matched ('crossdated') with one another so that a given ring can be assigned to a specific calendar year. Sometimes a felling time within a year can be identified. Figure 1 shows a piece of structural oak from a tower in North Greece, the construction document of which survives. Work was begun on the monument in May 1597 and finished in December 1597. The timber itself was cut in late April/early May 1597 as only the springwood vessels of 1597 have formed. Clearly the timber was felled within a very narrow window of time and was used (as we know from the document) almost immediately thereafter. Dendrochronology is the only form of archaeometric dating with this kind of annual or sub-annual resolution. The method works only with species having clear, annual growth rings; it works with dry wood, wet wood (bog sites or shipwrecks), and burned wood (charcoal). Figure 2 shows two crossdatable pieces of sanded charcoal from a Middle Bronze Age palace in Turkey (19th century B.C.) Species in which the annual ring-boundaries are non-existent or indistinct, e.g., tropical trees, and most fruit or orchard trees (whose ring-growth may reflect merely the assiduity or the laziness of the gardener), cannot be crossdated.

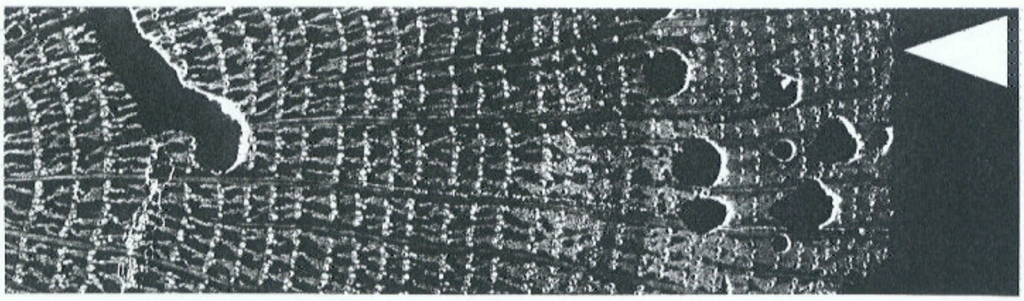


Figure 1: Oak chain-beam from the Frourio Vardari in Thessaloniki, North Greece. Earlywood vessels from 1597 had just formed when the tree was felled, indicating a cutting-date of late April/early May 1597.

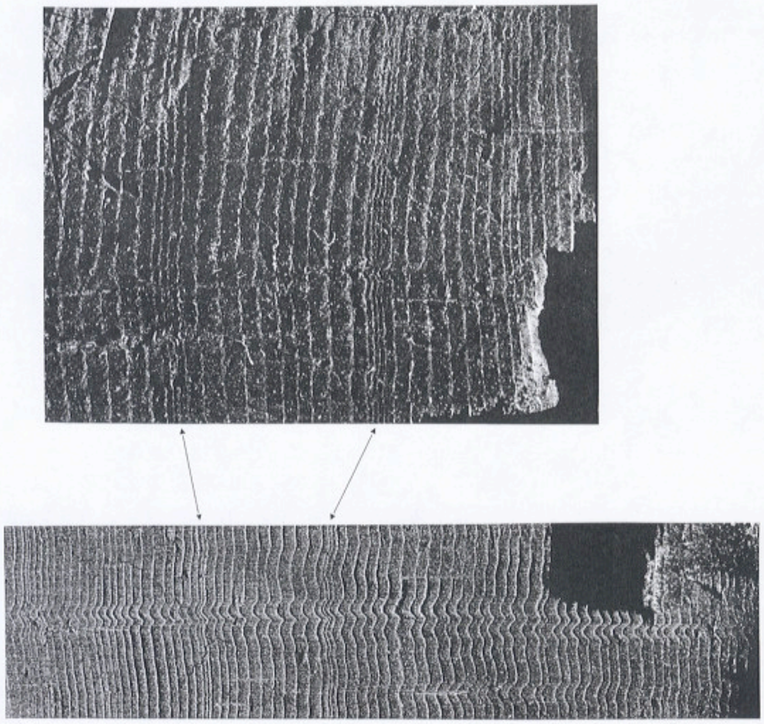


Figure 2: Two crossdated pieces of charcoal from a Middle Bronze Age palace in Turkey (19th century B.C.). Note the two extraordinary signatures. Several dozen other signatures confirm the correctness of the crossdating.

Crossdating is the fundamental principle upon which all dendrochronology is based and therefore deserves further explanation. The researcher has to be assured that rings from two or more specimens were formed in the same year. Simple ring-counts are not sufficient. Neither is a single pattern of co- variation in ring-width (a 'signature'). In order to avoid the possibility of an accidental (but spurious) 'match,' dendrochronologists try to compare samples which have at least 100 rings and multiple signatures rather than shorter-lived specimens which may not preserve enough signatures to guarantee the fit. These ring-patterns may be generated by a wild variety of causes. Fritts (1976), in one graph alone, lists eighteen possible causes for one narrow ring. The ring-patterns which are most usually crossdatable are the trees' mutual response to some mutual climatic stimulus; in some regions principally rainfall or lack of it; in others principally temperature; in yet others some combination of the two. This stimulus-and-response is therefore specific to a climatic region: i.e., the Southwestern USA, the extreme Northern timber-line (>~60 degrees N), Northern Europe, the Eastern Mediterranean, etc. The climatic boundaries for crossdating have been best determined, in practice, by trial and error. Sometimes they fit the map, sometimes not, and then an explanation for the apparent anomaly must be sought. Wood cut from a forest site in Calabria in Southern Italy, for example, crossdates with wood from Greece and Turkey, but it does not crossdate with wood from Spain, or over the Alps, or even Sicily. The first two non-fits are no surprise, but the non-fit with Mt. Etna in Sicily, only 80 kms. away, is, and therefore requires explanation. Sicily appears to belong more to the North African climate system rather than to that of the central/eastern Mediterranean.

Caveats to the dendrochronological method include the possibility of reused used wood: e.g., the Arizona mesas where wood cut in pre-Columbian times is still in use today; changing habits of users of wood: e.g., Renaissance painters who in different centuries tended to let their panels dry out for two, to five, to eight, to ten years before painting on them; heavily trimmed wood: e.g., cut boards or musical instruments; wood imported from some other climatic region: e.g., Abies (fir) at Herculaneum imported from the Alps, or Quercus (oak) panel paintings in England and the Low Countries which were imported as cut boards from the Baltic; wood which is so badly degraded that its ring- and cell-structures are not preserved; 'complacent' ring-sequences: i.e., little or no significant change from year to year; wood that has such erratic ring-sequences that they appear to fit in more than one place; or no wood preserved at all: e.g., the Baths of Caracalla or Diocletian in Rome with their hundreds of empty beam-holes. The standard cautions that govern an archaeologist's activities in the field apply to dendrochronology as well. Beware of singleton samples, wood from mixed fills, a single lump of charcoal selected randomly from a large pile, etc. A small bag of charcoal collected and submitted to the author as a single sample included as many as five different species of trees.

Brief history of the method

Tree-ring dating was discovered by the astronomer Andrew Ellicott Douglass in the early years of the 20th century in the course of his search for a pattern of plant responses to solar phenomena. If he had been a biologist, he probably would have considered all the reasons why the method ought not to work and would have abandoned it at the outset. It is a curiosity that "the Douglass Method," as it was called for decades after he practically singlehandedly dated the American Southwest (see Haury 1962, also Webb 1983), is still relevant and in use today. One needs only a razor blade to surface the wood, a pin to mark off the decades, graph paper on which to note down the micro-rings and other significant morphological details (unusually heavy or light latewood, partial rings, missing rings or rings missing on a particular radius, frost damage, outbreaks of insect infestation, etc.), and then the patience to match the pieces of graph paper until crossdating is achieved, confirmed by holding the two pieces of wood against each other.

Douglass's simple but highly-effective method ('skeleton-plotting'), used today principally in the American Southwest, does not work everywhere. In many other regions of the world where trees are not so highly-stressed, each ring has to be measured and the resulting graphs compared. A variety of measuring instruments are in use, and software packages for the statistical analysis of tree-ring information are announced regularly, but nothing quite replaces the human eye. Figure 3 shows two boards from an Egyptian sarcophagus in the Boston Museum of Fine Arts. Clearly, they were cut from the same tree. No statistical manipulation, no chi-tests, no r-square calculations are necessary. The danger in dendrochronology-by-the-numbers ought to be self-evident, yet there are still beginning workers who believe in the computer and a packaged software program rather than in the wood itself. Whether a low-technology or a high-technology method is used, the final result should be the same: a date that is accurate to the year and that can be replicated by other workers. For other cautions see Baillie's (1982) Appendix III.

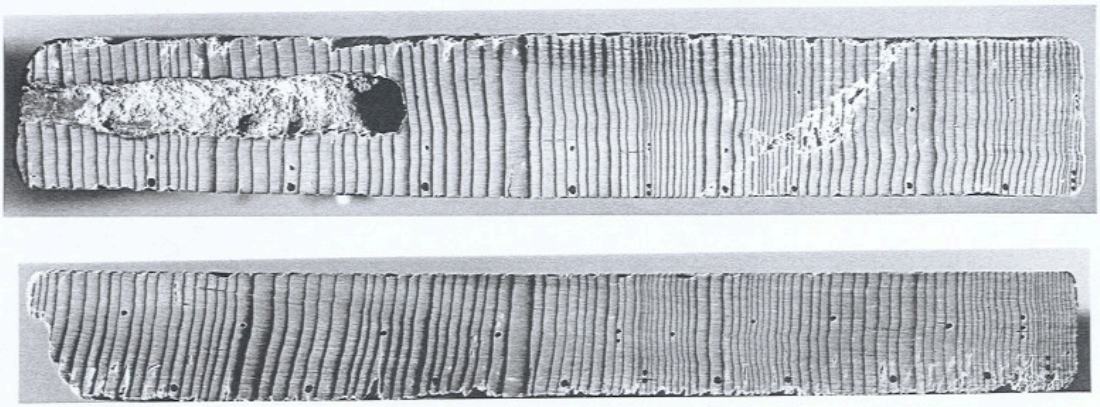


Figure 3: Two cedar boards from a Dynasty XII sarcophagus in the Boston Museum of Fine Arts. The signatures and other similarities in the ring-patterns show that the boards were cut from the same tree.

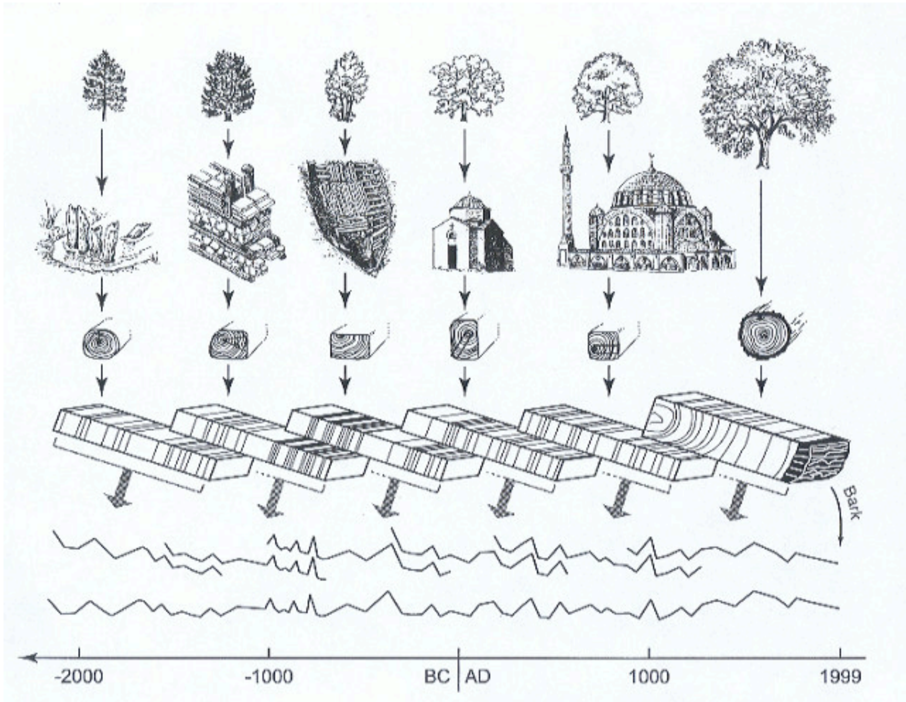
Techniques, sampling

Full cross-sections provide the greatest amount of information. When cutting these is either impossible or forbidden (from a living tree or from an important architectural monument), the dendrochronologist is obliged to resort to coring. A Swedish increment corer is used to extract thin radial cores from standing trees, and a variety of commercially-available drillbits are used to extract similar radial cores from intact architectural timbers. P. Klein and colleagues in the Hamburg laboratory have had good success with some 2000 oil paintings painted on wooden panels by surfacing the end-grain with a razor blade and measuring directly from the panel (Eckstein, et al., 1983; Klein 1980, 1986, 1991, 1993, 1994). On rare occasions a good, high-contrast photograph of the end-grain has allowed a piece of wood to be dated. The disadvantage of photographs is that microscopically-small rings are almost impossible to discern unless the photographer had the forethought to do some sanding and polishing before taking the photograph. For both sections and cores it is important to include as much of the sapwood where it is extant and to avoid knots, cracks, and other blemishes which distort the patterns of ring-growth. On any sample, if the bark is present (Figure 4a), or the 'waney edge' (an Anglicism for the surface immediately beneath the bark), the date when the tree was felled can be determined to the year. For oaks, (which have estimable even if region-specific amounts of sapwood), if a significant amount of sapwood is preserved (Figure 4b), the felling date can be estimated with varying degrees of precision to within several years. In other species, or in oaks with little or no sapwood and an unknown amount of missing heartwood (Figure 4c), only a *terminus post quem* date is possible.

Figure 4: Three dating possibilities from a single cross-section of Greek oak. **4A** is the most desirable sample with all the sapwood rings preserved out to the waney edge in 1439. **4B** is the next-best sample with some, but not all, of the sapwood rings present. The felling date therefore has to be estimated within five or ten years. **4C** is the least desirable sample with all of the sapwood rings and an unknown number of heartwood rings missing. The felling date cannot be estimated.

Techniques, analytical

The surface of the sample to be studied is prepared with fine sandpaper or a razor blade so that every ring can be measured and morphological oddities noted, usually under a binocular dissecting microscope. Then, whether a low- technology ('the Douglass method') or a more high-technology method is used, the latter including complete measurement of the ring-series and various kinds of statistical analyses (see the more recent handbooks listed below under 'Further Reading'), the rings have to be matched to one another. Once wood or charcoal specimens have been crossdated, they are then set in order (Figure 5), beginning with an absolutely-dated tree, and a chronology is built in step-wise fashion into the past as far back as the



evidence will allow.

Building the long chronologies

The backbone of all tree-ring research is the long chronologies to which all the dates are pinned. For North America the longest archaeological tree-ring chronologies, both Abies and Pinus (fir and pine) go back to about 300 B.C., and the Pinus longaeva (bristlecone pine) chronology is now over 8,400 years with a tentative extension to near 10,000. The European Quercus (oak) chronology is 10,479 years long, extending to 8,480 B.C. (numbers updated from Spurk, et al., 1998). A 2,012-year chronology of Pinus silvestris (Scots pine) when Europe was still too cold for oaks to grow (but which overlaps with the beginning of the oak chronology for more than 500 years) gives the European workers a complete tree-ring sequence from the present back into the last glaciation (numbers again updated from Kromer and Spurk 1998). The chronologies are expected to be lengthened in the very near future to include both the Lower and Upper Dryas. Aegean chronologies, principally Quercus, Juniperus, and Pinus (oak, juniper, and pine), total over 6,500 years with the longest single segment 1,636 years (Kuniholm 1996). In the Southern Hemisphere, the Southern Andes has a Fitzroya cupressoides (alerce) sequence extending back to 1,634 B.C., and New Zealand now has a 1,200 year chronology for Lagarostrobus colensoi (silver pine). In Tasmania a chronology of over 4,100 years has been developed for Lagarostrobus franklinii (Huon pine), but its archaeological significance is limited by the fact that exploitation of this tree dates back to only the early 19th century. Southern Africa's longest chronology is one of 413 years for Widdringtonia cedarbergensis or Clanwilliam cedar.

The Northern Hemisphere tree-ring chronologies currently have greater relevance to archaeology because they co-exist with vast amounts of archaeological activity. Tree-ring dates have been cited at annual archaeological meetings for the better part of a century for North America, for almost half a century for Europe, and for a couple of decades for the Aegean and the Near East. North America's lead in using tree-ring dates has a lot to do with the pioneering efforts of Douglass and his followers and also a lot to do with the lack of king-lists, written records, and other chronological indicators on which Old World archaeologists have so long relied.

Some 573 tree and shrub species have been investigated for tree-ring studies. Of these some 180 can be crossdated. Some of the important genera for archaeological research are (species investigated/species known to crossdate): Pinus or pine (63/54), Quercus or oak (44/27), Abies or fir (34/21), Picea or spruce (21/19), Juniperus or juniper (21/15), Larix or larch (9/9), Populus or poplar (10/7), Acer or maple (10/6), Betula or birch (15/5), Tsuga or hemlock (7/5), and Cedrus or cedar (4/4). See Grissino-Mayer (1993) for the complete listing as well as an assessment of each species' importance in dendrochronology.

Progress from 1963-1999

At this point the seriously-interested reader should consult two fundamental articles: B. Bannister in Brothwell and Higgs, eds. (1963) and Dean (1997). Bannister's is the classic exposition, and yet he forecast 'rapid future progress.' Dean's recent summary of that progress shows how prescient Bannister was and how the application of the dendrochronological method has practically exploded in the last generation to include a variety of sophisticated forms of climate and environmental reconstruction. H. Grissino- Mayer's website (http://tree.ltrr.arizona.edu/~grissino/Henri.htm) with links to several dozen laboratories around the world shows 6752 bibliographic entries as of September 1999, and more references are added regularly. Two journals devoted exclusively to dendrochronological subjects are the Tree-Ring Bulletin (1934-) and Dendrochronologia (1983-). Over 1500 archived tree-ring data sets are in the International Tree Ring Data Bank in Boulder, Colorado (http://www.ngdc.noaa.gov/paleo/ftp-treering.html), and a polyglot cross-referenced guide to dendrochronological terminology in seven languages is to be found in Kaennel and Schweingruber (1995).

As archaeology has grown from its rather primitive beginnings, so, too, dendrochronology has evolved from a relatively limited focus on the dating of monuments or archaeological strata. In addition to the simple ring-width measurements pioneered by Douglass (1919, 1928, 1936), whether skeleton-plotted or measured, new analytical techniques include X-radiography, X-ray densitometry, and neutron activation analysis, among others, to study morphological and chemical changes within particular rings or cells or to detect the presence of specific trace-elements and isotopes.

Applied dendrochronological topics now include the study of changes in both the immediate and distant environment (Dean 1988), the history and effects of pollution (summarized in Schweingruber 1988), stream erosion and infill (LaMarche 1966), forest fires (Swetnam 1993), earthquakes (Lamarche and Wallace 1972; Jacoby, et al., 1992), glacial movement (LaMarche and Fritts 1971; Schneebeli and Röthlisberger 1976; Kaiser 1993), volcanoes (LaMarche and Hirschboeck, 1984; Kuniholm, et al., 1996), tsunamis, seasonal river flooding, insect life-cycles, human intervention in the forest, and changes in wood utilization and exploitation (Billamboz 1988; Dean 1978), etc. Schweingruber (1988) provides an extraordinary illustrated listing, with bibliography, of many of these fields and sub-fields into which dendrochronological research has evolved. See also Schweingruber (1993, 1996) and Schweingruber and Schoch (1992) for the most recent work on dendroecology and the environment.

Case studies in dendrochronology

In contrast to some of the other archaeometric techniques where the laboratory scientists interact very little with the archaeologists, dendrochronology from its very beginning has been typified by close collaboration between the archaeologist and the dendrochronologist with the latter visiting the site, discussing its problems and interpretation with the excavator, and only then taking the sample. An ideal sample will be of value to both parties, i.e., datable and from a significant archaeological context. Instances where dendrochronology has been applied with noteworthy results to the interpretation of archaeological sites or archaeological or art-historical artifacts include the following, listed by the three principal regions where tree-ring dating has been done extensively.

A. North America:

At Pueblo Bonito (New Mexico) and other nearby sites Douglass not only provided absolute dates for forty-five monuments for the first time ever (Douglass 1929, 1935), but he also made observations on the possible use of dead timbers, or re-use of timbers, and on the effects of a great drought from 1276-1299 as well as over a dozen other droughts which must have had significant effects on the local population. In this ecumenical outlook Douglass, as a field archaeologist, was decades ahead of his time.

At Betatakin, Kiet Siel, and eleven neighboring sites in Northeastern Arizona Dean took Douglass's work a step further by providing dates for specific rooms and clusters of rooms (Dean 1969; Dean, et al., 1978), as well as integrating the tree-ring dates with interpretation of the ceramic evidence. He also was able to make a number of environmental inferences: that the environment of Betatakin has not changed in 700 years while that of Kiet Siel has; that one site exhibits the practice of stockpiling timbers before use and the other does not; that at both sites the re-use of old wood is common; and that patterns of population growth, of immigration, and of population decline can be demonstrated. Finally, Dean is able to make a number of inferences about the social organization of the villages--all beginning with the tree-rings!

In an early work that is little-known to European archaeologists, Giddings studied sea-side settlements in Northern Alaska at Point Hope and along the Bering Strait (Giddings 1942). Here he was able to show that some of these whalebone and wood buildings were made of trees that had drifted about the Arctic Circle for more than a century before they were incorporated into house walls.

B. Europe:

Here the chronologies are longer and the story is more complicated. In the Bodensee (Lake Constance) and other early lake-settlements near the Alps (Billamboz 1988, 1990, 1996; Schlichtherle 1990), not only have the earliest Neolithic levels been dated to the year, but the very shape of each oak post is an indication of its likely date, even before measurement (Billamboz 1987). In the first phase of the Neolithic all timbers are little more than saplings and must have been collected from near the lakeshore. In the second phase of the Neolithic the timbers are always halved or quartered, suggesting both that the supply of small-dimension wood was exhausted and that the technology to split somewhat larger trees had been developed. In the third phase even larger trees are cut into multiple segments. Technology had continued to develop so that the forest on the hillsides away from the lake could be exploited.

In Zürich and the Swiss lake district the work of Huber and Merz at Zug- Sumpf, Thayngen-Weier, and the Burgäschisee, and culminating now in the work of the Ruoff group has been exemplary. The Pfahlbauland exhibit at Zürich in 1990 was a creative setting-forth of the whole prehistoric past of the lakes: architecture, agriculture, animal domestication, ecological and environmental studies, and technological practices of all kinds (multiple references in Schweizerisches Landesmuseum Zürich 1990; Pfahlbauland videos 1990), all dated by dendrochronology.

Riverine Europe has been studied dendrochronologically from the headwaters of the Rhine (Kramer and Schlichtherle 1995; Billamboz and Martinelli 1996), Mosel, and Danube (Billamboz and Schlichtherle 1986) all the way to the Baltic, from the living oaks of the Spessart Forest back to the last ice age (Becker 1982; Becker, et al., 1984, with references to the work of B. Huber, the German analogue to Douglass), to new work in the medieval and prehistoric Netherlands (Jansma 1995), to the prehistoric trackways across the lower Rhineland (Schmidt 1987), to the early medieval and Viking settlements at Haithabu (Eckstein 1969, 1972; Eckstein, et al., 1983), to a long series of medieval buildings in the Rhineland (Hollstein 1980), to a thorough study of private houses in the Mosel Region (Schmidt, et al., 1990), to the imported Polish oak which served as supports for Netherlandish panel paintings (Baillie, et al., 1985; Eckstein, et al., 1986) and for wainscoting in English country houses, among other studies.

Insular Europe is being studied by the Belfast group (Baillie 1982, 1995), as well as the Sheffield and Nottingham groups; and the islands, as does the Continent, have wooden trackways such as the Sweet Track in Somerset dated by dendrochronology (Morgan 1988; Coles and Coles 1986), bogs, submerged forests, sunken boats, but also horizontal mills (Baillie 1982) and crannogs, small artificial islands formed inside circles of oak posts driven into lakebeds (Baillie 1995). The latter are split sections of enormous trees, often subdivided radially in halves or thirds with the result that 'phantom phasings' result: the interior third ends without sapwood as does the middle third some years later. Only the exterior third (with its sapwood present) reveals the true state of affairs. All three 'phases' are one. Indiscriminate radiocarbon analysis of the three sets of sections would have yielded nonsensical results. The Bodensee analyses by Billamboz (especially the timbers from his Neolithic III) are analogous to this.

Archaeological dendrochronology in Russia, notably at Novgorod (Kolchin 1963, 1967), in addition to providing firm dates for the churches and houses, also revealed a remarkable set of split-log roadways which, as they sank into the soft substrate, showed many signs of conflagrations. Novgorod, which we know from the chronicles was never attacked by anybody, suffered a catastrophic burning about once every twenty-four years over several centuries, not altogether surprising for a town built largely of wood. So much for some of the 'destruction levels' about which Near Eastern archaeologists so often read and write. Study of the Scythian kurgans from Pazyryk in the High Altai to Western Russia is still in its infancy and remains largely a project for the future, but the potential is considerable.

C. Aegean and the Near East:

Dendrochronological analysis of approximately two hundred medieval buildings in Greece and Turkey has been carried out since 1973 (Kuniholm and Striker 1987; Kuniholm 1994). One exemplar of how the method can change old ways of thinking is the Church of the Holy Apostles in Thessaloniki where a puzzling, long-misunderstood monogram which suggested a date of 1310-1314 is contradicted by the dendrochronological date of 1329 (Kuniholm and Striker 1990).

In the pre- and proto-historic Near East a series of dates for the Iron Age and the Bronze Age is available (Kuniholm 1996; Kuniholm, et al., 1996). The earliest work is at the Neolithic site of Ç Höyük where a 576-year chronology, wiggle-matched by radiocarbon (see explanation below) fairly closely to an end date of 6449 B.C. is in place (Kuniholm and Newton 1997; Newton and Kuniholm 1999).

Case studies in environmental and climatic reconstruction

A. North America:

Although climate reconstruction may be considered by some archaeologists as outside the scope of their immediate concerns, the successful study and analysis of palaeoclimate are having an increasing impact on archaeological thinking. For the method in general see Fritts (1976); Hughes, et al., (1982); Schweingruber (1996); for the Southwest in general see Douglass (1914, 1919, 1928, 1936) and Schulman (1956); for Western North America see Schweingruber, et al., (1991); for the Southern Colorado plateau see Dean and Funkhouser (1995); for the Sierra Nevada see Graumlich (1993); for the medieval warm period see Hughes and Diaz (1994); for the Southeastern USA see Reams and Van Deusen (1996) and Stahle and Cleaveland (1992); for Jamestown see Stahle, et al., (1998); for fire history and climate change in the California sequoia groves see Swetnam (1993).

B. Europe:

For Europe in general see Bartholin, et al., (1992) and Briffa, et al., (1986); for Western Europe see Schweingruber, et al., (1990, 1991); for Fennoscandia see Briffa, et al., (1990); for the medieval warm period see Hughes and Diaz (1994); and for southern Europe see Urbinati and Carrer (1997).

C. Aegean and the Near East:

For an early resumé see Kuniholm (1990), and now Hughes, et al., (submitted for publication).

Radiocarbon calibration and wiggle-matching

The story of the tree-ring calibration of the radiocarbon time-scale is or should be well known to most archaeologists (Suess 1970, Stuiver, et al., 1993, 1998; and for interpretation Renfrew 1979). What is less well-known is the application of 'wiggle-matching,' where selected decade-long slices cut from a piece of wood at specific intervals are individually radiocarbon-dated, and then the whole array of dates is matched to the radiocarbon curve (Kuniholm 1996). Figure 6 shows an example of wiggle-matching from the Early Bronze Age site of Lavagnone di Brescia in Northern Italy. The work is still in progress, but even a casual reader of graphs should be able to see that the seven radiocarbon dates as wiggle-matched to the calibrated radiocarbon curve limit the possibilities of placement of the chronology to about a decade either way. The fourth (or middle) date, about 3755 years BP, could just as easily be placed about 70-130 years earlier because of the wiggles that the radiocarbon curve takes at those points. However, because we know the relationship of the fourth sample to the other six, there is only one likely range on the curve where all seven samples can sit in comfort, and thus the two sets of 'wiggles,' both that of the master radiocarbon curve and that from Lavagnone may be said to 'match' each other at that one placement with a very small margin of error.

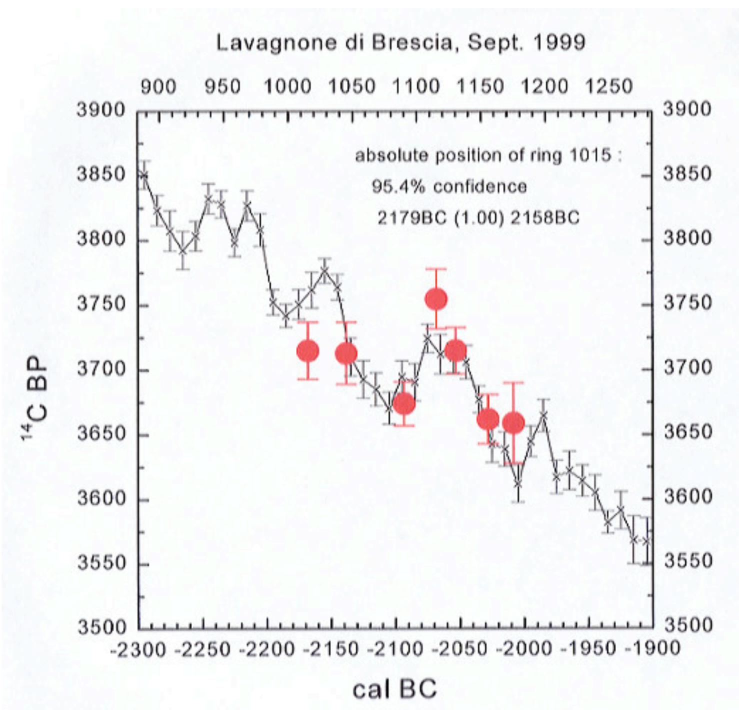


Figure 6: Radiocarbon wiggle-matching of an Early Bronze Age site. The seven decadal ring-sequences were sliced from a log at selected intervals. Since the exact number of rings between each pair of samples is known, it is possible to consider them as a single group. The radiocarbon counting errors are thereby minimized.

Future prospects

Baillie (1995) said: "In many ways people have been unprepared for the injection, into a predominantly radiocarbon-based chronological framework, of precise calendar dates...." This is equally true for parts of the archaeological world where chronologies traditionally have been based on king- lists, pottery types, and the written records where such exist. The fact that there are four different chronologies for Egypt, all based on the 'historical record,' should give one pause for thought.

There is continued reason, however, to be optimistic about future prospects in dendrochronology and its evolving applications. As the long tree-ring chronologies are extended and their relationships to one another are more clearly understood, as geographical gaps are filled in to create a web of absolutely-dated and interlinked chronologies world-wide, and as new methods of their interpretation are developed, projections on a hemispheric scale ought to be possible. Soon we will read when the Upper Dryas happened and exactly how many years it lasted in Southern Germany. Before some forty years of work by Huber and Becker and their followers this would have been unimaginable. In 1976 the writer was assured that there were four oak chronologies in Germany that would never match each other. Now there is one. Sixteen years ago Baillie (1983) asked rhetorically, "Is there a single British Isles oak tree-ring signal?" We now know that the answer is yes, and we also know that the British and German chronologies match each other,...indeed all of Western Europe oak from the Pyrenees to the Baltic can be crossdated. The accomplishments of the last thirty-six years, as the list of the case studies above should show, have been just what Bannister predicted in 1963. The effects that tree-ring dating ought to have on archaeology in the next generation and the refinements in archaeological thinking that will thereby be required are indeed going to be revolutionary.

Further reading

Handbooks and other basic explanations: Discussions of the method and useful illustrative material are to be found in Glock, 1937; Stokes and Smiley, 1968; Ferguson, 1970; Eckstein, et al., 1984; and Cook and Kairiukstis, eds., 1990. Collected conference papers: One reason for the successful development of dendrochronology is the extent to which workers have shared information, even raw unpublished data. A series of international meetings with titles that do not necessarily appear in electronic key-word searches has brought the tree- ring community together at irregular intervals, and the published proceedings form a sequence that charts the progress of the field. In chronological order they are: Fletcher, ed., 1978; Eckstein, et al., 1983; Ward, ed., 1987 [a compilation rather than a meeting]; Bartholin, et al., 1992; Hughes and Diaz 1994; Dean, et al., 1996; Stravinskiene and Juknys, eds. 1998.

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