The Role of Dendrochronology on Archaeology

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Dendrochronology is the science of tree-ring dating by which the annual growth layers of trees may be assigned to the exact year of their formation. Dendrochronology made a significant contribution to the science of archaeology. Dendroarchaeology provides a broad spectrum of information on the history of human activities including the treatment of trees as a natural resource and wood as a raw material, sources of timbers, season of wood procurement, and various specific wood use practices. Dendroarchaeology is practiced in many parts of the world, but is used most in the Southwest of North America. However, in the Middle East is still in the early stages of development. The purpose of this paper is to discuss the history of dendroarchaeology in North America, Europe, and the Middle East. We will also discuss the difference between the European and the American dendroarchaeology techniques.

Dendrochronology, a name derived from the Greek words for “tree” and “knowing the time”. It is a set of techniques by which (1) the annual growth layers of trees may be assigned to the specific year of their formation; and (2) the history of changes in the tree's environment may be reconstructed using various properties of annual tree rings, (e.g. their width, cell sizes, wood density, trace element composition, and radioactive and stable isotope ratios).

Stokes and Smiley (1968) established four principles for crossdating. This is a term used to describe the process of assigning year dates to annual tree rings by cross-comparison of rings from several trees growing in the same area (Figure 1).

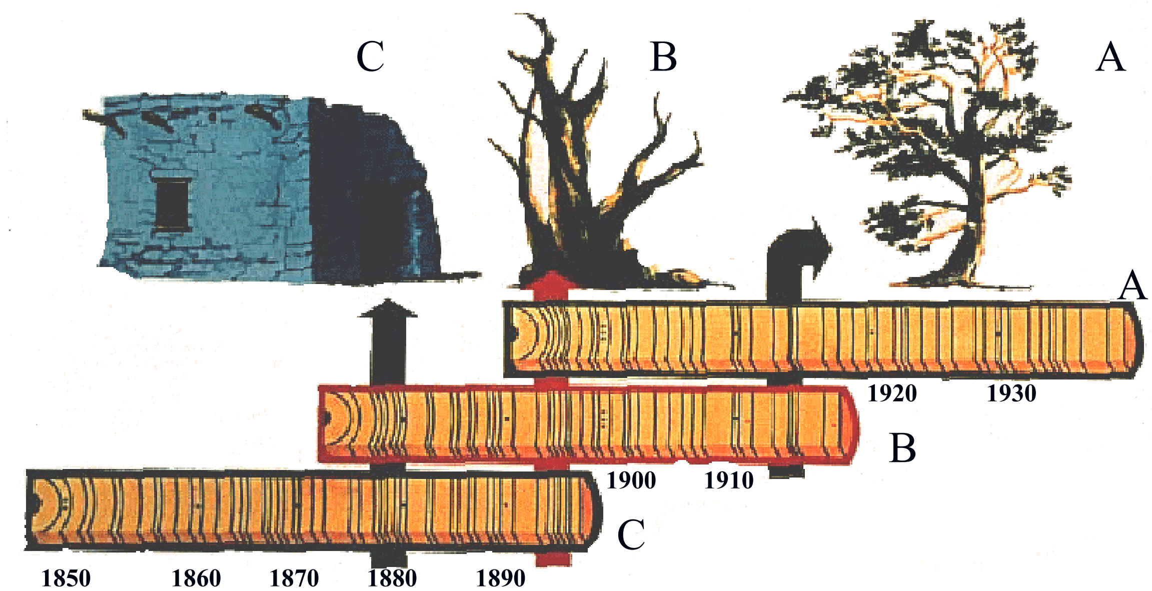

Figure 1. Extending chronologies by crossdating using living and dead wood.

1. The trees that will be used for crossdating should produce one ring for each year.
2. One environmental factor must dominate in limiting the annual growth such as precipitation or temperature.
3. The intensity of growth-limiting environmental factor must vary from year to year and the resulting annual rings faithfully reflect such variation in their growth.
4. The growth-limiting factor must be effective over a large geographical area.

Historical Background

Andrew E. Douglass established the scientific basis of dendrochronology in the early years of this century (Figure 2). He graduated from Trinity College (Connecticut) in 1889 and became affiliated with the Harvard College Astronomical Observatory. In 1894, he traveled to Flagstaff, Arizona, where he became assistant to the director of the Lowell Astronomical Observatory.

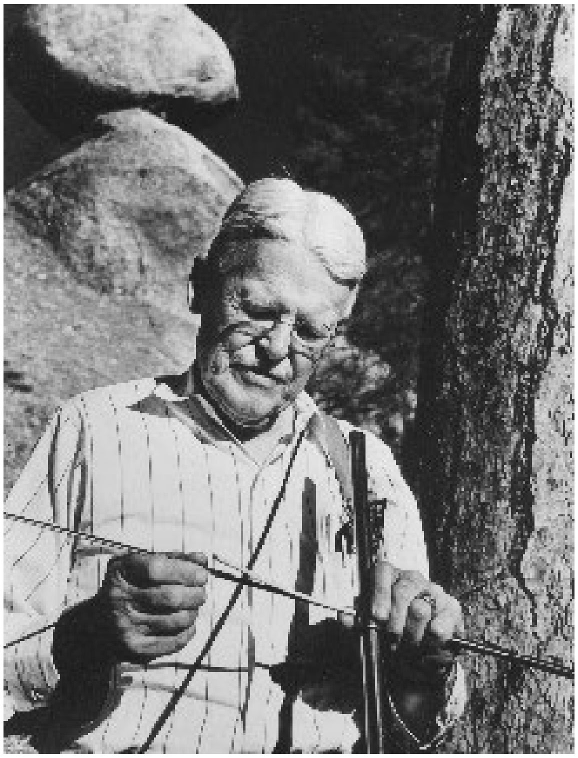

Figure 2. A.E. Douglass examines a Ponderosa pine core.

Douglass was interested in sunspot events. He was trying to understand the relationship between cyclic activity of sunspots and climate on earth, particularly precipitation, because he believed that sunspot activity might influence the weather on earth. He was not able to establish a clear relationship between the two.

Douglass first attempted to use tree ring growth to test the relationship between climate and sunspot activity in 1901 when he was on a trip to the forests of northern Arizona. On the sawed end of a log he noticed how the ring widths varied. He began to examine more specimens from the area surrounding Flagstaff. In examining six cross-sections of logs from a lumberyard, he noticed that a similar pattern of small rings twenty-one years inward from the bark occurred in all the logs. He then realized that the determination of the age of the trees does not depend on the existence of the outside bark. To prove his findings he examined a stump that had been cut some years earlier. He noticed the same pattern of small rings, but they were only eleven years from the outside. By matching the earlier samples with the rings on the stump, he concluded that the tree had been cut ten years earlier than his first group of samples. He had, in effect, established the technique of crossdating.

In 1906, Douglass was appointed as an Assistant Professor of Physics and Geography at the University of Arizona in Tucson. In 1909, he published an article on his tree-ring research in the *Monthly Weather Review* .

In 1911, Douglass recognized the significance of his observation when he examined trees from Prescott, 81 km southwest of Flagstaff. He noticed a similar pattern of wide and narrow rings to those that he had seen in the Flagstaff trees. He recognized that crossdating can be used over wide areas where the tree growth is limited by the same climatic factor.

He continued to derive the record of past climate by comparing and combining the tree-ring records of many different trees. This procedure is called chronology building. In 1914, he was able to build a 500-year long tree-ring chronology from ponderosa pine (*Pinus ponderosa*). He was also able to demonstrate a direct relationship between the annual ring width and total precipitation in the winter preceding growth of the ring.

In 1914, Douglass met Clark Wissler, an anthropologist at the American Museum of Natural History, New York, and presented a talk at the Carnegie Institution about his research. Clark Wissler was trying to date prehistoric Indian village sites in the southwestern United States. This meeting encouraged both to use the technique of crossdating to date logs from the Indian settlements. Over a twenty year period, Douglass studied the history of the villages by crossdating prehistoric wood found in the houses (Figure 3). He developed these chronologies by crossdating specimens from the ruins, and collecting samples from living trees surrounding those ruins to bring the chronologies to the present time. In 1929, Douglass was able to document the history of many Indian sites in the Southwest for periods where no written documents exist.

Figure 3. Large ruins at Tonto National Monument in southern Arizona where A.E. Douglass dated the construction periods for Puebloan ruins.

In 1937, he established the Laboratory of Tree-Ring Research (LTRR) which became the first institution devoted exclusively to tree-ring studies. Two students (Waldo S. Glock and Edmund Schulman) helped Douglass to develop chronologies for different purposes, using several species. Glock left the LTRR and later wrote extensive reviews of tree growth and climatic relationships, while Schulman continued his work in the Southwest. His two best known contributions were a monographic study on dendroclimatology and his discovery of 4500-year-old bristlecone pine (*Pinus longaeva*) (Fritts 1976).

Dendroarchaeology in United States

Douglass' pioneering work was far from unique in attempting to relate environmental factors to the size of annual rings. This had been done in Europe and elsewhere in the 19th century. His contribution was to establish systematic crossdating as the basis for rigorous work in this field, a development which has since been adopted in many countries. This made possible the growth of dendrochronology seen in recent decades.

In addition to the LTRR, several dendrochronological laboratories established after Douglass' 1929 discovery, such as Laboratories in Arizona (Flagstaff and Globe) and New Mexico (Santa Fe). During the same period dendrochronological research was conducted in Kansas, North Dakota, the southeastern United States, and Alaska. In the 1950s, all the tree-ring laboratories were closed except the LTRR in Tucson, Arizona. All the collections of the closed laboratories were transferred to the LTRR.

Many new laboratories were established in the US, such as The Tree-Ring Laboratory at the University of Arkansas; The PISCES Laboratory at the University of California, Los Angeles; INSTAAR Dendrochronology Laboratory at the University of Colorado; Lamont-Doherty Earth Observatory Tree-Ring Laboratory at Columbia University, New York; The Malcolm and Carolyn Wiener Laboratory for Aegean and Near Eastern Dendrochronology at Cornell University, Ithaca, New York; Tree-Ring Laboratory at the University of Georgia; Tree-Ring Laboratory at the University of Missouri-Columbia; Tree-Ring Laboratory at the University of Nevada, Reno; Vegetation Dynamics Laboratory at Pennsylvania State University; and the Laboratory of Tree-Ring Science at the University of Tennessee. All these laboratories did not conduct large scale dendroarchaeological research in the Western Hemisphere.

In 1950s, Breternitz (1966) made a significant use of dendroarchaeological records in dating southwestern ceramic complexes. Slightly later, other scientists (Damon et al., 1966; Ralph and Michael, 1967; Suess, 1967, 1970) initiated the use of tree-ring dated bristlecone pine samples to calibrate the radiocarbon time scale. In 1960s significant advances in the science of dendrochronology, dendroarchaeology, dendroclimatology, southwestern dendrohydrology, and dendroecology occurred because of the expansion of the LTRR and the transfer of collections from other laboratories. For example, Bannister (1962, 1965) refined the dating of several of the larger ruins in Chaco Canyon and expanded dendroarchaeological theory beyond that initiated by Smiley (1955). Robinson (1967) began using tree-ring sample collections to illuminate past human behavior by describing the impact of wood-use practices and stone ax use on Basketmaker III society (A.D. 600-750). Several scientists expanded the dendroarchaeology of other Southwestern groups (Towner, 2003), elaborated dendroarchaeological theory (Ahlstrom, 1985), and analyzed the influence of dendrochronology on American archaeology during the 20th century (Nash, 1999). In a study of 13th century Kayenta Anasazi cliff dwellings in northeastern Arizona, Dean (1969) explored all three aspects of dendroarchaeological research: chronology, human behavior, and environmental reconstruction. This project integrated tree-ring and archaeological data to formulate and test hypotheses concerning prehistoric social organization, human wood use, and behavioral adaptation to environmental variability.

Dendroarchaeology in Europe

In the 1930s, Douglass' initial dendrochronological accomplishments in the southwestern United States inspired Bruno Huber (1941) of the Forest-Botanical Institute in Munich, Germany, to develop long crossdated tree-ring chronologies for the express purpose of dating archaeological sites in southern Germany. At about the same time archaeological tree-ring work was begun in Scandinavia (Hoeg, 1944). These developments were interrupted by World War II and, except for Kolchin's (1967) pioneering work at the medieval site of Novgorod in Russia, dendroarchaeology was not resumed in earnest until around 1960 when growing interests in archaeological dating and calibration of the radiocarbon time scale stimulated a major expansion of European dendroarchaeology. Building on the work of Huber and his students, this growth eventually encompassed all of Europe and resulted in the current existence of scores of tree-ring laboratories engaged in archaeological dendrochronology ranging from

Northern Ireland to Siberia and from Scandinavia to the Mediterranean Sea (see various papers in Dean et al., 1996). These developments created a thriving dendroarchaeology that has produced thousands of dates from hundreds of buildings, roadways, ships, artifacts, and other contexts.

Dendroarcheology in the Near East

In the Near East, relatively few dendrochronological studies have been performed. A. E. Douglass, after his success in dating prehistoric timbers in the American Southwest, applied the same techniques to Egyptian wooden coffins stored at the Oriental Institute in Chicago but failed to establish crossdating among these elements. However, his former student Bryant Bannister was the first dendrochronologist to attempt systematic tree-ring dating of Near East archaeological sites (Bannister 1970). He collected and analyzed tree-ring specimens from an eighth century B.C. tomb in Turkey and carried out preliminary examination of wood samples from Egyptian coffins. He also collected and crossdated samples of Cedar of Lebanon (*Cedrus libani*) in Lebanon. Since Bannister's early investigations, various dendroachreological studies in the Near East have been performed. The most ambitious of these efforts is that of Peter Ian Kuniholm of the Malcolm and Carolyn Wiener Laboratory for Aegean and Near Eastern Dendrochronology. Expanding on Bannister's work in Tumulus MM at Gordion in Turkey, Kuniholm collected thousands of samples from archaeological and living-tree contexts in Anatolia, the Balkans, Greece, and the Aegean Islands. These sample have produced long tree-ring chronologies that underlie hundreds of archaeological tree-ring dates (Kuniholm, 1996). In addition, these chronologies have been used to illuminate natural events such as volcanic eruptions, particularly that of Thera on the Mediterranean island of Santorini (Kuniholm, 1991), and to investigate local variations in the radicarbon calibration curve (Kromer et al., 2001).

Cross-Dating Techniques

1. North American technique (Skeleton Plot)

Dr. A. E. Douglass invented the technique of crossdating by means of skeleton plots (Figure 4). A skeleton plot is a graphical illustration of tree-ring widths (Figure 4). It is a technique that aids the dendrochronologist in relating groups of specimens to each other by matching ring patterns and determining the exact date for each ring (see Stokes and Smiley 1968). This simple technique requires an experienced person with microscope, pencil and graph paper. This technique is faster than methods requiring ring measurements, but in some cases where the samples are complacent (tree-ring growth varies little from one year to the next) it is better to measure the samples and view the plots overlaid on a light table to determine the exact dates.

In skeleton plotting, the narrow rings in the undated sample will be compared. Each narrow ring on the sample will be marked as vertical line on the graph paper. The criteria of narrowness depend on the comparison between each ring to the immediate neighbors (three to five neighboring rings). The narrower the ring, the longer the drawn line on the strip of the graphic paper, but it should not be marked greater than 1 (10 squares on the strip of the graph paper represents the value 1). The innermost ring on the undated sample is plotted at zero which is an arbitrary numbering sequence. The plotting will continue from this point outward on the specimen. Crossdating will require matching common patterns of wide and narrow rings among two cores from the same tree and between trees.

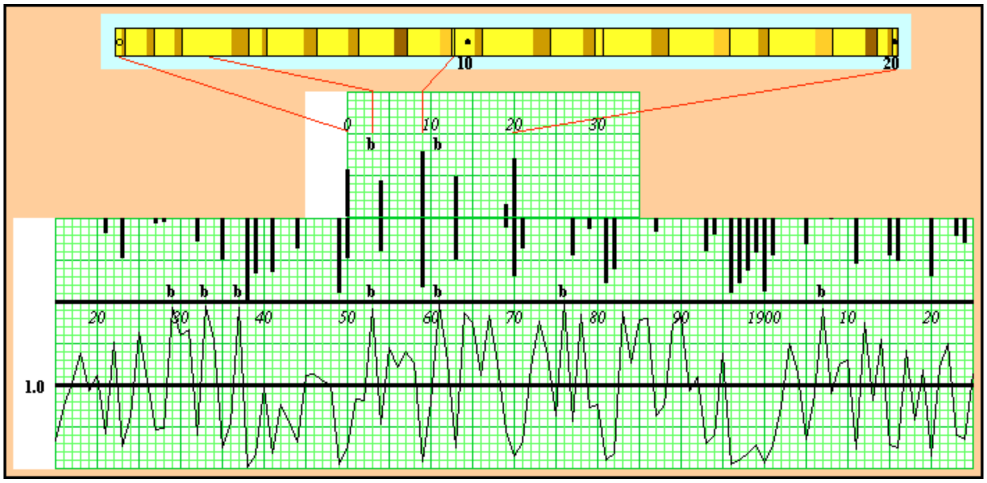

Figure 4. Using the skeleton plot technique for cross-dating (Sheppard, 2002).

2. The European Technique

From the beginning, European dendrochronologists were faced with tree-ring width series quite different from those confronted by Douglass. European tree-ring sequences tended to exhibit much less between-ring variation than their counterparts in western North America. Therefore, the skeleton plot dating method perfected by Douglass was difficult to apply in Europe. As a result, European dendrochronologists developed other techniques of representing tree-ring width variability and establishing crossdating, all based on measured ring widths. The first of these, the W statistic (also known as the gleichläufigkeitswert or coefficient of parallel variation), which tracks the number of cases in which ring widths in paired series rise or fall together, was developed by Huber (Huber et al., 1949). Given the quantitative data base, European dendrochronologists have developed several computer based crossdating programs. The most widely used of these is CROS (Baillie, 1982:82-85, 1995:20-21), which employs a *t* statistic to test the probability of each of a sequence of correlation coefficients for successive, one year incremental, matches between two tree-ring series. Ideally, a single significant *t* value identifies the match point and specifies the calendar date of samples of unknown age.

What is the Role of the Laboratory of Tree-Ring Research Now?

The application of Douglass' crossdating has been remarkably successful. Major contributions have been made to archaeology, quaternary geology, geophysics, solar physics, ecology, hydrology, and climatology. Using precise chronologies based on tree-ring dating, LTRR faculty and staff have been able to improve our understanding of processes in natural and human systems, and have made important estimates of the rates of these processes. They were also able to establish new tree-ring chronologies in many parts of the world.

Several hundred scientists around the world use dendrochronological techniques in many fields of science. The LTRR is the place to which they most commonly turn for advice and training. For example, more than twenty foreign visitors spend one week or more in the Laboratory in an average year, and 332 individuals attended a conference organized by the LTRR in May 1994 (Dean et al., 1996). Recent students and visitors have come from countries as diverse as Russia, Lithuania, Finland, Italy, Austria, Spain, Morocco, Tunisia, Syria, Lebanon, Jordan, Turkey, Oman, Saudi Arabia, Canada, Mexico, Chile, Argentina, South Africa, China, Japan and India.

International Tree-Ring Data Bank (ITRDB)

The ITRDB is a professional organization that stores dendrochronological data from around the world. The ITRDB was formed in 1974 at a workshop of dendrochronologists. The NOAA Paleoclimatology Program (World Data Center A for Paleoclimatology) is the home of the ITRDB. Its status as a component of the International Council of Scientific Unions (ICSU) World Data Center System means that its holdings are freely available for no more than the cost of reproduction. Over 1500 sites on five continents are included (Figure 5). The Data Bank includes raw ring width or wood density measurements, and site chronologies. Reconstructed climate parameters are also available for some areas.

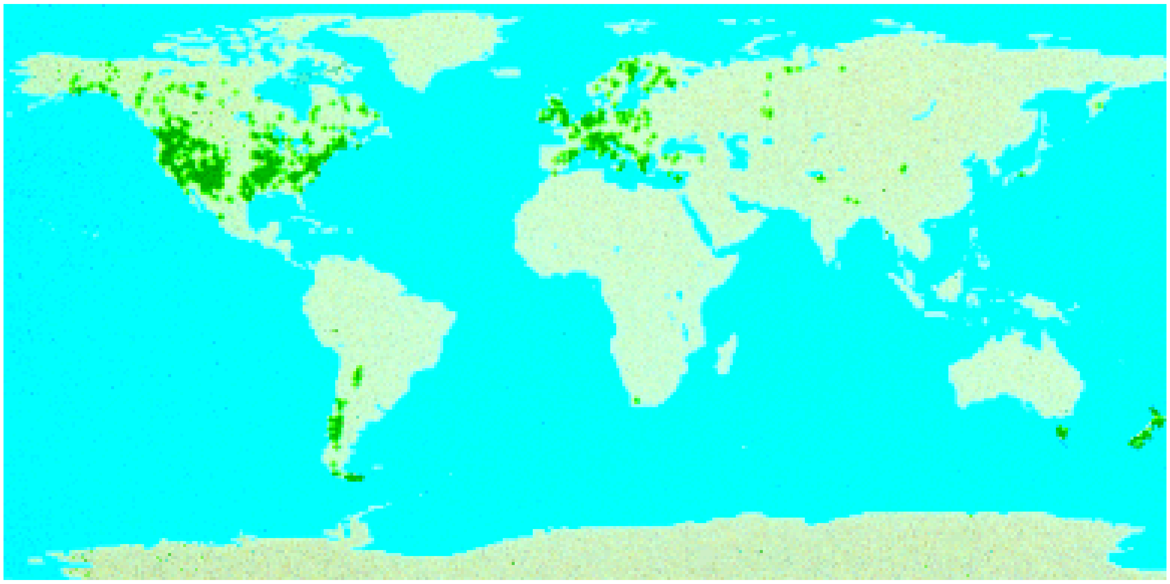

Figure 5. Location of tree-ring series stored in the ITRDB.

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