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17 *Dendrochronology*

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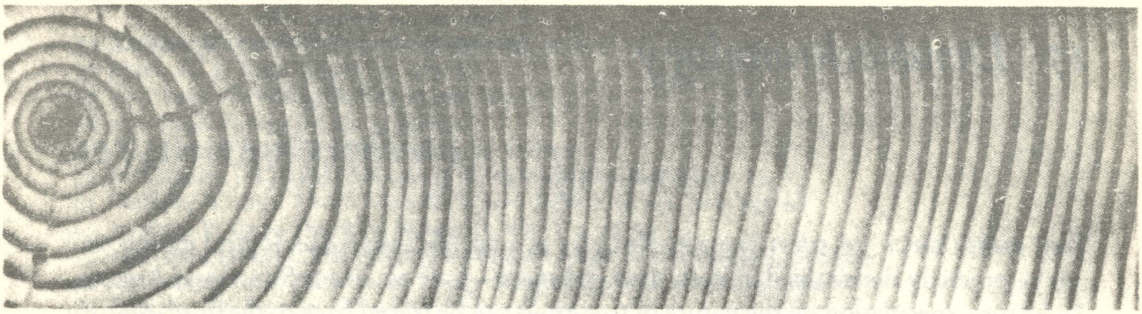
THE EMERGENCE OF DENDROCHRONOLOGY as a significant archaeological dating tool can be precisely determined in both time and space—June 22, 1929; Showlow, Arizona. To be sure, speculation on the nature of tree-rings can be traced back to the third-century BC writings of Theophrastus, and certainly the detailed observations of a long succession of botanists and naturalists have been instrumental in our understanding of growth rings and their implications.[85] But it remained for the astronomer A. E. Douglass, the recognized pioneer of the science of dendrochronology, to apply tree-ring phenomena in a systematic attack on the chronological problems of archaeology.

Douglass began his examination of tree-rings in 1901 while searching for a tool to be used in the study of sunspot cycles. He first became aware of the potential archaeological applications of his work some two decades later, at which time he commenced a ten-year investigation into the dating of the spectacular American Indian ruin Pueblo Bonito. This project stands out as a model of inter-disciplinary co-operation and culminated in the establishment of construction dates not only for Pueblo Bonito but for more than forty additional major ruins in the American South-West as well.[13,60] The dramatic conclusion to this historically important project took place on a summer night in the small town of Showlow where Douglass, after carefully studying the day's collection of tree-ring specimens excavated from a nearby ruin, realized that he had finally spanned the gap between a centuries-long floating chronology, made up from ancient construction beams, and a dated tree-ring record extending backwards from modern times.[14] The gap was bridged, scores of prehistoric ruins were immediately assigned absolute dates, and archaeological tree-ring dating became of age!

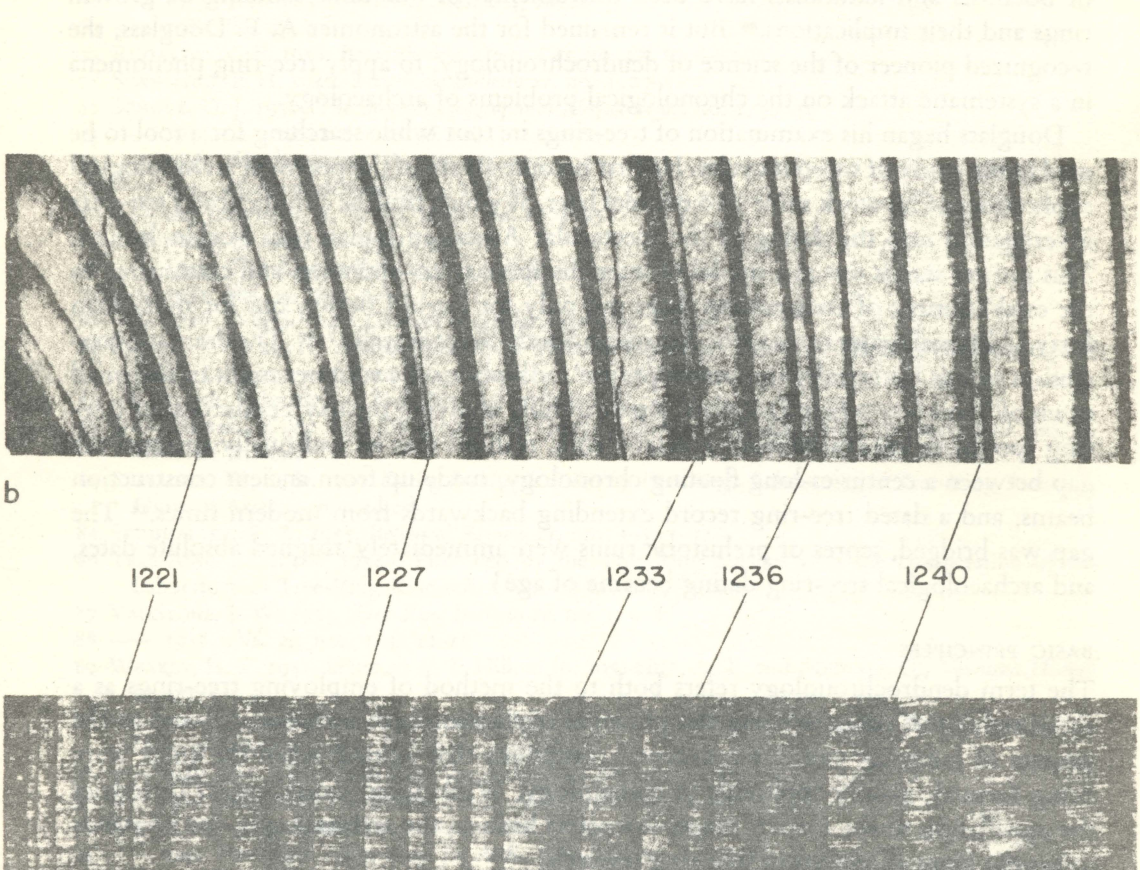
BASIC PRINCIPLES

The term dendrochronology refers both to the method of employing tree-rings as a measurement of time, wherein the principal application is to archaeology, and to the process of inferring past environmental conditions that existed when the rings were being formed, mainly applicable to climatology. While some would prefer to restrict the appellation to the former usage, it matters little to the archaeologist, for he stands to benefit from all aspects of tree-ring research.

The basic principles involved in dendrochronology are deceptively simple. Tree-rings, which are so obvious on the cross-sections of most trees, can be more accurately described as the transverse sections of successive layers of xylem growth—each layer having been formed by the tree in response to some environmental fluctuation, normally of an annual nature in seasonal climates. In conifers, the annual ring is composed of two parts: an inner band of large light-coloured cells that merges, sometimes very gradually, with an outer band of thicker-walled, dark-coloured cells which in turn usually termin-



a



b

c

Cross-dating and types of tree-ring series: (a) a complacent record lacking ring character; (b) and (c) sensitive tree-ring series which cross-date; (b) and (c) are from the thirteenth-century ruin Betatakin in northern Arizona.

PLATE VIII (see page 162)

ates abruptly, leaving a sharply defined outer edge. A number of angiosperms and shrubs have annual rings of somewhat similar gross characteristics, but tree-rings of considerable complexity are also known to exist.[44]

In those regions where dendrochronology has successfully been applied to archaeological specimens there are basically two types of tree-ring series commonly found (Plate VIII); or perhaps the two types should best be termed end points along a continuum of variation. In the first type, the rings are of relatively uniform thickness, as measured along a radius, and often exhibit a slow algebraic decrease in width as the tree approaches maturity. Such ring series lacking in distinctive character are termed complacent (Plate VIIIa). In contrast, the second type of ring record is distinguished by variability of individual ring widths, even though there may be a gradual decrease in the relative size of rings as the tree grows older. These series (Plate VIIIb, c) are called sensitive and are far more suitable for dendrochronological purposes.

Under certain conditions, contemporaneous ring records formed by sensitive trees will show remarkable similarity when compared with each other. The patterns of narrow and broad rings in one tree will closely match the patterns found in other trees (Plate VIIIb, c). Cross-dating, which is based on this phenomenon, can be defined as the identification in different trees of the same ring patterns, each series of rings representing exactly the same period of years. It is cross-dating that stands as the fundamental principle underlying tree-ring dating, and it must be present before either absolute or relative dates can be derived.

The cross-dating principle gives rise to the two most important facets of tree-ring research. First, in regions that contain modern cross-datable trees which can serve as controls, proper application will permit the assignment of calendar years to each of the individual rings within a specimen. It is this feature, of course, which has been responsible for archaeological tree-ring dating in the absolute sense. Even where modern tree-ring controls are not available, relative dating is still possible. Second, the very fact that ring patterns which lead to cross-dating are present in trees at all implies the existence of some environmental factor, or complex of factors, which not only fluctuates itself on a year-to-year basis (when dealing with annual rings) but also has the capacity to induce similar and simultaneous growth responses on the part of trees over a given geographical area. The isolation and understanding of such controlling factors has been of interest to tree physiologists and dendrochronologists alike.

It should not be assumed that the conditions responsible for cross-dating are the same wherever the phenomenon occurs. For example, in the semi-arid regions of south-western United States, soil moisture is apparently the dominant controlling factor, whereas in Alaska and other northern latitudes temperature seems to be the chief determinant. Nor should it be assumed that cross-dating is universally present, for, in fact, only certain trees in an area cross-date with each other, only certain areas in the world contain cross-datable trees, and cross-dating between separated areas is usually non-existent.

A considerable body of literature pertaining to the basic principles of tree-growth and its dendrochronological implications has been produced. In the American South-West a few of the more important works are by Douglass;[11,12,15] Ferguson;[24] Glock;[41] Glock, Studhalter, and Agerter;[44] and Schulman,[80] Bell,[3] Hawley,[47] Schulman,[77] and Willey[96] have treated the Mississippi drainage, while Weakly[91,92] and Will[94,95] have carried out investigations in the Great Plains of the United States. Lyon[57–59] has reported on New England tree-ring studies. The basic contribution to Alaskan dendrochronology is by Giddings,[28] although additional pertinent studies have been made by Giddings[30,31,33,35] and Oswalt.[68,69] Other treated regions in the Western Hemisphere include parts of Canada, western America, Mexico, and South America.[80]

Scandinavian scientists have produced a number of excellent studies. Some English-language summaries are Eklund[23] for Sweden, Høeg[48] for Norway, Holmsgaard[49] for Denmark, and Mikola[62] for Finland. Hustich[52,53] has dealt with trees throughout the northern latitudes. The works of Huber and Jazewitsch[50] of the Forestry-Botany Institutes of Tharandt and Munich are outstanding. Dobbs[9,10] and Schove[72,73] have been active in reporting tree-ring studies carried out both in the British Isles and in Scandinavia, and Messeri[61] has published on tree growth in Italy. To date little work has been done in Africa, although a few investigations have been made in Asia—Rudakov[70] in Russia, Gindel[37] in Israel, DeBoer[8] in Java, and Kohara[55] and Nishioka[63] in Japan. Bell and Bell[6] have provided a rather pessimistic view of the situation in New Zealand.

It should be emphasized that the above citations by no means constitute a complete list of tree-ring publications, although they are reasonably representative of the basic work being done in the designated regions. For the most part, these citations have been chosen because they deal with fundamentals and reflect the potentialities of tree-ring dating rather than merely recording archaeological results. Wherever possible, the more recent publications with bibliographies have been given so that the reader may investigate further if he wishes. A much more comprehensive review of tree-growth studies is presented by Glock,[42] with a highly critical assessment of dendrochronology in general.

REQUISITES OF ARCHAEOLOGICAL TREE-RING DATING

Before the tree-ring method can be applied to archaeological problems in any given region, there are several favouring circumstances that must exist and, unfortunately, these necessary conditions are by no means universal in nature. The first requirement is an ample supply of wood or charcoal tree-ring specimens in association with the archaeological environment to be dated. Not only must the prehistoric inhabitants of an area have used wood extensively, preferably for construction purposes, but the wood must be preserved so that both cellular and ring structure remain evident. Large areas of the world are immediately ruled out because either wood was not used extensively in ancient times or what was used has long since rotted away. On the other hand, certain regions are particularly favourable: the American South-West, northern Mexico, some arctic areas, Turkey, Egypt and various places in Europe and Asia where local conditions have ensured preservation. Charcoal, one of the most indestructible of materials as long as it remains uncrushed, is an excellent source of tree-ring records but its presence in quantity in archaeological sites is in part related to the cultural practices of the original inhabitants.[2]

The second major requirement for the establishment of tree-ring dating is that the specimens cross-date. As indicated previously, for cross-dating to occur the samples must contain clearly defined rings that show fluctuations of thickness throughout the series. The rings whether annual or multiple must be the result of a periodicity in growth factors which induces similar responses (measurable in variable ring widths) in trees within the region, and the specimens must contain enough rings to permit positive identification of like patterns in different pieces.

As long as tree-ring samples are available from a particular site and the specimens cross-date with each other, relative dates are possible. The establishment of absolute dates, however, is another matter. Even though contemporaneous relative dated specimens may be merged into a composite whole, forming a floating chronology, it is still necessary to build a known tree-ring chronology back far enough to overlap and cross-date with the unknown segment in order to achieve absolute dating. This is known as chronology building (Fig. 24) and although simple in concept usually requires considerable time and effort to accomplish. Starting with modern samples of known date, successively older and older specimens are cross-dated and incorporated into the matrix until a long-range tree-ring chronology is established. Depending on the materials available, this procedure may take many years to perform if, indeed, it is possible at all. Once a precisely dated master chronology is produced, however, the ring patterns contained in samples of unknown age may be cross-dated with the master chronology and assigned absolute dates.

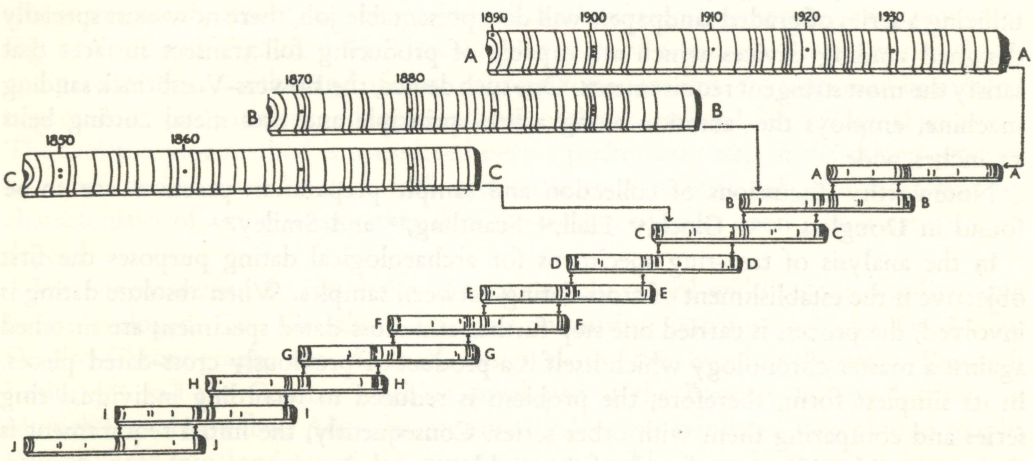


Fig. 24 Chronology building. A: radial sample from a living tree cut after the 1939 growing season; B–J: specimens taken from old houses and successively older ruins. The ring patterns match and overlap back into prehistoric times. After Stallings.[84]

COLLECTION AND ANALYSIS

The collection of tree-ring specimens is guided by the basic aim of preserving as complete a record of the ring series as possible. A full cross-section is preferable to a core or radial sample, although it often is not practical to obtain a complete transect when dealing with living trees or archaeological structures which are to be preserved. Various types of coring tools have been developed: among others, the Swedish increment borer which is designed for sampling living softwood trees, the brace-driven tubular borer with circular saw teeth which has proved effective on prehistoric beams,[12] and the power-driven long-core extractor developed by Bowers.[6] New type tools for sampling museum pieces and archaeological timbers are currently being tested.

Specialized techniques for collecting wood and charcoal from excavations are so closely related to particular field conditions that it is impracticable to describe them all. In general, however, special care must be exercised to prevent damage or loss of outside rings. Charcoal and certain types of wood usually need immediate application of some preservative. A solution of gasoline saturated with paraffin wax is both economical and effective but other preservatives may be equally useful. The standard archaeological procedures for handling any delicate and valuable artifact are called for, and detailed notes on provenience, physiology, and ecology of the collection area are vital.[41, 2]

Before actual study can begin, specimens must be surfaced so that cellular structure is visible and the ring series may be examined with clarity. The importance of this step cannot be overemphasized since adequate surfaces are absolutely essential in the process of achieving precise dates. Charcoal and soft or rotten wood can readily be prepared with a razor blade, a technique that is rapid but fairly difficult to master. Excellent surfaces on small sections can be obtained with a sliding microtome, but for large cross-sections sanding is highly recommended. Although small hand-held belt sanders utilizing a series of graded sandpapers will do a presentable job, there now exist specially designed sanding devices which are capable of producing full transect surfaces that satisfy the most stringent requirements. One such device, the Bowers-Vossbrinck sanding machine, employs the 'abrasion along a line' principle and uses metal cutting belts 12 inches wide.

Noteworthy discussions of collection and sample preparation practices are to be found in Douglass,[16–20] Glock,[41] Hall,[45] Scantling,[71] and Smiley.[81]

In the analysis of tree-ring specimens for archaeological dating purposes the first objective is the establishment of cross-dating between samples. When absolute dating is involved, the process is carried one step further and cross-dated specimens are matched against a master chronology which itself is a product of previously cross-dated pieces. In its simplest form, therefore, the problem is reduced to recording individual ring series and comparing them with other series. Consequently, the initial requirement is the positive identification of each of the visible growth increments within the sample. Rings that are present on only a portion of their circumference, so-called 'false rings' or 'lines' which do not represent a full season's growth, microscopic rings—these and other anomalies must be recognized before cross-dating can be attempted. The subject of ring 'reading' is treated in detail by Douglass,[20] Glock,[41] and Schulman.[80] Additional problems such as completely absent rings (see references above) can only be solved through the process of cross-dating itself.

All of the different systems of tree-ring dating, and there are several currently being used throughout the world, are nothing more than alternate ways of representing growth patterns and establishing cross-dating. For the most part, the various techniques have been adopted because they are particularly suited to certain local conditions of tree growth and certain types of ring chronologies. Since the best known of these, the Douglass System, is basic to most subsequently developed methods, it alone will be discussed here. Further explanations of this system are to be found in Bannister and Smiley,[2] Douglass,[11,12,20] Glock,[40,41] Schulman,[80] and Stallings.[84]

The Douglass method, which has been most successfully applied in the American South-West, is primarily useful where highly sensitive trees constitute the main source of datable specimens and the amount of correlation between ring records is often of a very high degree. The technique emphasizes, first, those rings which deviate from the normal—noticeably narrow or broad rings—and, second, the internal relationship of these rings within the overall series. Comparison of one ring record with another is accomplished in three ways: the memory method, skeleton plots, and precisely measured ring widths. The memory method simply entails memorizing all of the ring patterns encountered. It is, of course, a very rapid and convenient way of comparing specimens but it does require a thorough knowledge of the local chronology. For the experienced investigator, however, the memory method supplemented by comparative wood samples is perhaps the most satisfactory way of verifying cross-dating.

When one is working with large quantities of materials or in unfamiliar areas, either temporally or geographically, the skeleton plot has proved to be an exceedingly useful tool.[41,84] Basically a specialized graph depicting the relative widths of diagnostic rings (Fig. 25), the skeleton plot has the advantage of being free of any age trend within the specimen since the size of each ring is judged in relation to neighbouring rings (compare Fig. 25A, B, with Fig. 26A, B). Thus skeleton plots of a standard scale can rapidly be compared with each other and, if cross-dating is found to exist, the plots may be merged to provide an easily understood representation of the site or local chronology (Fig. 25A). The skeleton plot method is considered only a preliminary step in the dating process, however, and it must be used with caution since it records only the most striking characteristics of a ring series rather than the totality of traits upon which dating must depend.

Various measuring devices designed to accurately record widths along a radius have been developed. The Craighead-Douglass measuring instrument,[19] the De Rouen Dendro-Chronograph, the Addo-X designed by the Swedish Forestry Research Institute,[22] and the German machine developed at the Forestry-Botany Institute in Munich[54] are but a few. After the measured values are translated into plotted graphs (Fig. 26) both visual and statistical comparisons can readily be made. Since absolute values are involved, however, standardization or correction for the effect of age is frequently necessary before the material can be used for the study of the relation between climate and growth. Age trend line introduction and standardization processes employed in the Douglass System are discussed by Schulman[79,80] and by Smiley, Stubbs and Bannister.[83] After standardization, the plotted curves express yearly values as percentage departures from average growth. Fritts (personal communication) is currently engaged in adapting standardizing processes to electronic computor techniques.

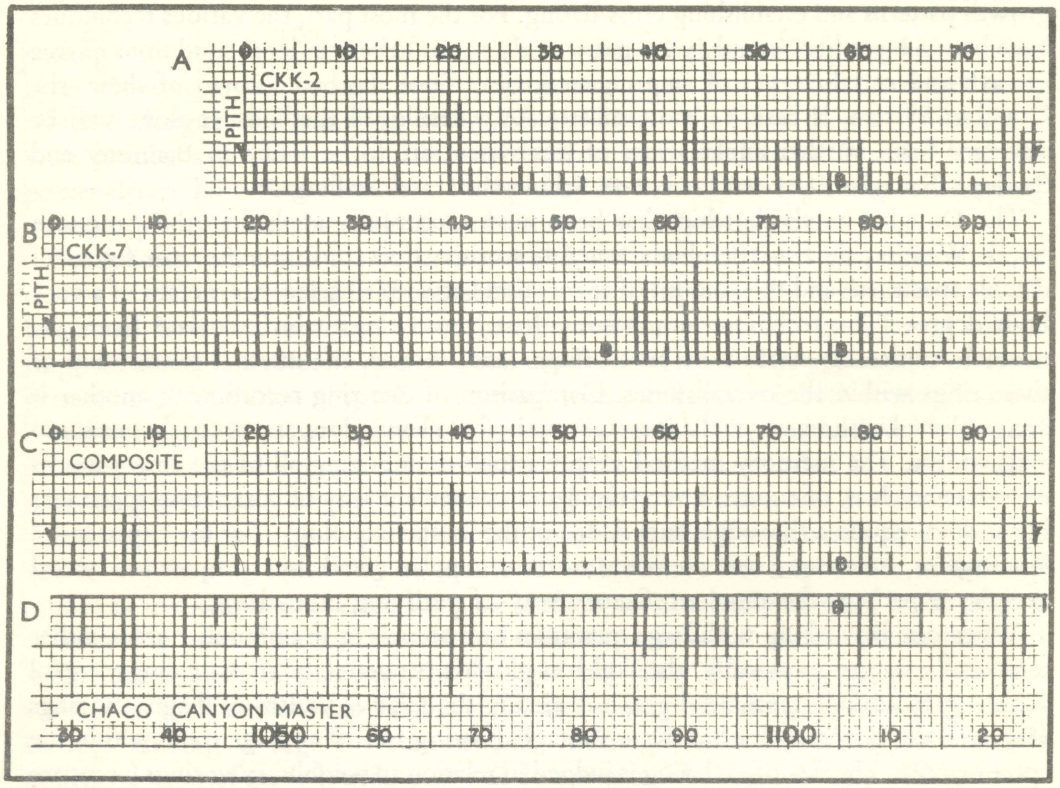


Fig. 25 Comparison of skeleton plots. A and B: skeleton plots of the ring series in two beams from the prehistoric ruin Kin Kletso, Chaco Canyon, New Mexico; C: composite plot of A and B; D: regional master chronology for Chaco Canyon. Matching of C with D establishes tentative dating of specimens (see text). The length of each vertical bar on the graph is inversely proportional to the relative width of the ring; average width rings are not recorded, and extra large rings are indicated by the letter B.

Another tree-ring dating method once used in south-western United States was developed by Gladwin.[38,39] This system depended upon a statistically constructed variation of the skeleton plot which recorded all rings. In Alaska, Turkey, Egypt, and New Zealand the Douglass System has been employed. In the wetter climates of Europe and in Scandinavia, the lack of highly sensitive trees with strong cross-dating tendencies precludes the use of the Douglass System. Various methods of statistical analysis involving coefficients of parallel and opposite variation, logarithmic plotting, special mechanical devices for automatically comparing series, and other innovations have been devised.

No matter what system of tree-ring dating is used, the validity of the results depends upon the preciseness with which cross-dating can be accomplished. Absolute identification can be secured by means of the forecast-and-verification method, wherein additional ring characteristics are sought and compared after test correlations have been made. When a sufficient number of positive verifications are found, the probability of chance correlations becomes increasingly remote and accurate cross-dating is assured.

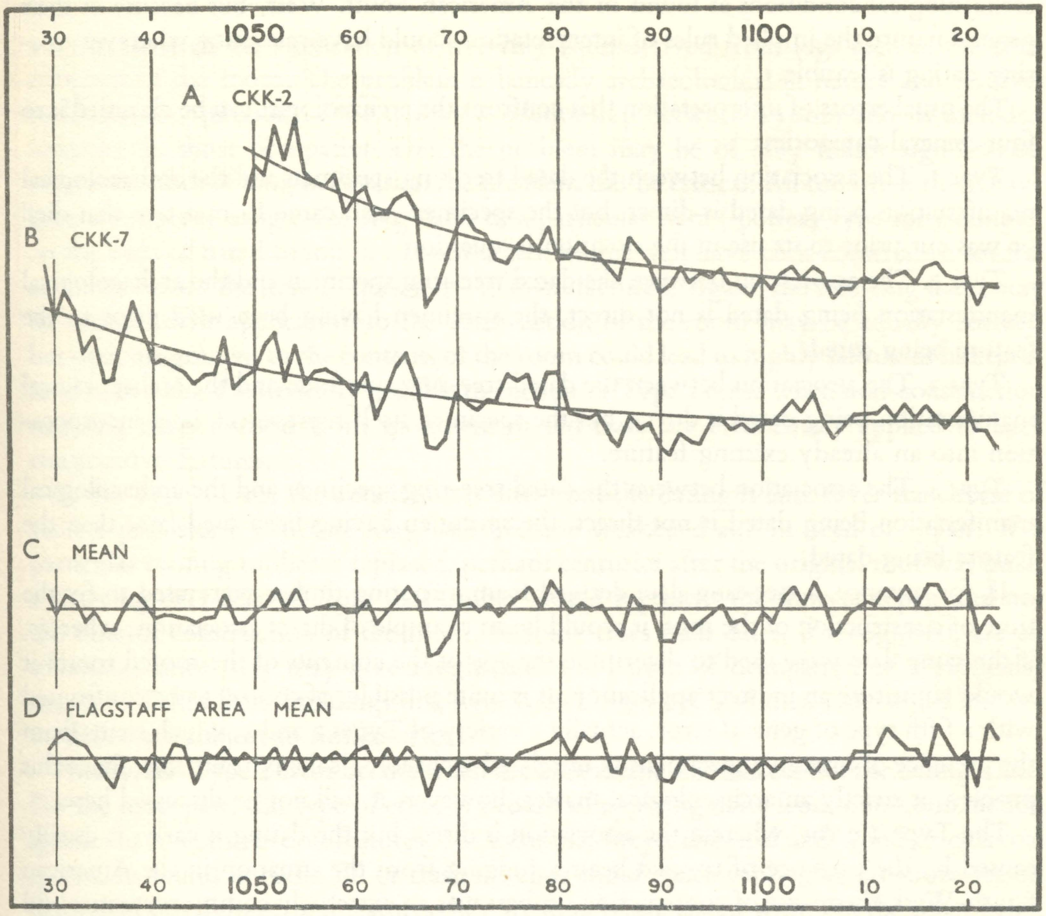


Fig. 26 Comparison of measured curves. A and B: measured ring widths (with standardizing lines superimposed) of the ring series in two beams from the prehistoric ruin Kin Kletso, Chaco Canyon, New Mexico; C: standardized mean of A and B with ring widths expressed as percentage departures from average growth; D: Flagstaff Area Mean in standardized form. Comparison of C with D leads to absolute dating of specimens (see text).

THE INTERPRETATION OF TREE-RING DATES

Once a tree-ring date has been established, its archaeological significance can vary greatly. After all, a tree-ring date can only be applied with authority to the specimen itself, and it may or may not be directly related to the archaeological context from which the specimen originated. There is a basic problem, consequently, of the time relationship that exists between the date of the specimen and the archaeological manifestation being dated.

Where the tree-ring dating method has been used extensively, as in Alaska and in the south-western United States, refined techniques of date interpretation have become increasingly necessary. The scheme that follows, therefore, is for the most part based on archaeological conditions as found in the American South-West, but because of their general nature the implied rules of interpretation should have relevancy wherever tree-ring dating is feasible.

The usual errors of interpretation that confront the archaeologist can be classified into four general categories:

Type 1. The association between the dated tree-ring specimen and the archaeological manifestation being dated is direct, but the specimen itself came from a tree that died or was cut prior to its use in the situation in question.

Type 2. The association between the dated tree-ring specimen and the archaeological manifestation being dated is not direct, the specimen having been used prior to the feature being dated.

Type 3. The association between the dated tree-ring specimen and the archaeological manifestation being dated is direct, but the specimen itself represents a later incorporation into an already existing feature.

Type 4. The association between the dated tree-ring specimen and the archaeological manifestation being dated is not direct, the specimen having been used later than the feature being dated.

If, for instance, a tree-ring date derived from a roofing timber were used to fix the time of construction of the roof, it would be an example of direct association; whereas, if the same date were used to determine the age of the contents of the roofed room, it would constitute an indirect application. It is quite possible, of course, to be confronted with a fifth type of general error, actually a variety of Types 2 and 4, which stems from the presence of intrusive specimens in unrelated archaeological environments. Since this problem is strictly an archaeological matter, however, it will not be discussed here.

The Type 1 error, wherein the association is direct but the dating is early, is usually caused by the presence of re-used beams. Judging from the situation in the American South-West, the re-use of construction timbers was an extremely common practice and hardly surprising when one considers that it was often far easier to salvage old logs from nearby abandoned structures than it was to fell growing trees with a stone axe. Obviously, the re-use of timbers in later structures can result in erroneous interpretation. Although the tree-ring date derived for the specimen may be perfectly correct, its application to the structure from which the specimen came would result in the assignment of too early a construction date. The aboriginal use of wind-fallen trees and driftwood logs, if not recognized as such, would introduce a similar tendency to overestimate the age of a feature incorporating this kind of wood. Even the stockpiling of beams before use would introduce a slight but consistent error of the same type.

In regions where wood was relatively scarce it is easy to envisage the problems caused by the re-use of old wood. Any wooden artifact might well tend to acquire heirloom status, and consequently any dates obtained would be subject to the Type 1 error. If a worked artifact were involved, even the process of shaping the wood could contribute to the magnitude of the error.

When the association is not direct but the dating is early, we are dealing with the Type 2 error. This usually comes about as a result of attempting to date artifacts within a room through the application of tree-ring dates derived from logs used in the construction of the room. The problem is basically archaeological in nature and resolves itself into the question of the temporal relationship between a room and its included contents. In short occupation sites the problem may be of only minor significance, whereas in sites of long occupation the problem can be critical. All too often there have been attempts to assign tree-ring dates to a particular item (pottery type for example) on the basis of dated beams in a room which might well have been constructed several centuries before the item in question was manufactured. Again, the tree-ring dates may be correct, their application to the construction of the room may be equally correct, but their assignment to the contents of the room could lead to highly fallacious interpretations. It is also theoretically possible to encounter Type 2 error when non-construction tree-ring dates derived from specimens in old trash are erroneously applied to later constructive features.

In the Type 3 error the association is direct but the dating is late. Over the course of years a prehistoric structure may well become weakened and in need of repair. If a particular roofing timber is replaced, perhaps centuries after the original roof was built, a tree-ring date derived from that timber would represent the time of repair and not the time of construction of the room. In some cases such dates, if recognized, are an advantage since they may give insight into the length of occupation of a particular structure. Dates from buildings that have been abandoned and then reoccupied and remodelled are subject to similar errors.

Finally, the Type 4 error occurs when the association is not direct but the dating is late. For the most part, this type of error is a result of applying dates from non-construction specimens to construction features. For example, firepit charcoal and wood or charcoal specimens found in room fill or trash mounds could conceivably give far more recent dates than the architectural features they are loosely associated with. On the other hand, non-construction dates used judiciously with construction dates from a single ruin may well indicate at least a minimum period of occupation.

Although the usual errors of interpretation can be identified with one or more of the four general types of error enumerated, it is not to be supposed that the specific error-producing situations mentioned are all that can be encountered. For one thing, these four types of chronological error can occur either independently or in combination with each other, and in the latter case the amount of error involved will either be increased or will tend to cancel out. Each dating problem, therefore, presents its own unique set of circumstances, and an understanding of both the dendrochronological and archaeological conditions involved is necessary for a satisfactory solution.

If it appears from the foregoing discussion that the chances of error associated with the time relationship problem are so high as to cast doubt on the interpretation of all tree-ring dates, it should be remembered that the extent of the danger involved is inversely proportional to the number of dated specimens from any given feature. If a single structure, for example, yields only one date, its interpretation is definitely subject to the types of error enumerated. If this same structure yielded 100 dated specimens the chances of fallacious interpretation would be greatly reduced. Errors of the Type 1 and

Type 3 varieties are particularly amenable to correction through the use of tree-ring date clusters. The fundamental premise is that if there are a number of tree-ring dates from a single structure or architectural feature which cluster about a single point in time, then dates that deviate from the cluster represent re-used or repair timbers, depending upon whether they are earlier or later than the majority. The same reasoning, with modification, would apply to groups of non-construction dates. In similar fashion, the clustering of archaeological traits or characteristics is useful when dealing with errors of the Type 2 and Type 4 varieties. Properly applied, the clustering techniques are powerful problem-solving tools, but they have limited use in those cases where there is an insufficiency of data.

A further complication in the interpretation of tree-ring dates is introduced when the condition of the outside of the dated specimen indicates that exterior rings have been lost through shaping, rot, burning, or some other eroding force. Again various techniques have been developed which tend to minimize this potential source of error. Both the time relationship problem and the problem of outside rings are discussed in detail by the author elsewhere.[1]

THE THREE MAJOR ARCHAEOLOGICAL APPLICATIONS OF TREE-RING DATA

A review of the archaeological applications of tree-ring data leads to a convenient threefold classification scheme. First, there are those applications wherein chronology, either relative or absolute, is the chief consideration. Second, there are those interpretations which depend upon the environmental histories recorded in the ring series themselves. And third, there is that class of fundamentally non-chronological information which stems from the juxtaposition of related dates and which gives rise to inferences of a cultural nature.

By far the most common use of archaeological tree-ring data has been in the field of chronology and the best example of this use is in the American South-West. Today in this area of heavy concentration of archaeological sites there exist a number of regional dendrochronologies which have relevance to fairly broad geographical areas, the longest extending back to the year 59 BC. In addition, more localized chronologies have been developed to aid in dating materials from specific locations.

The Laboratory of Tree-Ring Research at the University of Arizona in Tucson serves as a central repository for the major South-Western tree-ring collections and currently houses an estimated 125,000 individual archaeological specimens. These pieces come from about 2,000 prehistoric sites, some 800 of which have yielded at least one dated sample. Although precise numbers are difficult to determine, roughly 10,000 separate archaeological specimens from the South-West and adjacent regions have been dated.

A chronological history of the development of archaeological tree-ring dating in the South-West is given by Schulman,[80] and a more comprehensive view is to be found throughout the pages of the *Tree-Ring Bulletin* (1934 and following issues).[86] It would be impracticable to list all papers dealing with tree-ring dates in the region but recent summaries of dates have been published by Smiley;[82] Smiley, Stubbs, and Bannister;[83] and Bannister.[1]

As a result of the intensive tree-ring research carried out in the South-West, the prehistory of this area is better understood from the chronological point of view than it is in any other place in the world. Glock,[43] however, has questioned the accuracy of the South-West archaeological tree-ring calendars and has estimated that they may be 5% in error. Other workers, including the author, have confidence in the essential correctness of South-Western dendrochronologies, and this view is being continually confirmed by the cross-dating process and present-day research.

Outside the South-West there are numerous localities where the tree-ring dating method has been applied. Results range from the well-substantiated absolute dates of Alaska and Germany to the very preliminary analyses carried out on Turkish and Egyptian specimens. Not all of the studies here reported, however, have received unqualified acceptance by other workers. Bell[3] has established dates for the Kincaid Site in Illinois; five log cabins in the Mississippi Drainage have been dated by Hawley;[47] Will[93–95] has derived dates from a number of sites in North and South Dakota; three dated sites in the Great Plains have been reported by Weakly;[89,90] and preserved wood in New England has been dated by Lyon.[56] Present efforts in the Missouri River Basin are summarized by Caldwell;[7] a summary for the Mississippi Valley is given by Bell[4] and for Nebraska by Weakly.[91] A current and as yet unreported project by the author on specimens from the Casas Grandes Site of Chihuahua, Mexico, has resulted in the establishment of a 500-year floating chronology.

The many dated sites in Alaska and the tracing of driftwood origins are largely the work of Giddings,[26–29,32,34,36] Oswalt,[65–67] and VanStone.[87,88] Schulman[78] describes dating work carried out by Aandstad in Norway on six late structures whose approximate ages were already known. Ording[64] reports a floating chronology based on a hundred logs from Raknehaugen in south-eastern Norway, and Eidem[21] dated beams from eight houses in Flesberg. Høeg[48] has made a summary of Norwegian dating work.

Dendrochronological dating in Great Britain is documented by Schove[74,75] and Schove and Lowther,[76] while Zeuner[98] reports work on seventeenth-century wood from the City of London and on Beaker age stumps located near Clacton-on-Sea. Huber and his associates in Germany have succeeded in developing a relative chronology based on log palisades at the Bronze Age fort at Wasserburg or Bachau.[50,51] Other floating chronologies have been derived for the Neolithic sites of Thaingen Weier and Egolzwil III in Switzerland and Ehrenstein near Ulm in south Germany and for the Bronze Age site of Zug-Sumph in Switzerland.[51] Absolute dating was accomplished on beams from the medieval town of Zeigenhain near Kassel, Germany.[50] Two recent summaries of European tree-ring work are Dobbs[10] and Zeuner.[98]

A prehistoric floating tree-ring chronology in Russia is reported by Zamotorin[97] while Kohara[55] documents an attempt to date a five-storied pagoda in Japan. The Middle East would appear to be potentially an excellent area for the development of at least relative chronologies. Although problems of importation and re-use of wood are associated with Egypt, current research by the author on archaeological tree-ring specimens from Turkey and Egypt indicates that cross-dating exists in specific regions and that long relative chronologies are a definite possibility. Tree-ring dating in New Zealand is apparently not feasible because of the lack of cross-dating.[5]

The relationship of tree growth to climate has been the subject of many dendrochronological studies, and certainly information of past environmental conditions as estimated from tree-rings constitutes a major contribution to archaeological knowledge. On the whole, however, the present state of tree-ring research indicates that caution should be exercised in making such interpretations. Tree growth itself is an immensely complex mechanism, and the various external and internal factors that influence growth and are responsible for the existence of cross-dating between trees are as yet imperfectly understood. Certain dominant controls such as temperature and soil moisture may be isolated, but quantitative evaluations of even these factors in ancient times are presently unobtainable. On a relative basis it may be possible to speak of droughts and other climatic fluctuations, but all too often the archaeologist has seized on such relative indications and has used them to explain away highly intricate archaeological situations and cultural behaviour. Great strides in understanding the significance of dendrochronologies have been made,[80] but still the newest mathematical techniques of analysis continue to demonstrate that the final answers have not yet been reached.[25]

A third application of tree-ring data is concerned with the internal relationships of associated dates rather than their placement in time. For example, Haury,[46] among others, demonstrated the exact developmental process of a multi-roomed pueblo in Arizona. If enough comparable data were available, it might be possible to identify culturally motivated construction practices among primitive peoples. Similarly, Huber found frequent building periods in the houses of Ehrenstein near Ulm and gained insight into the technology and economic conditions of the time. From a study of cutting dates derived for beams from a single roof, Bannister[1] was able to conclude that the prehistoric population of Chaco Canyon in north-western New Mexico practised stockpiling of their timbers before use. Also, by means of the clustering of dates derived from beams re-used in a later structure he[1] was able to infer the prior existence of a building which had not been discovered through usual archaeological techniques. These are but a few of the many cases of this type of application and by no means represent the range of possibilities along this line.

There is no doubt that the results of tree-ring research will continue to be important within the field of archaeology. The expansion of the method into as yet untested regions, the improvement of our knowledge of the meaning of rings as climatic indicators, and the application of tree-ring dates to problems of culture stability and change—these are the areas in which rapid future progress can be expected to occur.

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