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Geochronology

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CHAPTER XI

DENDROCHRONOLOGY

Bryant Bannister and Terah L. Smiley

1. *Introduction*

Dendrochronology, or the tree-ring method of dating as it is sometimes called, can be defined as the study of the chronological sequence of annual growth-rings in trees. Proper application of the method allows the establishment of a one-to-one correspondence between annual tree-rings and the actual year in which they grew. Thus dendrochronology is capable of yielding dates in the precise terms of calendar years, and hence the method may be considered as absolute in the geochronological sense. An understanding of the tree-ring method, therefore, should be regarded as essential to the study of geochronology, for apart from the empirical data derived by the method itself, dendrochronology offers a reliable means of orientating and cross-checking the results obtained by some of the other geochronological methods discussed in this series of papers.

Speculation on the nature and meaning of tree-rings has been recorded as far back as the time of Leonardo da Vinci, and although the contributions of early workers in the field cannot be ignored, it was not until the first quarter of the present century that Dr. A. E. Douglass fully recognized the potential climatic histories contained in ring sequences and was able to establish a thoroughly scientific foundation for tree-ring studies. Perhaps the most spectacular outgrowth of Douglass' researches was the use of tree-ring dates in providing a time scale for the prehistoric Indian cultures of the Southwest. Today, however, the applications of dendrochronology are by no means limited to archaeological problems, but rather extend to a multitude of diverse and often quite surprising fields. The earth sciences in particular have benefited through tree-ring studies. The eruption of Sunset Crater in Northern Arizona (vulcanology) has been "dated" through the use of tree-rings (Smiley, 1955). Comprehensive studies on the formations and periods of recent geological deposits (geomorphology) are being undertaken at the University of Arizona Archaeological Field School at Point of Pines, by combining the results of dendrochronology, geology, and archaeology (Thompson, 1954). Long-range climatic fluctuations, as revealed by tree-rings, have been of importance in the development of the geologic-climatic studies of Bryan, Antevs, and others (See Chapter IX). It appears that certain dendrochronological methods and data from tree-ring studies can aid the study and correlation of varve sequences, initiated by De

Geer in Sweden and continued in this country by Antevs and others.

The Laboratory of Tree-Ring Research has been engaged in a comprehensive research problem involving centuries-long tree-ring records subjected to cyclic analysis. The results of this research may eventually make long-range climate prediction a reality. Dated tree-ring specimens have been used in checking the accuracy of the carbon-14 method in the time-periods where the results of the two methods overlap, and in all probability tree-ring dates will be used to help correlate pollen sequences and other temporal sequences obtained from some of the various methods of geochronology which are applicable to recent times. There are many other fields in which dendrochronology has been applied, including botany, paleobotany, ecology, hydrology, meteorology, and forestry.

Present-day basic dendrochronological research at the University of Arizona can be loosely divided into two separate but highly interdependent fields of study, differing not so much in techniques and methods as in final objectives. On the one hand there is that branch of research which is primarily interested in information inherent within the tree-ring records *per se*, whereas the second branch is fundamentally concerned with the establishment of a tree-ring date on a wood or charcoal specimen and with its application to some past event. The first type employs ring records obtained from modern trees and from long-range tree-ring chronologies derived from archaeological specimens, in order to study historical climatology, growth characteristics of various species, correlations of rainfall and river runoff, inherent cyclic patterns, and other related subjects. Certainly knowledge of long-range climatic fluctuations and of other aspects of this field of study affords many useful applications in the overall field of geochronology (see Schulman, 1945), but, as of today, the use of tree-ring data in problems of a geochronological nature has for the most part been restricted to the second type of basic dendrochronological research, wherein the actual date given to a tree-ring specimen is the item of intrinsic value. It is this type of research, popularly known as tree-ring dating, which has had such a profound effect on the development of Southwestern archaeology.

Although the tree-ring worker can supply absolute dates to other sciences, perhaps the most significant contribution that the dendrochronologist can make to geochronology at this time is in pointing out just how tree-ring dates can be properly evaluated for interpretive purposes. This is because the application of tree-ring dates can be considered as universal in that the problems encountered in dating archaeological events and structures are essentially the same as other problems of a geochronological nature. Since a large part of the history of tree-ring work has been in dealing with these specific problems, and since certain basic fundamentals have been devised for interpreting tree-ring dates, the emphasis in this paper will be on the second or dating branch of tree-ring research, particularly as it applies to the Southwest. Of necessity, discussion and illustrative examples of interpretation problems are limited to archaeological conditions, not through preference, but rather through lack of examples in other fields.

2. *Establishment of a tree-ring chronology*

The establishment, in any given area, of a satisfactory tree-ring chronology, permitting the dating of prehistoric materials, is possible only when the following four conditions are met:

1. There must be trees that produce clearly defined annual rings as a result of a definite growing season
2. Tree growth must be principally dependent upon one controlling climatic factor
3. There must have been an indigenous prehistoric population that made extensive use of wood
4. The wood must be well enough preserved so that it still retains its cellular structure

The absence of any one of these four conditions precludes the existence of a long-range tree-ring chronology such as we have in the Southwest today.

The first stipulation requires that trees have annual rings, that these rings be clearly defined, and that they be a result of a definite growing season. Nearly everyone is familiar with annual rings as they appear on the cross-sections of most trees. More specifically, annual rings can be described as the transverse sections of successive layers of xylem growth — one layer being added each year. These layers are in the form of sheaths, in that they enclose the entire woody part of the tree. Very generally speaking, the annual ring is the result of the cell-producing activity of the vascular cambium which is located between the bark of a tree and the xylem. During the growing season, some of the new cells manufactured by the cambial layer (those on the xylem side) differentiate into xylem tissue, which makes up the new annual ring, whereas the remainder (those on the phloem or bark side) move externally and differentiate into phloem tissue.

By a definite growing season it is meant that there is one, and only one, specific time interval of the year in which tree growth starts and stops, so that the ring is of an annual nature.

Unfortunately, not all trees exhibit these characteristics so necessary for tree-ring analysis. Many trees, palm trees for example, show no ring structure at all, while others, such as the lemon tree of Southern California, put down more than one ring each year (Robbins and Rickett, 1949, p. 91). In the Southwest, the majority of trees that meet the strict criteria necessary for tree-ring analysis are a few of the conifers of the pinaceae family. About 95 per cent of the dated Southwestern specimens are either ponderosa pine (*Pinus ponderosa*), Douglas fir (*Pseudotsuga taxifolia*), pinyon pine (*Pinus edulis*), or juniper (*Juniperus scopulorum*), and juniper in particular is of value only when obtained from rather limited areas in the north (Smiley, 1951a, pp. 2-3).

The second principle is that tree growth must be primarily dependent upon one controlling climatic factor. Aside from the physiology of the tree itself, the amount of growth is determined by many variables, such as changing edaphic, biotic, and climatic conditions. For the most part, however, particular edaphic and biotic conditions are confined to individual trees or individual stands of trees, and consequently their effects are of a limited or confined nature and are not widespread. Some of the individual elements of climate in the Southwest, such as solar radiation, soil- and air-temperatures, and atmospheric humidity, are relatively stable during the life of the tree, whereas soil moisture shows considerable fluctuation. It is when tree growth is fundamentally contingent upon just one, and only one, changing climatic factor that the variability of ring widths are homogeneous over that particular "climatic" area, for if two or more variable climatic factors are of equal influence in the growth of a tree, such homogeneity is disrupted and dendrochronological analysis is impracticable.

This single dominant climatic factor, extending over a wide area, or climatic area, is the control which gives rise to "crossdating." Crossdating has been known for at least a century, perhaps longer, but it remained for Douglass to put it to work in such a manner that tree-ring dating resulted. Crossdating was defined by Douglass (1946, p. 16) as ". . . the identifying of the same definite ring pattern in two or more trees, five at least being preferable, so that a dated ring in one tree gives the same date to that ring in the other trees." (See Figure 11:2, *A* and *B*, *C* and *D*). Not only is crossdating impossible without the predominant influence of a single climatic factor, but, conversely, the similarity in chronological placement of individual rings from different trees is the basic evidence for the climatic origin of the distinction between successive rings, for climate is the one changing factor that is continuously common to all trees (Douglass, 1932, p. 217, and 1946, pp. 16-17).

Although the existence of the phenomenon of crossdating indicates that a single climatic element is the controlling factor in annual ring growth, it does not mean that the same climatic element is responsible for crossdating wherever it occurs over the earth. Giddings has found that in Alaska there is a strong correlation between ring growth and mean June temperatures (1941, p. 75). In the semiarid Southwest, however, solar radiation, soil- and air-temperatures, and atmospheric humidity are all relatively stable from year to year, but soil moisture under particular conditions can change widely from one year to the next. Soil moisture is the one variable which strongly influences tree growth, and is considered to be the dominant climatic factor responsible for crossdating in the Southwest (Douglass, 1914, pp. 321-35).

Soil moisture can be derived either from the percolation of underground water, the "water table," or from direct precipitation. Whenever the roots of a tree can penetrate the zone of capillary water located just above the water table, the tree is able to obtain a constant supply of moisture which usually remains uniform over long periods of time. Since the other climatic factors are fairly constant, the tree puts down annual rings which vary little in thickness from year to year. Such trees, usually found growing in valleys or bottomlands, have ring patterns that are termed "complacent," and the lack of variations in ring thickness renders complacent tree-ring specimens relatively worthless from a dendrochronological point of view. On the other hand, trees that rely on soil moisture derived directly from local precipitation show correspondingly thick or thin rings depending on how the pattern of rainfall varies through the years; that is, during a "good" year (wet) a tree will produce a thick ring, whereas a "poor" year (dry) will show as a thin or narrow ring (Douglass, 1935, p. 8). Such trees and the sites upon which they grow, generally on steep and well drained slopes, are termed "sensitive," and it is the sensitive tree-ring specimens which in the main are studied and dated by the dendrochronological method (See Figure 11:1).

The third major condition is that there must have been an indigenous prehistoric population that made use of wood and wood products, and particularly used wood for construction purposes. The reason for this stipulation is simply that the dendrochronological worker must have an ample supply of tree-ring specimens in order to establish a long-range chronology. When ancient wood and charcoal specimens are not available, the development of tree-ring studies in any area is limited to chronological data derived from modern trees.

In the Southwest the evolution and rapid expansion of tree-ring studies can be attributed to the fortuitous proximity of the numerous and widespread indigenous Pueblo Indians, and to the fact that these Indians not only lived in areas most suitable

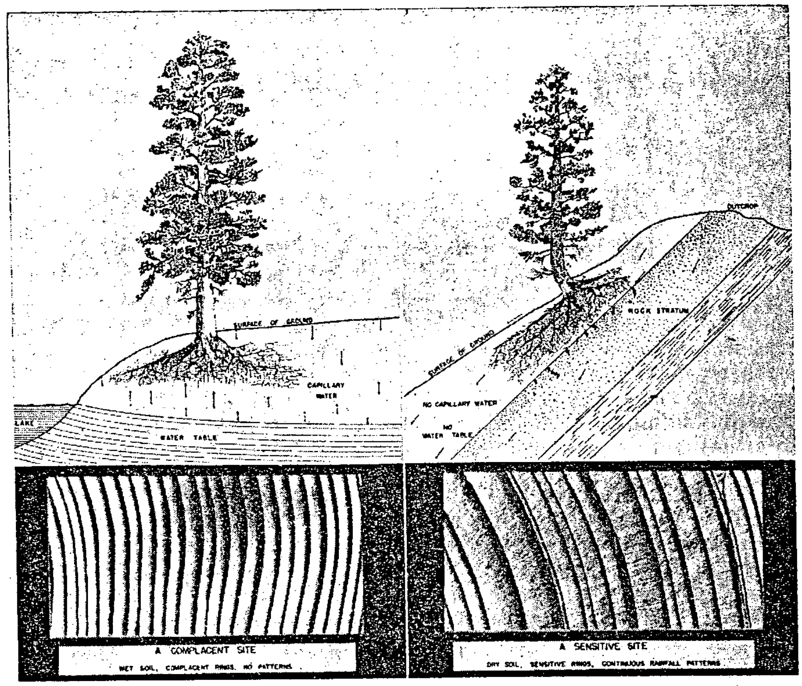

Figure 11:1.—Complacent and sensitive sites.

for tree-ring dating studies, but also used large quantities of wood in the construction of their dwellings.

The fourth necessary requirement for the development of an adequate tree-ring program is that the ancient wood of an area must be well enough preserved so that it still retains its cellular structure. It is self-evident that, no matter how much wood was originally used by prehistoric populations, the wood is of no help to the dendrochronologist unless it is preserved in a usable form. Prehistoric wood can be preserved for long periods of time in either of two forms: as wood or as charcoal.

In the conversion of wood to charcoal, there is no deterioration of the cellular structure unless the material has been crushed in the process, and since charcoal is composed of pure carbon it is otherwise practically indestructible. Charcoal then is one of the best forms of preservation known and is of particular importance in the Southwest. It is fortunate for archaeologists and dendrochronologists alike that the Pueblo Indians of the Southwest not only used wood extensively in the construction of their houses, but that they also used inside fires for cooking and keeping their houses warm. Occasionally sparks would get in the roof material and ignite it. The resulting fire would burn through the roofing timbers and the entire roof would collapse to the floor. Since these roofs were covered by a thick layer of mud for sealing purposes, the smoldering timbers would be smothered by the dirt before they were converted into ash. The result was that large quantities of charcoal were formed by burning houses, and in fact, charcoal specimens comprise the bulk of the dated archaeological material in the Southwest. Intentionally burned wood from fireplaces is also used extensively for tree-ring purposes.

Wood, in contrast to charcoal, will be preserved only under special conditions. Perhaps the most favorable factor is extreme dryness, a condition in which the Southwest is admirably suited. Dry caves in particular will preserve wood for indefinite centuries, and they have been used by Indians since earliest times. Wood coming from open sites is less likely to last, for in many areas humidity and soil acidity are such that wood will deteriorate and completely rot. There are localities, however, where wood from open sites has lasted for more than a thousand years.

The four basic principles just enumerated will determine whether or not it is possible to establish a long-range tree-ring chronology in any geographical area.

3. *Field collecting*

The techniques of collecting tree-ring materials in the field can be divided into two classes, the collection of modern specimens and the collection of archaeological specimens (Smiley, 1951a, pp. 1-13). When collecting either modern or archaeological specimens, it is necessary to obtain basic data on the physiography and ecology of the collection area. Information as to location, altitude, soil conditions, drainage, exposure, subsurface water conditions, and geologic formations help the dendrochronologist evaluate the physiographic features of the site, while data on the nearby trees, shrubs and undergrowth, and grasses are of value for understanding the ecology. Detailed notes of this type should accompany collected materials when turned over to the tree-ring worker. The field collector should also be able to make species identifications both in the living trees and in archaeological fragments.

In archaeological dating, modern samples are needed when working in an area that has received little or no previous study. Since most of the Southwest proper has been covered by modern tree collections, large scale core sampling is seldom practised today, although outside the Southwest extensive collections have been made in recent years. When modern samples are taken, the Swedish increment borer is the prnicipal tool used in extracting long, pencil-size cores from living trees.

Archaeological materials, as mentioned previously, are in the form of wood and charcoal, and require specialized collection techniques. In the Southwest, wood specimens are usually found in cave dwellings or multi-roomed pueblos with standing walls. The removal of such samples must be done without injuring or weakening the structures from which they come, and to this end the one inch "tubular borer" has been devised which allows a core to be taken from a beam. It is frequently possible to saw off a thin section of a protruding timber or to take a V-cut section from the end.

Somewhat different techniques are used in the collection of charcoal, for the specimens must be immediately preserved and wrapped to insure against their fragile nature. As with wood, the outer ring of a charcoal specimen is the most important key to the significance of the date and the outer rings must be carefully protected. Charcoal, when removed from moist earth, has a tendency to disintegrate if it is allowed to dry too rapidly; consequently it should be permitted to dry slowly under a thin covering of loose soil. All pieces of charcoal must be carefully preserved. One procedure is to completely immerse the specimen in a solution of gasoline saturated with paraffin, and then to bind it with string. For storage and shipment, charcoal specimens are wrapped in cotton and tied.

Field collected tree-ring samples should be tagged as soon as they are removed from *in situ*. Pertinent information such as the date, the name of the collector, and the precise location of the specimen should be given.

4. *Laboratory analysis*

When tree-ring material is received by the Laboratory of Tree-Ring Research at the University of Arizona, it is first checked to make sure that all samples are properly preserved and bound so that none of the outer rings can flake off. At the same time each specimen is catalogued and incorporated into the laboratory collection.

The initial step prior to actual study of the material consists of preparing each specimen with an adequate surface so that cellular structure can be seen and the ring patterns may be read. This process is of vital importance in achieving precision in dating and cannot be overemphasized (Douglass, 1946, p. 7). Surfacing is performed with a razorblade, different techniques being used on wood and varying grades of charcoal (Douglass, 1940, pp. 7-8; and Scantling, 1946, pp. 27-32).

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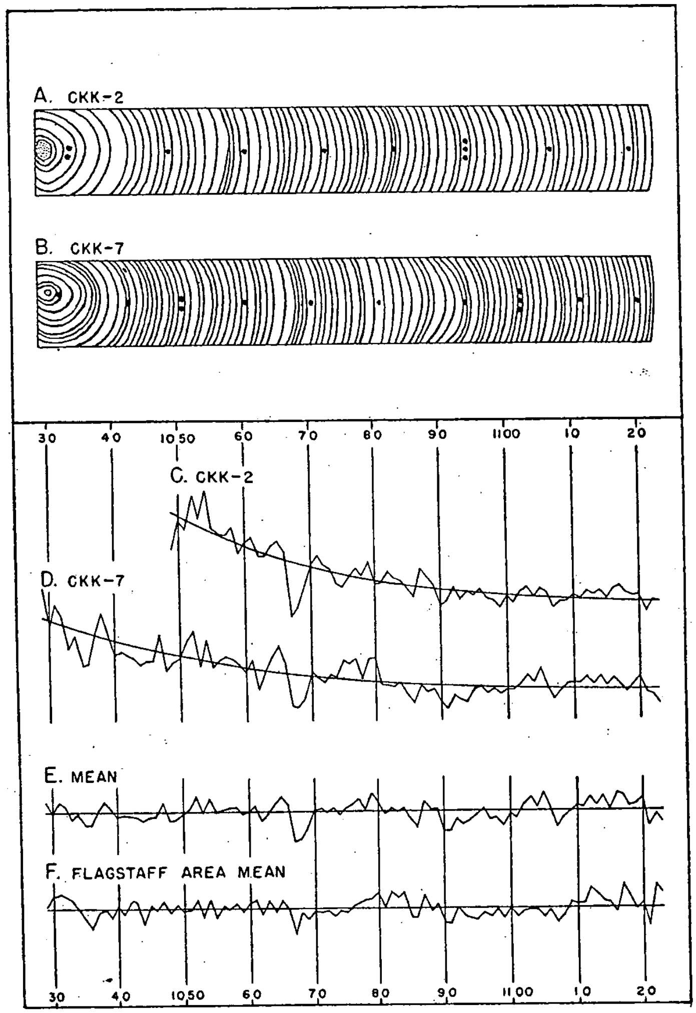

Figure 11:2.—Crossdating and comparison of measured curves. *A* and *B* are schematic drawings of the two wood specimens CKK-2 and CKK-7. *C* and *D* are the plotted measured ring widths of the same two specimens with trend lines superimposed on the growth curves. *E* is the standardized mean of the two growth curves. *F* is the Flagstaff Area mean for comparison purposes.

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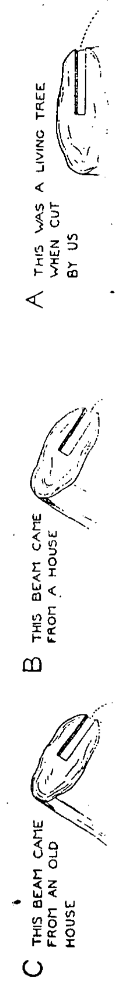
When a specimen has been properly surfaced, ring reading commences with the use of a 10-power hand lens and occasionally a binocular microscope. False rings, microscopic rings, and locally absent rings are carefully searched for and studied (Douglass, 1946, pp. 10-16). Through painstaking and technical analysis, and the application of the forecast-and-verification method, ring patterns of different specimens are compared one with another. Crossdating, if such exists, is worked out and the chronological locations of any locally absent rings are established (see Figure 11:2, *A* and *B*). Since dating work is largely a numerical placement of deficient rings (Douglass, 1946, p. 9), a memory of ring patterns is the most valuable tool of the dendrochronologist in the earlier phases of specimen study. When working in new or unfamiliar areas the tree-ring worker will sometimes make use of the "skeleton plot" as a tentative means of representing the ring patterns in a specimen (Stallings, 1939, pp. 12-13). Skeleton plots, and groups of skeleton plots from one local area worked into a composite plot, are frequently matched against a master skeleton plot in order to gain some insight into the actual placement of the specimen along the tree-ring chronology. Skeleton plots, however, are never used by themselves to "date" a specimen. Actual wood to wood comparison, that is, matching an unknown to a number of known specimens on a year-by-year basis, is considered to be an essential step in the process of dating. All tree-ring dating work is aimed at establishing crossdating between specimens, for without substantiated crossdating a tree-ring date is meaningless.

After crossdating is thought to have been achieved through visual comparison of wood against wood, the next step is to measure the entire ring series of each specimen. Measurements are made on a sliding micrometer scale (Douglass, 1943, pp. 5-8) to the nearest 0.01 millimeter, and ring by ring they are recorded in sequential order. The measurements are then plotted to a definite scale on graph paper. A trend line is introduced (See Figure 11:2, *C* and *D*) and the mean departure increments are standardized (Schulman, 1953, p. 27) in order to reduce the data so as to reveal fluctuations due to climatic causes and to eliminate growth trends inherent in the nature of the tree. The resultant standardized plots are then incorporated into a composite plot (See Figure 11:2 *E*) which in turn is compared with a master areal plot (Figure 11:2 *F*) previously established by means of *chronology building*. Chronology building is the process of starting with modern specimens of known date and continuously crossdating and incorporating successively older specimens into the matrix until a long-range tree-ring chronology is obtained (Figure 11:3). Favorable coincidence of the matched plots



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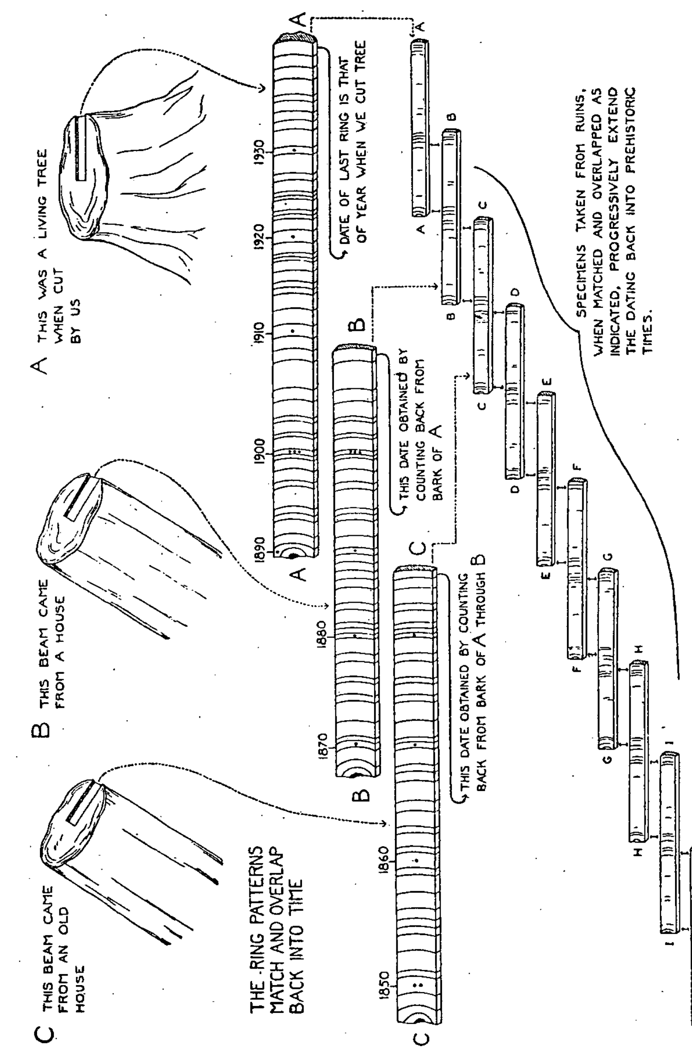

Figure 11:3.—Diagram to illustrate chronology building. (From Stallings: *Dating Prehistoric Ruins by Tree Rings*).

(Figure 11:2, *E* and *F*) serves to confirm the crossdating and to prove the dating of the specimens. As a final check on the dating, a complete recheck of all work is made by another competent dendrochronologist.

5. *Application of derived dates*

Although a tree-ring date may be considered as part of an absolute chronology because it has been crossdated with a tree-ring series built up of many thousands of specimens collected over a wide area, the date by itself is of little or no intrinsic value until it has been integrated with the natural or cultural environment from which it came. Despite the vast body of scientific knowledge and data that produces a tree-ring date, that date can only be applied with authority to the specimen in question. Since a tree-ring date can be defined as the calendrical year with which the outermost ring in any given tree-ring specimen has been equated, the only irrefutable conclusion that can be drawn about a tree-ring date is that the tree could not have died before the time of the date in question. Any conclusion beyond that fact is necessarily in the realm of interpretive conjecture and must be treated accordingly.

There are three categories of basic information that must be thoroughly investigated before a tree-ring date can be given proper evaluation for interpretive purposes. It must be known (1) how the dated specimen was originally used; (2) what relationship exists between the date of the specimen and the context in which it was found; and (3) how close is the date to the time that the original tree died. These three questions as stated apply specifically to tree-ring dates, but with some broadening of scope they can equally apply to other types of geochronological dates.

Failure to comprehend the basic data pertinent to a dated tree-ring specimen has sometimes resulted in the faulty application of that date. For example, there have been instances in archaeological literature where a single dated tree-ring specimen from a large prehistoric Indian pueblo has been used to define *the* date of the ruin. Obviously, no single date can have much significance when applied to a structure that may have seen many centuries of continuous occupation. It is well to remember that, in broadest terms, tree-ring dates alone can never "date" a structure (natural or artificial); they can at best date events with which they can be directly associated, they can be helpful in delimiting periods, and they can indicate time horizons for associated materials.

The first factor to be considered concerns the use to which the specimen was originally put. In other words, just how did the dated specimen come to be in the natural or cultural context in which it was found? To best illustrate the significance of this question, the viewpoint of the archaeologist will be considered. The archaeologist must determine whether the given specimen was initially used for construction purposes or for non-construction purposes. Specimens used for construction purposes would include the timbers used in the main framework of a dwelling or utilitarian unit as well as secondary roofing materials and assorted props, braces, and supports. The bulk of tree-ring dates from archaeological sites in the Southwest are from construction specimens and these can be referred to as "construction dates." On the other hand, non-construction specimens may represent a variety of original uses including room furnishings such as wall pegs and shelves, various furniture supports, wooden artifacts, and a wide assortment of specimens found in trash heaps, firepit areas, and the dirt fill in abandoned rooms.

It is apparent that when we are dealing with "construction dates," we are, in the main, attempting to date events; that is, the time of building of the unit from which the specimen or specimens came. Consequently, construction specimens are most useful in the following circumstances: when determining the time that a room or particular unit was built; when determining the time of the building of a group of rooms or an entire pueblo (only feasible with a great many "construction dates" representing an adequate spatial coverage of the ruin); and when determining the actual order of room by room development of a pueblo (see Haury, 1934, p. 58). All of these processes, however, involve the use of "construction dates," and thus the time of active building, and do not necessarily give any information on how long the dwelling was occupied. There is always the chance, of course, that "construction dates" from sites of long occupation will reflect new building activity up until the time of abandonment of the site, but at the same time there exists the likelihood that the later building developments will utilize older timbers salvaged from unused portions of the ruin.

"Non-construction dates," particularly those derived from trash heap specimens and firepit materials, are more apt to represent a time later than the "construction dates" from the same site. It is reasonable to assume that the gathering of firewood would continue until a pueblo was completely deserted and that any tree-ring dates obtained from firepit charcoal may well approximate the time when the ruin was abandoned. Of course old construction pieces may be used for firewood, in which case the preceding assumption would be invalid.

Discriminate use of "non-construction dates," however, along with "construction dates" may well add a third dimension to what would otherwise be a two-dimensional picture. When both ends of an occupational period are delimited, then the time horizons of the associated artifactual materials may be more clearly defined. It is most important, therefore, that the archaeologist who is using tree-ring dates for interpretive purposes have a thorough understanding of how the dated specimens were originally used and exactly how that knowledge may affect his conclusions.

Although the preceding discussion has been restricted to an archaeological problem, the same type of reasoning would apply not only to tree-ring dates derived from non-archaeological specimens, but would also be appropriate to dates obtained by any other geochronological method. In particular, an understanding of just how a dated tree-ring specimen was originally used or just how it happened to get in the context in which it was found is of great importance in answering the question posed by the second category of basic information necessary for the interpretation of a tree-ring date.

The second fundamental question involves the problem of determining whether the date of a dated specimen is a true representation of the age of the context in which the specimen was found. Although the date of a tree-ring specimen as given by a dendrochronologist may be perfectly accurate, the dated specimen itself may or may not have any significant relationship to its context. The problem then is to determine whether the specimen is intrusive into its context or whether it is an integral part of the medium being dated.

Again using an archaeological problem as an illustrative example, the question is whether the dated tree-ring specimen represents a reused timber, a repair timber, or neither. About the only way this particular problem can be solved is through the application of accumulative evidence. Just as one potsherd is of little value in describing a site, so one tree-ring date can be equally misleading in deciding the chronological placement of a ruin. If all of a large number of tree-ring dates from a given ruin appear to be much too early, then there would seem to be ample reason to question the validity of the archaeology or to instigate a search for some other unsuspected factor, such as the movement of the entire pueblo to a new location. If, on the other hand, just a few of many dates seem too early, then there exists the probability that the early dates are from reused timbers. "Early dates," if obviously out of context, can be used only with caution in the interpretation of the ruin from whence they came, but they may prove to be very valuable in indicating the presence of an older occupation or a nearby and unsuspected ruin.

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most or all of a number of dates from a ruin seem much too late, then probably the archaeological interpretation is at fault, but if just a few dates are later than the rest, then repair timbers are the likely answer. Dates from repair timbers, similar to late dates from firepit material, can be extremely useful in obtaining an idea of the length of occupation of a ruin.

Determining the context by the "clustering" of dates about a single point in time is possible only when there are enough dates to lend some degree of statistical backing to any conclusions that might be drawn. When dealing with archaeological phenomena such backing is frequently obtainable due to the fact that a single room or house may yield a multitude of datable specimens. On the other hand, the writers feel that some of the other geochronological methods, the carbon-14 method for instance, will always be handicapped by the paucity of "dates" from one confined location, and this fact, coupled with the limiting error of the method itself, will restrict the application of the "cluster" technique except perhaps on a relatively gross basis.

It should be self-evident that using tree-ring dates indiscriminately for interpretive purposes, without first determining the relationship of the specimen to its context, can lead to completely invalid conclusions. Admittedly, the problem of making this determination is sometimes a most difficult one to resolve, and on occasions the problem is unsolvable because of insufficient evidence.

The third factor to be considered involves the limiting conditions inherent in a given specimen because of the loss or illegibility of outer rings. This is information that the tree-ring analyst alone can supply, yet it is the responsibility of the user to understand the implied limiting factors and to appraise them in terms of the interpretative value of the dates.

Since a tree-ring date is the year of the outermost ring of the specimen, the date may or may not be the year in which the original tree died. The Laboratory of Tree-Ring Research releases all dates followed by a symbol which indicates the condition of the outer ring and which also gives an idea of how many outer rings may be lost. The symbol "B" following a date indicates that bark cells are present on the specimen and that the original tree could not have lived after the assigned date. The symbol "C" signifies that the outer ring is consistent around the circumference of the specimen and, although bark cells are not present, there are probably no rings lost. "G" indicates the presence of bark bettle galleries on the outside; consequently the "date" is within a few years, at most, of the true cutting date. The absence of any symbol at all or the use of "V"—variable—means that the outer ring is not consistent around the circumference and that there may be some rings lost from the outside.

If a particular specimen has neither a "B," "C," or "G" type of outside there are two main methods used for estimating the number of rings lost from the outside. The first method is exactly the same as when determining the possibility of reused and repair timbers. That is, if a number of dated specimens from one location tend to "cluster" about a certain year, and if these dates are mostly "B"s, "C"s, or "G"s, then the few earlier dates from the same location that might have rings lost from the outside were in all probability originally contemporaneous with the majority. The second method is applicable when wood specimens yield a heartwood-sapwood date (Smiley *et. al.*, 1953, pp. 10-11; and Douglass, 1939, pp. 3-6). The heartwood-sapwood date is the average date of the heartwood-sapwood line which separates the dead inner heartwood of the trunk from the living sapwood outside. Depending on species and locality, an estimate of the number of sapwood rings that would normally be present can be made and consequently a rough estimate of the number of rings lost from the outside can be determined.

The symbol, if any, following the date, therefore, should be just as important to the user as the date by itself. For example, the archaeologist who is confronted with the two tree-ring dates of 1134B and 1134 knows that in the first specimen the tree died in the year 1134, but the second specimen may have come from a tree that died anywhere from 1134 to 1200 or even later. Naturally the same interpretative qualities cannot be attached to both specimens.

It should be noted that the three categories of basic information necessary for the proper evaluation of tree-ring dates in archaeological as well as non-archaeological problems have general application in other forms of geochronological dating. When a date is based on the unique qualities of a particular specimen, then the answers to the following three questions must be determined before that specimen can be properly interpreted in terms of its environment: How was the specimen originally used or how did it come to be where it was found? What relationship does the dated specimen have to its context? What are the inherent limitations imposed by the dating method itself?

6. *Summary*

Dendrochronology is perhaps best known for its contributions to archaeology, but there exist a multitude of other fields in which dendrochronology has been applied or in which there are potential applications. There are two main types of tree-ring research being undertaken today at the University of Arizona, but only one, wherein the date itself is of intrinsic value, has received emphasis in this paper. The establishment of a long-range tree-ring chronology depends on four necessary conditions

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relating to the types of trees in an area, the factors controlling the growth of trees, and the existence and preservation of an adequate supply of specimens. Field collecting requires careful site classification and specialized techniques for handling modern and ancient specimens. Precision in dating tree-ring specimens is achieved through painstaking preparation of specimen surfaces allowing correct reading of ring patterns, and by the application of the principles of crossdating, the use of the forecast-and-verification method, and the objective techniques of measurement, presentation and comparison. Proper interpretation of tree-ring dates, as well as all other "dates" derived by a geochronological method, can in part be governed by recognizing three categories of basic information which concern the particular conditions and circumstances of the dated specimen and the limitations of the dating method itself.

The strength of the tree-ring method lies in the absoluteness of its dates and the completeness of its temporal coverage (from 59 B.C. to present) within the Southwest. This in turn is based upon the solidity of the tree-ring chronology. Well over seven thousand dated specimens (see Smiley, 1951b, p. 6) have been incorporated into the various areal chronologies of the Southwest and the number is increasing steadily. With such a mass of accumulated data, consolidated and checked by nearly half a century of practical use in several diverse disciplines, i.e. dendrochronology, astronomy, and archaeology, each new tree-ring date is backed by authority that is unmatched as yet in any other method in geochronology.

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