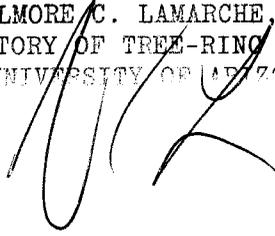


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# Concepts and Techniques of Dendrochronology

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## CONCEPTS AND TECHNIQUES OF DENDROCHRONOLOGY

*C. W. Ferguson*

**D**ENDROCHRONOLOGY may be defined as the study of the chronological sequence of annual growth rings in trees. The concepts and techniques of the science, as presented here, reflect the work and practice of the Laboratory of Tree-Ring Research at the University of Arizona in Tucson. Development of the science of dendrochronology—as opposed to the simple counting of tree rings in a stump—began in 1901 with an observation on aridity in relation to elevation by Andrew Ellicott Douglass,<sup>1</sup> an astronomer interested in sunspots, and continues up to our strongly computer-oriented age. The objective of this paper will be to acquaint the reader with some of the fundamentals so that he may better understand the tree-ring studies done on living trees<sup>2</sup> as well as in archaeological material.

In the southwestern United States most of the tree-ring studies have been conducted on four major species: Douglas fir (*Pseudotsuga menziesii*), ponderosa pine (*Pinus ponderosa*), pinyon pine (*Pinus edulis*), and Rocky Mountain juniper (*Juniperus scopulorum*). Much work also has been done on the giant sequoia (*Sequoia gigantea*). Although it reaches an age of about 3200 years, it is not a good dendrochronological species. In recent years, attention has been focused upon two species of the upper timberline: limber pine (*Pinus flexilis*) and bristlecone pine (*Pinus aristata*).

<sup>1</sup> A résumé of the work of Douglass and a complete list of his publications is contained in a memorial article in the *Tree-Ring Bulletin* 24, 3-4 (May 1962), 2-10.

<sup>2</sup> B. Bannister, "Dendrochronology," in *Science in Archaeology*, Brothwell and Higgs, eds. (New York: Basic Books, 1963), pp. 161-176.

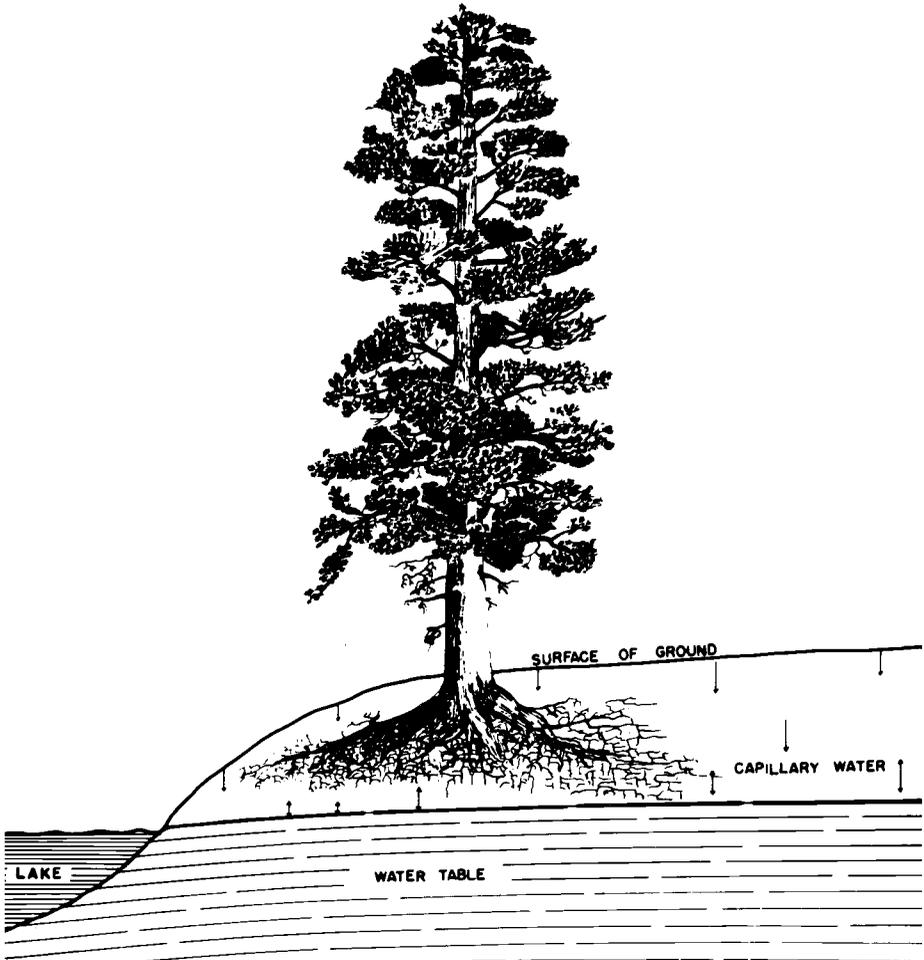


FIG. 1. A complacent site, with ample moisture, which would produce a tree that would have rings of uniform width.

### *Sampling Living Trees*

In dendrochronological studies, criteria for sampling include trees that (1) are not too close to other trees, as competition may overshadow climatic response; (2) have no subsurface supply of water, for example, an adjacent spring or perennial stream (figs. 1 and 2); and (3) have no outward appearance of injury or disease.

Sampling may be done by taking a cross section or, more conveniently, by using a Swedish increment borer, a precision tool designed to remove a small core  $\frac{3}{16}$  inch in diameter, without causing the living tree any harm. The tip of the borer has a razor-sharp cutting edge with external

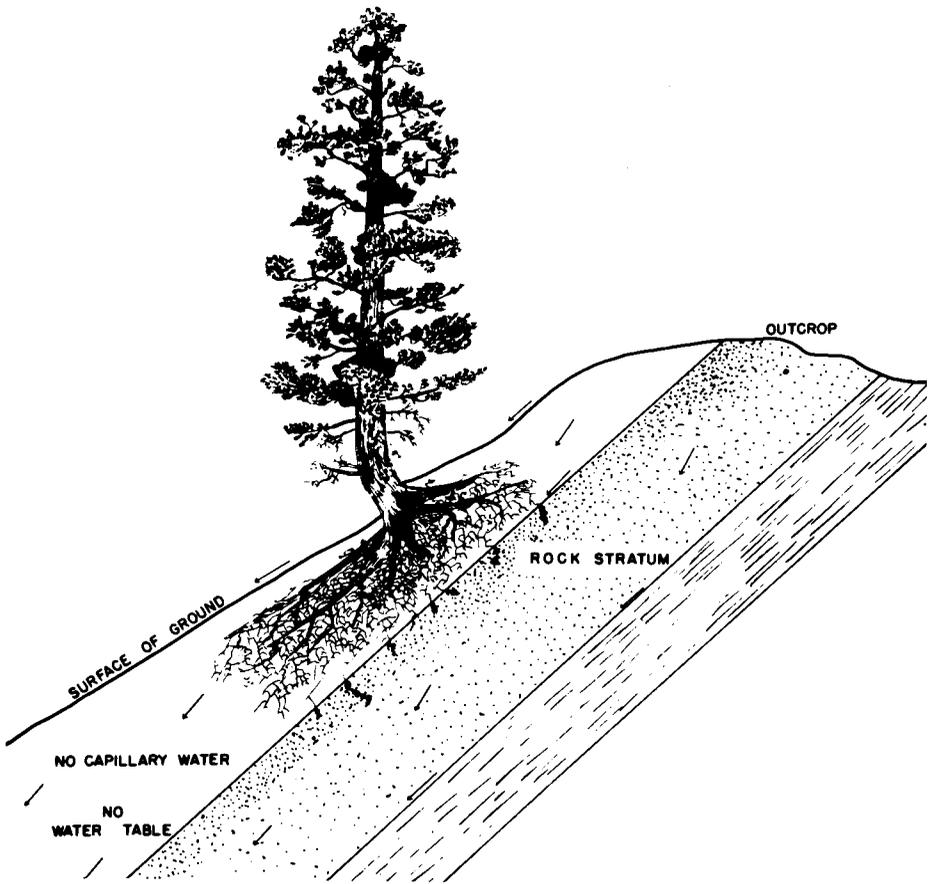


FIG. 2. A sensitive site where soil moisture drains or seeps off, and the tree will have annual rings that will vary in width in response to year-to-year changes in precipitation.

screw threads that draws the borer into the tree as the handle is turned. A sixteen-inch borer is a common size, but they can be obtained up to forty-eight inches in length.

Before the core is removed from the extractor spoon, it should be numbered. All data are handled with the bark (recent) at the right; hence, the core should be in this position. The reason is solely one of tradition; there is no reason the reverse could not be practiced. Comparison is facilitated, however, when preparation is standardized, and we do have what is by far the largest collection of tree-ring data. The somewhat fragile increment cores must be handled with care. If they are sound when removed, they may be carried loose in a large tubular container. If they are

not in one piece, however, they must be stabilized individually. Soda straws, into which a core fits, or corrugated cardboard sections are good containers for individual specimens. Cores may be laid down between the corrugations and taped in place.

Various site and specimen data are recorded. These usually include: exact geographic location, such as township, range, and section; slope (the steepness expressed in percent, and relative position on the slope, as mid, upper, and lower) and exposure (aspect) according to compass points; soil conditions (type and depth); associated plant growth (species and areal density); relation to other trees; physical characteristics of the tree, such as diameter of stem, height of crown, and general overall appearance; and any natural or man-made disturbance, such as lightning or fire damage, excessive grazing, lumbering, etc.

The Laboratory now uses two standard forms, on  $5 \times 8$  inch cards, to record data for the site and for the individual specimens. Thus the general description, map references, etc., do not have to be repeated for each tree sampled. A map, sketched as the collecting progresses, locates the individual trees. An embossed aluminum label, bearing either a field number or a permanent Laboratory designation, is attached to each tree. The procedure encompassing maps, labels, pictures, and notes serves not only to identify the tree, but is designated to permit resampling of individual trees at periodic intervals by a succession of field crews. In this way, the record can be kept up to date and perhaps strengthened by additional collecting in prime areas.

### *Preparation of Cores*

Cores are mounted in a grooved stick to facilitate handling and storage. The mount, specially milled from a piece of clear wood, is  $\frac{3}{8}$  inch wide by  $\frac{1}{2}$  inch high, and of sufficient length to accommodate the core. One of the narrow sides is grooved to hold half of the core, and the shoulders are sloped. Cores should be air-dried prior to mounting so that they will not shrink and crack after they are glued in place. When cores break in the field, sequential numbering of fragments will aid in reconstructing the core for mounting.

The specimen number and such notes as the species, site, and collection data are written on the mount in pencil. These data should agree with those on site and specimen cards and with the permanent Laboratory system of identification.

A thin stream of permanent glue (a plastic glue is preferred because it will not crystallize) is spread evenly in the groove, and the core is inserted with the bark end to the observer's right. The original vertical cell structure is placed in the groove tilted toward the observer at an angle of  $30^{\circ}$  to  $45^{\circ}$  above the horizontal. The cell alignment can be detected by examining the cell structure at either end and by the sheen on the sides of the core caused by the shearing action of the borer. The core is pressed firmly into the groove and wrapped tightly and evenly with string to hold the core firm while the glue is drying.

A surface may be prepared by either a microtome or a sanding technique. A razor blade, preferably a larger-than-average size, used in a sliding, drawing action will provide a smooth cut. A blade holder, especially one that will allow a little flexibility in the outer portion of the blade, will facilitate the operation. Some species and particularly specimens with heavy latewood may be more easily cut if the cores are moistened by immersing them in water for a few seconds. In specimens having fairly large, distinct rings, a surface may be prepared by sanding with a small belt sander, utilizing a series of grits from about 100 to 400. If this is to be the procedure, the cores should be mounted with the cells vertically aligned.

Discussion up to this point has been concerned solely with cores. In the case of hardwoods, however, which do not lend themselves to the coring technique, or of the occasional conifer sampled by sectioning, a cross section constitutes the study specimen. As with the cores that are sanded, a small belt sander is the best tool for preparing a surface on the cross sections.<sup>3</sup> Handling and examination of the specimen is made easier by removing dirt and dust with a jet of compressed air.

### *Examination of Cores*

The dark color of the latewood cells (fig. 3) may be deepened by a light coat of kerosene applied with a small cotton swab. Frontal light will be reflected by the concavity of the large-diameter earlywood cells exposed in the angle cut. The absorption of light by the thick-walled, smaller-diameter latewood cells will further sharpen the contrast between the two ring components and thus easily delineate the ring boundaries.

<sup>3</sup> C. W. Ferguson, *Annual Rings in Big Sagebrush, Artemisia tridentata*, University of Arizona Press, Papers of the Laboratory of Tree-Ring Research, no. 1 (1964), 12, 13.

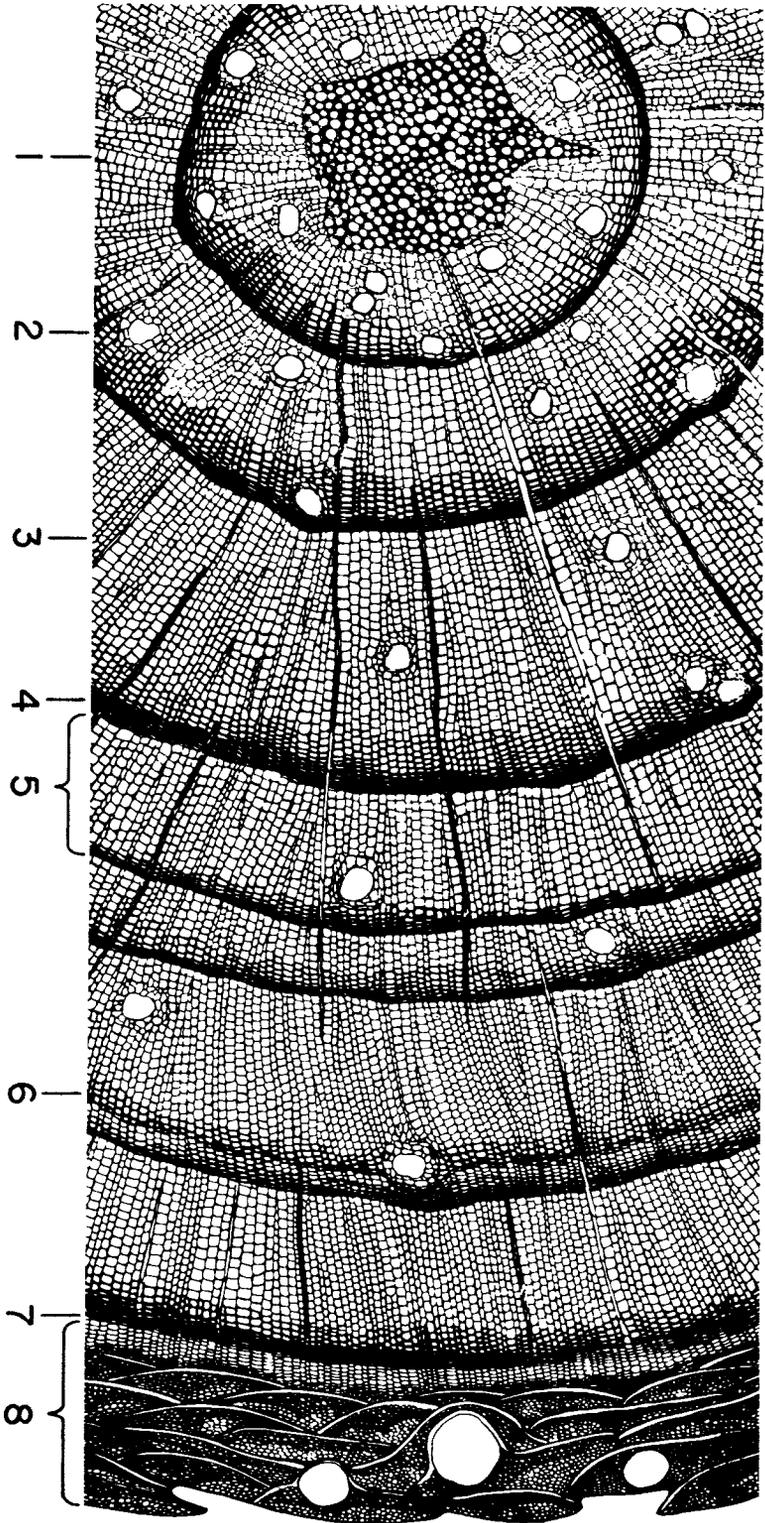


Fig. 3. Cross section of a typical conifer stem showing: (1) pith, (2) resin duct, (3) earlywood cells (light), (4) latewood cells (dark), (5) annual ring, (6) false interannular ring, (7) cambium, and (8) bark.

For all but the most difficult specimens, a 10-power hand lens is adequate. For cores showing smaller average ring widths or in instances of prolonged examination, a binocular microscope with a zoom lens is ideal.

The dating is marked on the core by making a pinhole on each decade ring, two on the half centuries, and three on the centuries. For convenience in reexamining, the centuries are labeled, 19 for 1900, etc., on the near shoulder of the mount. The innermost ring year is labeled on the far shoulder. Critical rings are noted on the near wall of the mount, as "1904 ab," "1934 m," for absent or micro rings. A summary of the work done should be noted on the mount, as "dtd. 1763 on 5-29-66, CWF," or "msd. 1800 on 5-30-66, PSM," when the specimen is dated or measured.

### *Chronology Building*

Basic to a tree-ring chronology is the fact that each consecutive annual growth ring is assigned to the calendar year in which it was formed. Thus cores taken through living tissue have the chronology control provided by an outermost ring with a precisely known date. Inward from this so-called bark ring, successive annual growth layers are assigned to sequentially earlier years. A pattern of wide and narrow rings, common to all radii and to different specimens due to the dominance of a single climatic factor, forms the basis for cross-dating among specimens (fig. 4). The master chronology is unique in its year-by-year pattern; nowhere throughout time is precisely the same long-term sequence (of 100-plus years) of wide and narrow rings repeated, because year-to-year variations in climate are never exactly the same.

When the quality of cross-dating<sup>4</sup> has been established and a modern chronology developed for a given area, it is possible to date tree-ring material, either wood or charcoal, from earlier periods. These records can be incorporated into the master chronology and thus extended further into the past (fig. 5). In the southwestern United States, this type of record, based upon archaeological material, now extends to 59 B.C.<sup>5</sup> In the same manner, wood of the millennia-old bristlecone pine, especially from remnants that predate the 4000-year-old living trees, has enabled us to

<sup>4</sup> Terms relating to, or derived from, the study of tree rings are defined in a glossary, compiled from many sources, at the end of this article.

<sup>5</sup> E. Schulman, *Dendroclimatic Changes in Semiarid America* (Tucson: University of Arizona Press, 1956), 142 pp.

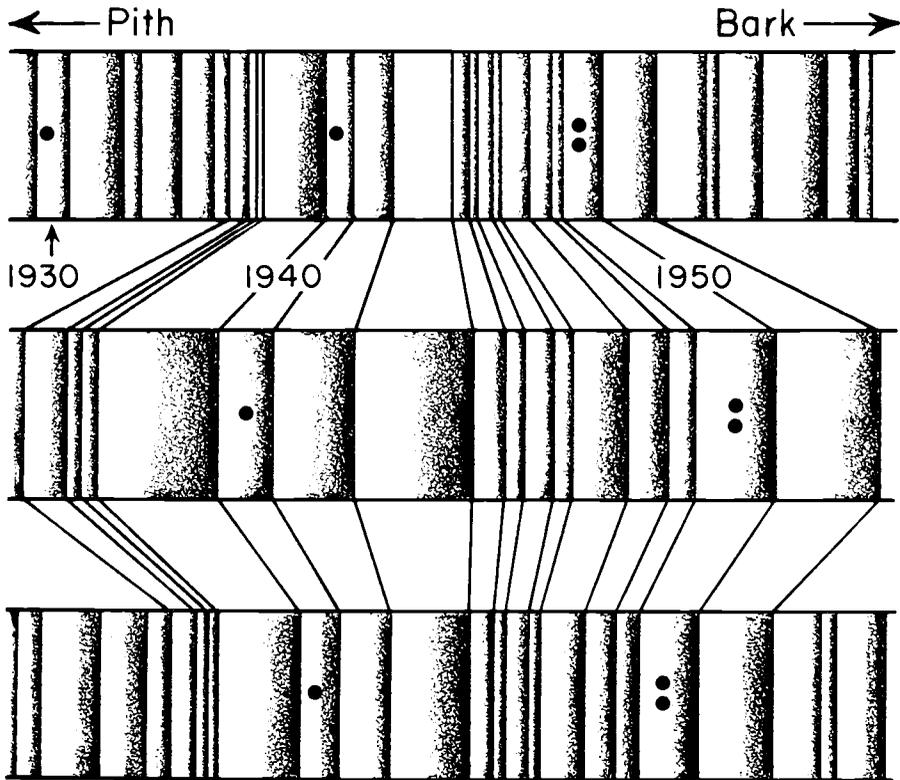


FIG. 4. Cross-dated ring patterns from three different trees. Rings vary in absolute width between specimens, but the relative widths are the same. Decade years are marked with a single pinhole, mid-century rings with two pinholes.

extend the chronology for the White Mountains in east-central California back to 5150 B.C., thus providing a continuous chronology of 7485 years.<sup>6</sup>

### *Statistical Analysis*

We have developed routine computer programs for calculating certain statistical measurements from tree-ring series.<sup>7</sup> The entire set of rings from the lower trunk of a mature tree can be related to yearly climatic variation

<sup>6</sup> C. W. Ferguson, "Bristlecone Pine: Science and Esthetics," *Science* 159 (1968), 839-846. C. W. Ferguson, "A 7104-year annual tree-ring chronology for bristlecone pine, *Pinus aristata*, from the White Mountains, California," *Tree-Ring Bulletin*, 29, nos. 3-4 (1969), 3-29. C. W. Ferguson, "Dendrochronology of bristlecone pine, *Pinus aristata*," XII Nobel Symposium: *Radiocarbon Variations and Absolute Chronology* (Stockholm: Almqvist and Wiksell, in press).

<sup>7</sup> H. C. Fritts, "Computer Programs for Tree-Ring Research," *Tree-Ring Bulletin* 25, 3-4 (1963), 2-7.

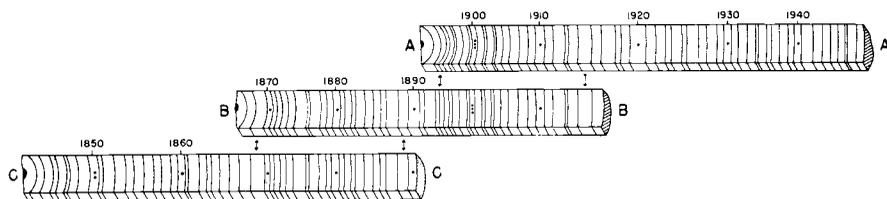


FIG. 5. A series of cross-dated specimens illustrates, in foreshortened form, the process of chronology building. Series A represents a specimen from a living tree with a known outside date. An archaeological specimen (B) is cross-dated with an early portion of the modern specimen and is identified as of intermediate age. An earlier archaeological specimen (C), when dated, extends the chronology further into the past.

by removing, statistically, the gradual changes associated with the age of the tree. An exponential curve is fitted to each series of ring-width values, and measured ring widths are divided by yearly values of the fitted curve. This process transforms the ring-width values to tree-ring indices which exhibit a mean of 1.00 and a variance that is independent of tree age, position within the trunk, and mean growth of the tree. Additional programs include (1) correlation coefficients, which give a measure of common relative variability of indices for pairs of cores from one tree or for different trees; (2) mean sensitivity, which expresses the relative year-to-year variation in the ring-index values; (3) first-order serial correlation, which measures the degree of dependence of a single growth-ring index upon the index of the preceding ring; and (4) standard deviation, which measures the variation about the sample mean.

From application of these statistical measurements to a particular site, one can infer how certain ecological conditions have limited ring growth.<sup>8</sup> An understanding of these relationships facilitates the search for sites and trees that contain sensitive records.

Mean sensitivity, defined as the average ratio of the absolute difference between each two successive widths divided by their mean,<sup>9</sup> is used as an index of the limiting effects of climate on tree-ring growth.<sup>10</sup> Standard deviation, which measures variability about the sample mean, resembles the mean sensitivity when the serial correlation is low and where, as in the more complacent series, there are few very narrow rings. The mean

<sup>8</sup> H. C. Fritts, D. G. Smith, J. W. Cardis, and C. A. Budelsky, in *Ecology* 46 (1965), 393.

<sup>9</sup> A. E. Douglass, *Climatic Cycles and Tree Growth*, Carnegie Institution, Washington, D.C., pub. 289, no. 1 (1919); 289, no. 2 (1938).

<sup>10</sup> Schulman, op. cit.

sensitivity values become relatively greater in a sensitive series, especially when rings are missing (missing rings are expressed as zero values for single years).

The quality of sensitivity is illustrated for two types of trees by photographs of cross sections (fig. 6). The "complacent" record exhibits little or no variation in ring width from year to year and is typical of trees on sites with characteristics favoring optimum growth. The fairly "sensitive" record shows variability in ring width from year to year.

As sensitivity increases, so, too, does the probability that rings will be missing. A tree-ring sequence exhibiting extreme sensitivity, having almost the appearance of erratic growth, may contain less than 90 percent of the annual rings along a single radius and thus be too difficult to use initially in chronology building, but ultimately it may provide an excellent climatic record. The relationship of chronology sensitivity and site factors is more fully discussed by Fritts.<sup>11</sup>

Dating of either modern specimens or archaeological materials<sup>12</sup> may be achieved by visual inspection (sliding coincidence or memory methods), by the use of skeleton plots (fig. 7), or by the use of plotted ring measurements (fig. 8). In instances where ring series cannot conclusively be dated by visual or plot techniques, a computer-programmed correlation routine may be used to measure all possible matches between two series of indices.<sup>13</sup> Correlation coefficients exhibit a normal random fluctuation within narrow limits around "zero" except at the match point, where a highly significant positive correlation may be obtainable. The correlation coefficients obtained by Scott<sup>14</sup> have a probability of less than one in 10,000 of occurring by chance alone.

<sup>11</sup> Fritts et al., op. cit.

<sup>12</sup> A more complete description may be found in A. E. Douglass, "Cross-dating in Dendrochronology," *J. Forestry* 39, 10 (1941), 825-831; R. D. Roughton, "A Review of Literature on Dendrochronology and Age Determination of Woody Plants," *State of Colorado Department of Game and Fish, Technical Bull. no. 15* (1962), 99 pp.; W. G. McGinnies, "Dendrochronology," *J. Forestry* 61, 1 (1963), 5-11. M. A. Stokes and T. L. Smiley, *An Introduction to Tree-Ring Dating* (Chicago: University of Chicago Press, 1968).

<sup>13</sup> A computer program was developed to provide a quantitative expression of the similarity between two tree-ring chronologies. This technique, providing evidence of cross-dating in instances too subtle for the eye to see, has been effectively used twice by Ferguson and Wright (1963, *Tree-Rings in The Western Great Basin*, in 1962 Great Basin Anthropological Conference, Carson City, The Nevada State Museum, Anthropological Papers, no. 1, pp. 10-16) and by Scott (see n. 14).

<sup>14</sup> S. D. Scott, *Dendrochronology in Mexico*, University of Arizona Press, Papers of the Laboratory of Tree-Ring Research, no. 2 (1966), 71, 72.

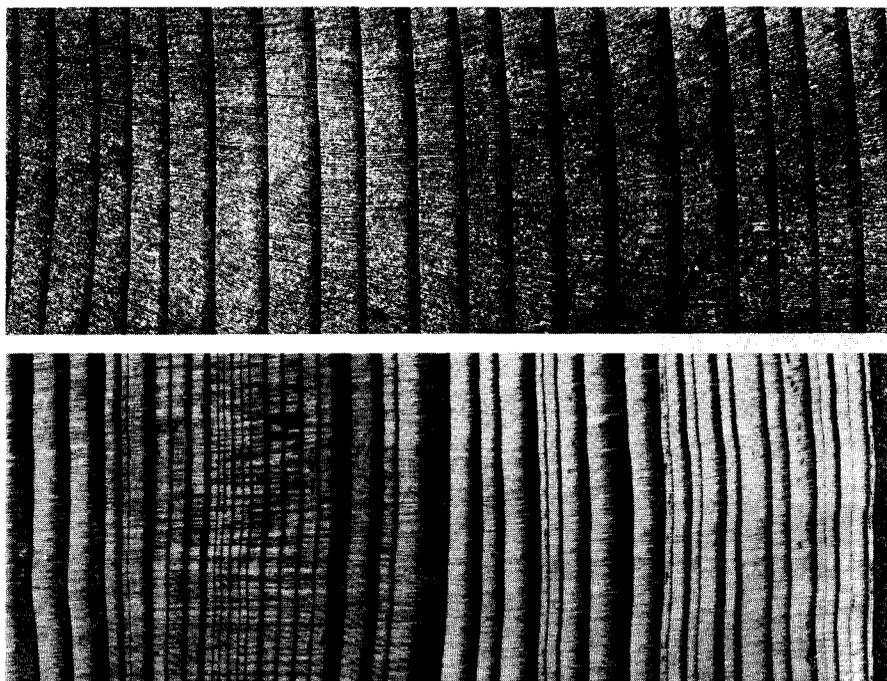


FIG. 6. A complacent ring sequence (top) compared with a sensitive pattern (bottom).

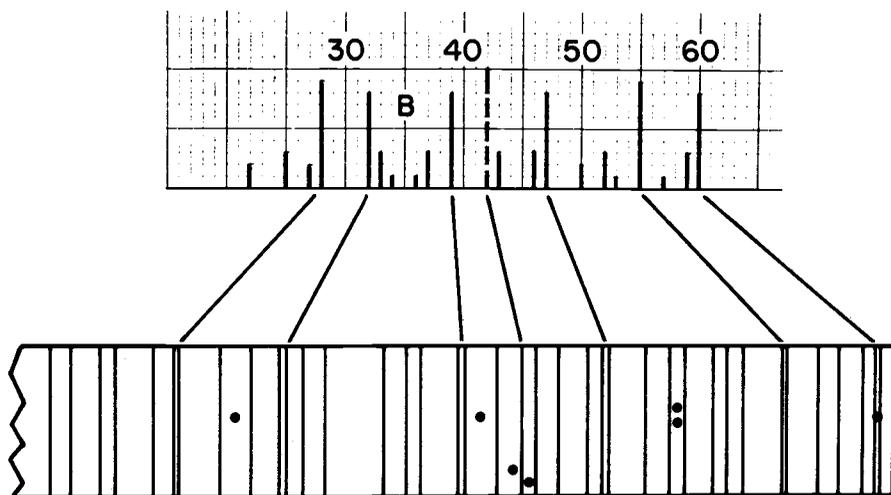


FIG. 7. Construction of a skeleton plot from an idealized tree-ring sequence. Ring widths are represented on the plot by vertical lines in an inverse proportion; that is, tall lines represent narrow rings. An exceptionally wide ring is designated by a "B" (big), and the location of a missing ring, marked on the specimen by offset pinholes, is identified on the plot by a full two-centimeter line in red (dashed). Horizontal scale is 1 year per 2 mm.

### *Archaeological Dating*

Four conditions permit the dating of prehistoric material:<sup>15</sup>

1. There must be trees that produce clearly defined annual rings as a result of a definite growing season.
2. Tree growth must depend principally 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.

### *Determination of Cutting Dates*

Identification of each growth ring by the year in which it was formed is the primary consideration of the dendrochronologist in the dating of archaeological tree-ring material. However, the correct interpretation of the dated ring sequence in terms of the cutting date for the specimen requires care on the part of the field archaeologist and some insight on the part of the dendrochronologist. Hence, bark or the indicated presence of bark on the outside would be the proof positive, and the outermost ring would represent the cutting date. In the case of eroded, rotted, burned, or shaped timber, however, an indeterminate number of ring years may be lost. Clues to the nearness to the bark may be present in the form of beetle galleries,<sup>16</sup> by scars formed on the log during transportation, and by the presence and amount of sapwood. The degree of certainty of the cutting (or bark) date can be classified, and this is used as an additional description to the tree-ring date. Discussions of this are given by Bannister and by Dean.<sup>17</sup>

<sup>15</sup> B. Bannister and T. L. Smiley, "Dendrochronology," in *Geochronology with Special Reference to Southwestern United States*, T. L. Smiley, ed., pp. 177-195, Univ. of Arizona Bull. 26, no. 2, Phys. Sci. Bull., no. 2 (1955).

<sup>16</sup> C. W. Ferguson and R. A. Wright, "Tree-Ring Dates for Cutting Activity at the Charcoal Kilns, Panamint Mountains, California," *Tree-Ring Bulletin* 24, nos. 1-2 (1962), 3-9.

<sup>17</sup> B. Bannister, *Tree-ring Dating of the Archaeological Sites in the Chaco Canyon Region, New Mexico*, Southwestern Monuments Association, Technical Series -6, Part 2 (1965); and J. S. Dean, *Chronological Analysis of Tsegi Phase Sites in Northwestern Arizona*, Ph.D. dissertation, Dept. of Anthropology, Univ. of Arizona, 1967. J. S. Dean, *Chronological Analysis of Tsegi Phase Sites in Northern Arizona*, University of Arizona Press, Papers of the Laboratory of Tree-Ring Research, no. 3 (1969).

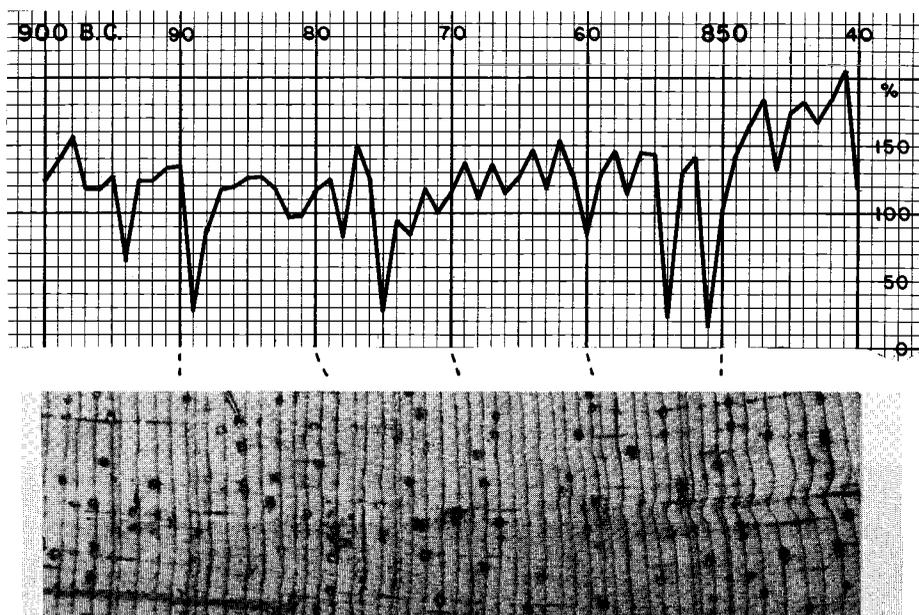


FIG. 8. A segment of the bristlecone pine master chronology, representing three trees from 900 to 840 B.C., used to date a fourth specimen, shown in cross section. The ring-width distribution is skewed, with a general complacency, but having a few rings that are noticeably smaller than average, such as the rings for the years of 894, 889, 875, 854, and 851 B.C. The ring for 851 becomes locally absent in the upper part of the photograph.

### *Interpretation*

So far, the discussion has dealt solely with the tree-ring dating of the wood or charcoal itself. Because of inherent problems and their relation to the acceptance of the dates provided by the laboratory dendrochronologist, some mention must be made of the interpretation of the tree-ring material. Only the date is provided by the dendrochronologist; the interpretation is developed by the archaeologist, first through correct association in the field, and then through the development of the proper relationship to other dates, artifacts, and features within the site. The usual sources of error in interpretation that confront the archaeologist are grouped into four general categories:<sup>18</sup>

<sup>18</sup> The basic pitfalls in interpretation have been presented by Bannister in "Dendrochronology," chap. 17, in *Science in Archaeology*, Brothwell and Higgs, eds. (New York: Basic Books, 1963) and further developed by Dean (op. cit.) and W. S. Robinson, *Tree-ring Materials, as a Basis for Cultural Interpretations*, Ph.D. dissertation, Dept. of Anthropology, Univ. of Arizona, 1967.

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. In this category would be reused timber, snags that were dead when cut, driftwood logs, wooden artifacts that had assumed the status of family heirlooms, and stockpiled logs.

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. Thus tree-ring dates for the construction of a room may be applied to the contents of the room only when the temporal relationship of the room and its contents is known. In small sites with a short-term occupation, this problem may be of only minor significance. In sites with a long occupation, however, the problem becomes more critical.

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. The most common forms are timbers used for remodeling or replacement, perhaps following reoccupation. This may turn a problem into a solution by indicating the time of remodeling or by helping to delimit an occupation period.

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. This is somewhat the reverse of the second type of error source. Here, dates from an artifact or from charcoal in a fire pit are associated with a room constructed somewhat earlier.

#### *Application in a New Area*

If a tree-ring study is to be initiated in a new area, the foregoing procedures may have to be modified. Even though the ultimate focus may be on a single species and in a more or less uniform ecological area, this would be learned only as the result of a systematic search of the existent complex of species through diverse geographic, topographic, and ecological areas.

In the broad initial survey, certain species may be ruled out because of poor ring structure, complacency, short life, or general scarcity of the species. Within a species, ring characteristics may be modified by elevation, latitude, or microenvironmental conditions. Because of these possible

variations, the initial survey should take the form of a transect oriented at right angles to the suspected gradient.

Even when working with a species of established quality, often it is necessary to sample young trees which may be used to validate interpretations or to solve problems in the tree-ring chronology. Thus all age classes should be included within the species and site transects. For example, a younger tree or one on a better site may contain evidence of a ring of minimum width that may be locally absent or entirely missing in older, slower-growing specimens.

For a potentially usable species, correlations should be made between ring widths and various components of the climatic environment, not only to ascertain the climatic factors governing growth, but, more importantly, to verify the annual nature of the periodic growth increment.

In terms of possible tree-ring dating of archaeological materials, a thorough understanding of the species found in the area now is first necessary.<sup>19</sup> Obviously, if these are not interpretable, then there is nothing to be gained in attempting to date comparable specimens found in an archaeological context.

Potentially datable wood found in an archaeological context may provide a "floating" archaeological chronology, which, although it cannot be assigned a calendar date, would serve to relate various structures to one another. As the floating chronology is lengthened and gains depth in the number of specimens and geographic areas represented, it will become more valuable internally and as a potential extension to the chronology developed from living trees.

### *Relation to Radiocarbon*

The production rate of radioactive carbon-14 in the atmosphere varies only slightly throughout the A.D. period.<sup>20</sup> The pattern derived from radiocarbon analysis of dated wood from a variety of archaeological sources is substantiated by the carbon-14 dates of bristlecone pine wood from com-

<sup>19</sup> C. W. Ferguson, "Growth Rings in Woody Shrubs as Potential Aids in Archaeological Interpretation," *The Kiva* 25, 2 (1959), 24-30.

<sup>20</sup> Various aspects of related radiocarbon studies are summarized in Hans E. Suess, *J. Geophys. Res.* 70 (1965), 5937; Paul E. Damon, Austin Long, and Donald C. Grey, *J. Geophys. Res.* 71 (1966), 1055; Froelich Rainey and Elizabeth K. Ralph, *Science* 153 (1966), 1481; Minze Stuiver and Hans E. Suess, *Radiocarbon* 8 (1966), 534; and various authors in the proceedings of the XII Nobel Symposium: *Radiocarbon Variations and Absolute Chronology* (Stockholm: Almquist and Wiksell, in press).

parable time periods. Dates derived from the radiocarbon analysis of tree ring-dated bristlecone pine wood have the advantage of being from a single species, from a long series, and from a single geographic area. With this consistency, a single radiocarbon laboratory, working under constant conditions and within a short space of time, could analyze precisely dated wood in five- or ten-year units throughout the total range of the medieval period. The resultant framework of dendrochronologically calibrated carbon-14 dates would permit a more accurate interpretation of carbon-14 dates derived from structures or artifacts associated with the medieval archaeology.

### GLOSSARY

*Age class.* An arbitrary grouping of plants of essentially the same age.

*Annual increment.* The three-dimensional sheath of secondary xylem added to stems and roots each year. The annual increment has the appearance of a ring (*annual ring*) when a concentric stem is viewed in cross section. An annual ring, especially in conifers, may be reduced in width completely about the ring's circuit. It is then called a *microscopic ring*. Such a ring may be small to the point of being totally absent about some portion of its circuit. It is then referred to as being *locally absent*. When no growth layer was deposited in the visible portion of the specimen in a given year, the ring for this year is *absent* or *missing*. A growth ring showing two (or more) surges of growth in one year is a *double* (or *multiple*) *ring*. The second layer in the double ring is a *false ring*.

*Annual ring.* See Annual increment.

*Bark.* A general term for the tissues outside the vascular cambium in trunks and stems of woody plants.

*Cambial activity.* The process, in woody plants, by which cambial initials divide and form derivatives which differentiate into phloem cells toward the outside and xylem cells toward the inside.

*Cambium.* A tissue located in the woody stems and roots of many higher plants, including trees, in which cells divide and form new tissues, producing xylem (wood) toward the inside and phloem (inner bark) toward the outside. Cork cambium lies outside the phloem and produces layers of cork that constitute most of the outer bark.

*Complacent.* Descriptive of a ring series that does not vary appreciably in width from year to year. Also descriptive of the site producing such a ring series. Antithesis of "sensitive."

*Conifer.* Trees that produce naked seeds in cones, as opposed to fruits, and are typically needle-leaved evergreens.

*Cross-dating.* The systematic comparison of ring patterns, permitting the establishment of absolute dating for each growth ring as the calendar year

in which it was formed, between radii of a single tree, between trees, between species, between age classes within a species, and between sites and major geographical areas in relation to one another and to climatic and historic data.

*Crown.* That part of a tree which has leaf-bearing branches, often supported by a branch-free trunk (stem) or multiple stems.

*DBH.* Diameter at breast height. Approximately 4½ feet above the ground is the standard height for diameter measurements of tree trunks.

*Deciduous tree.* A tree that normally produces new leaves every spring, loses them in the fall of the same year, and overwinters in a leafless condition.

*Dendrograph.* Instrument attached to a tree to obtain a continuous automatically recorded plot of radial stem growth.

*Dendrometer.* A nonrecording instrument used to obtain periodic measurements of change in a radius of a tree trunk.

*Diffuse-porous wood.* Nonconiferous wood having vessels of fairly uniform size evenly distributed throughout each annual increment.

*Earlywood.* The distinct inner component of an annual ring, formed during the first part of the growing season. Earlywood is recognized in diffuse-porous and nonporous woods by differences in density, cell size, cell-wall thickness, and color; and in ring-porous wood by the aligned vessels.

*Evergreen trees.* Trees, such as most conifers, that retain green leaves all winter.

*Full bark.* Descriptive of a tree having a trunk completely covered with bark, in contrast to one with lateral dieback of the stem cambium.

*Growth increment.* The amount of stem or tip material added as a result of periodic or annual growth. *See also* Annual increment.

*Hardwood trees.* A general term, used mostly in the lumber industry, referring to broad-leaved trees of nonconiferous species.

*Latewood.* The distinct outer component of an annual ring. *See also* Earlywood.

*Lobe.* The form, when seen in cross section, of the outer portion of the cleft and irregular stem that is characteristic of many shrubs and some trees, especially of the older plants. A lobe may terminate either in an area of living tissue or in one which died at some time in the past.

*Nonporous wood.* Wood of conifers, characterized by tracheids instead of vessels in the xylem.

*Phloem.* Food-conducting tissue formed by the vascular cambium and constituting the inner bark.

*Pith.* Tissue in the center of stems composed of a mass of parenchyma cells.

*Radial growth.* Increase in radius at a given height. Total radial-growth increment of the xylem for a given year is ring width of that year.

*Rays.* A layer of cells extending radially in the wood and inner bark of tree trunks.

*Release.* A change in the external environment of a tree that reduces competi-

tion with other trees, as would result if the surrounding trees were removed; a decrease in suppression.

*Ring.* Two-dimensional cross section of an annual stem increment. *See also* Annual increment.

*Ring-porous wood.* Nonconiferous wood in which large-diameter vessels comprise the inner (earlywood) component of the annual stem increment.

*Root.* The underground parts of plants on which, as opposed to stems, there are no buds, leaves, or leaf scars.

*Sensitive.* Descriptive of a ring series that varies greatly in width from year to year, as, for example, in response to annual changes in precipitation. Also descriptive of the site producing such a ring series. Antithesis of "complacent."

*Signature.* A short, easily identifiable sequence of large and small rings.

*Softwood trees.* A general term, used mostly in the lumber industry, referring to coniferous trees.

*Stand.* A group of trees growing in a continuous area.

*Stem.* Any of the above-ground parts of a tree which bear or have borne buds and leaves. The trunk and all branches are stems.

*Suppression.* A condition of growth retardation usually associated with competition. *See also* Release.

*Terminal growth increment.* An annual increment of longitudinal growth of the main stem.

*Tracheid.* A tubelike, water-conducting cell. Tracheids also serve for support, and are especially characteristic of conifers.

*Trunk.* The main stem of a tree, generally the branch-free part below the crown.

*Vessel.* Specialized water-conducting tissue in the xylem of nonconifers.

*Xylem.* Water-conducting tissue of most plants and supporting tissue (wood) of trees; develops inward from the cambium.