PRINCIPLES OF TREE-RING DATING

Introduction

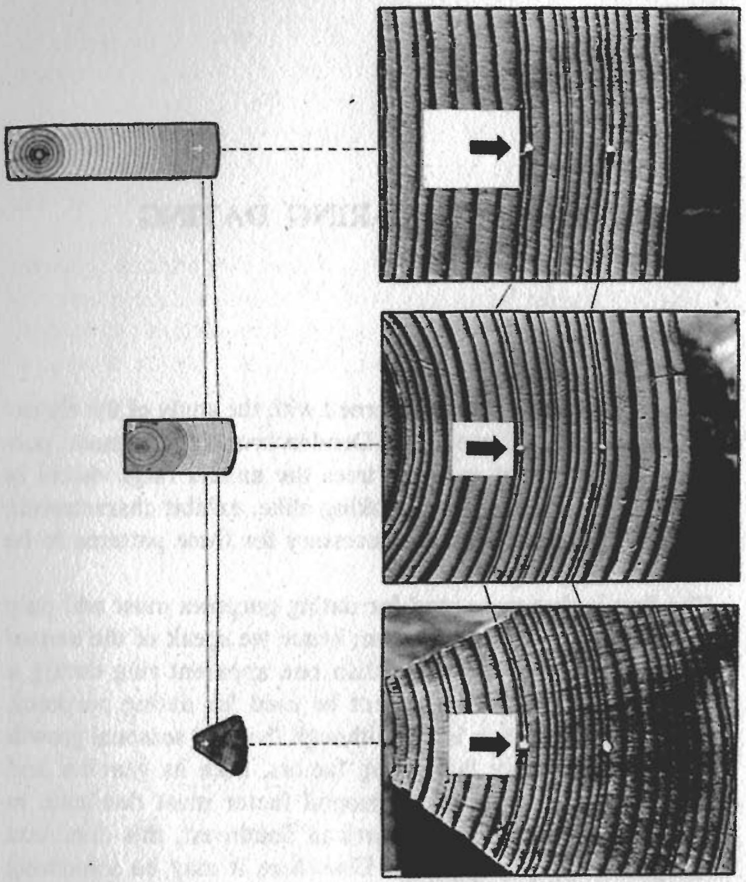
The dendrochronologist is concerned with the study of the chronological sequence of tree rings. Dendrochronology is made possible by the fact that in many trees the annual rings visible in cross section, rather than all looking alike, exhibit characteristic patterns. Four conditions are necessary for these patterns to be usable in dating a specimen.

The first is that trees used for dating purposes must add only one ring for each growing season; hence we speak of the *annual* ring. Species which add more than one apparent ring during a growing season cannot at present be used for dating purposes.

The second condition is that although the total seasonal growth is the result of many interacting factors, such as genetics and environment, only one environmental factor must dominate in limiting the growth. In the American Southwest, this dominant limiting factor is precipitation. Elsewhere it may be something different. In Alaska, for example, it is temperature.

The third condition is that this growth-limiting climatic factor must vary in intensity from year to year and the resulting annual rings faithfully reflect such variation in their width. Although the ring width is not necessarily directly proportional to precipitation, the rings must be narrow in drought years and noticeably wider in rainy years.

It is this recognizable sequence of wide and narrow rings that makes possible cross dating, or the matching of ring patterns in one specimen with corresponding ring patterns in another. It has



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been observed that over a long enough period of time, the sequence of narrow and wide rings is never repeated exactly. For example, a dendrochronologist who is familiar with Southwestern chronologies readily recognizes the period A.D. 611 to 620 by its characteristic ring pattern and can match this pattern in one specimen with similar patterns from other specimens. Figure 1 shows this distinctive pattern in three different specimens, and

Figure 2 shows how the process of cross dating can be applied to specimens of different ages to produce a composite or master chronology covering a longer period of time than any of the individual specimens. In essence dating is accomplished by this pattern-matching, but as in many fields, the theory is simpler than the practice. Chapter 3 describes the mechanics of this process.

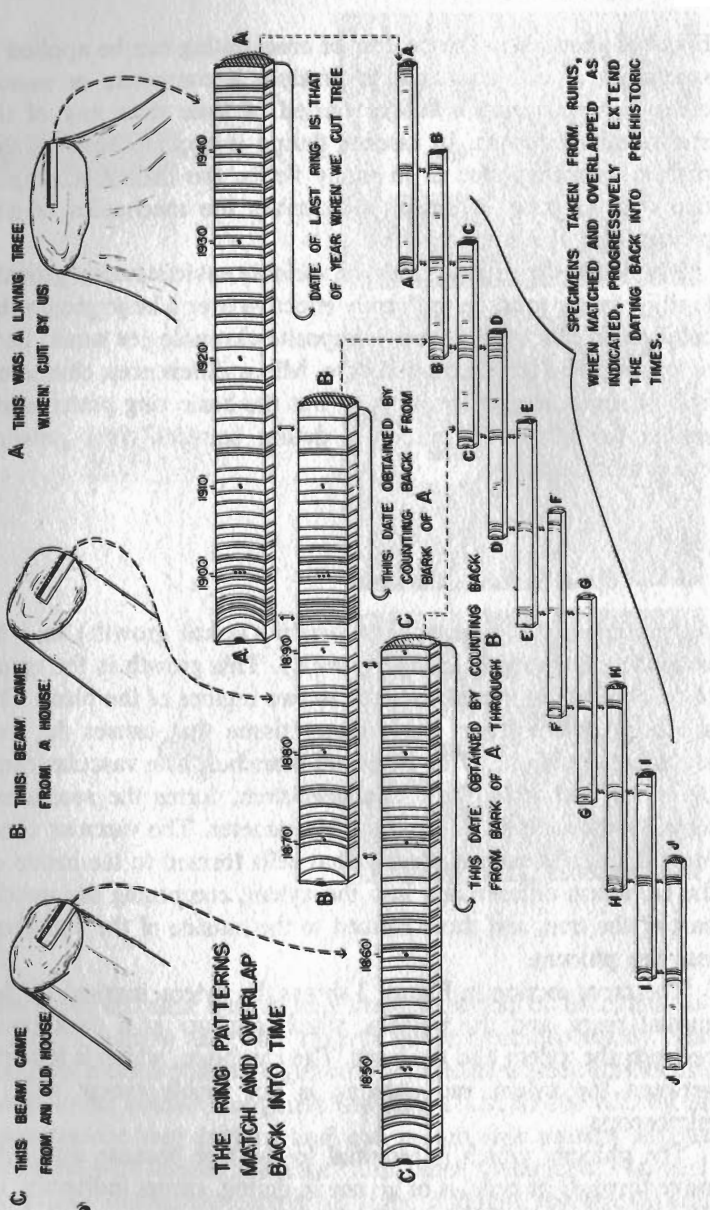
The fourth condition is that the variable environmental growth-limiting factor must be uniformly effective over a large geographical area. If this were not so, composite chronologies would have to be compiled for each small area. Minor differences, characteristic of small areas, always exist, but the basic ring patterns are similar enough to permit cross dating between trees growing many miles apart.

Cross Section of a Stem

A tree grows by increasing in height (apical growth) and by increasing in breadth (radial growth). This growth is the result of cell activity in meristem tissue in two regions of the plant. The apical meristem forms the primary tissue that causes the tree to extend the length of its stem and branches. The vascular cambium, derived from the lateral meristem, forms the secondary tissue that results in an increase in diameter. The vascular cambium divides in such a manner that cells formed to the inside of the cambium differentiate into the xylem, composing the woody part of the tree, and those formed to the outside of the cambium into the phloem.

The cross section in Figure 3 shows the xylem, marked by the annual rings, and the phloem, which appears as a dark band between the xylem and the bark. The cambium, which is located between the xylem and phloem, is not visible except with a microscope.

The phloem, which is essential to the tree because nutrients move through its cells, is of no use in dating, except indirectly, in that its presence on a specimen is assurance that no xylem is



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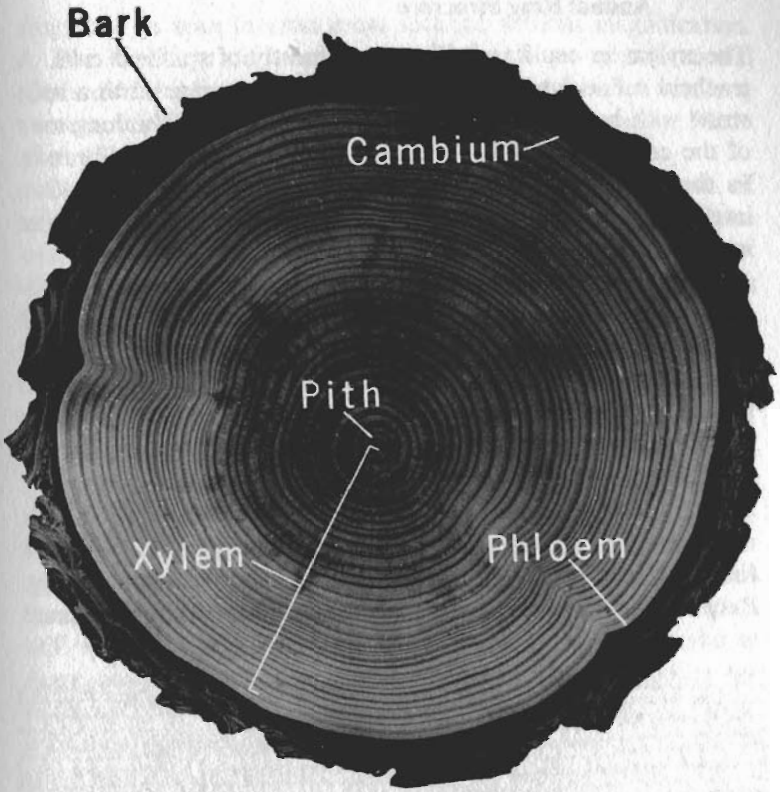

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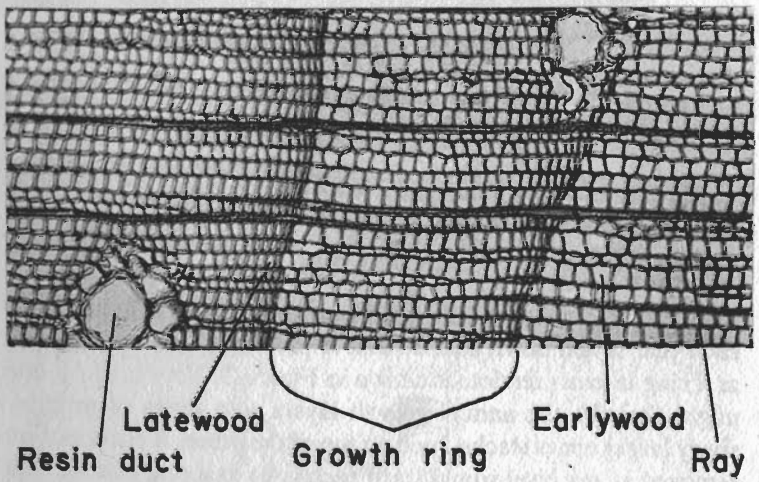
missing. The bark continually sloughs off so that only a few years of growth remain, and this remaining portion has no ring structure useful for dating.

After the primary tissue has been formed, the xylem growth each year is laid down outside that of previous years and appears as a ring in cross section as shown in Figure 3. Very crudely, one might describe the annual growth layers as a series of progressively larger cones stacked one on top of the other. A cross section removed at any level would show each cone as a ring and the pith as a disk at the center.

Annual Ring Structure

The xylem in conifers is composed mostly of tracheid cells. A tracheid cell is long and thin and might be compared to a soda straw with both ends slightly tapered and closed. The long axes of the cells run parallel to the long axis of the stem or branch. In the microscopic cross section in Figure 4, the view is down into the cells, and they appear as openings almost rectangular in shape.

The annual ring is divided into two parts, earlywood and latewood. As the names imply, earlywood tracheids are formed at the beginning of each growing season and during the period of rapid radial growth, whereas latewood trachieds are formed toward the end of the growing season when cambial activity slows down. In latewood, tracheid walls are thick and strong and appear dark in color, and their cavities become progressively smaller. It is the sharp contrast between the last-formed latewood cells of one growing season and the first-formed earlywood cells of the following season that delineates the boundary of an annual ring. Because of the sharp contrast between the two cell types, annual rings can be seen in most cross sections without magnification.



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The two large circular areas in Figure 4 are cross-sectional views of resin ducts. These ducts are found in resinous conifers, some species having only a few and others having many. Piñon pine (Fig. 4) has many resin ducts.

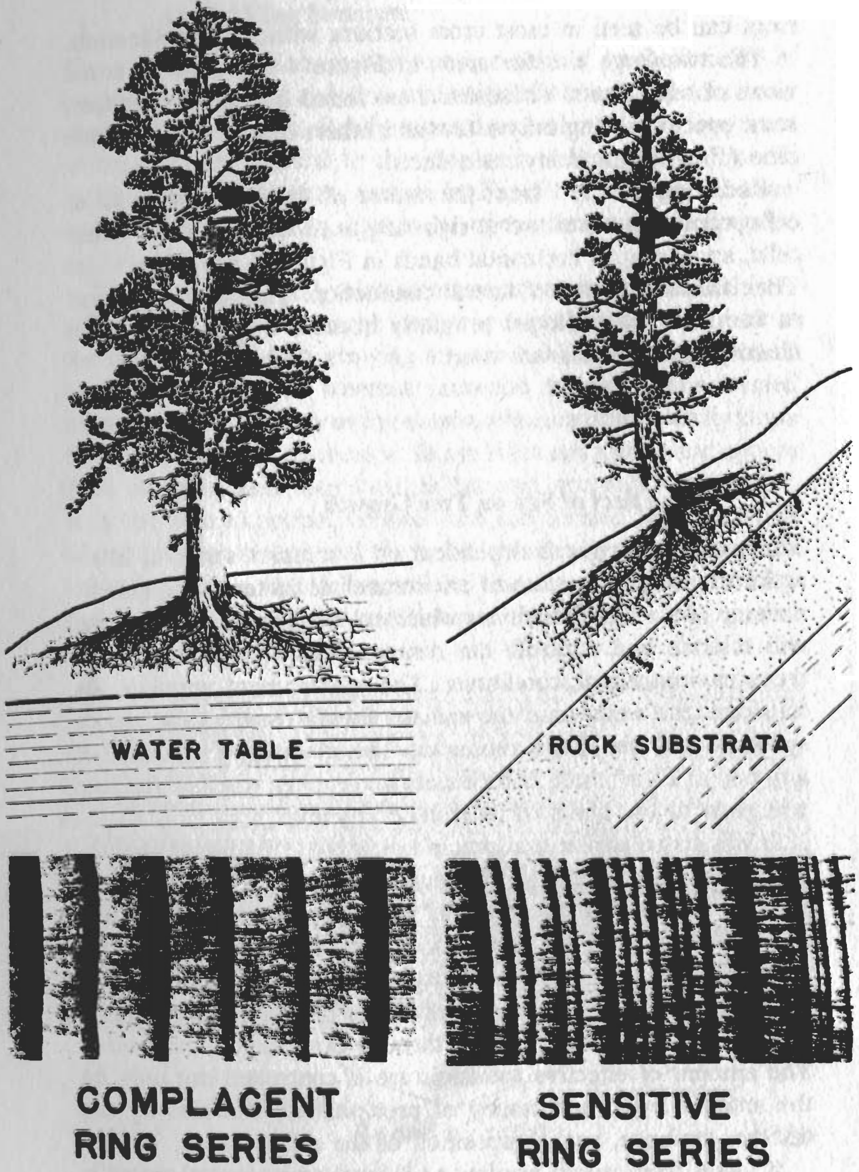
Radiating outward from the center of the stem are rows of cells whose long axes are at right angles to the tracheids. These cells, appearing as horizontal bands in Figure 4, are called rays. Their function is that of lateral conduction. They are of interest to the dendrochronologist primarily because they are an aid in identifying the species of wood.

The Effect of Site on Tree Growth

The growth of a tree is dependent on a complex series of interactions between genetic and environmental factors. The genetic makeup of the tree determines which environments the individual will tolerate and controls the response this tree will make to these environmental conditions. The environment supplies the nutrients, the water, and the radiant energy required for photosynthetic and metabolic processes. The abundance, or lack, of any one or all of these constituents determines whether the tree will grow to the limits of its genetic potential.

It was stated earlier that precipitation is the dominant growth-limiting climatic factor in the Southwest and that growth varies with the amount of precipitation. This is essentially true if the trees to be sampled are chosen with care. More accurately, this growth-limiting factor is the effective soil moisture content, which is defined as the amount of available subsurface water coming from all sources minus that lost through evaporation and runoff. The amount of effective soil moisture is controlled not only by the amount, type, and timing of precipitation, but also by the texture, drainage, and composition of the soil.

If losses from runoff are low or if local underground water is available to the trees, the effective soil moisture content will be



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sufficient in most years for a tree to produce optimum growth. When this occurs, the ring pattern is complacent—that is, there is insufficient variation in ring widths to produce any recognizable sequence. The sequence of rings may be uniformly wide or uniformly narrow. Figure 5 shows a typical complacent site and resultant ring series. Trees growing under these conditions may be excellent botanical specimens, but they are useless for dating purposes.

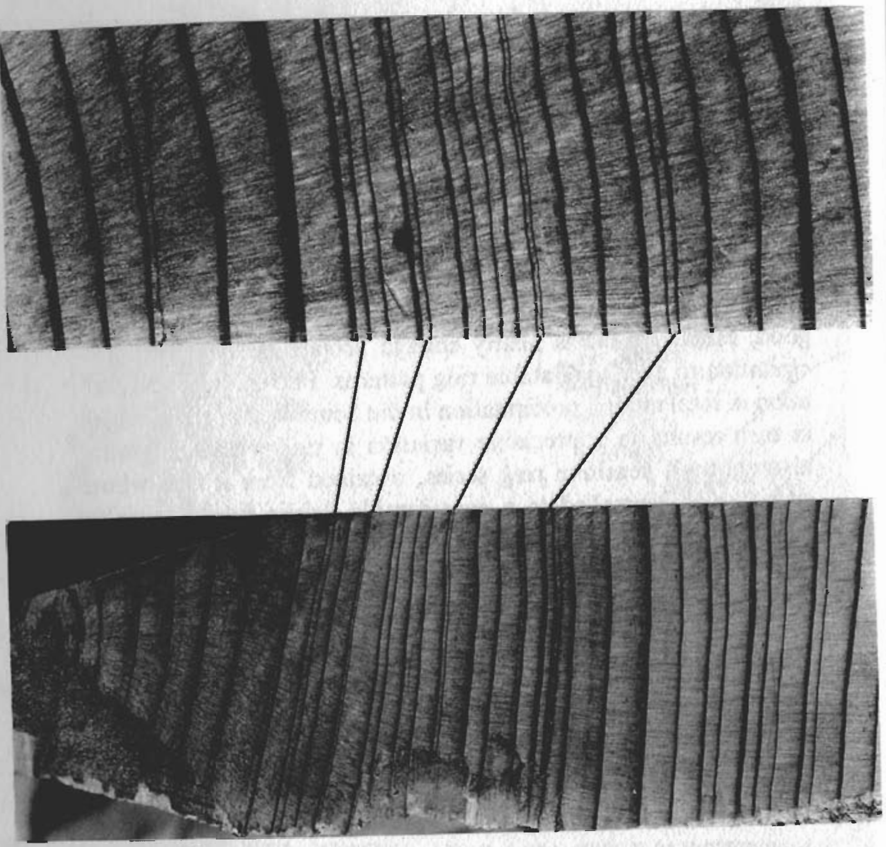
If sampling sites are selected so that no permanent underground water is available for growth and the soil drainage is good, radial growth is nearly enough proportional to total precipitation to produce datable ring patterns. Fortunately, the variation in total annual precipitation in the Southwest is great, which in turn results in appreciable variation in ring widths. Figure 5 also shows a sensitive ring series, obtained from a tree whose growth was controlled to a considerable degree by the variable condition of precipitation.

Through experience it has been found that generally lakeside, river valley, and roadside locations, as well as flat areas near slopes, produce trees with complacent rings. As a result, dendrochronologists are often found scurrying along rocky hillsides or clinging precariously to a tree with one hand to avoid falling down a steep slope, while removing a core sample.

Cross Dating

Atmospheric circulation, rainfall patterns, and mountain ranges divide the earth's surface into numerous "macroclimatic sites." Some areas, like the Sahara Desert in Africa, are large, and some, like the Olympic Peninsula rain forest in the northwestern United States, are small. In these climatic macrosites the annual meteorological conditions vary uniformly on a relative scale, and we consider each area to have, therefore, a homogeneous climate.

For example, in the Southwest a mountain may have a high annual precipitation on its crest and low annual precipitation at its



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base. During a wet year, however, the precipitation will generally increase in both locations. As an added example, the annual precipitation in Tucson, Arizona, is approximately ten inches, whereas in Flagstaff, Arizona, 250 miles to the north, the precipitation is about twenty-five inches. If a "dry" year occurs, precipitation may drop to four or five inches in Tucson and to a proportional amount in Flagstaff.

Since the precipitation drop is roughly proportional throughout the climatic area, the ring patterns throughout this area should be similar. This has been found generally to be true with the result that trees within this area can be cross dated—that is, their ring patterns can be matched. Certain local or "microclimatic" differences are reflected in individual ring patterns, but usually these can be reconciled by adjustments.

It is perhaps necessary to point out that while all datable trees growing on sensitive sites within the climatic area produce similar patterns, the total growth differs greatly. As stated before, total precipitation varies greatly within the area; but other non-variable environmental characteristics, such as soil, also influence the amount of growth. Frequently, trees of unequal average ring widths are compared. The process of cross dating these specimens can perhaps be explained by the following hypothetical example.

Place a rubber band along the specimen having the narrower rings and mark on this band the ring-width pattern of this specimen. Place this band along the "longer" or wider-ringed specimen and stretch it until the band and the specimen are the same length. If the time periods are the same, the ring patterns on the band and the wood specimen can be seen to be essentially the same. There may be places where the match is not perfect, but supplemental stretching and shrinking of the band over these sections will provide a satisfactory correspondence.

Figure 6 shows two specimens which have been correctly cross dated.

Locally Absent Rings

One complication which sometimes arises in the process of cross dating is the absence of an annual ring at the location in the tree where the sample was taken.

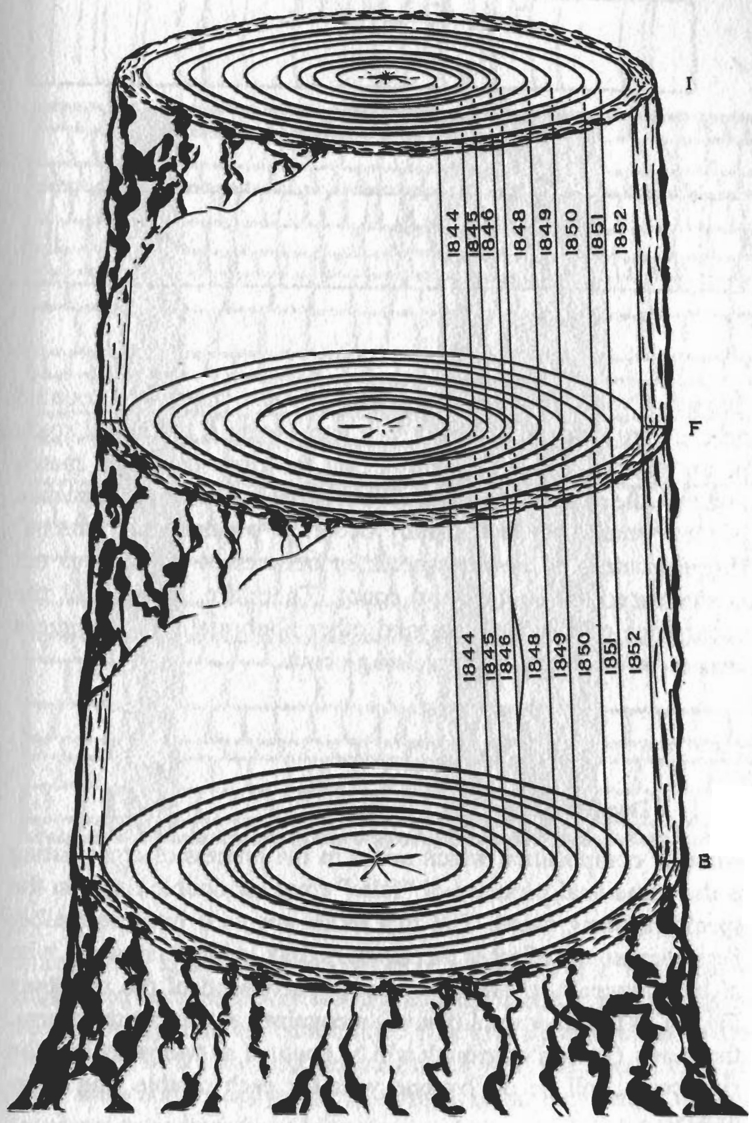
A ring has been compared to a long, thin cone. The thickness of this "cone" is uniform neither in circumference nor along any line drawn on the stem; and therefore, the relative widths of rings at any place of sampling will vary slightly. Generally, the annual growth appreciably exceeds these variations so that the over-all ring pattern is not sufficiently different from sample to sample to complicate cross dating. The amount of total annual precipitation varies from year to year, and the growth response to this variation usually exceeds the differences between samples removed from the same tree.

Problems do arise, however, when rings of very dry years are encountered. A ring is formed every growing season (year), but in years of extremely little growth this ring may not show at every point on the cone. During such years, growth in the tree is likely to occur only at points of stress, such as the downhill side of a trunk or at a point near and under branches. Since these are the areas normally avoided in sampling, it is possible to obtain a core or cross section where a ring cannot be seen.

These "missing" rings can most easily be detected during the process of cross dating several specimens. The ring patterns will match ring-for-ring up to the year where a ring is missing in one of the samples. The ring count will be one year off after this point, unless correction is made by inserting a "ring" at the proper place in the sequence. Since a ring is never missing over the entire surface of a stem or branch, the term "locally absent" is used to denote a ring missing at the point sampled. The missing ring on the sample is marked by pricking the rings immediately preceding and following it (See Fig. 8).

Figure 7 (after Glock) diagrammatically illustrates the base portion of a tree stem. It shows three levels of cross-sectional surface, and each corresponding ring is connected with a vertical line. The ring representing 1847 is missing on the lowest section, appears as a lens between *B* and *F* and shows as a smaller ring in sections *F* and *I*.

Figure 8 is a schematic drawing of two specimens, which have been cross dated. The latewood is represented by lines and the earlywood by the spaces between the lines. Up to point *A*, cross-dating was done correctly by actually dating each ring by pattern recognition. The absent ring before point *A*, indicated by a broken line, was recognized, and the rings were carefully matched with this in mind. The solid lines drawn between the two plots



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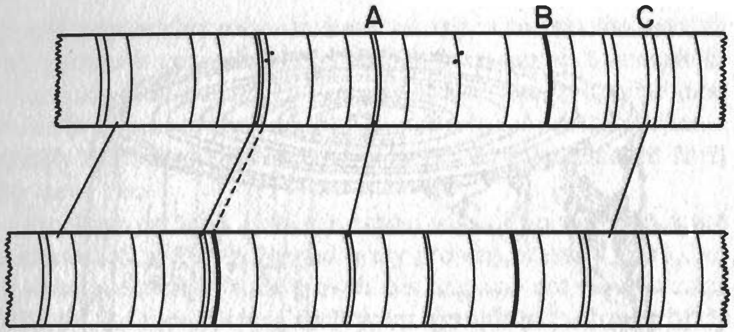

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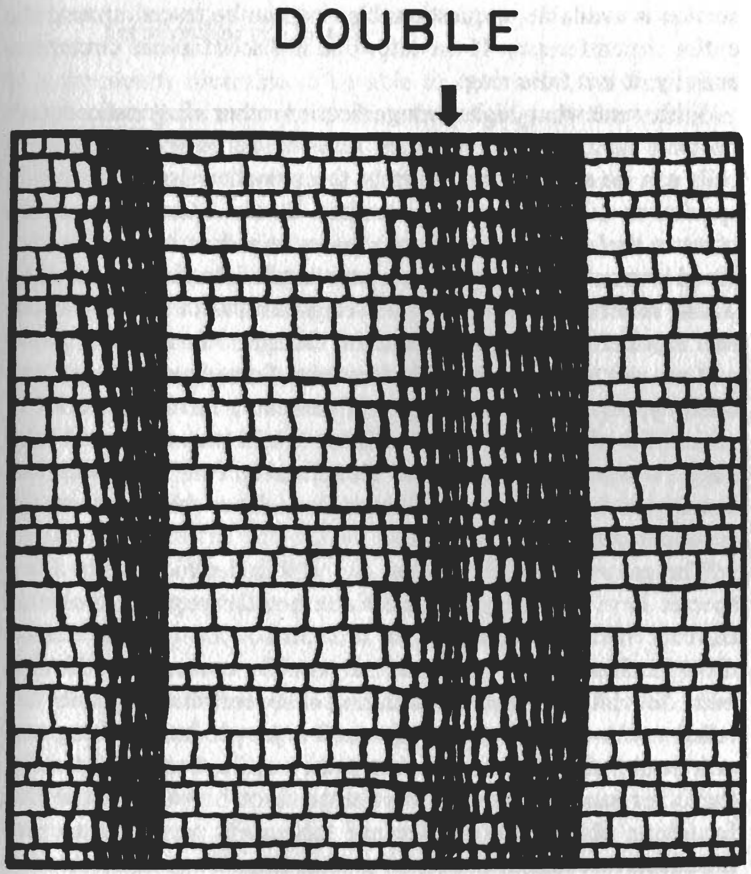
join rings with the same date. After point *A* rings were counted on each specimen and joined by a line (point *C*). Careful study of the pattern at point *C* shows that the rings no longer match and that the count is off (i.e., differs between the two specimens) by one year. This discrepancy occurred because the "absent" ring indicated on the first specimen between *A* and *B* was not compensated for in the ring count. Therefore, because of the occurrence of missing rings and other abnormalities, specimens cannot be dated by a simple ring count.

Double Rings

Another complication which arises in the process of cross dating is the occasional presence of "false" rings, or double rings, in the specimen being dated. The two terms are used interchangeably here because the effect is the same. A dark-colored latewood type of band appears in the light-colored earlywood of the ring (see Fig. 9). If this abnormality is not recognized in the dating process, the year's (season's) growth will be counted as two years and the ring count will be off by one year for each double ring overlooked.

There are several possible ways of detecting false rings. Frequently the last-formed latewood of a false ring is not clearly delineated because the latewood gradually blends in with the light-colored earlywood on either side. This gradual transition at the outer edge of a false ring, as contrasted with the abrupt change from latewood to earlywood in normal rings, is the most distinguishing characteristic of false rings and one which is fairly easily detected with a hand lens on a well prepared surface. If a cross



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section is available, a questionable ring can be traced around the entire circumference. If the latewood is discontinuous circumferentially, it is a false ring.

With somewhat higher magnification other diagnostic details become noticeable. Sometimes thin-walled earlywood type of cells can be seen to pass entirely through the false latewood. In specimens with resin ducts common in the latewood, one can observe that false latewood terminates at a duct while true latewood surrounds the duct incorporating it into the annual ring. These criteria for detecting false rings are useful for only a limited number of tree species, such as Douglas fir and a few pines, and are not always applicable for these. Some species (e.g., Arizona cypress and several types of junipers) have ring series in which it is often impossible to distinguish between true and false rings. When these methods of identification fail, false rings can sometimes be detected when specimens from the same site are cross dated ring-by-ring.

The causes of false rings are not well understood. Only a few species have been studied, and these not thoroughly. Abnormal climatic occurrences, such as a sudden, mid-growing season drought, have been suggested as possible causes; but this has been difficult to verify. Cross dating of several trees on a site has failed to show that double rings tend to be produced during certain years, as one would expect if the causes were climatic. On the other hand, climatic influences cannot be ruled out in the formation of false rings. Because false rings generally are not produced throughout the entire growth ring, it is possible to miss them in sampling either by core or cross section. This makes it difficult to correlate false ring production between trees and to correlate these rings with climatic variations. Currently, the role of auxin in production of false and true rings is being investigated. Some of the causes of false rings are apparently genetic because the tendency for production is more pronounced in some species than in others.

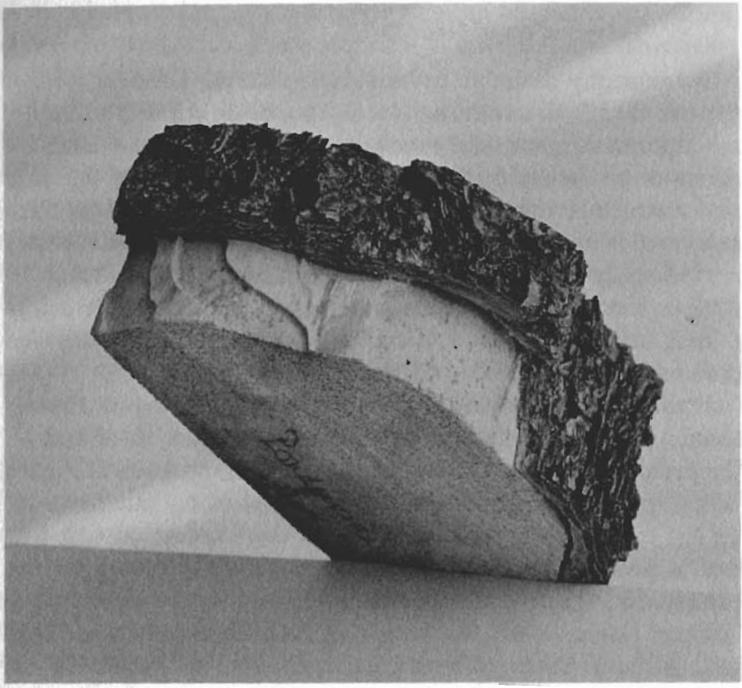
Termination of Growth

It is frequently desirable to be able to determine the date when the tree died from natural causes or from being cut. For example, this information is useful to an ecologist studying past environments or to an archaeologist attempting to determine the date that a structure was built. Unfortunately these cut or dead trees recovered in achaeological sites frequently have had their surfaces eroded so that an indeterminate amount of xylem is missing. In this situation the date of termination of growth cannot be determined, and all that can be said with certainty is that the tree died on or after the date of the outermost ring.

Sometimes there is evidence that the outermost ring on a specimen is the last one. The most conclusive evidence is, of course, the presence of bark. The outside date on the specimen in Figure 10 can positively be designated as the terminal or "cutting date" (if the tree was cut while alive and if the last-formed ring was not "absent"). To indicate this fact, a "B" is placed after the outside date on specimens retaining bark.

Good evidence that the outer ring is the terminal one or near to it is the presence of bark-beetle galleries, the "channels" in the specimen in Figure 10. These channels are made when beetles burrow into and through the soft, newly formed cells of the xylem and phloem. These insects attack recently killed trees that still have the bark or living trees that are weakened or dying from some cause. Since no healed galleries, which would be indicated by rings formed outside these galleries, have been found among the many thousands of trees studied in the Laboratory of Tree-Ring Research, we conclude that trees die soon after invasion by bark beetles. These galleries are usually only a few rings deep. Their presence indicates the outermost ring is very close to a true terminal date. When galleries are observed on a barkless specimen, this fact is noted with a "G" after the outside date.

The other two pieces of evidence for terminal growth are based on probability. If the outside ring extends around the entire circumference of a specimen, the probability is low that exactly the same number of rings eroded away around the entire specimen.



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This evidence for terminal growth is noted with a "C" placed after the outside date.

Even in the absence of bark-beetle galleries, or of a continuous outer ring, it is sometimes possible to estimate terminal dates by comparing the outside dates of all of the wood samples from a single structure. Thus, if there are ten specimens from a single structure, all from different trees and all having nearly the same outside date, the probability is high that these dates are close to the terminal or cutting dates for these specimens. It is unlikely that all ten would erode or fracture so uniformly that exactly the same number of rings would be removed from each specimen.