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TREE-RING DATING

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Dating the recent past has aroused increasing amounts of interest as known methods have become more accurate and as new methods have been developed. In addition to similarity of objective, the methods of dating described in the present symposium have this essentially in common: they depend upon the fluctuation of one or more environmental factors. The periodicity in the time scale of the fluctuations determines the accuracy of the chronology.

In order to facilitate an explanation of certain factors in tree-ring dating, the subject will be discussed briefly under three headings: the basis of dating, the technique of dating, and relationships to tree growth in general.

The Basis of Dating

The formation of tree rings, along with glacial varves and layers of anhydrite, depends upon fluctuations in depositional conditions. If those fluctuations are annual, dating may be done with confidence; if they are not annual, being either a fraction or a multiple of a year, a precise chronology may be established only with great difficulty, if at all. Therefore, dating attains exactness only where the annual period, or the period whatever its length, leaves an increment which can be positively identified in relation to its true time span.

Such increments in trees are commonly called "tree rings" or "annual rings" because of their concentric appearance on a two-dimensional surface such as on the end of a log. Actually tree rings are layers of wood partially or completely covering trunk, branches, and roots; they are "growth layers" in the proper three-dimensional[1] sense of the term, a term and concept that lend clarity and precision to a proper consideration of tree growth against its physiological background.

To call a growth layer an "annual" ring is of course an assumption unless or until it has been proved to be so beyond reasonable doubt. This brings up two matters which are fundamental: the recognition of the time unit in tree growth and an understanding of the factors which control that growth.

Without observational or experimental proof the dating of growth layers in their proper time units depends upon one or the other of two assumptions: first, that a tree lays down one and only one sharply bordered growth layer per year; or second, that the annual increment, no matter how multiple or partial in areal extent it may be, can be identified positively. This statement may be too rigorous but it clears the air as to

[1] Hence, the terms thick and thin emphasize the three-dimensional aspect of growth layers in contrast with the terms wide and narrow which emphasize the two-dimensional aspect of tree rings.

what we are doing when we devote our major attention to problems of chronology rather than to problems of plant physiology and ecology.

Factors which influence growth in trees may be classified roughly as genetic, physiologic, reproductive, pathologic, and ecologic, with the added effect of hormones, electrical potential, and polarity. It is known that these factors fluctuate in degree and in time. Certain of them, such as soil moisture and temperature, fluctuate over an interval of a year or less and are held to have a decisive recognizable effect on growth. Because the combined effect of temperature and rainfall is assumed to operate on an annual basis in so far as recognizable growth increments are concerned, dating has been carried on and chronologies have been constructed.

That there are ecologic situations where accurate dating can be done seems beyond question; that there are other ecologic situations where accurate dating cannot be done seems equally beyond question. The area of transition between the two extremes brings forward all the problems having to do with the identification and evaluation of partial and intra-annual growth layers. At what point between the two extremes do errors appear? To what extent has there been the possibility of error in dates already determined, dates from the wood of trees whose course of growth has not been determined by rigorous methods? These two questions should be answered before all dates can be accepted without reasonable doubt.

The basis of dating, therefore, depends upon a major annual periodicity in the factors which control growth and a completely recognizable response in the xylem of the trees to conform to that periodicity.

The Technique of Dating

The explanation of method which follows in this section presumes the positive identification of the annual increment.

In living trees the date of any particular growth layer is obtained simply by counting inward from the current, or outer, growth layer. In historic trees the dates of whose outer growth layers are unknown, recourse must be had to tree-ring analysis, a name applied formally[2] by the writer in 1933 to the system of dating devised by A. E. Douglass. Mechanical details of the system have been elaborated elsewhere[3] and need not be repeated.

To be usable under the Douglass system, growth-layer sequences must be variable; that is, a sequence must contain a mixture of thin and thick growth layers. It is necessary to use wood materials which grew under the influence of those environmental factors whose variations affected the amount of xylem formed.

Tree-ring analysis involves three steps preliminary to the dating of

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[2] At the Las Cruces, New Mexico, meeting of the Southwestern Division, Amer. Assoc. for Advance. of Sci., May 1, 1933. Published as "Tree-Ring Analysis on Douglass System," Pan-Amer. Geol. LX:1-14, 1933.

[3] Principles and methods of tree-ring analysis. Carnegie Inst. Wash. Publ. No. 486:1-30, 1937.

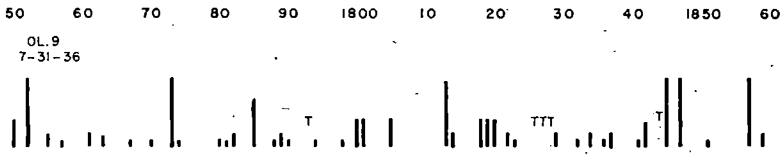

FIG. 1

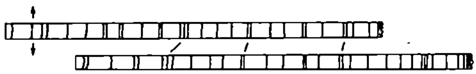

FIG. 2

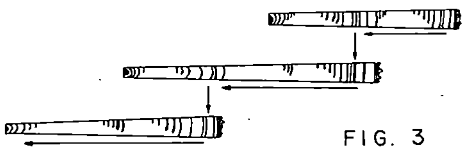

FIG. 3

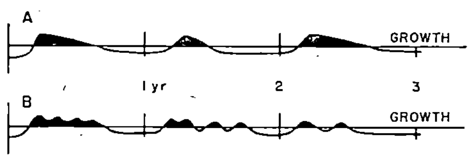

FIG. 4

Fig. 1. Skeleton plot made by judging visually the relative thicknesses of the growth layers—the longer the line the thinner the growth layer. Uncommonly thick growth layers are marked by a letter "T".

Fig. 2. Crossdating on the wood depends primarily upon thin growth layers and the intervals between them. Many specimens are more easily crossdated if each is first turned into a skeleton plot.

Fig. 3. Diagrammatic illustration of chronology building into the past by means of extension from one sequence to another.

Fig. 4. A. Fluctuations of growth factors in degree and resultant growth, giving thick and thin growth layers. B. Fluctuations of growth factors in time, giving multiple growth layers. Diagrammatic.

an unknown. They are plotting, crossdating, and chronology building or the construction of a tree-ring calender.

Plotting.—Growth layers, which are conspicuously thin in relation to the immediately preceding and succeeding layers, and their locations in the sequence serve as diagnostic criteria for the construction of skeleton plots. The plotting is done on suitable coordinate paper (tenths of an inch, or two-mm. units) where the horizontal axis is time in years and the vertical axis is relative thinness of the growth layers on arbitrary scale. Figure 1 shows a skeleton plot derived from a wood specimen. Note should be made of the fact that the height of the lines on the plot varies inversely with the thicknesses of the growth layers. Note should also be made that the majority of the growth layers do not receive a line. In fact, out of 110 growth layers on the plot about one in ten has actual diagnostic value because of consistent and striking thinness.

This brings up the oft discussed topic of "reading" tree rings preliminary to the construction of skeleton plots, by the method devised by Douglass and so ably applied by him to the dating of certain Indian Pueblos. His method entails visual judgment aided by a 10x or 15x hand lens and is essentially qualitative in the sense that no actual measurements enter into the opinion of diagnostic thinness of a growth layer in relation to its immediate neighbors. Douglass has taught some of us to turn visual judgment into visual memory so that judgment gives the skeleton plot, and memory of thin rings and of their spatial incidence permits rapid dating of an unknown sequence in terms of a regional master sequence. Certain thin rings and the patterns of spacing they create stand out prominently and are easily recognized among many trees. Apparently, ecologic similarities produce effects in tree growth sufficiently uniform among a portion of the trees of an area to be recognized by the student of that area.

Serious criticism of the methods of Douglass has been made by a few workers because of his ability to "read" rings, an ability they feared others perhaps might not possess. It seems that there are some who cannot use, and who distrust, the method. In fact, one of the writer's students threw down a specimen in utter futility either because he had difficulty in determining diagnostic thinness or because he lacked the patience necessary to familiarize himself with the sequence. Many students, in contrast, pick up the method with great rapidity and apply it with ease and effectiveness. Other methods have been suggested to place the judgment of thinness on a quantitative basis and to eliminate what has been called the strongly personal factor in the Douglass method.

Thus two rather severe criticisms have cropped up concerning Douglass and his methods: the one decries the qualitative tendencies of the methods whereas the other alleges that his ability to "read" rings is so strongly personal that many others would have great difficulty in imitating or repeating his work. The writer can not agree to the validity of these criticisms. Visual judgment concerning relative thicknesses of adjacent rings can be highly quantitative. And as regards the personal equation, it should be stated that several of us have "read" and dated the same specimens independently. We came to the same conclusions and our derived skeleton plots were almost identical. If there is any weakness in Douglass's method of reading and dating it most assuredly does not lie in any personal factor. The writer has used the Douglass method for many years and to his knowledge no other method approaches that of Douglass in facility, effectiveness, and pleasure of application.

Crossdating.—This process, the matching or correlation of different sequences, depends primarily upon the incidence of thin growth layers and the intervals between them (Fig. 2). By far the simplest and most rapid crossdating is done directly on the wood by visual judgment and memory. When large numbers of specimens are involved it is easier to "read" the single specimen, construct a skeleton plot therefrom, and match it to the others as they are made.

Two points merit attention. First, not all people are equally successful in changing ring sequences into skeleton plots and in crossdating them. This in no wise should deter those who can do so. Second, it should be understood that all trees of an area or all specimens of a collection do not necessarily crossdate with each other—ecologic factors may vary in short distances and by sufficient amounts to vitiate crossdating or to prevent it completely.

Chronology building.—The construction of a so-called tree-ring calendar or standard plot is begun by merging the records of many living trees of an area; the chronology is continued by extension of the merged record backward in time by crossdating successively older sequences onto the known dated materials. Figure 3 gives a purely diagrammatic example of chronology building by extension. By means of repeated extension backward in time and by means of bridging between a relatively dated standard and the early end of the dated standard, the calendar in our Southwest has been carried back nearly to the beginning of the Christian Era.

The existence of the standard or master plot makes it possible to date an unknown specimen if it came from the ecologic area represented by the master and if its sequence resembles those which were merged originally into the master plot. Several questions come to mind. How long should the overlap be to give authentic extension? How long should the unknown sequence be to date it securely by means of the master? Whether 50, 100, or more years are sufficient depends primarily upon the number of diagnostic growth layers. If they are few, then a long sequence is necessary for safe correlation. In a calendar over 1500 years long what are the chances that patterns may be duplicated within the range of variation existing among trees? This thought has been so disturbing to some interested in archeology that stratigraphic dating is given first place and tree-ring dating within stratigraphic limits second.

The accuracy with which an unknown is dated depends upon the character of the master. This master should not be based on so few specimens that it gives a purely local phase of the areal sequence, or on so many specimens that the individual variations among the trees dilute the value of diagnostic growth layers and complicate the patterns beyond recognition.

It should be realized (1) that individual trees vary among themselves in the same locality not only because ecologic factors vary from place to place but also because the impact of those factors and the physiological reactions vary from tree to tree; (2) that many trees of a locality and many prehistoric specimens in a collection do not crossdate with the rest of the trees or specimens upon which the standard has been based; (3) that the reliability of a tree-ring calendar depends upon the length of overlap of an unknown on the known and the number of specimens participating in that overlap; and (4) that the physiological activities of trees which produce wood may vary not only in space but also in time.

The writer, in summary, does not agree with the adverse criticism directed at the Douglass system of "reading" rings, of plotting them, and of simple crossdating. If further study of the matter is justified it would seem to be rather along one of the four points mentioned in the paragraph above.

Relationships to Tree Growth

Crossdating, it will have been seen, depends upon variations in growth-layer thicknesses—the striking variations of highly variable sequences. But not all sequences possess variability; some are made up of growth layers whose thicknesses have a high degree of uniformity whereas others spread over a wide range intermediate between uniformity and excessive variability. The upper part of the Ponderosa Pine Zone, the Canadian Zone, and higher elevations in the Southwest, have uniform sequences in general. Variability increases progressively downward toward the lower forest border and becomes excessive at the desert's edge.

The lower forest border, however, is not characterized solely by variability. In that zone and beyond, in the extreme lower forest border, multiplicity of growth layers in the annual increment has been proved to be characteristic. Reference is here made not to growth layers with diffuse margins and hence easily distinguishable as false but to growth layers with sharp margins and in no way distinguishable from true annuals. As a matter of fact, field work has revealed the presence of such multiplicity and it has been continuously checked by four methods of absolute dating: by natural frost injuries, by artificial frost injuries, by the relation between diameter flushes and tip flushes, and by periodic tip-growth measurements over the years.

In much the same fashion as growth layer thicknesses increase in fluctuation, growth factors, especially soil moisture in all its relationships, fluctuate increasingly with approach to the lower forest edge. The more violent the fluctuations are—that is, the greater the amplitude and the more variable the wavelength—the greater the contrast between thick and thin growth layers and the greater the opportunity for multiple layers in an annual increment. A study of the growth habits of trees at the extreme lower forest border has well shown the effects of variable growth factors.

Near or in the lower forest border, growth factors may be said to fluctuate in degree and in time. Figure 4 is an attempt to show this graphically. Fluctuations in degree would give thick and thin growth layers whereas fluctuations in time would yield multiple growth layers during a year. If this is essentially true, how can a thin growth layer due to variation in degree (annual) be distinguished from one due to variation in time (intra-annual)? Such distinction would appear to be impossible if the intensity of the growth rhythm sharply delimits the individual growth layers.

It happens that crossdating is at its best near and at the lower forest border in the Southwest; it is at its best well within the zone of probable multiplicity, multiplicity impossible to detect by sight alone. An estimate, therefore, of the amount of multiplicity present in the region where much dating has been done may be ventured at this time. This comes out to be a maximum of 15 and an average of about 5 per cent. This takes into account not only the work done in the extreme lower forest border but also allows for genetic differences.

Tree-ring dating, whether or not it is entirely accurate, has given a great impetus to the study of tree growth under different habitat conditions. We are learning something about how and when a tree grows.

POLLEN EVIDENCE

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Anyone who suffers from hay fever or pollen allergy will appreciate that there are a number of plants that release, annually, large quantities of buoyant pollen into the atmosphere. While it may not be immediately obvious, the existence of wind-pollinated plants is very much at the basis of researches on pollen concerned with the history and prehistory of vegetation and with relative dating. As a matter of fact, conspicuous elements in North temperate vegetation (e.g. many kinds of trees) are wind-pollinated and have in various ways been related to prevailing types of climate and soil. In a broad sense, some of these elements have been considered to be indicators of successional phenomena relative to generalized types of climate and soil. Such plants contribute to a seasonal precipitation or rain of pollen over the years. If some receptive reservoir could receive, preserve and retain this vegetable evidence, we would have recorded the history of the prominent characteristics of the vegetation of the region. As has been already suggested by Dr. Wright, such documentation of past to present-day vegetation actually does take place. Airborne pollen eventually descends to earth in greatest quantity close to its source—the pollen-producing plants. The most desirably-receptive surfaces are lakes and wet bogs. Here the pollen grains are retained over the years and often to a remarkable degree preserved in stratified sediments, particularly if anaerobic or poorly oxygenated and acidic conditions prevail. In the case of lakes, the rain of pollen eventually de-