SOME ASPECTS OF THE USE OF THE ANNUAL RINGS OF TREES IN CLIMATIC STUDY

BY

PROF. A. E. DOUGLASS
University of Arizona

FROM THE SMITHSONIAN REPORT FOR 1922, PAGES 223–239

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I. AFFILIATIONS.

Nature is a book of many pages and each page tells a fascinating story to him who learns her language. Our fertile valleys and craggy mountains recite an epic poem of geologic conflicts. The starry sky reveals gigantic suns and space and time without end. The human body tells a story of evolution, of competition and survival. The human soul by its scars tells of man's social struggle.

The forest is one of the smaller pages in nature's book, and to him who reads, it too tells a long and vivid story. It may talk industrially in terms of lumber and firewood. It may demand preservation physiographically as a region conserving water supply. It may disclose great human interests ecologically as a phase of plant succession. It may protest loudly against its fauna and parasites. It has handed down judicial decisions in disputed matters of human ownership. It speaks everywhere a botanical language, for in the trees we have some of the most wonderful and complex products of the vegetable kingdom.

The trees composing the forest rejoice and lament with its successes and failures and carry year by year something of its story in their annual rings. The study of their manner of telling the story takes us deeply into questions of the species and the individual, to the study of pests, to the effects of all kinds of injury, especially of fire so often started by lightning, to the closeness of grouping of the trees, and to the nearness and density of competing vegetation. The particular form of environment which interests us here, however, is climate with all its general and special weather conditions. Climate is a part of meteorology, and the data which we use are obtained largely from the Weather Bureau. Much

[1] Address of the president of the southwestern division of the American Association for the Advancement of Science, Tucson, Ariz., Jan. 26, 1922. Reprinted by permission from the Scientific Monthly, Vol. XV, No. 1, July, 1922.

helping knowledge needed from meteorology has not yet been garnered by that science. For example, the conditions for tree growth are markedly different on the east and west sides of a mountain or on the north and south slopes. The first involves difference of exposure to rain-bearing winds, and the second means entirely different exposure to sun and shade. The latter contrast has been studied on the Catalina Mountains by Forrest Shreve. Again, the Weather Bureau stations are largely located in cities and, therefore, we can not get data from proper places in the Sierra Nevada Mountains of California, where the Giant Sequoia lives. Considering that this Big Tree gives us the longest uninterrupted series of annual climatic effects of known date, which we have so far obtained from any source, it must be greatly regretted that we have no good modern records by which to interpret the writing in these wonderful trees, and, so far as I am aware, no attempt is yet being made to get complete records for the future.

In reviewing the environment, one must go another step. One of the early results of this study was the fact that in many different wet climates the growth of trees follows closely and sometimes fundamentally certain solar variations. That means astronomical relationship. It becomes then an interesting fact that the first two serious attempts to trace climatic effects in trees were made by astronomers. I do not know exactly what inspired Professor Kapteyn, the noted astronomer of Groningen, Holland, to study the relation of oak rings to rainfall in the Rhineland, which he did in 1880 and 1881 (without publishing), but for my own case I can be more explicit. It was a thought of the possibility of determining variations in solar activity by the effect of terrestrial weather on tree growth. This, one notes, assumed an effect of the sun on our weather and recognized trees as one of nature's great recording mechanisms.

But the possible relationship of solar activity to weather is a part of a rather specialized department of astronomical science, called astrophysics. And there is a great deal of help which one wants from that science, but which one can not yet obtain; for example, the hourly variations in the solar constant. I would like to know whether the relative rate of rotation and the relative temperatures of different solar latitudes vary in terms of the 11-year sun-spot period. These questions have to do with some of the theories proposed in attempting to explain the sun-spot periodicity. We do not know the cause of the 11-year sun-spot period. Here then is work for the astronomers.

Yet another important contact has this study developed. The rings in the beams of ancient ruins tell a story of the time of building, both as to its climate and the number of years involved and the order of building. This is anthropology. It will be mentioned on a later page.

Viewed through the present perspective, there is one way of expressing the entire work which shows more clearly its human end, a contact always worth emphasizing. If the study works out as it promises, it will give a basis of long-range weather forecasting of immense practical value for the future and of large scientific value in interpreting the climate of the past. This statement of it carries to all a real idea of the central problem.

II. YEARLY IDENTITY OF RINGS.

The one fundamental quality which makes tree rings of value in the study of climate is their yearly identity. In other words, the ring series reaches its real value when the date of every ring can be determined with certainty. This is the quality which is often taken for granted without thought and often challenged without real reason. The climatic nature of a ring is its most obvious feature. There is a gradual cessation of the activity of the tree owing to lowered temperature or diminished water supply. This causes the deposition of harder material in the cell walls, producing in the pine the dark hard autumn part of the ring. The growth practically stops altogether in winter and then starts off in the spring at a very rapid rate with soft white cells. The usual time of beginning growth in the spring at Flagstaff, Ariz. (elevation 7,000 feet), is in late May or June and is best observed by Dr. D. T. MacDougal's "Dendrograph," which magnifies the diameter of the tree trunk and shows its daily variations. This spring growth depends upon the precipitation of the preceding winter and the way it comes to the tree. Heavy rains have a large run-off and are less beneficial than snow. The snow melts in the spring and supplies its moisture gradually to the roots as it soaks into or moves through the ground. There is evidence that if the soil is porous and resting on well cracked limestone strata, the moisture passes quickly and the effect is transitory, lasting in close proportion to the amount of rain. Trees so placed are "sensitive" and give an excellent report of the amount of precipitation. Such condition is commonly found in northern Arizona over a limestone bed rock. If the bed rock is basalt or other igneous material the soil over it is apt to be clay. The rock and the clay sometimes hold water until the favorable season is past and the tree growth depends in a larger measure on other factors than the precipitation. For example, the yellow pines growing in the very dry lava beds at Flagstaff show nearly the same growth year after year. It is sometimes large, but it has little variation. Such growth is "complacent."

Yearly identity is disturbed by the presence of too many or too few rings. Surplus rings are caused by too great contrast in the seasons. The year in Arizona is divided into four seasons, two rainy and two dry. The cold rainy or snowy season is from December to March, and the warm tropical summer, with heavy local rainfall, occurs in July and August. Spring and autumn are dry, the spring being more so than the autumn. If the snowfall of winter has not been enough to carry the trees through a long dry spring, the cell walls in June become harder and the growing ring turns dark in color as in autumn. Some trees are so strongly affected that they stop growing entirely until the following spring. A ring so produced is exceptionally small. But others near by may react to the summer rains and again produce white tissue before the red autumn growth comes on. This second white-cell structure is very rarely as white as the first spring growth and is only mistaken for it in trees growing under extreme conditions, such as at the lowest and driest levels which the yellow pines are able to endure. Such is the condition at Prescott or at the 6,000–7,000-foot levels on the mountains about Tucson. A broken and scattered rainy season may give as many as three preliminary red rings before the final one of autumn. In a few rare trees growing in such extreme conditions, it becomes very difficult to tell whether a ring is formed in summer or winter (that is, in late spring or late autumn). Doubling has become a habit with that particular tree—a bad habit—and the tree or large parts of it can not be used for the study of climate.

But let us keep this clearly in mind: This superfluous ring formation is the exception. Out of 67 trees collected near Prescott, only 4 or 5 were discarded for this reason. Out of perhaps 200 near Flagstaff, none has been discarded for this reason. Nearly 100 yellow pines and spruces from northwestern New Mexico have produced no single case of this difficulty. The sequoias from California, the Douglas firs from Oregon, the hemlocks from Vermont, and the Scotch pines from north Europe give no sign of it. On the other hand, 10 out of 16 yellow pines from the Santa Rita Mountains south of Tucson have had to be discarded and the junipers of northern Arizona have so many suspicious rings that it is almost impossible to work with them at all. Fossil cypresses also give much trouble.

The other difficulty connected with yearly identity is the omission of rings. Missing rings occur in many trees without lessening the value of the tree unless there are extensive intervals over which the absence produces uncertainty. A missing ring here and there can be located with perfect exactness and causes no uncertainty of dating. In fact, so many missing rings have been found after carematch, there are correspondences in climatic cycles to which attention will be called later.

Cross-identification is practically perfect amongst the sequoias stretching across 15 miles of country near General Grant National Park. Trees obtained near Springville, some 50 miles south, show 50 to 75 per cent resemblance in details to the northern group. This was far more than enough to carry exact dating between these two localities. Cross-identification in some wet climate groups was extremely accurate. A group of 12 logs floating in the river mouth at Geffle, Sweden, showed 90 to 95 per cent resemblance to each other. The range was 100 to 200 years and there were no uncertain years at all. The same was true of some 10 tree sections on the Norwegian coast and of 13 sections cut in Eberswalde in Germany. A half dozen sections cut in a lumber yard in Munich did not cross-identify with each other. A group of 5 from a lumber yard in Christiania was not very satisfactory. A very recent group of coast redwoods from Santa Cruz, Calif., proved very unsatisfactory. The vast majority, however, have been absolutely satisfactory in the matter of cross-identification. Nothing more is needed to make the one ring a year ideal perfectly sure in the work here described, but if there were it would come in such tests as frequently occur in checking the known date of cutting or boring, with a set of rings previously dated. That has been done on many occasions in Arizona and California. To give final assurance, the record in the yellow pine was compared with statements of good and bad years, and years of famine, flood, and cold, reported in Bancroft's "History of Arizona and New Mexico," and it was found that his report identified with the character of the growth in the corresponding years of the trees.

Three results may be noted before leaving this important subject. Deficient years extend their character across country with more certainty than favorable years. A deficient year makes an individual ring small compared to those beside it. Large rings, on the other hand, are more apt to come in groups and so do not have quite the same individuality. Nor are they as universal in a forest. If they occur at a certain period in one tree, the chances are about 50 per cent that the corresponding years in the neighboring trees will be similarly enlarged. If, however, a very small ring occurs in a tree, the chances are over 90 per cent that the neighboring trees will show the same year small.

Second, with many groups of trees where the resemblance between their rings is strikingly exact, a small number of individuals such as 5 will answer extremely well for a record, and even fewer will give valuable and reliable results. But the central part of a tree has larger growth and is less sensitive than the outer part. Its character is somewhat different. To get a satisfactory representation through several centuries, therefore, it is better to combine younger trees with older ones to get a more even and constant record of climatic conditions.

The third thought is this. The spreading of a certain character over many miles of country stamps it in almost every case as climatic in origin, because climate is the common environment over large areas.

III. NUMBER AND LOCATION OF TREES.

The whole number of trees used is nearly 450 and includes cone-bearing trees from Oregon, California, Arizona, New Mexico, Colorado, Vermont, England, Norway, Sweden, Germany, and Bohemia. The total number of rings dated and measured is well over 100,000. The average ages found in these various trees are very interesting. The European groups reach for the most part about 90 years, although one tree in Norway showed 400 years of age, and 15 were found beginning as early as 1740. The Oregon group of Douglas firs goes back to about 1710, the Vermont hemlocks reach 1654, the Flagstaff yellow pines give a number of admirable records from about 1400.

The oldest trees, of course, were the great sequoias from the Sierra Nevada Mountains in California. They were found to have ages that formed natural groups, showing probably a climatic effect. There are very few under 700 years old (except the young ones which have started since the cutting of the Big Trees). A number had about that age. The majority of the trees scatter along in age from 1,200 up to about 2,200 years, at which age a large number were found. One or two were found of 2,500 years, one of 2,800, one of 3,000, one at just under 3,100, and the oldest of all just over 3,200. The determination of this age of the older sequoias in the present instance is not merely a matter of ring counting, but depends upon the intercomparison of some 55,000 rings in 35 trees. In 1919 a special trip was made to the Big Trees and samples from a dozen extra trees obtained in order to decide the case of a single ring, 1580 A. D., about which there was some doubt, and it was apparent that the ring in question stood for an extra year. This was corrected and it now seems likely that there is no mistake in dating through the entire sequence of years, but if not correct the error is certainly very small.

IV. TOPOGRAPHY.

The late Prof. W. R. Dudley, of Stanford University, in his charming essay on the "Vitality of the Sequoia" refers to the fact that the growth of the Big Trees depends in a measure on the presence of a brook near by. This agrees with my own observations. Size is far from a final indication of age. The General Grant tree, which has no running water near it and is the largest in the park of that name, has a burnt area on one side in which the outer rings are exposed, allowing an estimate of its average rate of recent growth. From much experience with the way the sequoia growth is influenced by age, it was possible to assign 2,500 years as the approximate time it took this giant to reach its present immense diameter of close to 30 feet. But about 3 miles west near a running brook is a stump which is over 25 feet in diameter, but is only about 1,500 years old. That is the effect of contact with an unfailing source of water.

Perhaps the most general characteristic which stands out in the different groups of dry-climate trees is a close relationship of this kind between the topography and the growth produced. For that reason, I have visited the site of every dry-climate group and indeed have examined the stumps of almost every tree in my collection.

It was found that dry-climate trees which grew in basins with a large and constant water supply, and this refers especially to the sequoias, usually produced rings without much change in size from year to year. This character of ring is called "complacent." The opposite character is the " sensitive " ring where a decided variation is shown from year to year. Sensitive trees grow on the higher elevations where the water supply is not reliable and the tree must depend almost entirely on the precipitation during each year. Such trees grow near the tops of ridges or are otherwise separated from any collection of water in the ground. In case of the basin trees, one could be sure that a ring was produced every year, but owing to the lack of individuality in the rings for certain years, it was difficult to compare trees together and produce reliable data. In case of the sensitive tree growing in the uplands there was so much individuality in the rings that nearly all of the trees could be dated with perfect reliability, but in extreme cases the omission of rings in a number of trees required special study. Of course, these cases were easily settled by comparison with other trees growing in intermediate localities.

Trees growing in the dry climate of Arizona at an altitude where they have the utmost difficulty in getting water to prolong life become extraordinarily sensitive. In the same tree one finds some rings several millimeters across and others microscopic in size or even absent.

In order to express this different quality in the trees a criterion called mean sensitivity is now under investigation. It may be defined as the difference between two successive rings divided by their mean. Such quotients are averaged over each decade or other period desired and are believed to depend in part on the relative response of the trees to climatic influences. The great sensitiveness of the yellow pines as compared with the best sequoias is evident in any brief comparison of dated specimens.

V. INSTRUMENTS.

In the course of this long attention to the rings of trees and in studying such a vast number of them, special tools to secure material and to improve and hasten the results have very naturally been adopted or developed. One goes into the field well-armed, carrying a flooring saw with its curved edge for sawing half across the tops of stumps, a chisel for making numbers, numerous paper bags for holding fragments cut from individual trees, a recording notebook, crayon, a shoulder bag, camera, and especially a kindly, strong-armed friend to help in the sawing. In the last 18 months the Swedish increment borer has been used extensively to get records from living pine trees. Hardwoods and juniper are too tough. It has previously been considered that the little slender cores, smaller than a pencil, so obtained, would hardly be worth working on. But the method of mounting them has been raised to such a degree of efficiency, and the collection of material becomes so rapid that the deficient length and the occasional worthless specimen are counterbalanced. Besides, it is often easy to supplement a group of increment cores by some other form of specimen extending back to greater age. The Mount Lemmon group, near Tucson, has eight cores giving a good record from about 1725 to the present time; a saw-cutting from a large stump in Summerhaven carries the record back 150 years earlier. It should, however, be supported by at least one more long record and this can be done by the tubular borer described next.

The tubular borer was designed especially for the dried and sometimes very hard logs in the prehistoric ruins. It works well on pine trees and junipers. It gives a core an inch in diameter, which means a far better chance of locating difficult rings than in the increment borer cores which are only one-fifth of that diameter. The borer is a 1-inch steel tube with small saw teeth on one end and a projection at the other for insertion in a common brace. A chain drill attachment is also provided to help in forcing the drill into the wood. The difficulty with this borer is the disposal of sawdust and the extraction of the core. For the former, a separate hole is bored with a common auger just below the core (if in an upright tree) and in advance of it to catch the sawdust. The core is broken off every three inches and pulled out to make more room for the sawdust. To extract the core a small steel rod is provided with a wedge at one end and a screw at the other. One and two foot tubes are carried so that it is possible to reach the centers of most pine trees. It would not be difficult to develop an instrument much more efficient than this and it should be done. Soon a borer will be needed to pass through a 35-foot tree or to sound the depths of the great Tule trees of southern Mexico.

The tools just mentioned are technical, yet in no sense complex. A measuring instrument has just been completed whose usefulness will be extensive and whose details of construction are too complex for present description. It is for measuring the width of rings. It makes a record as fast as one can set a micrometer thread on successive rings. The record is in the form of a plot drawn in ink to scale on coordinate paper so that the values can be read off from it at once for tabulation. This form of record was desired because individual plots have long been made to help in selecting the best trees and in studying their relation to topography. The instrument as constructed magnifies 20, 40, or 100 times, as desired. It can be attached to the end of an astronomical telescope and used as a recording micrometer capable of making a hundred or more settings before reading the values. It seems possible that it will have other applications than the ones here mentioned.

Another instrument of entirely different type has been developed here since 1913. Its general principle has been published and will not be repeated, but in the last three years it has been entirely rebuilt in a more convenient form through the generosity of Mr. Clarence G. White of Redlands. This instrument is now known as the White periodograph. It could be called a cycloscope or cyclograph. Its purpose is to detect cycles or periods in any plotted curve. It differs from previous instruments performing harmonic analysis in that it is designed primarily to untangle a complex mixture of fairly pronounced periods while others determine the constants of a series of harmonic components. For example, the periodograph can be applied to a series of rainfall records to find if there are any real periods operating in a confused mixture. It is also designed to get rid of personal equation and to get results quickly. The instrument as reconstructed is far more convenient and accurate in use and has already given important results. It enables one to see characteristics in tree growth variation which are not visible to the unaided eye. It is specially arranged now to give what I have called the differential pattern or cyclogram because this pattern not only tells the periods or cycles when properly read but shows the variations and interferences of cycles and possible alternative readings. Tests on the accuracy of solutions by this instrument show that its results correspond in precision to least-square solutions.

VI. CORRELATIONS.

It is no surprise that variations in climate can be read in the growth rings of trees, for the tree ring itself is a climatic product. It is an effect of seasons. The geologists use the absence of rings in certain primitive trees as an indication that no seasons existed in certain early times. Whatever may have been the cause of that absence, we recognize that the ring is caused primarily by changes in temperature and moisture. Now if successive years were exactly alike, the rings would be all of the same size with some alteration with age and injury. But successive years are not alike and in that difference there may be some factor which appeals strongly to the tree. In northern Arizona, with its limited moisture and great freedom from pests and with no dense vegetable population, this controlling factor may reasonably be identified as the rainfall. If the trees have all the moisture they can use, as in north Europe about the Baltic Sea and other wet climates, we look for it in something else. It could be—I do not say that it is—some direct form of solar radiation. It could be some special combination of the ordinary weather elements with which we are familar. Shreve has studied this phase in the Catalinas. If the abundance of moisture is so great as actually to drown the tree, then decrease in rainfall which lowers the water table below ground will be favorable. A fact often forgotten is that more than one factor may enter into the tree rings at the same time, for example, rainfall, temperature, and length of growing season. These may be isolated in two ways. We may select a special region, as northern Arizona, where nature has standardized the conditions, leaving one of them, the rainfall, of especial importance. Or we may isolate certain relationships as in any other investigation, by using large numbers of observations, that is, many trees, and averaging them with respect to one or another characteristic. For example, I can determine the mean growth curve of the Vermont hemlocks and then compare it separately with rainfall and solar activity, and I may, and do, find a response to each. For that reason, I have felt quite justified in seeking first the correlation with moisture. A temperature correlation doubtless exists and in fact has been noted, but its less minute observance does not lessen the value of the rainfall relationship.

The first real result obtained in this study was in 1906, when it became apparent that a smoothed curve of tree growth in northern Arizona matched a smoothed curve of precipitation in southern California since 1860. That degree of correlation is now extensively used in the Forest Service. This was followed almost at once by noting a strikingly close agreement between the size of individual rings and the rainfall for the corresponding years since 1898, when the Flagstaff weather station was established. The more detailed comparison between rainfall and ring growth was made with Prescott trees in 1911. Some 67 trees in five groups within 10 miles of Prescott were compared with the rainfall at Whipple Barracks and Prescott which had been kept on record since 1867. The result was very interesting. For most years the tree variations agree almost exactly with the rainfall, but here and there is a year or two of disagreement. The cause of these variable years will sometime be an interesting matter of study. Taken altogether the accuracy of the tree as a rain gauge was 70 per cent. But a little allowance for conservation of moisture raised the accuracy to 85 per cent, which is remarkably good. The actual character of this conservation is not evident. At first thought it might be persistence of moisture in the ground, but the character of the mathematical formula which evaluated it allowed a different interpretation, namely, that in a series of poor years the vital activity of the tree is lessened. During the dry period, from about 1870 to 1905 or so, the trees responded each year to the fluctuations in rainfall but with less and less spirit. This lessening activity took place at a certain rate which the meteorologists call the "accumulated moisture" curve. This suggested that the conservation was in the tree itself. There is much to be done in this comparison between tree growth and rainfall, but the obstacle everywhere is the lack of rainfall records near the trees and over adequate periods of time. The five Prescott groups showed that in a mountainous country nearness was very important. But the nearest records to the sequoias are 65 miles away and at 5,000 feet lower elevation. The best comparison records for the Oregon Douglas spruce are 25 miles away. It is so nearly everywhere. The real tests must be made with records near by.

In 1912, while attempting to test this relationship of tree growth to rainfall in north Europe, I found that the Scotch pines south of the Baltic Sea showed a very strong and beautiful rhythm, matching exactly the sun-spot cycle as far back as the trees extended, which was close to a century. The same rhythm was evident in the trees of Sweden, and perhaps more conspicuous in spruce than pine. Near Christiania the pines were too variable to show it, but it reappeared on the outer Norwegian coast. To the south near the Alps it disappeared, and in the south of England it was uncertain but probably there. In this country it shows prominently in Vermont and Oregon, but the two American maxima come one to three years in advance of the sun-spot maxima. There is evidently an important astronomical relationship whose meaning is not yet clear.

It is to be noted that it appears in regions whose trees have an abundance of moisture, and it thus appears to be a wet-climate phenomenon.

But the correlations do not stop at rain and sun-spot periodicity. The pines of northern Arizona, which are so sensitive to rainfall, show a strong half sun-spot period. And on testing it one finds that the rainfall does the same and that these variations are almost certainly related to corresponding temperature variations and to the solar period. Thus, the Arizona trees are related to the weather, and the weather is related in a degree, at least, to the sun. Thus, we find evidence in forest trees that the 11-year sun-spot period prevails in widely different localities and in many places constitutes the major variation. This introduces us to the study of periodic effects in general.

VII. CYCLES.

Considering first that cycles, as we have just shown, are revealed in tree growth, second, that the trees give us accurate historic records for hundreds and even thousands of years, and third, that simple cycles or even some more complex function could give a basis for long range weather forecasting, we recognize the vital importance of this elemental part of the story told by the trees. It was exactly for this purpose that the periodograph was designed and constructed and some 10-score curves have been cut out for analysis, after minute preparation of the very best yearly values. In fact the major time for two years has been given to this preparation of material. It is hardly done yet, but it is far enough along to anticipate its careful study in the near future. Our present view may be profoundly modified, but it is safe to say that the sun-spot cycle and its double and triple value are very general. The double value, about 22 years, has persisted in Arizona for 500 years, and in some north European localities for the century and a half covered by our tree groups. The triple period, essentially Brückner's cycle, has operated in Arizona for the last 200 years and in Norway for nearly 400 at least. A 100-year cycle is very prominent throughout the 3,000 years of sequoia record and also in the 500 years of yellow pine. A hypothesis covering all these sun-spot multiples will be tested out in the coming months. Should a real explanation be found a step will have been made toward long-range prediction and an understanding of the relationship of the weather and the sun. Other periods, however, than the multiples of the sun-spot period do occur, and general analysis shows that different centuries are characterized by different combinations of climatic cycles. This suggests to us a great and interesting problem. If we can establish the way in which different regions act and react at the same time, then it may become possible to determine the age of an ancient buried tree by finding the combination of short cycles its rings display and then determining when this combination or its regional equivalent existed in our historic measuring tape, the great sequoia.

VIII. PREHISTORIC RECORDS IN TREES.

A new method of investigating the relative age of prehistoric ruins has been developed in connection with this study of climate by the growth of trees, and is being applied to the remarkable ruins at Aztec, in northwestern New Mexico, with its 450 rooms, now in process of excavation by the American Museum of New York City. The ceilings were built of tree trunks placed across the width of the rooms. Smaller poles were laid across these beams and covered with some kind of brush and a thick layer of earth. The beams used in this ceiling construction are almost entirely of yellow pine or spruce and for the most part are in good condition. Many of the rooms have been hermetically sealed for centuries. The beams which have been buried in dust or adobe or in sealed rooms are well preserved. Only those which have been exposed to the air are decayed.

In 1915, Dr. Clark Wissler of the American Museum offered sections of such beams for special study of the rings, knowing the writer's work upon climatic effects in the rings of trees. This offer was gladly accepted, and some preliminary sections were sent at once from the Rio Grande region. These first sections showed that the pines and spruces were far better than cedars for determining climatic characteristics.

The next lot of sections came from Aztec and was cut from loose beams which had been cleared out of the rubbish heaps. Six of these sections cross-identified so perfectly that it was evident that they had been living trees at the same time. This success led to my visit to Aztec in 1919 and a close examination of this wonderful ruin. It was at once apparent that an instrument was necessary for boring into the beams to procure a complete sample of the rings from center to outside, and that the process must avoid injuring the beams in any way. Such an instrument was developed in the tubular borer as already described. This tool was sent to Mr. Morris and during 1920 he bored into all the beams at Aztec then available and sent me the cores.

These cores, together with other sections of beams too frail for boring, finally represented 37 different beams in some 20 different rooms scattered along the larger north part of the ruin. Practically all of these show similar rings near the outside, and by counting to the last growth ring of each it was easy to tell the relative dates at which the various timbers were cut.

In order to help in describing given rings in these various sections, a purely imaginary date was assumed for a certain rather large ring which appeared in all the timbers. This was called R. D. (relative date) 500, and all other rings earlier or later are designated by this system of relative dates. Many interesting results were evident as soon as the various relative dates were compared. In the first place, instead of requiring many hundreds of years in construction as any one would suppose in looking at the ruin, the larger part of it was evidently erected in the course of 10 years, for the dates of cutting the timbers found in the large north side include only eight or nine years. The earliest timbers cut were in the northeast part of the structure. The later timbers are at the northwest, and it is evident that the sequence of building was from the easterly side to the westerly side, ending up with the westerly end and extending toward the south.

In one place beams from three stories, one over the other, were obtained. The top and bottom ceiling timbers were cut one year later than those of the middle ceiling, showing that in vertical construction the three floors were erected in immediate succession. A floor pole from Pueblo Bonito was cut one year later than the latest beam obtained from that ruin.

An even more interesting fact was soon after disclosed. A study of the art and industries of neighboring ruins had satisfied Mr. Nelson and Mr. Morris of the American Museum that some of the ruins in Chaco Canyon, some 50 miles to the south, were not far different in age from those at Aztec. The only beams immediately available from the Chaco Canyon ruins had been collected in the Pueblo Bonito ruin 25 years before by the Hyde expedition. Accordingly sections were cut from seven beams which this expedition had brought back to New York City. One of these sections was a cedar and has not yet been interpreted, but the others were immediately identified in age both among themselves and with reference to the Aztec timbers. It was found that these Pueblo Bonito beams were cut within a few years of each other at a time preceding the cutting of the timbers at Aztec by 40 to 45 years. Many of the timbers of each ruin were living trees together for more than 100 years and some even for 200 years, and there seems no possible doubt of the relative age here determined. This result showing that a Chaco Canyon ruin was built nearly a half century before Aztec is the first actual determination of such a difference in exact years. A single beam from Peñasco, some 4 miles down the Chaco Canyon from Pueblo Bonito showed that its building was intermediate between Pueblo Bonito and Aztec.

Another association of growth rings with prehistoric deposits has rapidly developed in the last two years. In 1904 the writer discovered an Indian burial at a depth of 8 feet in a cultivated field near Flagstaff, Ariz. A skeleton and two nests of pottery were revealed by a deep cut which a stream of water had made through the land. Near the burial was an ancient pine stump standing in place 16 feet underground. The tree was later discovered by a neighbor and became part of a bridge support. The Indian remains were given away except a red bowl of simple pattern and a good piece of black-and-white ware which is now in the Arizona State Museum. In 1920 the search for these buried trees was resumed and more than a half dozen in excellent preservation were found at depths from 4 to 12 feet. Mr. L. F. Brady of the Evans School gave most important help in getting out sections of these. In the summer of 1921 he again resumed the search and found several more buried trees and especially determined several levels at which pottery and other Indian remains are plentiful. These buried trees have been preserved by their pitch and show here and there quantities of beautiful little white needle-shaped crystals, which Doctor Guild has discovered to be a new mineral and to which he has given the name "Flagstaffite."

Several conclusions are already evident in the study of these buried trees. In the first place they supply much desired material from which some data regarding past climates may be obtained. The trees buried most deeply have very large rings and a certain kind of slow surging in ring size. Both of these features are characteristic of wet climates. The stumps at higher levels show characters common in dry climates; that is, general small rings and a certain snappy irregularity with frequent surprises as to size. This variation with depth gives a strong intimation of climatic change. The cycles dominant at these different levels also may be read from these sections and are likely to prove of great value.

In the second place this material will help in determining the age of the Indian remains and perhaps even of the valley filling in which these objects were located. There are several ways of getting at this which will take time in working out but there is one inference immediately evident. One log was buried about 2 feet, yet its rings do not tally with the 500 years of well determined rings of modern trees in that neighborhood. Allowing about a century for the sapwood lost from the buried tree and a half century more necessary to detect cross-identity, we have an approximate minimum of 350 years from that 2 feet of depth. The age of Indian relics at 9 and even 4 feet must be very considerable. It is interesting to add that this log cross-identified perfectly with another found at about the same depth a hundred yards away.

These then are the first results of the application of the general study of tree rings to archeological work and suggest further possibilities. Not only does it seem probable that this beginning of relative chronology of the wonderful ruins of the Southwest will be extended to include other ruins in this region, but this study of the prehistoric writing in trees will help in the clearer understanding of the climatic conditions which existed in those earlier times when the largest bona fide residences in the world were being built.

IX. CONCLUSION.

The economic value of this study of tree rings and climate is to be found in the possibility of long-range weather forecasting. In noneconomic terms, we are trying to get the interrelationships between certain solar and terrestrial activities by the aid of historical writing in the trees. The work is not done; a wide door is open to the future. Hence it is impossible to make an artistic conclusion. There is no real conclusion yet. Some definite results have been reached and they encourage us to hope for larger returns in the future. Through this open door we can see attractive objectives looming above us and we note the outlines of some of the hills to be surmounted. To climb these metaphorical hills we need groups of trees from all parts of this country, from numerous specially selected spots and areas, from distant lands; we need ancient tree records from Pueblo ruins and modern Hopi buildings, from mummy case and viking ship, from peat bog and brown-coal mine, from asphalt bed and lava burial and from all ancient geologic trees in wood and stone and coal. We need measuring instruments, workers, museum room for filing and displaying specimens. And we need great quantities of climatic data obtained with special reference to tree comparison. With all this and with a spirit behind it, we shall quickly read the story that is in the forest and which is already coming to us through the alphabet of living trees.