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SURVEY OF SEQUOIA STUDIES, II*

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The following studies of sequoia ring records, made chiefly between 1915 and 1927, had as a first and major objective the dating of the prehistoric ruins in the Pueblo areas including Arizona and New Mexico. Local search for specimens went on in the Pueblo area while these attempts at dating them by sequoia records were carried out. The results of this long work on the sequoias seemed at the time disappointing because the above objective was not reached. However, now one can realize that more vital results were secured in the advance of methods and understanding of the problems of dendrochronology, advances which later enabled us to reach the same objective in a different way.

RING-RECORD CHARACTERS IN SEQUOIAS

There are three species of sequoias: (1) coast redwoods at low elevations along the California coast, (2) fossil redwoods in Yellowstone National Park and other areas, and (3) the giant sequoias growing at 4000 to 8000 feet elevation in the Sierra Nevadas. The two living species differ in their methods of withstanding the pressure of the powerful westerly winds to which they are subject. The coast trees protect each other by growing close together. The trees are slender, with little taper. Under heavy wind pressure a great strain in produced near the base; this stimulates the growing layer and large and erratic rings are produced. Thus basal sections of the coast redwoods are almost completely useless for historic ring records. Upper sections in these trees are a little better, though highly complacent.

The giant sequoia, on the other hand, withstands wind pressure by a pronounced taper, i.e., larger lower stem and large supporting bulges at the base, which helps maintain an isolated tree that towers above the surrounding forest. The bulges have localized effect on the rings. This has been studied (Climatic Cycles and Tree Growth, I and II) under the title of "gross rings." On the stump top these effects can be seen and a radius can be selected that largely escapes them.

Though the giant sequoia is greatly superior to the other two species, its individual groves show differences due to latitude effects on precipitation. The Calaveras grove to the north at some 4000 feet elevation can be eliminated at once on account of the effect of increased precipitation. The southerly groves are much better and have cut-over areas where stumps may be studied.

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*Continued from the April, 1945 *Bulletin*. The climatic basis of crossdated ring variations had been recognized for some years when this sequoia work was started. A large part of the reductions here described were done in the laboratories of the University of Arizona as "Climatological Researches" in association with the Department of Ecology, Division of Plant Biology, Carnegie Institution of Washington, to each of whom my sincere thanks are here given. The only publication other than the "Sequoia Topography" (II, p. 100) here referred to has been some brief references in the Carnegie Institution Yearbooks.

The land contours in these southerly groves at 6000 to 8000 feet vary between well-watered basins and steep upland slopes in which the trees do not get "imported" water but must depend more on the snow and rain immediately about them. Hence they give better ring records; that was what we found out in this seemingly fruitless work.

SEQUOIA CHRONOLOGY BUILDING

Chronology building was a slow assembling of the best sequoia records, with the aid of an improving judgment of quality and recognition especially of the influence of the immediate surroundings of any trees. The immense age of the trees made each trial of method a formidable operation, and for that same reason the results were important and convincing.

Basic dating. Any long record in modern trees must have a correct beginning with unquestioned outside ring date. By good fortune, a reliable dating of the outside ring was made at the very start in July, 1915. On that first morning, above Camp 6 in Redwood Basin while getting v-cuts from trees nos. 1, 2, 3, and 4, I heard the fall of a nearby sequoia. An examination an hour later of this tree, called no. 5, showed a very soft, outside, incomplete ring next the bark, which was the ring for 1915 without any possible doubt. The outer centuries of rings in tree no. 5 are illustrated in the figure.

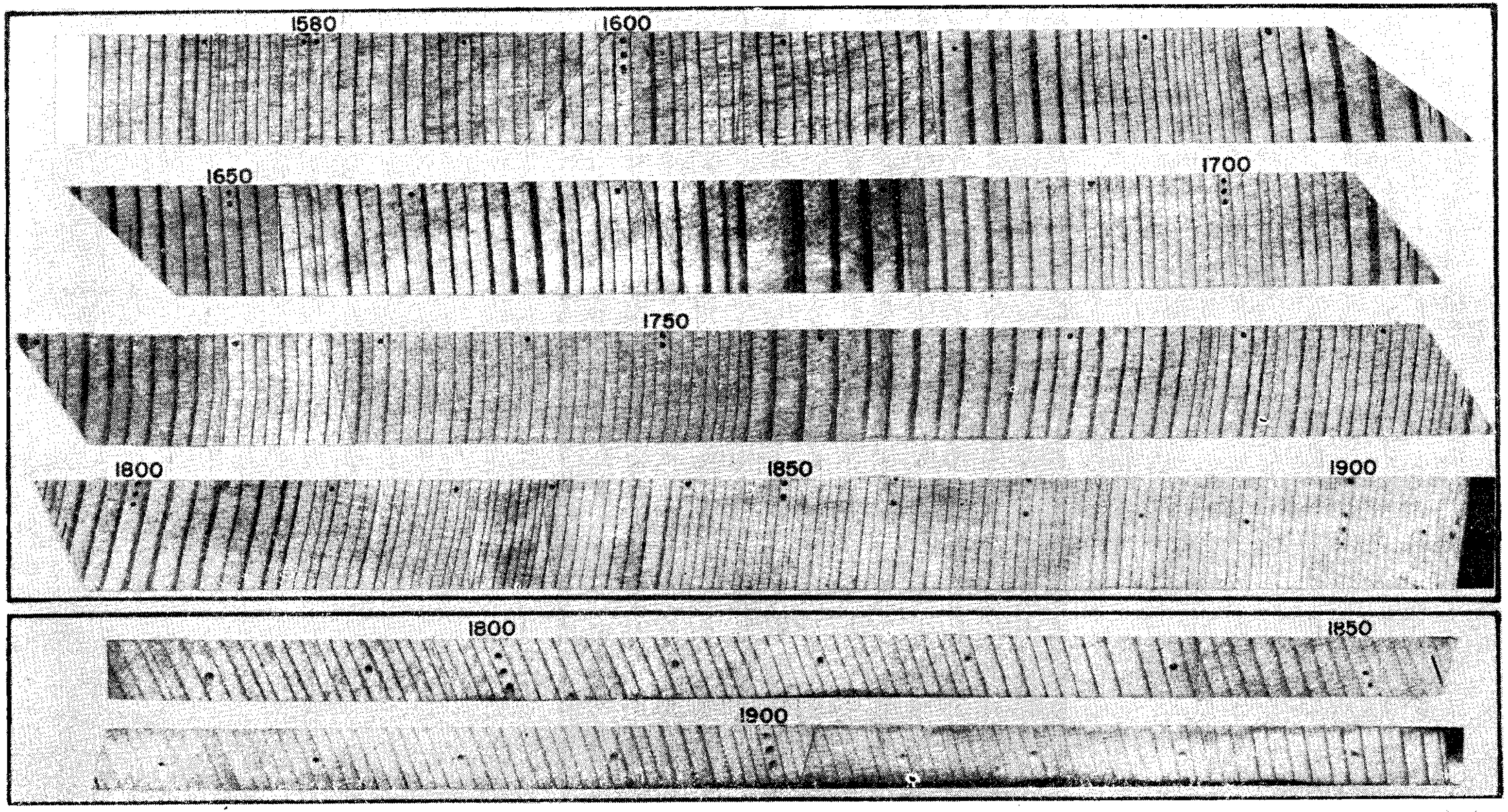
In 1924 an attempt was made to establish basic dating in Calaveras Grove, but it was not satisfactory on account of too much "complacent" growth both in the sequoias and in the surrounding pines. The dating of those sequoias, however, had no question, since crossdating with the long sequences of the southerly groves was completely convincing in the very long ring records available.

In 1925, the collection of the Springville sequoias gave another opportunity to check basic dating by borings in living sequoias. Borings (by Swedish increment borer) were made in young trees still enclosed by branches way down to the ground, but the very large, complacent, "infancy" rings gave no identification of outer ring patterns.

Borings were then made on older, but still youthful, trees through the thick bark at points as high from the ground as we could reach, but though they seemed to confirm the previous dating the rings were somewhat complacent, and in the relatively short borer records there were fewer dating checks than one wanted. The difficulty with all those Springville sequoias was that they were complacent, a fact not recognized till some years afterwards.

In 1931 a very satisfactory basic dating test was made in the Sequoia National Park on living trees. Superintendent White supplied us with a truck, a guide, and a ladder; we bored a half dozen smaller but mature sequoias showing stems with red bark and no branches. This meant real ring series that could be dated although not having the high quality of old age when the rings are at their best. But the test was completely successful and verified the dating of 1915.*

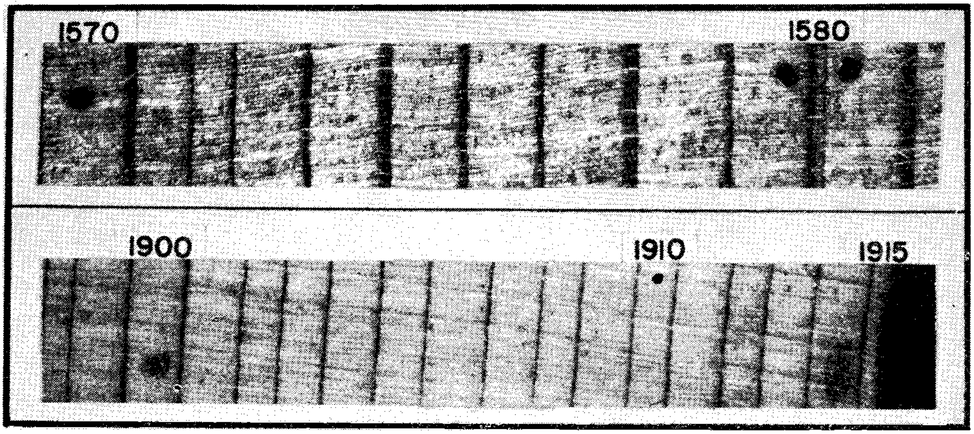
*This group has other items for this record. SP (Sequoia Park) no. 1 is from the 125-foot level of the tree whose 10-foot section is in the Arizona State Museum. No. 2 is the General Sherman Tree. Nos. 3, 4, 5, 6, and 7 all give good basic dating by showing the ring for 1931 and a sufficient number of good dating checks. No. 6 is especially strong in checks back to 1826. No. 8 is from the tree beside the "auto log" and has a fine record from 1635 to 1917 when it was injured. The group SP 3 to 8, standardized, has been plotted and examined for cyclic data.



Photographs by Frederick H. Scantling.

Figure 1. Upper: D-5, collected by Douglass August 20, 1915, in uplands of Redwood Basin, Camp 6, Kings River Canyon. A.D. 1563-1915 in photograph; 1915 ring incomplete. Half centuries are titled, decades are dotted. The outside dated ring of 1915 is shown connected to the strongly identified ring of A.D. 1580. Identifying character is small ring-width. Some of the many satisfactory dating checks by which dates are carried to nearly all sequoias are: 1571-72, 1613, 1632, 1655, 1729, 1755-56, 1777-83, 1795-96, 1812-13, 1829, 1841, 1851, and 1924 (lower panel). Magnification x1.4.

Lower: SEQ-1897, collected by Schulman August 6, 1945, on trail along upper slope about 200 yards northwest of Lincoln Tree, Sequoia National Park headquarters area. A.D. 1774-1945 in photograph. 1945 ring incomplete. Magnification x4.3.



Photographs by Frederick H. Scantling.

Figure 2. Enlargement of selected portions of D-5 in Figure 1. Magnification x9. Upper: Narrow ring at A.D. 1580 and dating checks at 1571-72. Lower: Incomplete ring at A.D. 1915.

In September, 1935, during a brief visit to the sites of sequoias numbered 1 to 5, increment cores were secured from two full grown sequoias, each of which shows a strong ring for 1935 unmistakably connected to a number of satisfactory, dating-check rings.

Finally, on the basis of collections in early August, 1945, Schulman has completely confirmed this basic dating (see lower set in Figure 1).

Doubtful ring, 1580A. The second essential in a long ring record is that it may not leave doubt about any ring on the way backward from the outside toward or to the center of the tree. The following quotation from I, p. 112, gives the procedure at a time when we did not know what to do with a ring that appeared in some trees and not in others.

". . . . settling an uncertainty regarding the ring provisionally called 1580A . . . the region near the General Grant National Park was visited and 12 new trees were very carefully selected as to their water-supply, drainage, and distance from other trees, and short radial samples were cut from them. It did not seem necessary to have these include more than the last 500 years of growth. The radial piece, therefore, was made very small, but especial attention was given to procuring a continuous and reliable record. Critical examination showed at once that occurrence of the ring 1580A was dependent on locality. The trees from the uplands, where identification was easy, largely failed to show the ring, but in specimens from swampy basins, where crossidentification was difficult and sometimes uncertain [but counting was easy], the ring was nearly always present. A complete decision, therefore, in favor of its real existence was satisfactorily obtained and the necessary corrections were made in the text and tabular matter."

Attempts to produce the best sequoia chronology. In recognition of the importance of large numbers of data to get average results the first chronology produced was the weighted average of all dated trees. The weights simply corrected differences in mean ring size. Trees used, including those of greatest age, were nos. 2, 3, 4, 5, 7, 8, 9, 10, 14, 15, 20, 21, 22 and 23. The results were published in I, pp. 117-123. This chronology and others mentioned below were compared with the prehistoric ring sequences from the Pueblo area, in an attempt to date the latter, but gave no satisfactory result.

Too many internal differences still remained in this arrangement and so the dated trees, now increased in number, were grouped by areas. Thus Redwood Basin trees were separated from Converse Basin trees, and so forth. But there still remained internal difference within the areas greater than the differences between separate areas. Evidently, the groups still were not homogeneous and could hardly be good enough for comparisons with Arizona's prehistoric curves with any expectation of reliable dating.

So certain pragmatic group selections were made that resulted in several important millennia-long curves. In 1918, our dated trees were extended by numbers 16 to 23. In 1919, further collections of twelve trees were made, in the form of shorter radials, to give the last 500 years, in the study of ring 1580A. Of these, numbers 24 to 31 were in Redwood Basin and thus we had some 21 trees from that area; all were dated and measured.

The prehistoric record in the Pueblo area was called the "Best Selected Old H" group (see below.) This was viewed in the cycloscope in close comparison successively with each sequoia record of the last thousand years or so, similarly placed in analytical form in the cycloscope. Four sequoias that showed significant similarity to the Pueblo series were nos. 4, 16, 20, and 21. These gave a series, called 4H, from about 200 B.C. to A.D. 1900.

A similar selection of sequoias, that showed resemblance to the sunspot cycle by this analytical method, gave the 4SS group of nos. 3, 12, 20, and 23. Each of these groups had strong climatic qualities.

The Springville sequoias. One of the reasons for failure to date prehistoric records might be their very early date and the lack of high quality in the early sequoia ring records already available. So we looked for more early records. Huntington's studies showed a number of possible B.C. records at Enterprise, near Springville, south of Sequoia Park. We already had two 3000-year trees from there; so the trip of 1925 was made and five fine records extending into the B.C.'s were secured. At least one long Springville record was made by combining nos. 37, 39, 41, 42, 43, 44, 45, 47, 49, 22, and 23. Of these, 37 and 39 were only 500 years long, 42 began at 490 B.C., 41 at 500 B.C., 45 at 629 B.C., 23 at 1000 B.C., 43 at 1096 B.C., and 22 at 1120 B.C. They showed favorable resemblance to 4H and 4SS when compared by the analytical method.

Best selected sequoias. A fourth selection of similar length was made that excluded those parts of each sequoia record which had obviously imperfect rings. This was called the "Best Selected Sequoias" group, BSS. It included some of the Springville records collected in 1925.

CALIFORNIA-ARIZONA CROSSDATING

It will be recalled that the preceding development of long sequoia records was the attempt to discover some California record that would match into Arizona and Pueblo area records and give the dates of the ancient ruins. The Pueblo records had been selected with great care. Some 19 Aztec specimens were chosen with respect to dating qualities and combined into a record about 100 years long, which had crossdated two ruins 50 miles apart. When plotted, this record, called the "Best Selected Old H," could be compared with plots of the sequoias.

Comparisons in this way were made in July, 1922, by direct comparison of plots, using the Aztec plot matched first against the single curve of D-2 and later against each of the combined sequoia curves "Best Selected," 4SS, and 4H. All this was without definite result.

Comparisons were then made in a very extended way by cycle analysis, that is, by placing the original curves close together in the cycloscope and observing each in the analyzing pattern. The method was standardized by trial dating of Flagstaff 250-year sequences, lifted by an assistant from the 500-year Flagstaff series and unknown to me in date. They were identified only by the letters A, B, C, etc. Many comparisons were made of the unknown Flagstaff curves with many different 500-year sequoia records. It was found that if 50 percent of perhaps a dozen trials converged toward one dating area of 10 or 20 years that area was right.

Skeleton plot. In 1926, the curve of sequoia no. 2, 0-1914 A.D., was plotted on an enlarged horizontal scale (x2), in order to make better comparison of the curves themselves. In August of that year,the deficient years were marked on this 1900-year plot by placing a vertical line directly below each low point of the curves and at the lower margin of the paper. This was done for the prehistoric curve also, to call attention to the chronological placement of the deficient years and to aid in the comparison. That was the beginning of a very extensive use of such a skeleton plot, for it was found highly convenient as a method of recording any specimen and a guide to its dating. Long efforts were made with such plots to get the dating of the prehistoric ruins, but no direct correspondence was found satisfactory.

In February, 1928, certain other characters were tried, to see if they would solve our problem. They were plots of (1) mean sensitivity, (2) curves constructed upon skeleton plots of deficient growth, and (3) curves based on the intervals between years of maximum growth. Meantime, it was noticed that in the last 500 years of known ring records there averaged about six precise agreements in deficient years per century between sequoia and Pueblo curves and two agreements plus or minus one year. The agreements showed signs of a 16-year cyclic effect.

THESE STUDIES LEAD TO A BASIC PRINCIPLE OF DENDROCHRONOLOGY

In 1926-27, an important study was finally made of *Sequoia Topography* upon 21 trees from Redwood Basin with special reference to site of each tree and its water supply, its mean ring growth per year, and its display of the largest number of dating checks or years of agreement with the largest number of trees.And then, at once, we saw the vital importance of the site of each tree, especially as to water supply (II, pp. 103-106). The basin and upland contours are the features to be watched. The upland trees give the best results, and the basin trees are practically useless. The evidence of the value of a locality is the crossdating between the trees therein. This promised important results in the future by using trees growing in more critical climatic sites than had been found. Since the work described above, a ring record of upland trees, nos. 1, 2, 3, and 4, extending to about 300 B.C., has been made (*Bulletin*, April, 1945). In order to extend this record still farther back, it might be worthwhile to add nos. 16 and 20; because of their very general use heretofore, they are probably the best ones to reach perhaps 900 B.C.

In evaluating this long and expensive study of the sequoias, one realizes that first of all it developed our understanding of the existence of climatic records in trees and some ideas of why they occur and how to find them. The analytical-method comparisons in the cycloscope simply smooth the data a little, not by running means but by cyclical means. In comparing thousands of years of continuous data, this is not only simpler and more rapid but it keeps before the eye the possibility of climatic cyclics. And that made very evident the difference between basins and uplands in their capacity to reproduce the cyclics that are in climatic records, in the sequois described herein and those in the more sensitive Arizona trees, in terms of their "resolving power" of cyclic changes. Thus, without seeking great precision, the cyclic limit of the best Arizona and Southwestern trees could be taken as 5 or 6 years and perhaps sometimes 2 years; the sequoias here referred to find it hard to get below 8 or 10 years in their resolving power.

The study in 1919 of the doubtful ring 1580A, by which that ring became assured as ring 1580, had used much the same area and nearly the same trees as this sequoia topography of 1926-27. Though 1580A was thought of merely as a special case, it certainly prepared the way for the more general concept of the influence of topography on tree growth. At that time (1926-27) this concept was not deliberately expressed as a principle of dendrochronology but it emphatically took its place as such and guided us forthwith. It could have been in such terms as these: in the dry areas of the Southwest, where the trees exist on a minimum of water supply, trees growing at, or near, places reached by no water except precipitation and places in which water has little or no chance for conservation are the ones most likely to have ring records which crossdate from tree to tree.

Even though not formulated in this fashion, these ideas became our guide in making large collections and the experiences of the next few years led to more formal statements.

SEQUOIA RINGS AND RAINFALL

Sequoia chronologies, like all others, are built upon crossdated ring patterns. Crossdating in the Southwest depends on moisture supply as a controlling factor. Hence direct comparisons of ring growth with rainfall are most important. The difficulty in early tests was the great distance from the trees to the nearest rainfall records, that is, from the Sierra Nevada groves to Fresno or San Francisco. Our best comparison was published in 1928 (II, p. 100); the figure shows substantial agreement. I am confident that recent collections by Schulman coupled with modern precipitation records close by will give satisfactory results.