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Survey of Sequoia Studies.....A. E. DOUGLASS

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SURVEY OF SEQUOIA STUDIES

A. E. DOUGLASS

The giant Sequoia (*Sequoia gigantea*) is an important climate-recording tree because of its immense life span, its ability to live in scattered formation free from the influences of close grouping, its persistence in surviving deficiency of moisture and attacks of pests and, finally, because its ring-growth in sites of special character does show an obvious relation to precipitation. The excellence of the rainfall records in its rings has only become verified in recent years because this ability depends so much upon the immediate surroundings of the tree. Recognition in Arizona of the vital importance of local surroundings to the quality of the tree-ring record has been a very great aid in evaluating this quality in the sequoias.

The early studies of the sequoia by the writer began in 1915, the year following a suggestion from Dr. Clark Wissler that beams from prehistoric ruins might prove of interest. The possibility of precise dating of rings had become well recognized by 1913 and it seemed worthwhile to try known crossdating methods in an attempt to date the prehistoric logs of Arizona by the rings of the giant sequoias of California. Hence sequoia collections grew rapidly for several years and ring identification and measurement were carried to very large numbers of trees. A large number of comparisons in ring records were made between Arizona and California, and then long-continued attempts were made to crossdate by means of cyclic characters. This crossdating from one region to the other was not successful and the matter was dropped without publishing detailed accounts of all this specialized work on the sequoia rings.¹

Now with the assurance of getting real climatic records in sequoias if we properly understand the effects of local sites, this work in collection, dating, measurement, and in measuring cyclics takes on a real value in the study of past climates. This review is therefore a preliminary re-examination of our long-stored sequoia material for the purpose of pointing out those parts of it of most worth in terms of our present knowledge. This leads, of course, to the exclusion of many trees from averages in order to improve the resulting index of precipitation.

The giant sequoia grows in the Sierra Nevadas of California at elevations of 4000 to 7000 feet or more. We have radials from about fifty different trees of that species. They all show the full length of the radius except for most of a group of twelve which was secured from stumps in 1919 to get the last 500 years in each, and three incomplete radials which were obtained from the Calaveras Grove to the north. The largest collection came from the vicinity of the General Grant National Park and another of almost equal importance came from the old Enterprise Mill site east of Springville.

COLLECTION TRIPS

The first sequoia trip was made in 1915, financed by the Elizabeth Thompson Science Fund of the Harvard College Observatory under the direction of Professor Edward C. Pickering. Subsequent trips were aided by grants from the American Association for the Advancement of Science and the

¹Extensive general reports on the sequoias are published in Climatic Cycles and Tree Growth, Carnegie Inst. Wash. Pub. 289, Vol. I—1919, Vol. II—1928. These are referred to in the text as I and II.

Carnegie Institution of Washington through Dr. F. E. Clements of the Division of Plant Biology.

1915. The first five specimens, numbered* 1 to 5, came from the high uplands above Redwood Basin at Old Camp Six of the Hume Bennett Lumber Company. These five proved to be among the very best of the whole sequoia collection. Their high quality and the reasons for it will be discussed under a separate topic.

Nos. 6 to 11 carried a line across the center of the wet, swampy part of Redwood Basin. This line extended from a point near the old Camp Six houses in a westerly direction, turning north and ending near the outlet of the basin at a point that was used by the writer for a camp in 1919. These, therefore, were emphatically basin trees with practically permanent and abundant water supply.

Nos. 12 to 15 were obtained from Indian Basin, an open, shallow, rather dry valley about two miles west of Hume Lake; today it is circled to the north by the paved highway going to Kings River. Nos. 12 and 13 were near the lower part of the basin and had unsatisfactory rings so that they were very difficult to date. No. 14 was a little higher in a shallow valley that ran north from the east end of the basin; this was the only one of these first 15 that was not found in 1935 (see below) and is thought to have been covered by the built-up highway. No. 15 was still farther up this shallow valley.

The chronology, fully measured and published in I, pp. 117-123, included numbers 1 to 5, numbers 7 to 10 which we now see made a weak contribution, and nos. 14 and 15.

1918. The trip of 1918 was made for the purpose of securing specimens from the oldest possible trees. Camp Seven, a few miles east of Camp Six, was visited and no. 16 was found at the top of a very long talus slope facing east. Its quality is high.

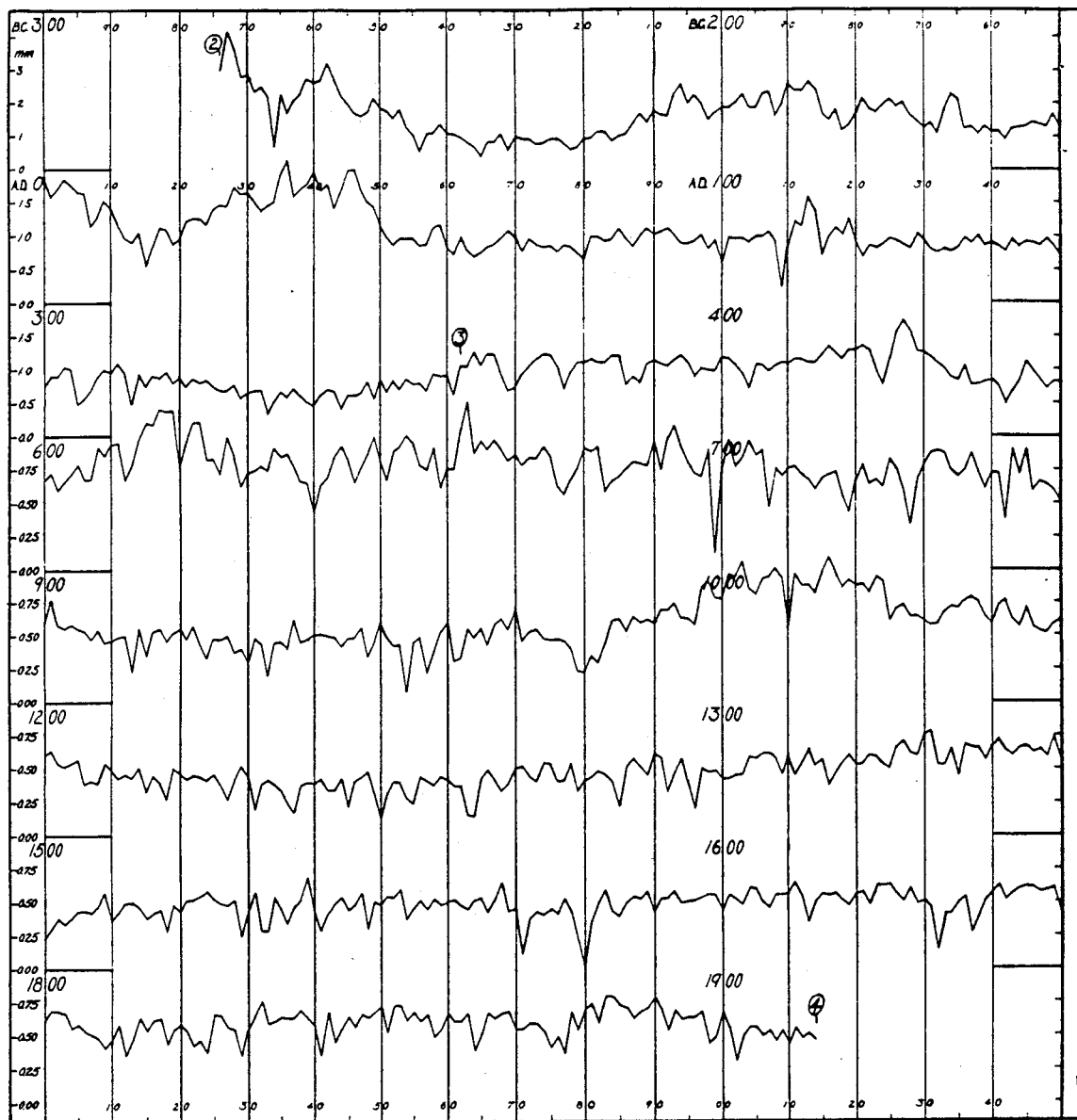
No. 17 was just west of Camp Seven in a close group of sequoias; it was cut from a log end. The Forest Service, which very kindly made a search for all these stumps in 1935, did not find it. It was a tree that had been measured by assistants of Huntington². The outer thousand years were badly compressed and unreadable, but the central thousand were easily dated by our usual skeleton-plot methods. My own attempt to approximate the dating in the outer thousand years was 40 years in error. The report in Huntington's publication shows an error of 300 years, that is, the center was really 300 years earlier than supposed.

The search for very old trees was continued in the high ground to the east of Redwood Basin. No. 18 was a "movie" tree whose fall made part of an early motion picture. A log of no. 19 appears in II, Plate 7A, lying in a slanting position close to the roadbed of the railroad in left center of the picture. Neither of these specimens was regarded as of the first importance. Nos. 20 and 21 were secured from Converse Basin, about 5 miles north of General Grant Park. No. 20 had a good location near the top of a hill and proved to contain about 2900 years. It is shown in I, Plate 6A. It was used in certain groups of measures known respectively as 4 H, comprising nos. 4, 16, 20, 21, and 4 SS, comprising nos. 3, 12, 20, 23. The studies of these groups will be given later after the discussion of the quality of the specimens. No. 21 proved to be the oldest of all the trees but it was not far from moist ground in Converse Basin and was very complacent although slow-growing.

The Enterprise Mill site east of Springville was then visited and two of Huntington's trees were sampled, like all preceding ones, by a V-cut.

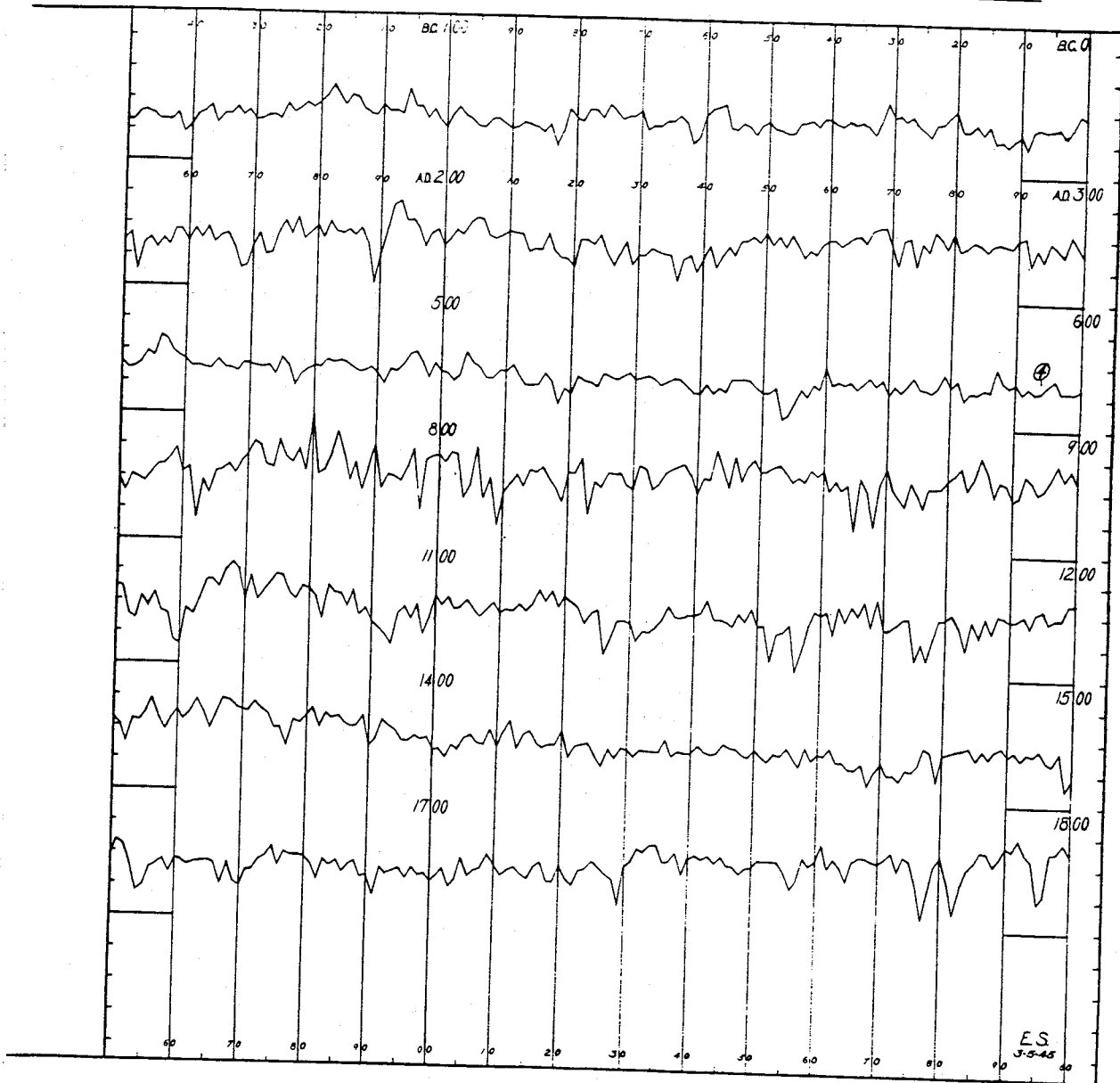
*All sequoia specimens were given the group identification letter D: thus no. 1 is sometimes referred to below and in other publications as D-1.

²E. Huntington. The climatic factor as illustrated in arid America, Carnegie Inst. Wash. Pub. 192, 1914.



Sequoia growth curve for Redwood Basin, $7\frac{1}{2}$ miles NE of General Grant Nat. Park. This represents the most sensitive records in our collections and is based on four long-lived trees as follows: D-1 (the usable measured record begins at 594 A.D.), D-2 (274 B.C.), D-3 (274 B.C.), and D-4 (362 A.D.). For convenience in plotting, the vertical scale has been changed at 0 A.D. and again at 600 A.D. The D-1 measures have been reduced to $\frac{1}{3}$ and the D-4 series to $\frac{1}{2}$ before averaging in order to roughly equalize the mean growth rates of all specimens: as a result there are only slight discontinuities in the curve at 362 and at 594 A.D.

In addition to the numerous microscopic rings there were locally-absent rings as follows (all A.D.):



D-1: 1580.

D-2: 699 954 1156 1580.

D-3:	189	865	1091	1156	1499
	477	913	1092	1175	1580
	553	933	1093	1177	1777
	554	954	1098	1237	1875
	762	961	1126	1250	1877
	809	979	1131	1263	1902
	823	980	1152	1264	

D-4:	954	982	1156	1777
	979	1059	1468	1782
	980	1060	1580	

Up to this point the V-cuts had been very substantial triangular pieces of lumber because of the kind aid of the lumber companies in having that work done. Nos. 22 and 23, however, were cut by members of our own party, and were about 6 inches on three sides by 10 or 12 feet in length. Nos. 22 and 23 proved each to be about three thousand years old; their stumps are shown in I. Plates 7A and 7B. No. 22 was in the central moist area, and no. 23 was a quarter mile to the west near the brook that came from the same swamp area. Neither one is of the highest quality.

1919. The trip of 1919 was made especially to settle the question of a suspected ring, which proved to be that of 1580 A.D. This was my experience with a situation that everyone engaged in this kind of work meets and which every student ought if possible to encounter in order to appreciate the simplicity and precision of the solution. Among some 23 specimens in hand and dated by the spring of 1919, just about half showed a possible ring which was called A.D. 1580A; the other half failed entirely to show it. The question was, was this a real annual ring or not?

This was exactly the same type of question that arose in the Prescott material of 1911. In the Prescott case the bad practice of numbering rings in from the outside was still in use; it is bad because numbers were reversed with reference to chronology. A suspected ring was given the number 6A but in fact it was formed before ring number 6. Its establishment as a separate ring was not completed until the Flagstaff series was crossdated with Prescott rings and showed an extra ring at that point—1904.

So in the case of the year 1580 A.D., in order to settle the matter Redwood Basin was visited and eight more trees secured from areas between the wet basin and the dry uplands, nos. 24 to 31. This series began on the west side, 50 to 75 feet above moist ground. No. 25 was near a dry wash; no. 26 was somewhat lower. No. 27 was on the east side but its roots were found to be in a wash that sometimes carried water. Nos. 28 and 29 were well up on the hills to the east. No. 30 was in the uplands to the southeast draining into the basin, but it did not prove to be a very good record. No. 31 was even higher up than nos. 1 to 5 but proved to be very complacent. This however, was due to its roots reaching a flow of water that lower down came out in the form of a spring.

Converse Basin was then visited for four additional trees, nos. 32 to 35. Of these, nos. 32 and 35 were well placed, but nos. 33 and 34 were near water and had little value except for settling the quality of ring 1580A. These trees decided the question of 1580 A.D., for it was seen that the presence or absence of the deficient year was a matter of topography.

1924. Calaveras Grove of big trees was visited in 1924 in order to see whether the dating characters of the southerly groves extended to this northernmost grove of the big tree area. These trees were uncut and standing for the most part and so very few long sequences were obtained. Two increment borings were made in living trees, three V-cuts were obtained on fallen trees, and a tracing of the rings in the Dance Hall Tree was given me. The Calaveras sequoias were found to date easily in terms of the dating at General Grant Park and Enterprise, although their records were complacent. None of them was used in the climatic studies of our long continuous records.

An excellent series of borings in pine trees was made at the same time. The sites of these pines form a line centered at the Calaveras grove and extending in an east-west direction fully a mile.

1925. The trip of 1925 to the Enterprise Mill site was for the purpose of securing more very old trees like nos. 22 and 23. Huntington's assistants had found a number of such trees and it was proposed to examine them. The collection of 1925 was made to include cuttings also from stumps of young trees. The early numbers, 36 to 41, began with small trees. They extended from the center of the mill site in a southerly direction to the mar-

gin of the area. Nos. 40 and 41 proved old. No. 42 was back close to the central location of the mill. No. 43 was only 10 feet from no. 22 and eventually proved to have about 3100 rings. Nos. 44, 45, and 46 were to the northeast on higher ground. It is probable that they give a little better record of climate than do the others, which had a too-large moisture supply. No. 47 was a specimen from the California Tree, shown in II, Plate 4B. No. 48 was secured some two miles down to the west at the old Frazier Mill site and a little farther down bearing a short distance north of the road. No. 49 was obtained from the Brownie Meadow near where Mr. Elster once had a mill. No. 50 was a large sequoia from Sequoia National Park about half a mile north of headquarters.

The Enterprise Mill site is located on a saddle between two deep valleys east and west and with mountains north and south. Mt. Moses to the north is very high and the lower hills on the south separate this site from Balch's Park. This site has a great deal of snow in winter but is a bit too level for the drainage necessary to produce good climatic trees. A very great amount of work has been done on the sequoias from this area.

1931. The trip of 1931 included a visit to Sequoia National Park, where a number of borings were made in sequoias and pines in order to give an independent assurance of the dating of recent centuries in the sequoia chronology. The dating already published in I and II was completely supported.

Among the other trees tested by increment borings the General Sherman Tree was the most important on account of its very great age, which was estimated at perhaps 3500 ± 500 years. Some six or eight borings were made in this tree by courtesy of Superintendent John R. White.

Through his courtesy also, a section was cut for us from a fallen tree one-half mile from headquarters and later in the season it arrived at the Tree-Ring Laboratory. It was called no. 50. The rings of a small cut at a level originally 100 feet above the ground were measured and used in the growth tables. The beginning date was 212 A.D.; the ring series was complete. The tree had been blown down in 1913-14 and many sections had been taken from the log. Our large section, just 10 feet in diameter, is on exhibit in the Arizona State Museum.

1935. The trip in 1935 was made by stage to the Sequoia National Park where further checking was done for the purpose of comparisons between sequoia growth and pine tree growth in that area. The hotel courtesies of the Park were extended to us by Mr. Mauger and Colonel White kindly drove us over to the General Grant Park some 20 miles away. From there we went to Hume Lake and by horseback up to Redwood Basin and found the specimens whose samples had been taken so many years before. A photo was made of a young sequoia, near no. 35, which had grown perhaps ten feet since a previous photo of the same in 1919.

CLIMATIC QUALITIES

In evaluating the relative qualities of these sequoias in climatic recording, one has recourse to a criterion of climatic reaction in trees which has been watched many years and whose reliability has been receiving more and more support through that time.

Since deficient water supply permits little conservation of moisture year-to-year and an abundant and certain supply permits much more carry-over to succeeding years it is reasonable to expect to find shorter cyclics in the dry regions of little conservation and only the longer cyclics in the wet regions of much conservation. Thus the dry upland areas might give all cyclics from 5 years up, the midland areas might give all from perhaps 10 years up and wet areas if not too much affected by local influences might give cyclics from 20 or 30 years up.

Thus the Flagstaff pine trees of moderate sensitivity show a 14-year cyclic in much of the last 400 years while Schulman's superb Douglas fir records

from the Colorado drainage area show long continuities of the 6-year Hellmann cycle, or half sunspot cycle. This 6-year cyclic shows in the pines on the very edge of the Grand Canyon but not so well in most of the groups near Flagstaff.

Since very old trees need some protection from wind and weather they do not commonly grow in the high well-drained places of much exposure where the best quality of records are found. So it turns out that in nos. 1 to 5 we have high quality trees that give us records to near 300 B.C.; the records before that from midland or basin areas are of lower quality.

Even in our better quality trees another factor enters. The "infancy" rings of these sequoias for say the first 100 years are often large and wholly without dating value. The early 500 or 600 years sometimes have less character than does the growth during maturity, so the best records go back to about 200 or 300 A.D. and before that some of them are good but not excellent.

A long chronology like that of the sequoias is easily constructed from midland trees which have moderate sensitivity and few absences. But highland trees of high sensitivity and sometimes more absences are necessary for accuracy of detail in chronology. We see also that upland and basin trees cannot be averaged in order to test the reliability of the sequoias in recording climatic changes (as has been tried) without full crossdating between them; this can be accomplished only by careful study of the three groups, highland, midland, and basin trees.

SITES OF BEST TREES

With the growing understanding of the effect of local environment on the rings of the tree, we now make selections of the better trees in the preceding list with an attempt to bring out the favorable features of their surroundings and the resulting characteristics of the ring sequences. We conclude this first part of the sequoia survey with a discussion of the relatively sensitive records from Redwood Basin; a mean growth curve for this site is given in the figure.

D-1: Located on a high promontory on the west side of a dry ravine which forms the west part of this highland area. The elevation is much above the other trees. A root of this tree was traced 100 feet reaching across the dry ravine. The rings had the highest sequoia sensitivity observed with many microscopic rings in the last 700 years. The original dating was very difficult, and it was actually one of the later trees to be dated. Apparently in good winters there was abundant moisture locally so that the rings grew large but in dry years growth was likely to be very small.

D-2: Near the bottom of the dry wash in an easterly direction from D-1 and more than one hundred feet lower on the mountain side. This gave what has ever since been considered the best individual sequoia record that we have. There are several absences in 2200 years, but the general run of ring thickness is highly typical of all the better trees.

D-3: On the dry, rocky ridge between the dry ravine on the west and the larger and slightly more moist channel just east of it. The outer rings are much crowded and there are 34 missing rings in all.

D-4: East of a tiny flow of water in the east ravine. The rings are regular and satisfactorily sensitive so that from end to end they are very readable indeed. This was better than expected—in spite of nearness to water the tree was evidently far enough away to give a good record.

D-5: A young tree lower down than the other four, located on the flattened ridge between the two ravines a short distance above the old railroad trestle. Even though this tree was but 700 years old it gives a workable record. However, because of its youth it was omitted from the Redwood Basin curve.