File Bristlecone Project

Ramifications of Chronology Building in Bristlecone Pine*

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Introduction

As part of a survey to find long-lived trees that ~~were~~ are sensitive to year-to-year changes in climate, efforts were oritented toward upper timberline species in 1952 and 1953 (Schulman 1954). ~~Of these species~~, bristlecone pine, Pinus aristata, Engelm., and limber pine, Pinus flexilis, ?, proved to be the most suitable species, and extensive survey collections were made (Schulamn, Edmund and C. W. Ferguson. Appendix C. Millenia-old pine trees sampled in 1954 and 1955. ~~XNxSchulx~~ In Schulman 1956). Because these studies indicated a much greater age in bristlecone pine, efforts were focused on this species in 1956 and 1957 (Schulman 1958).

The range of bristlecone pine (Figure 1, after Munns 1938) was surveyed and it was found that an area, since set aside as the Ancient Bristlecone Pine Forest, in the White Mountain district of the Inyo National Forest in east-central California (Figure 2) held the most promise (Schulman 1958). Schulman's death in 1958 brought a temporary halt to the study; when it was renewed in 1961, work was concentrated in the White Mountains. The present study has verified the work of Schulman and has begun to strengthen and lengthen the tree-ring chronology of bristlecone pine in the White Mountains (Ferguson and Wright 1963). This paper will deal with ~~the problems~~ various aspects of chronology building and ~~their application~~ its application to radiocarbon dating.

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* This text is rewritten from a tape recording of the author's talk on "Bristlecone Pine and Radiocarbon Datin g" at the Geochronology Colloquium, November 21, 1963.

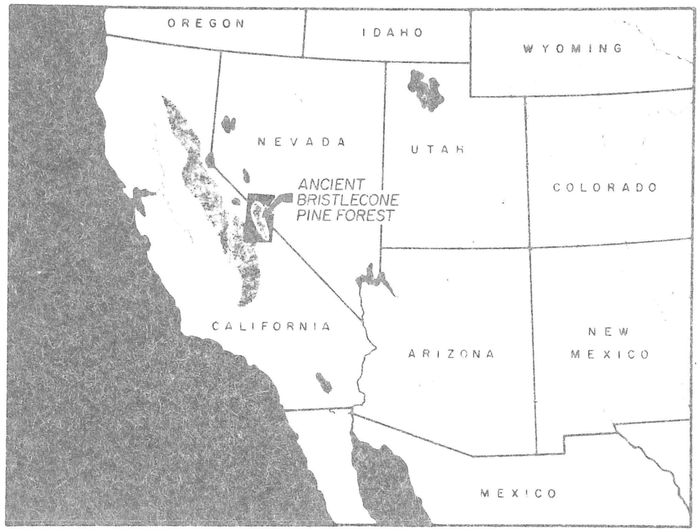

Fig. 2. Location of the Ancient Bristlecone Pine Forest in relationship to the Sierra Nevada. The Sierra, lying to the west of the White Mountains, effectively ~~robs~~ removes the moisture~~-laden~~ from the Pacific storms and ~~places~~ leaves the Owens Valley and the bristlecone pine areas in a strong rain shadow. Thus, even though the conifers are growing at elevations of ten to eleven thousand feet, they are in an arid environment.

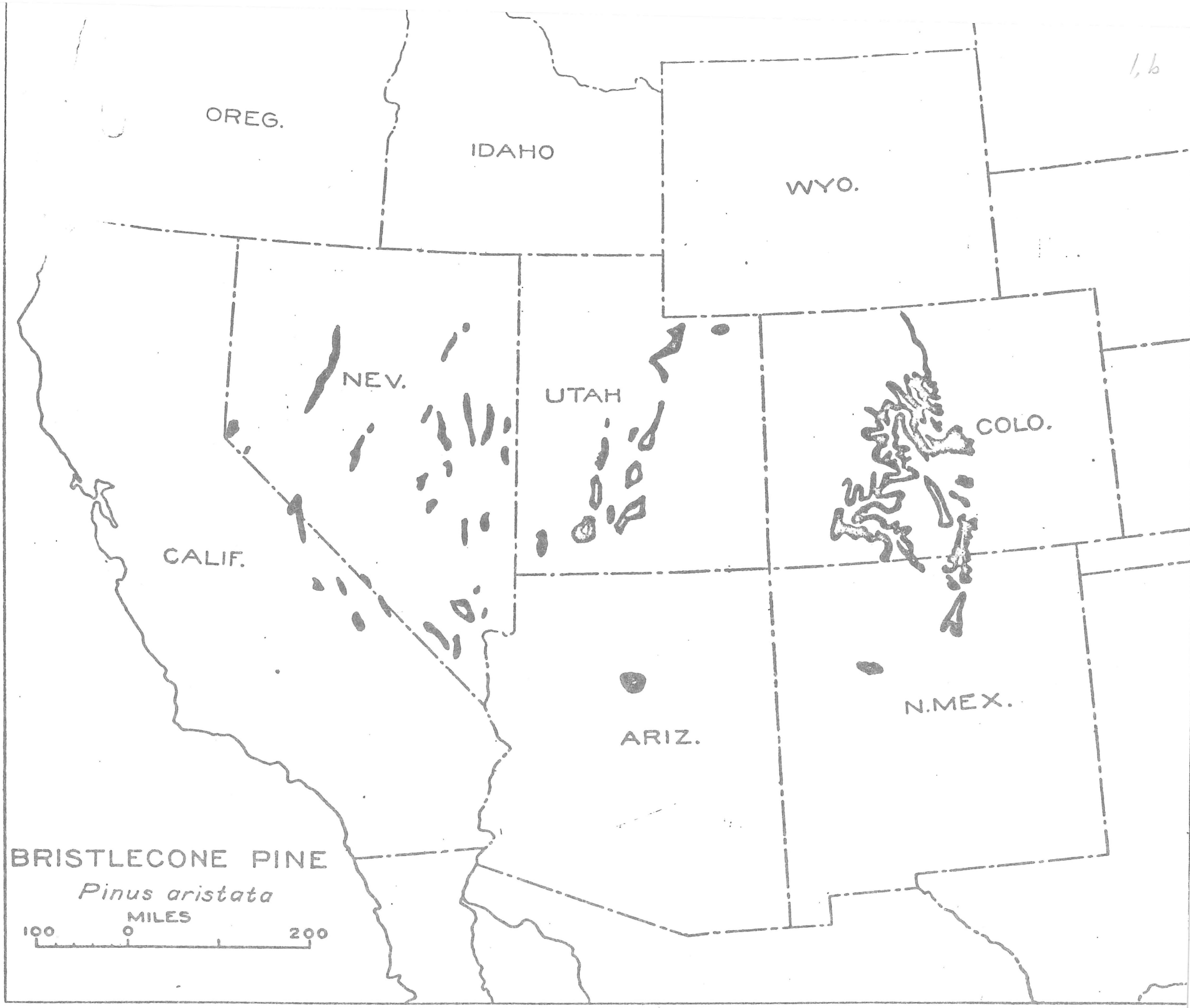

Figure 1. Distribution of bristlecone pine (Munns 1938)

Chronology Building

Chronology building in bristlecone pine, because of tree age and quality of ring record, requires care in documenting the analysis of specimens that are submitted to both tree-ring and radiocarbon dating. Some of the specific dendrochronological problems involved are unique and will be discussed in detail. The numerical depth of the bristlecone pine collections and their chronology relationships are shown diagrammatically (Figure 3). The White Mountains were an unknown area for tree-ring dating, but there were usable controls nearby. Across the Owens Valley in the Sierra Nevada, the sequoia record goes back about 3200 years to 1250 B.C. (Douglas 1919, 1928). The Southwestern chronology extends to 59 B.C. (Schulman 1952, 1956). The record of limber pine goes back to A.D. 25 in central Nevada (Schulman and Ferguson, op. cit.).

Fritts (1963), using data from Schulman (1956), has shown, through statistical correlation studies worked out on an IBM 7072 computer system, that the bristlecone pine chronology shows significant correlations with chronologies as much as 1000 eastward and southward and about 300 miles to the north. Because tree-ring records from areas to the east, in the Great Basin and in the area of the Four Corners do show a significant relation to the bristlecone pine, the Southwestern tree-ring chronologies can be used to provide effective control for the establishment and verification of the White Mountain chronologies, even though the degree of correlation is not constant throughout the total record, primarily because of the distance involved. Both the Southwestern and the sequoia chronologies were used in building the bristlecone pine chronology (Schulman, unpublished); and the studies serve to validate Schulman's work.

Since the first survey in the White Mountains in 1953, roughly 1000 trees have been sampled. The cataloging record is not up to date, so the summary (Figure 3) is only a generalized presentation. The upper unit of the block-form curve represents

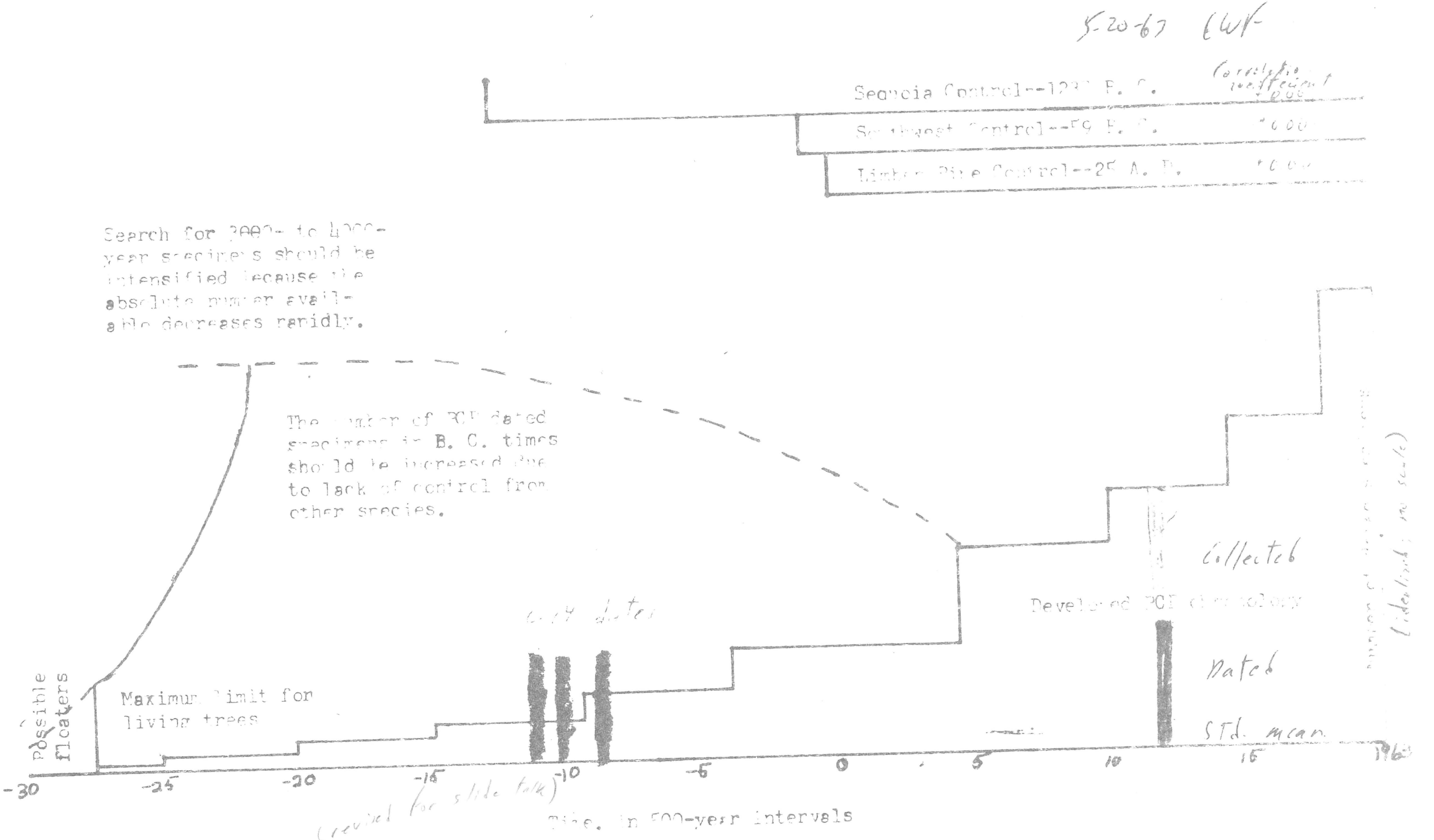

Fig. 3. ~~Idealized~~ diagrammatic representation of the numerical depth of the bristlecone pine collections, in terms of total number collected, dated, and incorporated into the master chronology. A time relation is indicated for the chronology control of the sequoia, Southwestern, and limber pine records, and of the radiocarbon dates. N.B. This diagram is a precursor of the one used as a slide; the latter is not available.

the total number of specimens that have been collected for successive time intervals. With a complete tabulation, this generalized curve would assume the form of a vertical bar x graph. The total number of specimens in the period from 1000 to 2000 B.C. decreases rapidly. In addition to having a more restricted internal control in the bristlecone pine itself, this early period is beyond the time range provided by the adjacent chronologies used as controls. However, there is substantiating evidence for great age in bristlecone pine in wood that has been dated by the radiocarbon method or by both the tree-ring and radiocarbon methods.

Radiocarbon Dating

Wood from the inner part of one of the oldest known specimens of bristlecone pine (WHT_W 4779, Schulman 1956) has been analyzed by radiocarbon laboratories at the Applied Science Center for Archaeology (A.S.C.A.), University of Pennsylvania, and the Geochronology Laboratories, the University of Arizona, Tucson. The material was independently collected and, while it was from the same area in the stem, the results of the two analyses do not represent dates for specimens of identical time origins. Carbon-14 dates on five specimens ranged from 3820 to 4260 B.P. (1960), based upon a half-life of 5730 years (Interim Report, A.S.C.A.). The single Arizona date was 4090 B.P. (1950 base), based upon a half-life of 5760 years (Damon, unpublished). These dates are presented here without the plus-or-minus factor, which is about 150 years. The Pennsylvania dates would be slightly greater if the half-life were increased 40 years to make it comparable with the figure used by the Arizona laboratory.

Additional C-14 dates have been derived for trees with somewhat lesser ages and for "floaters" -- small isolated fragments with a provenience unrelated to a source tree, either living or dead. These radiocarbon dates have been compatible with the known or expected age and, in that they support the above figures, serve to confirm the antiquity of these trees.

The chronology development in bristlecone pine (Ferguson and Wright 1963) is at a stage where soon it will be possible to precisely relate the tree-ring chronology in the 4000-year range to the exact unit of wood used in radiocarbon analysis. As this point in chronology building is approached, the validity of both the initial age figures of Schulman (1956, 1958) and the C-14 dates become more certain.

Time has permitted an analysis of only a small portion of the specimens on hand. Schulman's data have been surveyed by Ferguson and Wright. Only the sites and specimens with a proven or indicated value for chronology building were selected for study, and probably only a third of these have been dated, in all or in part. These are represented by the second curve (Figure 3). Of these specimens, some chronologies are further refined. The ring series are measured and plotted, the plots are checked, and, ultimately, these are incorporated into a mean master chronology. For the final presentation, the measurements are punched on IBM cards and the data are processed on the computer to be standardized and incorporated into a mean master chronology. The scale of the unit representing the master chronology has been expanded vertically in order for year-to-year width variations to be visually evident (Figure 3). The present workable master chronology has been extended back to 1900 B.C. with units available for a total length of over 4600 years. A definitive chronology is limited ultimately by the number of specimens that are available. The tree ages have an upper age limit, probably close to 5000 years. However, the record provided by living trees can be extended by the use of the record of dead trees, both standing and fallen, and of old stem fragments that may contain a ring chronology predating that of the living trees.

A maturity of thought has caused the dendrochronologist to take increasing care in the preparation of specimens for radiocarbon analysis. Shortly after the discovery of the age of the bristlecone pine, an early C-14 date from this species was of interest in itself. Such a date from the inner part of a tree that was 4000 years old was of extreme value, not only as a C-14 date in this time range, but also as a bit of substantiating evidence for the age of the tree. Now, because of the development of the bristlecone pine chronology, it soon will be possible to tie this time unit of wood with a Carbon-14 date to our precisely dated tree-ring chronology. It now becomes important to know exactly what unit of the ring series, in either a dated specimen or one with an unknown date, was taken for radiocarbon analysis.

Figure 4 illustrates the process in establishing this relationship. The specimen (TRL 62-123), a floater from Methuselah Walk, was a small fragment found on the ground and selected for study because of indicated age, sensitivity of ring record, and length of series. This cross section, with only 4 to 4½ inches of radius, contained 575 annual rings. The total ring sequence is represented by the plotted ring measurements in Figure 4. Specimens such as this are of value in building a tree-ring chronology, because of the length of record, relative fidelity due to the extent of surface available on the cross section, and the period of time in which it falls. These same factors make floaters of value in radiocarbon analysis. The section illustrated was retained as the tree-ring control. An adjacent section, shown diagrammatically and slightly enlarged in Figure 4, was trimmed around the edges to remove the weather stained wood and five 50-year units were split out. This was done carefully so that each unit was of constant width and contained the predetermined number of rings. An outline of the rings bounding the 50-year portions was marked on the specimen, and each unit was split out with a small chisel. The specimens were examined under a microscope and the outside rings were

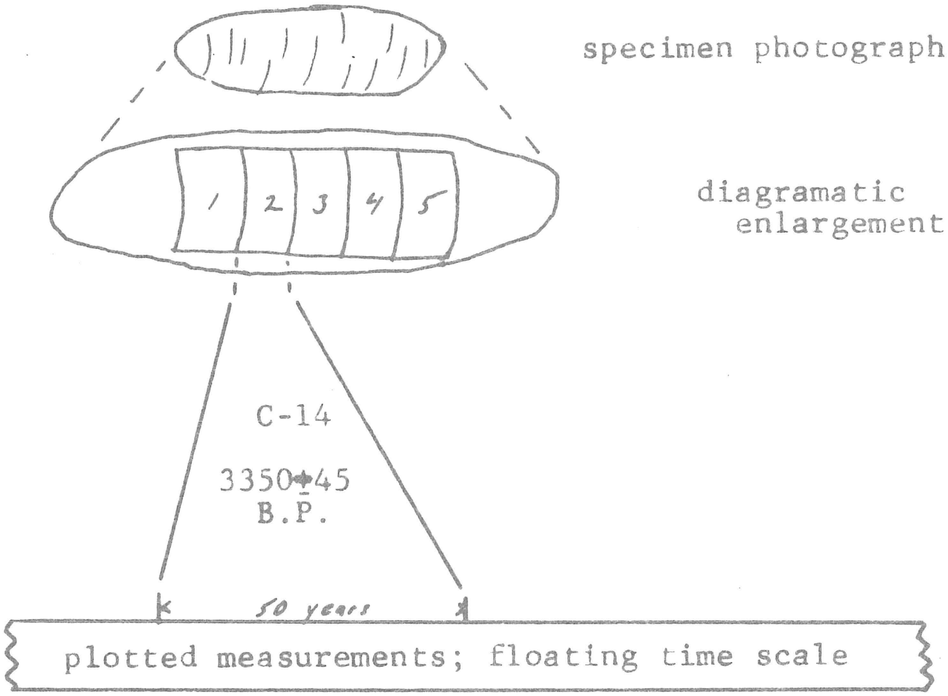

Fig. 4. The relationship of a wood specimen (TRL 62-123) to the unit used for Carbon-14 analysis and to the tree-ring chronology the specimen contains.

compared with the plotted measurements. The inner and outer ring of each piece were followed around its circuit and the edges found to vary no more than two or three rings. The extent of variation in each unit was noted on the plot. With this system of control, the unit of chronology upon which the C-14 date was based is precisely known. This specimen has been analyzed at The University of Arizona and, on the basis of the half-life of 5570 years, gave a date of 3350 $\pm$ 45 years B.P. (with the present fixed at 1950), which has a midpoint of 1400 B.C. Now, the chronology building has passed this point, but time has not permitted a reanalysis of the specimen.

At the time that The University of Arizona laboratory derived a C-14 date for #4779 (June 13, 1963), the tree-ring chronology was not well developed prior to 1100 B.C. Possibly, #4779~~2~~ could be dated prior to this presentation (November 21, 1963). Parker and I spent two weeks trying to tie the fairly complete crossdating of the inner part of #4779 to the pith area of the Methuselah walk pickaback that contains a chronology which goes back to 1900 B.C. and is comprised of a measured radius from each of four sections and supported by a study of the full section. This effort to compress two years of research into two weeks met with abysmal failure. The chronologies used as controls were not strong enough (their development was still incomplete) to enable us to pick up the dating with any degree of confidence. Isolated intervals occurred where the chronology seemed to crossdate for 20 to 30 years. When a check was made of the rings on either side, the tentative ~~date~~ dating could not be substantiated. The problem probably arises from the high percentage of missing rings in the specimen. This is the major cause for difficulty in dating bristlecone pine. Wright (manuscript, 1963) made a detailed study of TRL 62-68 (Figure 5) and comparable sections from two other trees. He found that a given radius, represented

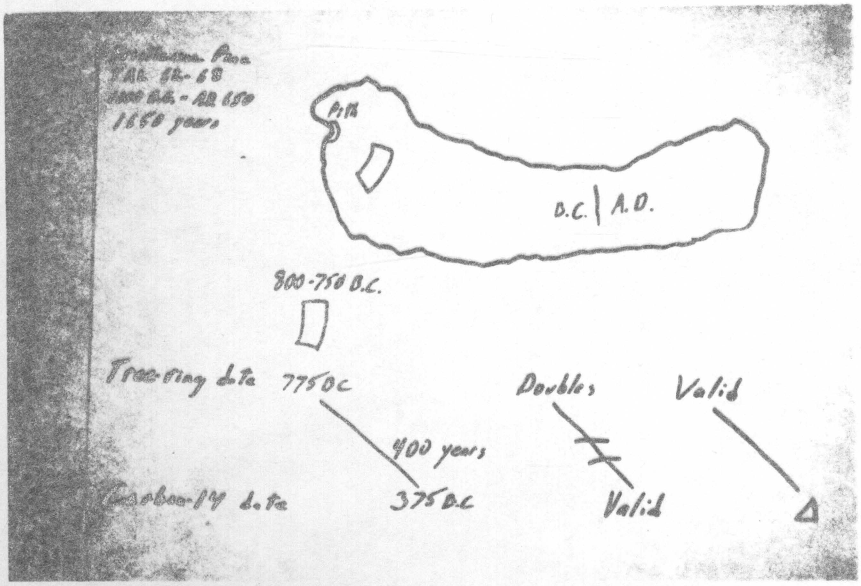

Fig. 5. Possible interpretations of radiocarbon and dendrochronological dates from one specimen (TRL 62-68).

by a single line through the center of the section, on this type and size of tree, contained about 95 percent of the total annual rings. This means that 5 percent of the rings were small to the point of being absent. If the breadth of the specimens were searched, about half of those missing on the radius measured could be located at some point on the specimen so that the specimen as a whole was lacking only approximately 2½ percent of the chronology. By going to specimens from sites with more rapid growth, these few years of minimum growth could be identified and the evidence for their occurrence incorporated into the chronology. (Recently, we have been examining specimens with less than 1 percent missing rings.) Reexamination of the original cross section material often would reveal a few cells forming a little lens which would represent the ring which was missing on the radius. We have come to feel that there is a great value in the study of this type of bulk material in preference to cores. Pieces as small as 2 x 10 centimeters are brought back for detailed study.

Only one specimen (TRL 62-68), the top portion of a fallen ~~dead and downed~~ snag, has been dated by both methods. A large piece of this tree was collected because increment borings are only 3/32 of an inch in diameter and do not provide the volume of material required for radiocarbon analysis, nor do they provide a large surface for tree-ring study. The tree-ring chronology was identified after some effort, because Wright and I were attempting to date it in too recent a time period. It ultimately dated and was found to have a good ring series from a pith at about 1000 B.C. to an outermost ring near A.D. 650. A unit of the wood between B.C. 750 and 800, roughly indicated on the outline of the specimen (Figure 5), has been dated by the radiocarbon method (Damon, unpublished). On this specimen, the unit that was dated by both methods had a mid-point of 775 B.C., as determined by tree-ring dating and a mid-point of 375 B.C. for the radiocarbon date. This is a discrepancy of 400 years with the C-14 date the more recent. This specimen is only a single unit and is thus only indicative of the relationship, but the same relationship occurs between the known or expected date and the radiocarbon date in the Egyptian material (Damon 1963). We now have indications that this same relationship is duplicated in the bristlecone pine. If this relationship occurs, it could be due to either of two theoretical causes. If the radiocarbon date is accepted as valid and there was the same discrepancy in the tree-ring date, it could be due to the presence of double rings (annual growth increments that produce more than one distinct layer per year). Intense studies have shown that the occurrence of double rings in bristlecone pine is exceedingly rare and when this tendency does occur, it can be easily detected. In the second situation with the tree-ring date accepted as valid and with the same discrepancy, this difference ~~becomes~~ could be due to variation of the concentration of radioactive C-14 in the atmosphere.

Evidence is beginning to accumulate that will show a constant relationship between the two independently derived dates. Damon has a radiocarbon date from the Silver Canyon specimen (WHT_W 4779). This was one of three trees cut by Dr. Schulman for detailed study and museum display. Unfortunately, the trees he collected had the most extreme growth characteristics possible, and while they had age, there were problems in dating. Because Damon wanted to complete this study, we made a very serious effort to complete the dating. We were within striking distance and thought if luck were on our side, we might make it by the time this paper was presented.

A diagrammatic cross section drawing (Interim Report, A.S.C.A.) of the Silver Canyon tree is presented in Figure 6. Growth progressed from the area of a hollow center along a curvilinear radius to a narrow strip of bark. A smaller section, shown in the upper right, was used for detailed

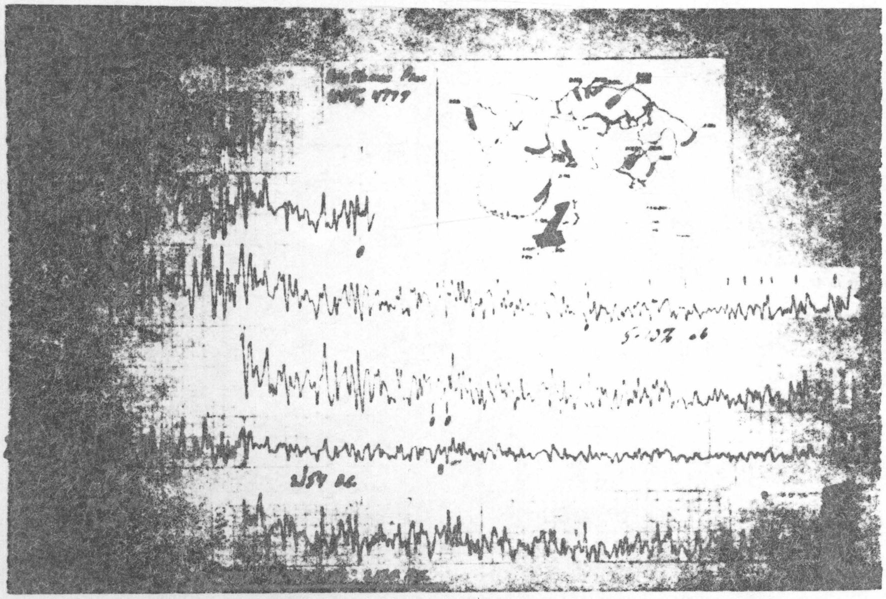

Fig. 6. Diagramatic cross-section drawing of the Silver Canyon specimen, showing, in black, the portions analyzed by Carbon-14, and plots of the measured pith-area radii.

study because it could be examined without being cut. Initially, four nearly equidistant radii were measured with the primary objective of getting the earliest ring on the specimen and building, through crossdating, a chronology for the inner portion. The absolute ring widths were relatively large, but the growth curve ~~tapered off~~ became linear within a few centuries. However, the comparison of these four radii from the same cross section in the early growth of the tree provided an excellent record containing about 300 years. As the crossdating progressed, difficulties could be seen. The presence of rings that were locally absent, particularly on one radius, was determined. Even in the very rapid early growth period, problems such as this exist on sites of greater stress. Intervals of overlap of the various measured radii provided a more workable specimen chronology in that it had a maximum replication weight of four. But problems still occurred. On two radii only inches apart, one contained from 5 percent to 10 percent missing rings in relation to the adjacent radius on the same cross section. This percentage varies depending on the total interval of ~~the~~ time studied, but in a portion of the tree there may be smaller intervals with more than 10 percent missing rings. A cross section would be expected to contain half of the rings that are missing on a single radius (Wright 1962); hence, there may be intervals that contain missing rings common to both and a third radius or another specimen would be needed to verify their occurrence. Dr. Schulman, on a count basis, estimated that the innermost ring represented the year 2255 B.C. However, we assume he was counting only the rings he saw and did not make allowances for the 6 to 10 percent that are missing. We do not know where ~~x~~ he started his count. He may have started it from the bark or from as early as 780 B.C., which was the limit of his chronology. I do not believe he had a good chronology control for a period earlier than from 780 to 400 B.C. From that point, going back to over 2000 B.C. he probably would have missed about 200 rings and this would extend the date by that amount.

This specimen has been analyzed at xThe University of Arizona radiocarbon laboratory and one set of data indicates 128 years on the sample. The interval on the wood, as nearly as we can tell, was chiseled out and varied many years on the outside boundary. There are some differences as to what actually constituted this unit of wood. The xxdxx radiocarbon date was 4090 B.P.

The University of Pennsylvania collected material from the stump of #4779. The specimen drawing in Figure 6 represents their section and the portions analyzed. The Arizona specimen thus was comparable to the Pennsylvania specimen and the earliest units for which C-14 dates were derived perhaps were within a hundred years, because of similar positions on the cross sections. The University of Pennsylvania's date was 4150 B.P., which is in the same range as the 4090 B.P. for Arizona. From the previously presented evidence, it can be seen that an absolute date for this specimen would be extremely valuable and this is what we have tried to establish in the past weeks.

Chronology units extend for varying intervals into the past (Figure 7). There is an extremely great vertical column for the outer 200 years. Dr. Fritts and John Cardis have studied the outer centuries of a great number of trees. Big sagebrush in the White Mountains has 200-year plants that follow the same chronology (Ferguson 1964). The statistical samples and the sagebrush provide an effective local control. Over and above these are the adjacent limber pine and the regional controls provided by the Southwest chronology and by the Sequoia. The absolute measurements and standardized values that have mbeen included in the master chronology are still quite limited. The initial unit of Dr. Schulman's master chronology consisted of 14 specimens back to A.D. 1000, ten to 800, seven to 500, and four to 300. Another unit was established from 400 B.C. to A.D. 400 and consisted of four specimens which were measured and tabulated. These specimens

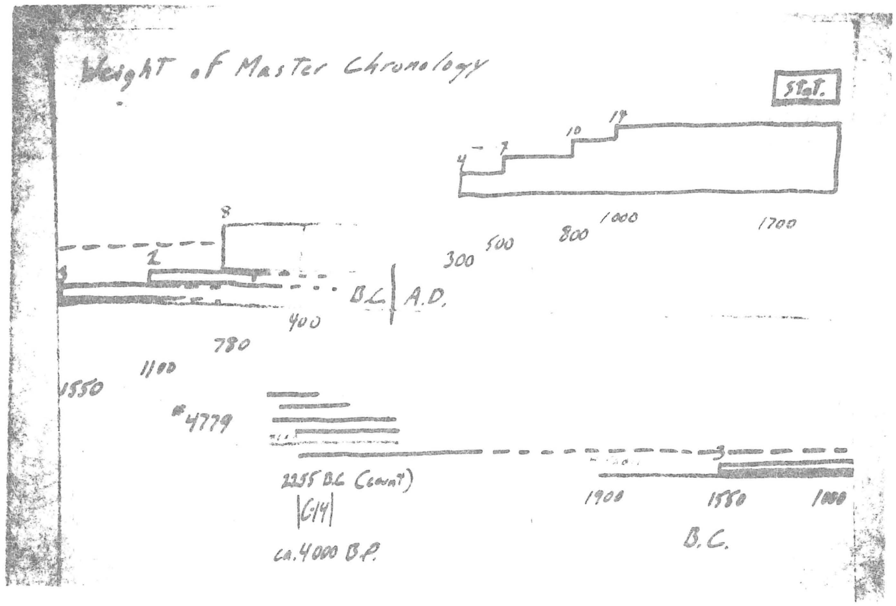

Figure 7. Depth, in diagramatic form, for the developed units of the bristlecone pine chronology. The solid step unit in the upper right is Schulman's. The limits of recent extensions are in the lower left. The lower portion contains a record for the Methuselah pickaback and, in detail, for #4779.

had tage ends which provided an extension to 780 B.C. This last extension consisted solely of pinhole dating on these four cores. These had not been measured, but the dating was quite well refined. These specimens were measured by Ferguson and Wright and the measurements were tabulated to form a mean of four. This has been added to by the incorporation of four more specimens, bringing the master chronology back to 780 B.C. up to a weight of eight specimens. The next major extensions was a unit of two specimens to 1100 B.C. This was increased to three specimens to 1550. The Methuselah pickaback (Schulman 1956), one of three trees that were cut for detailed study, has an excellent record that extends back to a pith at about 1900 B.C. It has been dated throughout a considerable portion of its total length, and the inner part has been intensely studied. These data consist of a single radius on each of four seccessive cross sections (the unit labeled "four radii" in Figure 7). These have been measured and plotted and are being worked out one against the other. Ultimately, the total breadth of the specimen will be searched in an effort to pick up all of the locally absent rings. As this is being done, many other specimens which have been plotted and tentatively dated in this time range will be either used as controls or concurrently checked and dated.

What is nneded for a control on the early radiocarbon dates is an absolute tree-ring date on the inner portion of #4779. The four lines represent four radii (Figure 7). The red line (labeled "mean") represents the master for the specimen. The bottom line was the fifth radius that was measured. If the inner part could be extended out to where it would overlap with the 1900 sequence, it could be tied in. The plot for the fifth radius goes to only about 800 B.C., but there is another unit of nearly 3000 years that goes well into the A.D. period. In the interval of overlap, the tape is represented by the broken line. There seemed to be crossdating, but the proof did not materialize. My strongest feeling for a date was such that it would have added about 300 years to Dr. Schulman's count. This was within reason, and I felt pretty good about it; then Parker said, "Hey, look, I think it fits here." This was a point 300 years more recent than mine, which would indicate that perhaps Schulman had anticipated many missing rings and added the percentage himself. It is this interval of overlap that is our problem; we just could not bridge the gap.

What we are doing in our general program is building up the depth of our chronology. We have many dated specimens that support the evidence for the modern unit. When we ent back to review Dr. Schulman's data, we found that for his chronology at 800, he had tabulated mean of 10 specimens, but the year 809 was listed as 0.00 mm for each of the ten. We accepted his interpretation on faith, but felt it would be wise to find out what the evidence for this year was. In the summer of 1962, this was my first objective -- to find trees that started growing in the 700's and that had a rapid flush of growth through this early interval. Some specimens have been measured back to 2400 or 2500 B.C. on a count basis and in these there are solid units of as much as a hundred years that crossdate. As af additional portions crossdate, the intervening intervals of 200 or 300 years will differ by perhaps 5 or 10 years, indicating that there is a problem of missing rings and we need to do some refining of our chronology.

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