TREE-RING DATING AND ARCHAEOLOGY IN THE AMERICAN SOUTHWEST

WILLIAM J. ROBINSON

Laboratory of Tree-Ring Research
The University of Arizona

ABSTRACT

The relationship between archaeology and tree-ring dating, or dendrochronology, is reviewed. Until the past decade, the applications of tree-ring dating to archaeological problems had not been thoroughly exploited. Now, in addition to providing the most precise dating control in the world, dendrochronology is making contributions to behavioral archaeology and to the reconstruction of past environments.

The systematic study of tree rings began more than 70 years ago as a product of the inspired mind of a single individual. Yet it was not until two decades later that the tree-ring phenomenon was applied as a dating tool in archaeology (Bannister 1963:162). The entire period of its development, however, is basic to the understanding of the applications of the method in archaeology and the reasons behind some of the failures to use the phenomenon to maximum advantage in interpretation of either its purely chronological or its behavioral aspect.

CROSSDATING (1901-1914)

It seems somehow consistent in the context of the development of archaeology that the study of tree rings was first applied in other fields. Many, if not most, of the quantitative dating techniques used today in archaeology had their origins in other sciences. In the case of dendrochronology, it was astronomy. Andrew Ellicott Douglass, the man whose fertile mind first saw and developed the potential of tree rings, was an astronomer at the Lowell Observatory in Flagstaff, Arizona, before the turn of the 20th century. His particular interest lay in the cyclic nature of solar activity, particularly sun spots, and its relation to terrestrial climate. Since the written record of solar activity extended farther back in time than the record of terrestrial weather, he envisioned tree growth as a proxy measure of climate. Douglass' investigation began in 1901 and was based on the following premises: (1) that the rings of a tree are a measure of its food supply; (2) that the food supply depends largely on the amount of available moisture, especially in drier climates where the quantity of moisture is limited and the life struggle of the tree is against drought rather than competing vegetation; and (3) that therefore the rings are a measure of precipitation (Douglass 1914:321). His method involved first the preparation of a tree-growth curve, and for this purpose pine trees growing in the environs of Flagstaff were chosen. In addition to convenience, these trees had two obvious advantages. First, the moisture available to the trees was primarily in the form of precipitation and, second, the average age of the trees was nearly 350 years, with some living over 500 years (Douglass 1914:322). This latter quality allowed a large backward extension of the growth curve in the record of a single tree.

As he worked on the growth curve, Douglass noticed that the same pattern of thick and thin rings could be identified in different trees that grew during the same time period. He also noticed that the same patterns could be seen in trees growing near Prescott, Arizona, which was nearly 100 miles to the southwest of Flagstaff and more than 1000 feet lower in elevation. The recognition of the recurrent patterns in the rings was the first step in the formation of the fundamental principle of all tree-ring investigation which is referred to as crossdating.

Crossdating was first established experimentally by Douglass in 1904 when he recognized the ring pattern in a dead stump which allowed him to specify the actual date of cutting – a fact that was verified by the man who had cleared the land.

For the next decade Douglass continued his work on rings as climatic indicators and on the establishment of long growth curves. He succeeded in crossdating living trees growing as far away as southern Arizona (Douglass 1914:325) and devoted much effort in the investigation of the sequoia of California which at that time held promise of extremely long growth records. It was during this period that Douglass' long association with the University of Arizona began in 1906.

At the end of this period of the development of the basic principle of dendrochronology, the crossdated sequence extended back in time nearly 500 years, based mainly on Flagstaff area trees.

RELATIVE DATING (1914-1929)

Although Douglass never lost sight of tree growth as a climatic indicator, an event occurred that led him off on a tangent. This was the application of the dating potential of tree growth to past events in man's history. In 1914 Douglass delivered a paper at the Carnegie Institution of Washington on the relationships between tree growth and climatic cycles. The substance of the paper came to the attention of Clark Wissler of the American Museum of Natural History who offered Douglass some beams for his general inspection (Douglass 1935:10). These materials were received in 1916 and were sections of living trees growing near prehistoric ruins. As a result of his examination of the sections, Douglass became convinced that trees from as far away as northwestern New Mexico had a potential of crossdating with his Flagstaff trees (Douglass 1921:27). A few years later Earl H. Morris sent Douglass a small selection of prehistoric beams from the Aztec Ruin and from Pueblo Bonito in Chaco Canyon. The sections from Aztec were immediately crossdated among themselves, but not those from Pueblo Bonito. In hopes of obtaining an exact age correspondence for the Aztec beams, Douglass tried futilely to match them to the three millennia sequoia record. Later in 1919, Douglass visited Morris at the Aztec Ruin and secured 37 additional specimens. These, with the original pieces, formed the basis for the first relative, often referred to as "floating," chronology. As a result of this initial success, Douglass formulated the dating technique that ultimately proved successful. In a letter to Wissler in 1919, he stated that the technique " . . . consists in obtaining groups of timbers of different ages so that one group will overlap another, and after combining them by crossdating, we may bridge over a great many hundred years in the past." Wissler's response to this suggestion was to send more beams from Pueblo Bonito, collected many years before during excavations by the Hyde Expedition. Without undue effort these sections crossdated well with each other.

But a great step forward was achieved when it was found that the Pueblo Bonito logs crossdated with the sections from Aztec. Thus Douglass was able to announce that Aztec was constructed 40 to 45 years later than Pueblo Bonito (Douglass 1921:28). This event consumated the marriage between tree-ring dating and archaeology, and for the next 20 years Douglass concentrated on chronology building.

In 1922, Neil M. Judd, who had begun work under National Geographic Society auspices at Pueblo Bonito the previous year, encouraged the Society to support the approach that Douglass had suggested in 1919. Thus a program was established to gather successively older groups of beams back from the present with the specific objective of dating Pueblo Bonito (Judd 1930:169-71).

The First Beam Expedition, sponsored by the National Geographic Society, operated in 1923 under the field leadership of J.A. Jeançon of the State Historical and Natural History Society of Colorado and O.G. Ricketson of the Carnegie Institution of Washington. They collected about 100 beam specimens from occupied pueblos, historic mission churches, and prehistoric ruins from the Hopi Mesas to the Rio Grande and to Mesa Verde. Douglass in the meantime obtained additional beams from Wupatki, a ruin northeast of Flagstaff, Arizona. It was hoped that the sections from the Hopi villages and from the mission churches would crossdate at the early end of the chronology developed from living trees and, in turn, extend back far enough to crossdate with the outer rings of the prehistoric specimens. Although the desired result was not immediately achieved, it was recognized by the nature of the crossdating of many of the specimens that the entire area of collection acted as a climatic unit as regards tree growth. This crossdating also resulted in placing other ruins within the relative date chronology first developed from the Aztec and Pueblo Bonito beams. One ruin so placed was Wupatki. The link with the living tree chronology remained elusive, however.

In addition, a second relative or "floating" chronology was developed from Wupatki specimens that did not immediately crossdate with the established relative chronology. This was termed Citadel Dating, as it included the ring record of a specimen from the Citadel, a ruin near Wupatki. Other ruins also fitted into this second chronology, including samples from Mummy Cave Tower in Canyon de Chelly and sections from the classic cliff dwellings of Mesa Verde.

This second chronology was approximately 140 years long without any suggestion of its correct placement in time. On the basis of ceramic seriation, however, Judd assured Douglass that it should fall between the living tree chronology and the one developed from Aztec and Pueblo Bonito beams.

As analyses proceeded on the collections made by the First Beam Expedition, more and more specimens gradually yielded to crossdating within one or the other of the two relative chronologies. These two were ultimately merged, in 1928, to form a single chronology of prehistoric ruins with a length of 585 years. The status, then, of chronology building early in 1928 consisted of two long records. The absolute chronology extended from the present back to about 1400 with confidence, and weakly – because it was based on few trees – to about 1300. The other was a floating chronology of 585 years of unknown absolute age based on specimens from approximately 30 prehistoric ruins.

In an attempt to strengthen the chronology before 1400, the Second Beam Expedition was organized in the summer of 1928 under the field supervision of Lyndon L. Hargrave. Since it was already known that material in the early end of the known time scale, was present at the Hopi village of Oraibi, the expedition concentrated on early historic beams throughout the Hopi villages. Emphasis was placed on the abandoned sections of Oraibi and on beams that exhibited stone axe-cut beam ends. In all, over 200 specimens were collected from Oraibi and other Hopi villages.

Since the chronology had already been developed for most of the time period represented by the new specimens, over 140 were quickly crossdated by Douglass into the known sequence, and he succeeded in extending the chronology back to near 1300 with confidence. A single specimen seemed to carry the series even farther back to about 1260. Still no crossdating was evident with the floating chronology of the prehistoric ruins.

Toward the end of the summer Hargrave collected from ruins in the Jeddito area, just east of the extant Hopi villages, with the hope that the material there would predate Oraibi. Earl H. Morris was excavating at Kawaikuh and was encouraged to look for and send charcoal or wood from his excavations to Douglass. In October of that year a piece of charcoal from Morris' excavations crossdated with the living tree series in the 15th century. Thus Kawaikuh has a double distinction: it was the first prehistoric ruin tied to calendar dates by the tree-ring method and it provided the first charcoal for dating. This latter success opened up a new and less restrictive source of material.

Shortly afterward, material from two other ruins was successfully crossdated into the known chronology. These were Kokopnyama in the Jeddito area and Chaves Pass southeast of Flagstaff, both dating in the 14th century.

The Second Beam Expedition, then, provided the first prehistoric ruin dates and served to extend and strengthen the known chronology, but no overlap was yet established with the 585-year long relative chronology that included the chronology from Pueblo Bonito.

It was evident by the close of 1928 that the collection of the proper material to close the gap, as it became known, would have to change from more or less random, easily obtainable, collections to excavation. Late in the 1928 Expedition much attention was paid to the pottery assemblage of the sites, and it soon became evident to Hargrave, Judd, and Douglass that the latest sites in the relative dating chronology were characterized by red background polychrome pottery, whereas the earliest sites in the known chronology had orange and yellow background pottery. The search was then on for sites that fulfilled a threefold qualification: first, a site must be ceramically placed between ruins with orange and yellow pottery at the early end of the known chronology and the latest prehistoric ruins such as Kiet Siel, in Tsegi Canyon, with red background polychrome; second, a site must evidence burning in order that preservation be possible in the form of charcoal; and third, a site must lie in or near pine forests (Figure 1). Of all the candidates, the ruins of Pinedale, Showlow, Kin Tiel, and Kokopnyama were chosen as the most likely.

Excavations were begun in June, 1929, at the Showlow Ruin by Hargrave and Emil W. Haury (Haury 1962:12). On completion of that work, Haury went on to excavate at the Pinedale Ruin while Hargrave undertook Kin Tiel and Kokopnyama (Haury and Hargrave 1931).

The solution to the problem came quickly. Toward the end of June, Douglass and Neil M. Judd visited Haury and Hargrave at Showlow to check on the progress. One charred log, designated in the field as HH-39, seemed very promising. It had an outside ring near 1380 and extended back to 1237 (Haury 1962:13). It did not, however, immediately crossdate with the prehistoric sequence. That night Douglass, whose memory for ring sequences was phenomenal, mentally reviewed HH-39 against the known and relative chronologies and by the next morning was satisfied that it crossdated with the relative chronology in such a way that the gap was closed between the two series. Actually, no gap had existed. Rather, an overlap of about 25 years had been present but unrecognized because only one specimen (BE-269) of the known chronology extended inside 1300 and because of the extreme variability of the growth pattern between 1276 and 1299 – a period soon characterized as the Great Drought. Later many pieces of charcoal from both Showlow and Pinedale verified the merging of the two series and strengthened this segment of the total chronology.

Figure 1. A.E. Douglass coring in the Forestdale Valley, south of Show Low. The picture was probably taken in May, 1929, just before the successful work at the Showlow Ruin closed the "gap."

Thus, nearly 40 prehistoric Southwestern ruins were dated in terms of the Christian calendar (Douglass 1935:41-5) and an absolute chronology was developed based on tree-ring patterns from 1929 back to about 700.

ABSOLUTE DATING (1929-1950)

After the joining of the two chronologies into a single one of over 1200 years, much of the effort in the succeeding 30 years was directed toward extending the chronology back in time and toward strengthening and detailing many segments of the established chronology. Both of these efforts had the side effect of dating hundreds of prehistoric ruins.

Shortly after the gap was closed a charcoal specimen was submitted by Earl H. Morris in 1931 from the La Plata district (Morris 1939) that bound together several short floating chronologies into a longer, but unplaced, series of 356 years. This was referred to as the Johnson Canyon Dating (JCD) by Douglass (1946:9). As has happened so many times before and after, this floating chronology did not crossdate with any known sequence. Shortly thereafter, however, in 1932, a piece from the ruin of Chetro Ketl in Chaco Canyon was dated from roughly A.D. 650 to 800 and, on its inner series, crossdated with the JCD. This, then, tied the Johnson Canyon dating sequence to the known chronology and extended the latter back to 475. The crossdating was confirmed by an excellent specimen excavated from the ruin at Allantown, Arizona, by Frank H.H. Roberts, Jr. (1939).

As early as 1927 Douglass had recognized yet another floating chronology which he termed the Early Pueblo Dating (EPD) that was based on specimens from Mummy Cave in Canyon del Muerto (Douglass 1946:9). Further collections were made in 1930 and 1931 by Earl H. Morris from Mummy Cave and from caves – notably Broken Flute and Obelisk (E.A. Morris 1959) – in the Red Rock district of northeastern Arizona. These were of high dating quality and soon allowed Douglass to identify the ring patterns in the known chronology and again make a leap back to A.D. 11. Thus by 1933 the Southwestern tree-ring chronology had attained a length of nearly 2000 years.

The last significant work until very recently on the backward extension was achieved by Edmund Schulman. Just before the Second World War, Douglass received a number of specimens from Earl H. Morris from very early sites in the area of Durango, Colorado (Morris and Burgh 1954). Although Douglass was able to date some of these in the first few centuries A.D., the war interrupted complete analysis. After the war Schulman, who was both a student and associate of Douglass, took up the work where Douglass had left it (Schulman 1949a, 1949b). Schulman's work was greatly aided by a long piece, collected by Deric O'Bryan of Gila Pueblo, from Mummy Cave that extended the known chronology to 59 B.C. Although this piece still held the distinction of containing the oldest dated ring, its series allowed placement of many of the specimens from the Durango area. As a consequence, the earliest outside, and therefore archaeological, date was placed at 20 B.C. and the earliest established bark, or actual death, date at A.D. 46 (Schulman 1952).

In the midst of this activity, the Laboratory of Tree-Ring Research was formally established at the University of Arizona in December 1937. A.E. Douglass was joined by E.W. Haury, Anthropology, and E.F. Carpenter, Astronomy, on the initial staff. Douglass continued to serve as Director nearly until his death in 1962 as both research interests and staff increased with increasing applications of dendrochronology.

In the two decades between 1930 and 1950, other individuals and institutions also became involved in tree-ring studies, particularly from the archaeological point of view. At the Museum of Northern Arizona, John C. McGregor, who had been trained by Douglass, engaged in independent tree-ring studies from 1930 to 1940. Basing his work on that begun by Douglass in the areas around Flagstaff and in the Tsegi Canyon – Marsh Pass area, McGregor (1934, 1936a, 1936b, 1938) established chronologies and dated many ruins under investigation by the Museum of Northern Arizona. His work was partially reviewed by Harlan (1962).

Douglass recognized certain discrepancies in the ring patterns of material from east of the Continental Divide in New Mexico as early as the First Beam Expedition. He suggested, therefore, shortly after 1930 that an independent chronology-building program be based at a New Mexico institution to pursue the so-called Rio Grande chronology with the same methodology that had culminated in success west of the Divide. W.S. Stallings, Jr., another of Douglass' students, was soon at work at the Laboratory of Anthropology in Santa Fe. He used the method suggested and started to build back from growing trees to Spanish missions and historic pueblos to late prehistoric ruins, and so back. Stallings began in 1931 and, perhaps because of the lessons in chronology building already learned, had soon extended the Rio Grande chronology back to A.D. 930 (Stallings 1939:16). The Second World War interfered with the research program, and the study of Stallings' collection was continued and completed by Smiley, Stubbs, and Bannister (1953).

The fourth and last institution to engage seriously in tree-ring studies was Gila Pueblo in Globe, Arizona, under the direction of Harold S. Gladwin. The first dating of material was done by Emil W. Haury (1931, 1934, 1936) using Douglass' methods. Soon, however, Gladwin embarked on different techniques inspired by his lack of confidence in, and inability to use, Douglass' methods (Gladwin 1940:9). He was concerned mainly with the use of subjective judgments on relative ring widths and sought a more quantitative method of recording and manipulating ring widths. These efforts led to a series of disputes with archaeological sequences and chronological associations that had been established by followers of Douglass (Gladwin 1943, 1944, 1946, 1947). Although Douglass never directly refuted the methods used by Gladwin, Douglass' methods have survived the test of time and are in general use today.

Most of the dating work produced by Gladwin and those associated in his method was never published. Gila Pueblo did, however, accumulate a large collection of tree-ring specimens through excavation and, in 1940 and 1941, through the collection activities of Deric O'Bryan, then a member of the Gila Pueblo staff. This collection duplicated by site, and often by actual beam, many of the samples already in the collections of the Laboratory of Tree-Ring Research.

By 1950 all these institutions had ceased their efforts in tree-ring dating and ultimately the collections were transferred to the Laboratory of Tree-Ring Research for preservation and further analysis.

As a result of the efforts of the Laboratory of Tree-Ring Research only, Smiley (1951:6) was able to compile tree-ring data that listed over 5600 individual dated specimens from 365 Southwestern sites. This valuable work served for more than a decade as the basic reference to prehistoric chronology in the Southwest. Three years later, a similar summary was published (Smiley, Stubbs, and Bannister 1953) based on the collections made by W.S. Stallings, Jr. for the Laboratory of Anthropology and concentrated in the northern Rio Grande. This effort ushered in a decade in which archaeological tree-ring dating was relatively inactive for the first time in thirty years.

From 1953 to approximately 1963, the Laboratory of Tree-Ring Research gave less emphasis to its archaeological program with Douglass returning to climatic research until his death in 1962 and T.L. Smiley's increasing interest in the broader aspects of geochronology (Smiley 1955). Despite this trend, however, Bannister (1965) continued a research interest in archaeological tree-ring dating which resulted in an important statement on the interpretation of tree-ring dates (Bannister 1962, 1963). In addition, this period saw the Laboratory involved in the dating of structures to establish periods of land use for the Navajo Land Claim (Stokes and Smiley 1963, 1964, 1966, 1969). Nearly 4,000 samples were collected from about 400 structures lying for the main part beyond present boundaries of the Navajo Reservation or within disputed areas such as the Navajo-Hopi Joint Use Area. The dating information derived from this project was presented as evidence during the Navajo Land Claim. Although this material must contain an abundance of information bearing on the dynamics of Navajo settlement for the past 300 years, little effort has been expended to extract it.

Another research effort during this period was directed toward the objective of dating the ruins at Casas Grandes, Chihuahua (Scott 1966). Crossdating was established for the construction beams of Casas Grandes, but possibilities of an absolute chronology appeared dim due to the failure to find living trees of sufficient age to crossdate with other archaeological chronologies from far to the north. Ultimately, a statistical correlation procedure was used to establish absolute dates for Casas Grandes and some of the Sierra Madre cliff dwellings (Scott 1966:69-72).

Finally, tree-ring dating was passively involved with the large reclamation projects of the late 1950s such as Glen Canyon and Navajo Reservoir (Harlan 1966), processing large amounts of material with little feedback from the archaeologist. Somewhat more successful was the involvement with the Wetherill Mesa Project (Nichols and Harlan 1967) which marked the rebirth of the study of the climatic variations inherent in tree-rings (Fritts, Smith, and Stokes 1965).

RECENT APPLICATIONS

The past decade has seen a revitalization of the uses of tree-ring dating in archaeological problems of both a purely chronological and of a non-chronological nature.

The advances in dating grew from the recognition in the early 1960s that the full scientific potential of tree-ring dating was yet to be realized. There were, at that time, vast accumulations of unstudied material, a large portion of the samples studied up to that time lacked quantitative documentation, and dating results presented by different individuals and institutions were in a confusing array of formats leading to increasing misunderstanding in interpretation. The Laboratory of Tree-Ring Research undertook to rectify these shortcomings with a now-completed project of review and reassessment. This project has yielded an impressive array of dating statistics and a series of publications which present the data for the first time in a complete and systematic manner. Thus, in the Southwest, there are currently over 20,000 tree-ring dates available from 1,320 separate sites. The sites range in time from near modern historic buildings to Basketmaker II pit houses and include Spanish colonial occupations, Navajo and Pueblo Indian dwellings, and a wide assortment of prehistoric structures and features. The longest of the Southwestern tree-ring chronologies developed now extends to 322 B.C. (Dean 1975).

Concurrent with the dating of archaeological samples and the strengthening of regional chronologies, Southwestern dendrochronologists have increasingly focused on the development of new concepts and techniques for more rigorous archaeological interpretations through the use of tree-ring data. For example, Robinson (1967) examined both dated and undated tree-ring samples for evidence bearing on the prehistoric practice of felling trees for construction purposes (seasonal patterning, felling on a communal or an individual basis, tools and felling methods employed); others have investigated such culture-related activities as the stockpiling of timbers for future construction (Bannister 1965:151), the use of freshly cut beams for repair purposes, the reuse of wood salvaged from older structures, and the differential utilization of various species of tree available to the builders. Under favorable circumstances where large numbers of dates have been obtained from a single site or a group of related structures, and where close provenience control of the specimens has been maintained, detailed analyses of both inter- and intra-site relationships have yielded archaeological information which far transcends simple time placement (Dean 1969). Information on the nature of social units may also be derived from an analysis of village growth (Dean 1969:190-192).

A parallel potential for tree-ring dating in ethnographic studies would seem to be obvious, although generally unexploited. In addition to clarifying settlement dynamics by intensive areal sampling, alluded to in the preceding discussion of the Navajo Land Claim, tree-ring dating could profitably be included in investigations of village growth and development among sedentary peoples such as the Southwestern Pueblo. Precise chronology developed by dendrochronology would be of considerable value in all problems of stability and change.

Problems of prehistoric environment may be approached through two routes utilizing tree-ring data. The first involves the comparison of the prehistoric assemblage of tree species represented at an archaeological site or area with the tree species presently growing in the same area. This approach provides insight into the changes undergone by the local environment in the years between the two points of comparison, but suffers from potential sampling errors. The second and much more powerful approach lies in the analysis of the relationships between variations in ring width and fluctuations in the tree's external environment.

Although the variability of ring widths in tree-ring series from drought sensitive conifers in the semiarid American Southwest has long been known to contain a significant amount of climatic information (Douglass 1914; Schulman 1956), recent research in dendroclimatology has produced a number of powerful analytical techniques for extracting this information (Fritts 1965, 1974; Fritts and others 1971). Long ring-width chronologies, constructed of ring series from many individual trees, provide data on annual variability in rainfall and temperature during the time spans encompassed by the chronologies. Thus, tree-ring chronologies derived from archaeological materials from the American Southwest provide a vast reservoir of information on past fluctuations in climate throughout most of the region. These data on climatic variability over the past two millennia are just beginning to be tapped.

The Laboratory of Tree-Ring Research has constructed a network of dendroclimatic chronologies based on archaeological materials from many areas within the Southwest. Merging the archaeological chronologies with tree-ring series from living trees growing near the same sites will produce a network ranging from the present far into prehistoric times.

The specially-constructed network of dendroclimatic chronologies provides a basis for rather detailed reconstructions of relative areal and temporal variability in climatic conditions during the last 2000 years (Dean and Robinson, in press). Such reconstructions are vital to an adequate understanding of the adaptations of plant, animal, and human populations to changing environmental conditions. The reconstructed variations in past precipitation and temperature can be compared with known events in prehistory – migrations, abandonments, subsistence shifts, population changes, etc. – to estimate the possible effects of environmental changes on past human behavior.

Thus, the ideal conditions for tree-ring analysis that prevail in the American Southwest, coupled with the long history of dendrochronological effort undertaken there, have culminated in the establishment of the finest prehistoric temporal controls in the world. It is precisely because these controls exist that the southwestern United States has become a laboratory for recent trends in behavioral archaeology. Prehistoric settlement patterns, population movements, demographic estimates, rates of culture change, and evolution of style can now be studied with a precision not otherwise obtainable in the absence of such refined chronological control. The association between tree-ring dating and archaeology that began as little more than idle curiosity has developed into a strong and necessary relationship.

REFERENCES

Bannister, Bryant
1962 The interpretation of tree-ring dates. *American Antiquity* 27:508-514.
1963 Dendrochronology. In *Science in archaeology*, edited by Don Brothwell and Eric Higgs, pp. 162-176. Basic Books, New York.
1965 Tree-ring dating of the archeological sites in the Chaco·Canyon region, New Mexico. *Southwestern Monuments Association, Technical Series* 6, part 2.

Dean, Jeffrey S.
1969 Chronological analysis of Tsegi phase sites in northeastern Arizona. *Papers of the Laboratory of Tree-Ring Research* 3.
1975 *Tree-ring dates from Colorado W: Durango area.* Laboratory of Tree-Ring Research, The University of Arizona, Tucson.

Dean, Jeffrey S. and William J. Robinson
n.d. Dendrochronology of Grasshopper Pueblo. In "Multidisciplinary research at the Grasshopper Ruin," edited by W.A. Longacre. *Anthropological Papers of The University of Arizona* (in press).

Douglass, A.E.
1914 A method of estimating rainfall by the growth of trees. In "The climatic factor," by Ellsworth Huntington, pp. 101-122. *Carnegie Institution of Washington Publication* 192.
1921 Dating our prehistoric ruins. *Natural History* 21:27-30.
1935 Dating Pueblo Bonito and other ruins of the Southwest. *National Geographic Society, Contributed Technical Papers, Pueblo Bonito Series* 1.
1946 Researches in dendrochronology. *University of Utah Bulletin* 37(2), *Biological Series* 10(1).

Fritts, Harold C.
1965 Tree-ring evidence for climatic changes in western North America. *Monthly Weather Review* 93:421-443.
1974 Relationships of ring widths in arid-site conifers to variations in monthly temperature and precipitation. *Ecological Monographs* 44:411-440.

Fritts, Harold C., David G. Smith, and Marvin A. Stokes
1965 The biological model for paleoclimatic interpretation of Mesa Verde tree-ring series. In "Contributions of the Wetherill Mesa archeological project," assembled by Douglas Osborne, pp. 101-121. *Memoirs of the Society for American Archaeology* 19.

Fritts, Harold C., T.J. Blasing, Bruce P. Hayden, and John E. Kutzbach
1971 Multivariate techniques for specifying tree-growth and climate relationships and for reconstructing anomalies in paleoclimate. *Journal of Applied Meteorology* 10:845-864.

Gladwin, Harold S.
1940 Tree-ring analysis: Methods of correlation. *Medallion Papers* 28.

Gladwin, Harold S., continued
1943 A review and analysis of the Flagstaff culture. *Medallion Papers* 31.
1944 Tree-ring analysis: Problems of dating I: The Medicine Valley sites. *Medallion Papers* 32.
1946 Tree-ring analysis: Problems of dating II: The Tusayan Ruin. *Medallion Papers* 36.
1947 Tree-ring analysis: Three-rings and droughts. *Medallion Papers* 37.

Harlan, Thomas P.
1962 A sequence of ruins in the Flagstaff area dated by tree-rings. Unpublished master's thesis, Department of Anthropology, The University of Arizona, Tucson.
1966 Tree-ring dates from the Navajo Reservoir district. In "Prehistory in the Navajo Reservoir district, northwestern New Mexico," by Frank W. Eddy, pp. 516-522. *Museum of New Mexico Papers in Anthropology* 15.

Haury, Emil W.
1931 Kivas of the Tusayan Ruin, Grand Canyon, Arizona. *Medallion Papers* 9.
1934 The Canyon Creek Ruin and the cliff dwelling of the Sierra Ancha. *Medallion Papers* 14.
1936 The Mogollon culture of southwestern New Mexico. *Medallion Papers* 20.
1962 HH 39: Recollections of a dramatic moment in Southwestern archaeology. *Tree-Ring Bulletin* 24:11-14.

Haury, Emil W. and Lyndon L. Hargrave
1931 Recently dated pueblo ruins in Arizona. *Smithsonian Miscellaneous Collections* 82(11).

Judd, Neil M.
1930 Dating our prehistoric pueblo ruins. *Explorations and Field-Work of the Smithsonian Institution in 1929*, pp. 167-176.

McGregor, John C.
1934 Dates from Tsegi. *Tree-Ring Bulletin* 1:6-8.
1936a Dates from Tsegi and Nalakihu. *Tree-Ring Bulletin* 3:15-16.
1936b Additional dates from Tsegi. *Tree-Ring Bulletin* 2, p. 37.
1938 Southwestern dated ruins: III. *Tree-Ring Bulletin* 4, p. 6.

Morris, Earl H.
1939 Archaeological studies in the La Plata district. *Carnegie Institution of Washington Publication* 519.

Morris, Earl H. and Robert F. Burgh
1954 Basket Maker II sites near Durango, Colorado. *Carnegie Institution of Washington Publication* 604.

Morris, Elizabeth Ann
1959 Basketmaker caves in the Prayer Rock district, northeastern Arizona. Unpublished Ph.D. dissertation, Department of Anthropology, University of Arizona, Tucson.

Nichols, Robert F. and Thomas P. Harlan
1967 Archaeological tree-ring dates from Wetherill Mesa. *Tree-Ring Bulletin* 28:13-28.

Roberts, Frank H.H., Jr.
1939 Archeological remains in the Whitewater district, eastern Arizona. Part 1, House types. *Bureau of American Ethnology Bulletin* 121.

Robinson, William J.
1967 Tree-ring materials as a basis for cultural interpretations. Unpublished Ph.D. dissertation, Department of Anthropology, The University of Arizona, Tucson.

Schulman, Edmund
1949a Early chronologies in the San Juan basin. *Tree-Ring Bulletin* 15:24-32.
1949b An extension of the Durango chronology. *Tree-Ring Bulletin* 16:12-16.
1952 Extension of the San Juan chronology to B.C. times. *Tree-Ring Bulletin* 18:30-35.
1956 *Dendroclimatic changes in semiarid America.* University of Arizona Press, Tucson.

Scott, Stuart D.
1966 Dendrochronology in Mexico. *Papers of the Laboratory of Tree-Ring Research* 2.

Smiley, Terah L.
1951 A summary of tree-ring dates from some Southwestern archaeological sites. *University of Arizona Bulletin* 22, *Laboratory of Tree-Ring Research Bulletin* 5.

Smiley, Terah L., editor
1955 Geochronology, with special reference to southwestern United States. *University of Arizona Bulletin* 26(2), *Physical Science Bulletin* 2.

Smiley, Terah L., Stanley A. Stubbs, and Bryant Bannister
1953 A foundation for dating of some late archaeological sites in the Rio Grande area, New Mexico: Based on studies in tree-ring methods and pottery analyses. *University of Arizona Bulletin* 24(3), *Laboratory of Tree-Ring Research Bulletin* 6.

Stallings, W.S., Jr.
1939 Dating prehistoric ruins by tree-rings. *Laboratory of Anthropology, General Series, Bulletin* 8.

Stokes, Marvin A. and Terah L. Smiley
1963 Tree-ring dates from the Navajo Land Claim. I: The northern sector. *Tree-Ring Bulletin* 25:8-18.
1964 Tree-ring dates from the Navajo Land Claim. II: The western sector. *Tree-Ring Bulletin* 26:13-27.
1966 Tree-ring dates from the Navajo Land Claim. III: The southern sector. *Tree-Ring Bulletin* 27:2-11.
1969 Tree-ring dates from the Navajo Land Claim. IV: The eastern sector. *Tree-Ring Bulletin* 29:2-15.