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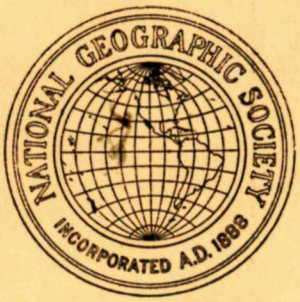
PUEBLO BONITO SERIES NUMBER 1

Dating Pueblo Bonito and Other Ruins of the Southwest

By

A. E. DOUGLASS

Director of Steward Observatory
University of Arizona



WASHINGTON
1935

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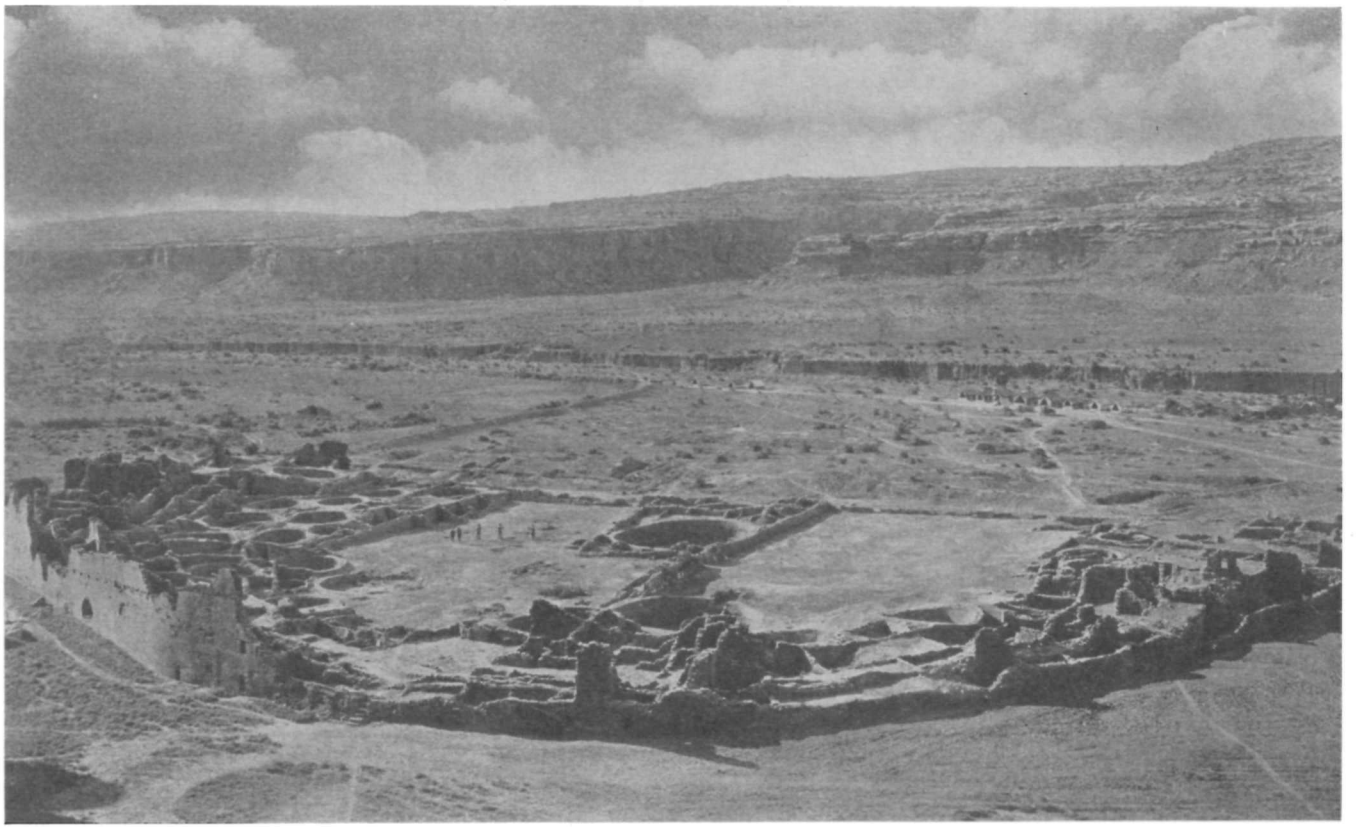
TABLE OF CONTENTS



Photograph from National Geographic Society

PUEBLO BONITO, WHOSE DATING BY TREE RINGS WAS ACCOMPLISHED AFTER 10 YEARS' STUDY

The oldest timber recovered here was cut A. D. 919; a major period of construction occurred between 1050 and 1085.

FOREWORD

Upon recommendation of Dr. Gilbert Grosvenor, President, and of Dr. Frederick V. Coville, Chairman of its Research Committee, the National Geographic Society invited me in 1920 to make an archeological reconnaissance of the Chaco Canyon area, northwestern New Mexico, where stand some of the most notable ruins in North America. Following that survey, The Society undertook exploration of Pueblo Bonito, largest and oldest of the principal Chaco Canyon ruins, and of Pueblo del Arroyo, its nearest neighbor. Beginning in 1921, and continuing to their conclusion in the autumn of 1927, annual investigations at these two prehistoric villages were conducted by the National Geographic Society under the leadership of the undersigned.

Our archeological researches were planned to disclose, as fully as possible, the distinctive civilization of the Bonitians. We hoped to be able to suggest the conditions under which they lived; to solve the mystery of their cultural rise and fall. Today Chaco Canyon is a semi-arid waste that repels all but a few scattered Navajo families. Was it so a thousand years ago?

We hoped to discover the methods whereby the not inconsiderable population of Pueblo Bonito attained economic independence and far-flung communal prestige in a region where agriculture is now all but impossible. We sought to learn the connection, if any, between the 17 major ruins and the hundreds of lesser structures within the borders of the Chaco Canyon National Monument. Our 1920 reconnaissance disclosed evidence suggesting that pine forests were readily accessible to the builders of Pueblo Bonito. Did these ancients exhaust those forests and, if so, what penalties did they pay? What was the resultant effect upon their water supply, upon their agricultural practices, and upon the physical appearance of Chaco Canyon itself? These and many other questions were before us as we began our investigations in the early summer of 1921. The better to solve such problems as lay beyond our own experience, specialists of national reputation were invited to cooperate with us.

Among the latter was Dr. A. E. Douglass, Director of Steward Observatory at the University of Arizona, whose newly formulated "tree ring technique" then seemed a fairly promising means of extending our historical calendar back into prehistoric times. As an astronomer, Dr. Douglass was naturally interested in sun spots and their apparent relation to climate. Pursuit of this interest had led to his observation that growth rings of newly felled pines in the forests of northern Arizona often were strikingly similar; that rings for a given sequence of years were occasionally duplicated, even in trees from widely separated localities; that annual growth

rings could be accepted as trustworthy gauges for estimating rainfall in past centuries.

These observations had in due course come to the attention of Dr. Clark Wissler, of the American Museum of Natural History, who immediately saw in them a possible archeological application and who generously furnished toward this end sections of timbers gathered by his aids from Pueblo ruins in New Mexico. When, in 1918, Dr. Wissler inquired whether it were possible to determine the comparative ages of Pueblo Bonito and Aztec Ruin, the now famous "tree ring calendar" was definitely launched. For Dr. Douglass replied by giving not only the time of year during which groups of beams from each ruin were cut but the actual number of years separating the two groups. Thus students of prehistory will never cease to be grateful to the American Museum, which supplied the material, and to Dr. Wissler, who furnished the incentive, for that initial query which ultimately led to the successful dating of Pueblo ruins.

As previously stated, at the very inception of The Society's Pueblo Bonito explorations, Dr. Douglass accepted our invitation to advise with us. We knew the relative age of the great ruin but desired, if possible, to ascertain its actual age. Tree-ring chronology appeared the most feasible means toward this end. We saved sections of the larger timbers exposed during our 1921 excavations and were agreeably surprised at the information Dr. Douglass derived from them. Methods of procedure were still uncertain at that time and I strongly suspect our astronomical colleague was more intent upon sun spot influences than the age of Pueblo Bonito. The very idea of dating prehistoric ruins from their old ceiling beams seemed altogether fantastic and I readily confess that I was none too sanguine as to the outcome, even though I could vaguely picture a succession of annual growth rings leading from living forests back across the broken walls of 17th-century missions to ruins which surviving Pueblo clans claimed as their ancestral homes.

It was not until December, 1922, while listening to data presented by Dr. Douglass before a group called by the Carnegie Institution of Washington to consider cyclic phenomena, that this whole gossamer fancy suddenly crystallized into reasonable certainty for me. It was purely an inspiration and one for which I claim little credit. But I was confident that, with patience, the unknown distance between existing forests and the charred timbers of Pueblo Bonito could eventually be crossed. The actual age of Pueblo Bonito became a definite objective. Dr. Douglass agreed to examine all samples collected; the National Geographic Society's Committee on Research earnestly recommended the necessary search and allotted the necessary funds. Thus came about the three Na-

tional Geographic Society beam expeditions, whose magnificent results Dr. Douglass first described in an article entitled "The Secret of the Southwest Solved by Talkative Tree Rings" in the NATIONAL GEOGRAPHIC MAGAZINE for December, 1929, and which he presents more fully in the following pages.

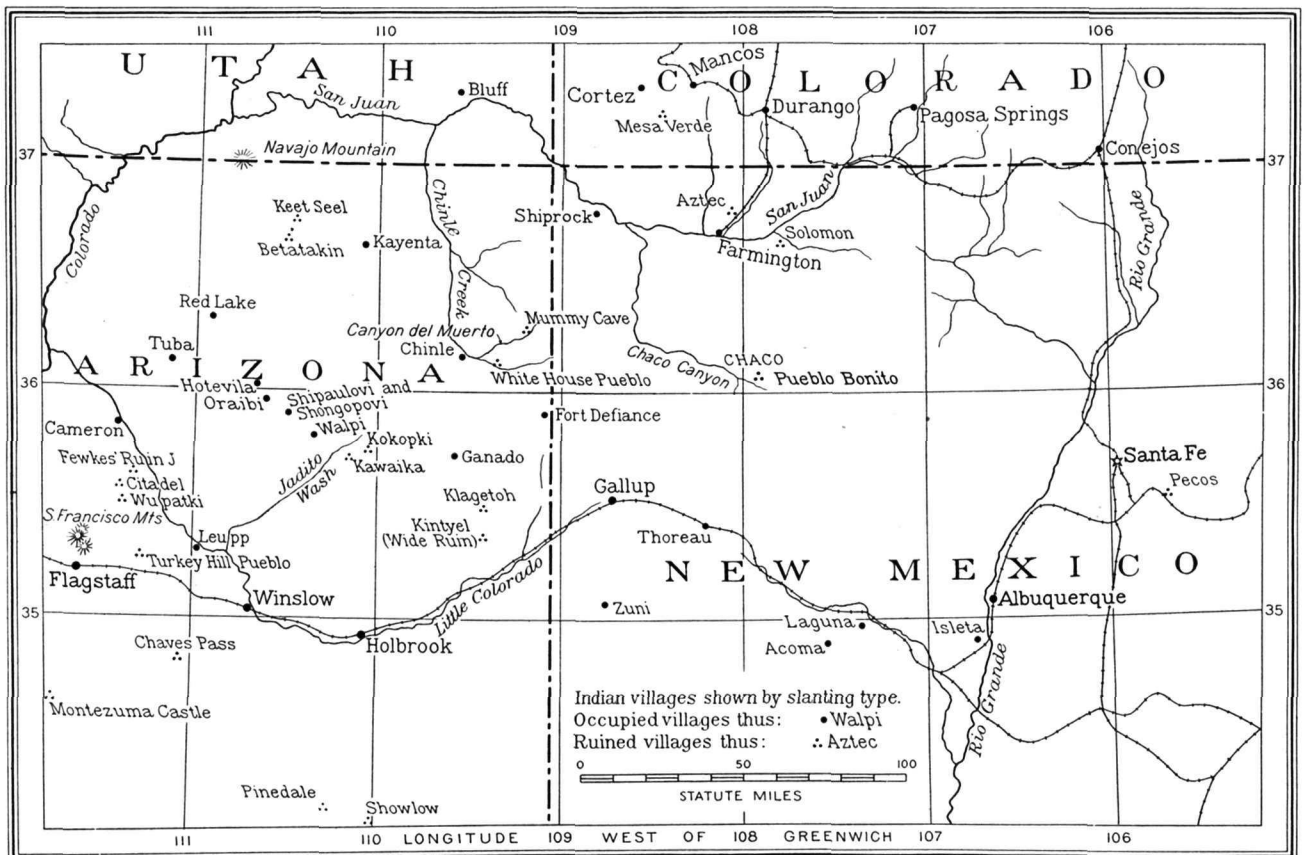
Beginning as a more or less casual inquiry into climatic influences, expanding into a study of natural factors influencing growth, and then suddenly turning from the main trail into a by-path that led to an entirely different goal, these researches throughout furnish an incomparable example of precision of method. Cross-identification of annual growth rings in different trees from the same forests, extended to the different timbers of a prehistoric ruin, and then to fragments of charred ceiling beams in various ruins became a time leveler that culminated in the dating not only of Pueblo Bonito but of more than 40 other southwestern ruins abandoned prior to the Spanish conquest; that lengthened our American calendar by nearly eight centuries beyond Columbus' memorable voyage of 1492 and gave us an unbroken climatic record 1200 years in extent.

And the end is not yet! Dr. Douglass has in hand another floating chronology, based chiefly upon material collected by Mr. Earl H. Morris, that eventually will join the present series and reach backward to date the rude structures of the so-called Basket Makers. And who may predict what facts climatologists will deduce from this constantly lengthening sequence of annual growth rings? It is somewhat embarrassing to an archeologist to admit that the most important contribution to American archeology in the past quarter century has been made by an astronomer. But all archeologists will readily join me in paying tribute to the tree ring technique developed by Dr. Douglass and in congratulating him upon the unparalleled achievements already attained.

It was my original desire to see the findings of The Society's Pueblo Bonito explorations published at one time, together with the observations of those cooperating with us. Circumstances quite beyond my control have conspired, however, to delay completion of those sections I delegated to myself. For this reason it now seems preferable to abandon the earlier intention and issue our results in a number of independent papers to be known as the Pueblo Bonito Series. Dr. Douglass' monograph is the first of these; others will follow as opportunity offers.

NEIL M. JUDD,
Leader of the National Geographic Society's Pueblo Bonito Expeditions.

Washington, D. C.
February 23, 1935.



Drawn by A. H. Bumstead, Chief Cartographer, National Geographic Society

TREE RINGS HAVE DATED INDIAN RUINS SCATTERED OVER A WIDE AREA IN THE SOUTHWEST

DATING PUEBLO BONITO AND OTHER RUINS OF THE SOUTHWEST

By A. E. Douglass

Director of Steward Observatory
University of Arizona

I

THE METHOD

The following pages describe the first application of a new method of dating prehistoric ruins, the tree ring method. Its general principles had been discovered in previous climatic work, but much of its development for archeological purposes took place in solving, for the National Geographic Society, a definite problem: namely, the age of Pueblo Bonito, a great thousand-room ruin in northwestern New Mexico (see page 2). This prehistoric Indian village, with its stone walls and adobe roofs supported on large logs, is perhaps the most famous of the thousands of ruins in the Pueblo area of our southwestern United States, that semi-arid region where the ancient work of primitive man has been well preserved for study in our time.

With everyone on seeing these ruins the first thought is, When were they built? For many of them, this question need no longer go unanswered because the same dry country that has preserved these evidences of former habitation has produced this method of measuring the exact age of the ruins and even of outlining a partial story of the drouth troubles that forced their abandonment. It is a story written in trees—a diary of struggles for food supply—strongly marked in the same ruthless drouth years that destroyed the great Indian villages by ruining the food crops. The story we have partly deciphered was written by Mother Nature within the tree trunks, with signs and glyphs placed each year in layer after layer of wood cells forming the annual rings of growth in the pines of northern Arizona (see illustration, page 9).

Our study of that writing began years ago in an attempt to solve certain astronomical problems related to solar changes and their indirect effects on tree growth. This relation takes place through rainfall, whose quantity we believe to be influenced by radiation from the sun. Rainfall in turn, in our dry climate, produces definite effects in the ring growth of pine and fir trees. Such effects are best seen by noting carefully the irregularity of ring size in any radial line from center to bark, such as partly shown on page 11, upper left. Unexpected differences of size, here larger, there smaller,

provide the steps of a ladder on which we descend into the past. Very small rings and the exact intervals between them become absolutely characteristic of groups of years, 10 to 50 in number, and lead to their recognition when seen. An example of such a definite arrangement of rings characteristic of an ancient decade also is shown on page 11, upper left figure.[1]

By careful study we have found that each year the trees near the forest-desert boundary in the Pueblo area respond to heaven's gracious supply of rain and grow more if the supply is above the average and less if it is not. These unexpected variations from year to year, which have caused the failures of the weather prophet, provide us with a key to unlock the secrets of the past, for they produce in the trees irregular successions of large and small rings that, as a group, have not been duplicated in the past twelve centuries, but are reproduced with marvelous exactness in thousands of different trees living at the same time. This duplication from tree to tree we recognize and by its aid we can identify with precision the rings that grew in each particular year.

Perhaps it will prove helpful if I indicate at this point the method by which tree rings may reveal the age of a prehistoric ruin. Ancient roof logs, like recently felled pines, contain a definite and precise succession of annual growth rings (page 11, upper left) any one of which may be nearly identical throughout the Pueblo area and yet given groups of which have not been duplicated closely in a millennium. On examining an old beam the first question is: Do its annual rings include any sequence found also in living trees or in those felled in a known year? Our record of these modern trees reaches back 500 years. If we find in that record the particular sequence sought, our problem is solved at once. We merely count from the latest dated ring back to the group and so ascertain the age of the latter. But rarely do we discover in Pueblo ruins beams so recent in point of time. How then can we extend our known succession of rings back to reach the unknown? The answer is simple: Go to houses that were built two or three centuries ago and seek logs cut at that time. The outer parts of such logs will match the inner parts of our modern 500-year-old trees and the inner rings of the old logs will extend our chronology of known rings farther back into the untrodden and unmeasured past (see page 11, lower

[1] The dating of Pueblo Bonito and other southwestern ruins, made possible by the interest and support of the National Geographic Society, resulted from researches prompted by The Society's Pueblo Bonito explorations, 1921-1927, under direction of Neil M. Judd. To these researches the American Museum of Natural History, the Museum of Northern Arizona, the University of Arizona and its Department of Archeology, and most of those archeologists actively engaged in the Southwest have made important contributions. The fundamental climatic investigation, begun in 1901, has grown more rapidly since 1915 through the valued help of the Carnegie Institution of Washington, the University of Arizona, the Research Corporation of America, Mr. Clarence G. White, and others.

Photograph by Neil M. Judd, 1929

A DAY'S CUT OF LOGS WHOSE ANNUAL RINGS GIVE STORIES OF THE PAST

Such stories form the climatic calendar that tells the age of ancient ruins (see page 7). This is in a yellow-pine forest, Flagstaff, Arizona.

left.) Logs from still older ruins will carry the line even farther back. Somewhere in this sequence of annual growth rings, if extended far enough, we may expect to find a group of successive rings exactly duplicating a given series taken from almost any prehistoric beam. Thus we date the ruins and at the same time develop a tree-ring calendar extending centuries into the past, a calendar that enables us quickly to learn the age of other ruins that fall within its range.

This dating process finds illustration in the story given below of the successful search for the age of Pueblo Bonito. The result took years to accomplish with the limited time that could be given the subject from my academic duties. Difficulties had to be overcome and mistakes corrected. Yet the successful identification of corresponding rings in different trees, or a new ruin added to the increasing number of those closely related in time, an unusually fine specimen of ancient timber or a long ring record adding scores of years to the calendar—all these kept alive a keen interest that grew and grew until our problem was finally solved.

With the development of such a calendar by so novel a process, a small special vocabulary naturally has come into use. The identi-

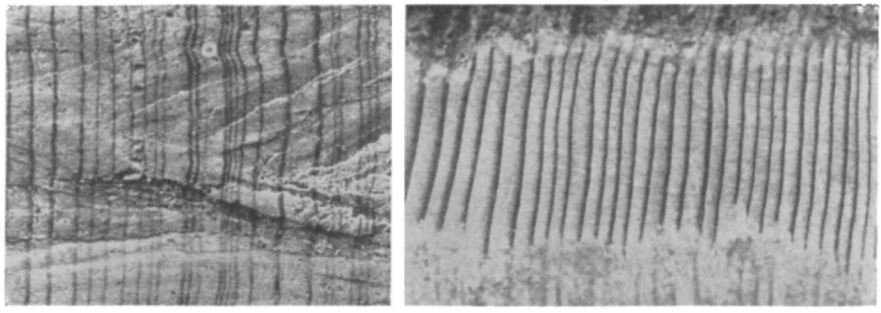
fication of rings from tree to tree is called "crossdating," illustrated on page 30.[1] A series of rings displaying a changing climatic effect from year to year is said to be "sensitive." If it does not show this sensitivity, the series is called "complacent" (see upper figures on opposite page). Specimens may be obtained in the form of thin sections, or as "cores" or "V-cuts" (see opposite page, lower right). Cores are made by a "tubular borer," a steel tube an inch in diameter with saw teeth on one end. Such cores are two to eight inches long, extending from outside to center of the log. The well-known Swedish increment borer makes smaller cores, about one-fifth inch in diameter, but this instrument is only adapted to living trees and cannot be used on the seasoned and weathered prehistoric logs. A "V-cut" is a small triangular piece secured from the end of a log by two slanting cuts of the saw. Charcoal specimens may be of any shape and may vary from an ounce to a pound or more in weight; one piece less than three inches long is shown on page 30, upper. The "skeleton plot" is a standard method of representing the deficient years in any sequence of rings. In it, normal and large rings are omitted; only the very small rings are put on record. These are represented by vertical lines whose length varies inversely with the thickness of the rings. Two skeleton plots are shown in position for comparison on page 36. Those trees of the Pueblo area in which the record of rainfall and climatic change is most easily read are the western yellow pine (*Pinus ponderosa*), illustrated on page 9, and the Douglas fir (*Pseudotsuga taxifolia*). The next best is the pinyon (*Pinus edulis*). Several species of juniper have in rare cases given very satisfactory results. Usually they are too difficult to be used.

II

EXPLORING THE PAST

In 1914, after my studies of climatic cycles as recorded by the growth rings of big trees had become known, Dr. Clark Wissler of the American Museum of Natural History, New York, offered me specimens of prehistoric wood for general examination. The offer was accepted and in the early part of 1916 a group of seven large sections was received, collected at Dr. Wissler's request in northwestern New Mexico. These specimens gave the first practical part of tree-ring technique: namely, the size and form of specimens and kind of wood. In February, 1919, six beam sections recovered by Earl H. Morris during excavations at Aztec (page 12) were secured and their rings were quickly crossdated. In this group a second item

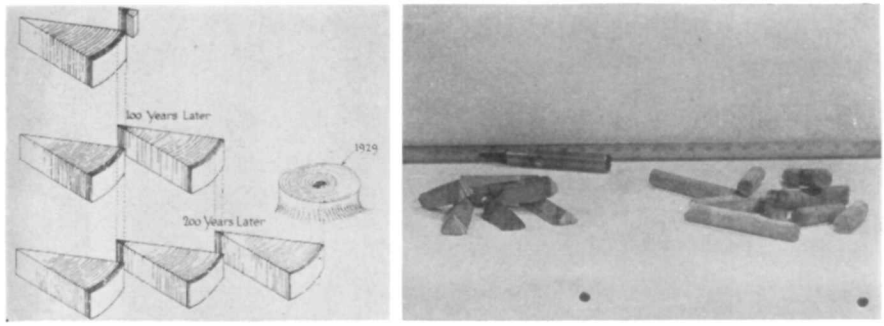
[1] The photographs of rings presented with this article are marked "Photographed at Steward Observatory." The technique involved has been worked out by Dr. E. F. Carpenter, Mr. H. F. Davis, Dr. P. C. Keenan, Mr. C. G. Keenan, Mr. A. R. Buehman, and the author.



Photographed at Steward Observatory

SOME RINGS ARE MUCH MORE INFORMATIVE THAN OTHERS

At the left are sensitive rings, essential in the dating process; note evident differences in width. These come from a large beam in Pueblo Bonito. The white circle indicates the year 893 (see pages 7, 8, 9, 10). At the right are complacent rings from Oraibi, too much alike in width. Such rings are rarely dated (see opposite page.)



Drawing by A. H. Bumstead. Photographed at Steward Observatory

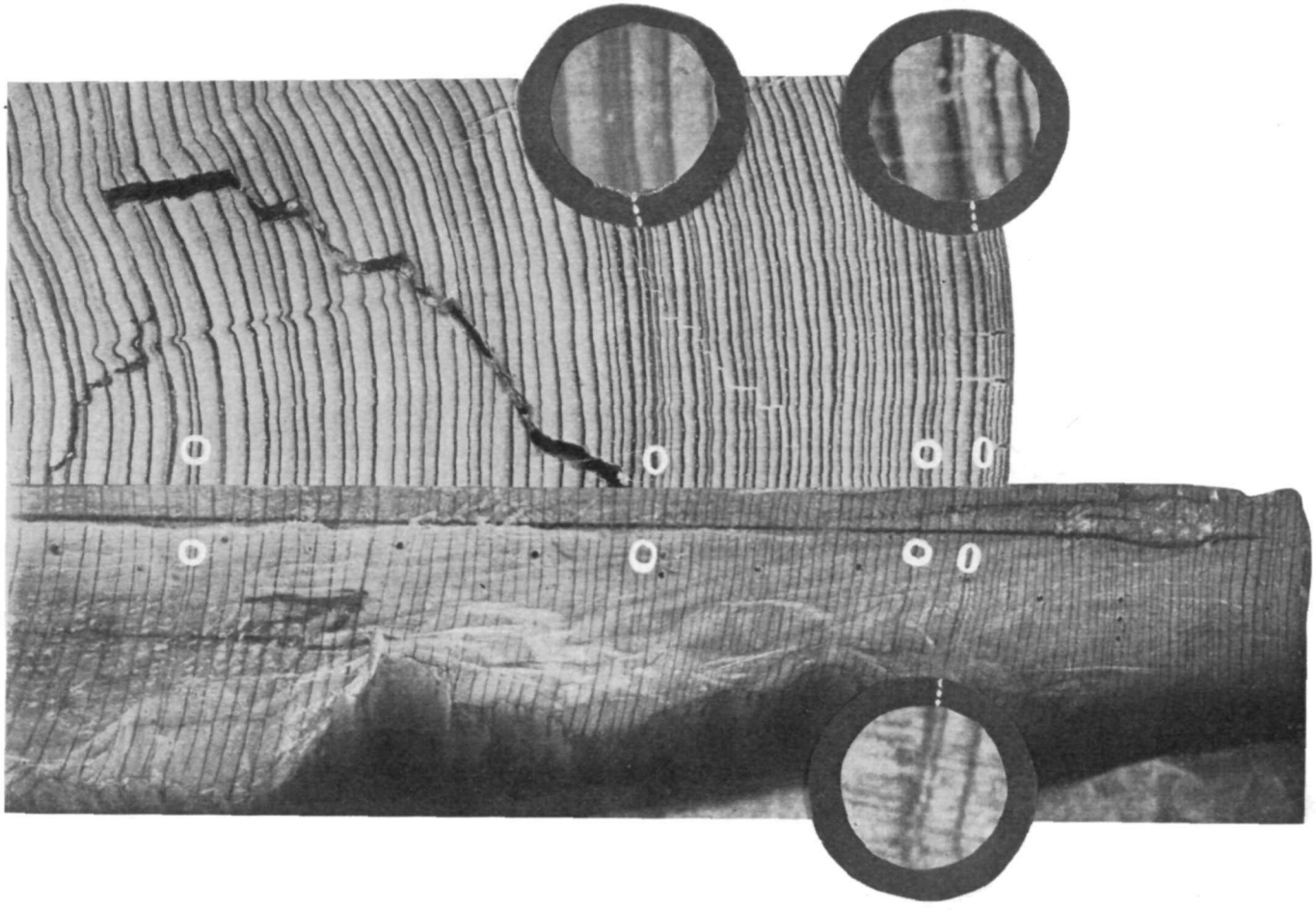
HOW THE CENTURIES ARE BRIDGED BY TREE RINGS

At the left is shown the "Bridge Method" of dating prehistoric timbers, by reckoning backward from the known date on the outside of a recently-cut stump and bridging from log to log and century to century (see pages 8 and 15). In the right-hand picture are shown V-cuts, left, and cores, right; a tubular borer for making cores lies in the background (see opposite page).

of technique was developed: namely, the use of a hypothetical or "floating" chronology, a measure that has become a necessary part of all dating by tree rings. This was the "Relative Dating" (RD), based on a certain large and distinctive annual growth ring which appeared in each of the prehistoric beam sections then in hand. To this outstanding ring I gave the purely hypothetical date "500"; its actual age was not determined until June, 1929. The ring before it was called RD 499; the one before that was RD 498, and so on to cover all rings whose definite relation to RD 500 was known. Such a series of numbers served to express the time relation between

Photograph by A. E. Douglass, 1919

AZTEC RUIN, WHOSE BEAMS BEGAN THE ANCIENT TREE-RING CALENDAR; IT WAS BUILT A. D. 1110 TO 1121 (SEE PAGE 14)



Photographed at Steward Observatory

FIRST CROSSDATING BETWEEN DIFFERENT RUINS, AZTEC AND PUEBLO BONITO, JANUARY 12, 1920

At the top is Pueblo Bonito log K-7; at the bottom is Aztec log H-9, showing the original surface on which this crossdating was done. The two are placed at corresponding dates. The added growth at the right end of the Aztec log shows 40 years later building time. The white circles, left to right, give the following dates: 1005, 1035, 1062, and 1067, which is a microscopic ring. Magnified views of the microscopic rings are shown in the insets (see page 15).

Photograph by A. E. Douglass, 1928

ORAIBI HAS BEEN OCCUPIED CONTINUOUSLY SINCE BEFORE 1400

This is a view of the part abandoned in 1906, taken 22 years later (see page 17).

different ruins, or different parts of a single ruin, whether known in terms of our own calendar or not. Such an assumed date is like "x" in algebra; it is a quantity that, itself unknown, can be built into all our equations of relative age and so used until the final solution comes.

Methods of dating prehistoric ruins took more definite shape in 1919 and 1920. This followed rather naturally from advances in general tree-ring technique, developed during the course of climatic studies in the preceding ten years. In 1911 the similarity of ring sequences in northern Arizona conifers was noted; it became possible to assign definite dates to individual rings in trees felled in a known year. This led at once to realization that the dating of ring groups by their own characters, and quite independently of the time when the tree was cut (first accomplished experimentally in 1904), was a process that could be applied generally over considerable areas. Lumber camps near Flagstaff provided an abundance of material for examination.

In 1915 I obtained my first long sequences of the giant sequoia (*Sequoia gigantea*); three years later their annual growth rings had been counted back to 1300 B. C. Upon securing a definite ring chronology from Aztec Ruin in 1919, I made every effort to find a

Photograph by A. E. Douglass, 1933

WUPATKI WAS UNDER CONSTRUCTION DURING MUCH OF THE TWELFTH CENTURY (SEE PAGE 21)

correspondence between Aztec and the well-dated sequoias, but without success. In spite of this, attempts were made for years to match the Arizona tree records into the long-lived sequoias.

The actual technique of Pueblo dating that later proved successful was first definitely formulated in 1919. It "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." [1] Thus the name "Bridge Method" came to be applied to this process, but its successful application appeared hopeless on account of the seeming impossibility of getting such great numbers of timbers.

But help was to come from the judgment of more competent persons, encouraged by the first definite step in building a prehistoric calendar. This first step was made on January 12, 1920. The American Museum supplied the needed link. They sent me nine sections cut from logs obtained in Pueblo Bonito by the Hyde Expedition of 1896-1899. These were promptly crossdated with each other and identified in terms of Aztec log rings. Page 13 presents photographs of the specimens on which this impressive result was obtained. The construction at Aztec was thus proved to have

[1] Letter to Dr. Wissler, May, 1919.

been 40 to 50 years after that at Pueblo Bonito. This agreed exactly with the fainter archeological evidence of the relative age of these two ruins and gave a precision never before dreamed of.

But it did more than that, for it opened the door to a tree-ring calendar of indefinite extent and appealed especially to Mr. Neil M. Judd who was just starting work at Pueblo Bonito for the National Geographic Society and who knew far better than I the marvelous resources in ancient timber possessed by many ruins of the Pueblo area. After a reconnaissance of the Chaco region in 1920, Mr. Judd began explorations at Pueblo Bonito the following summer and the next year forwarded to me a considerable number of beam sections. The rings of several were quickly identified in the sequences already developed. In September, 1922, I spent several days at Pueblo Bonito, as guest of The Society, and worked out the best methods of selecting and securing material for examination. By October some 75 specimens had been examined and I was able to report that beams from five different Chaco ruins all were cut for building purposes within the same score of years. This result had important significance, for Chaco Canyon has a dozen major ruins and the building of five of them at much the same time meant a very considerable number of inhabitants.

All this minor crossdating and the opportunity of watching tree-ring work in actual operation developed in Mr. Judd's mind a definite vision of a major dating process that might lead to the actual age of Pueblo Bonito. He believed it possible to obtain a sequence of beam sections from successively older Pueblo villages, beginning with timbers salvaged by the Hopi when they destroyed the Spanish missions in 1680 and which he had seen still in use at Oraibi in 1920. Mr. Judd's conviction took form on hearing evidence I presented at the First Conference on Cycles, in Washington, December 8, 1922.[1] He formulated a plan of procedure, won the approval of the Research Committee of the National Geographic Society, and thus brought about The Society's three beam expeditions which had for their sole objective the dating of Pueblo Bonito.

First Beam Expedition, 1923

With confidence in the possibility of dating old ruins the first need was obviously a large number of sections and borings from many places in the Pueblo area. These would show us, it was hoped, where intensive work must be expended to build a complete tree-ring calendar from the present time back to the period of Pueblo Bonito. The Society's first beam expedition set out from Flagstaff in June, 1923, under the joint leadership of Mr. J. A. Jeançon of

[1] Report of a Conference on Cycles. Supplement to the Geographic Review, Vol. XIII, No. 4, October, 1923. Reports of the Conferences on Cycles: Carnegie Institution, 1929. Judd: Dating Our Prehistoric Pueblo Ruins. Washington, 1930.

Denver and Dr. O. G. Ricketson, now of the Carnegie Institution of Washington. I accompanied them for the first ten days, during their visit to the Hopi villages, going first to Oraibi which was partly in ruins as shown on page 14. In this way I could communicate to them the limited experience already gained in collecting suitable material. Of the 22 specimens we obtained in the Hopi towns in 1923 only one was dated on the spot or, in fact, for several years. But I add for the encouragement of others that most of the sections were finally identified and the proportion of valuable and important specimens was unusually high. In fact, several of those pieces proved to be the keys that, five years later, opened the door to early Hopi chronology.

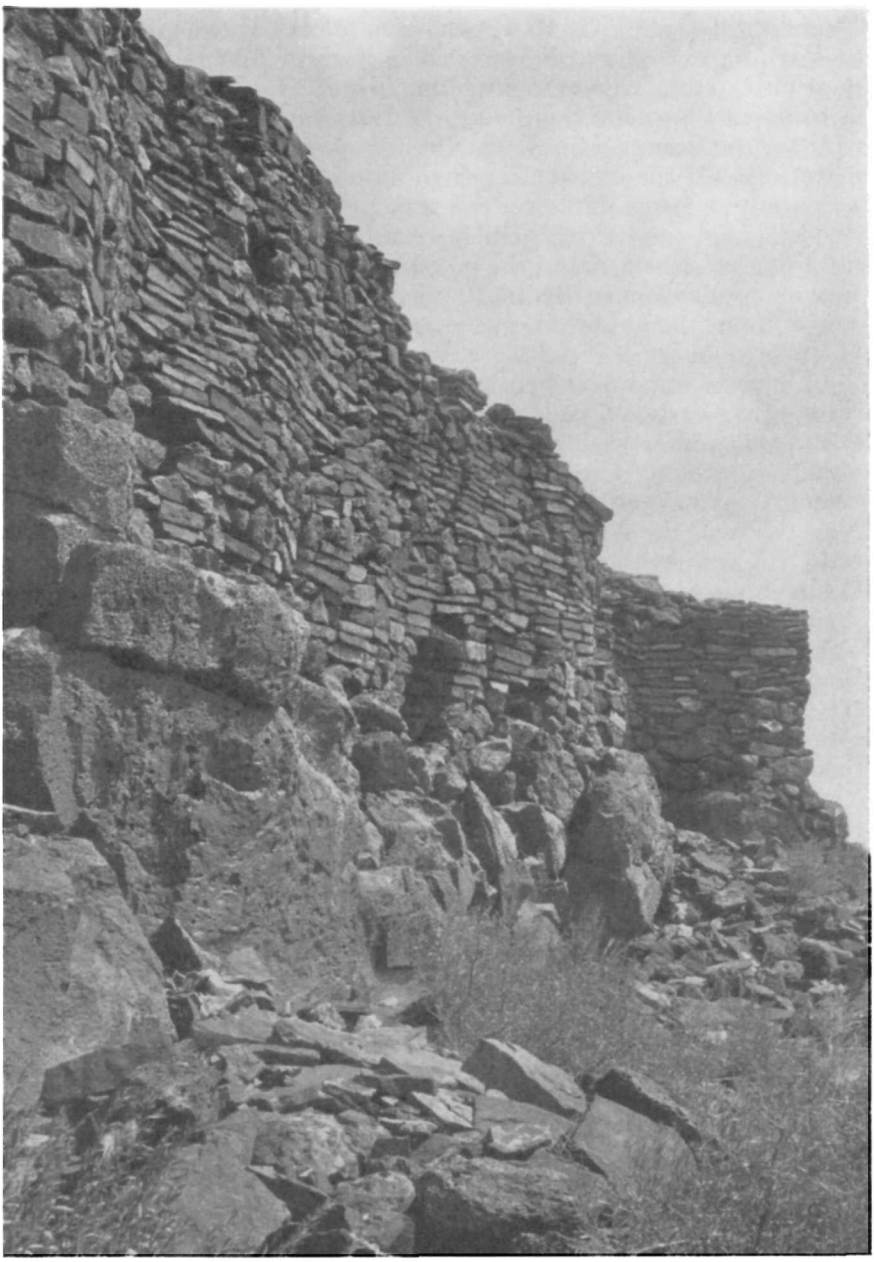
The expedition next went north to the Black Mesa without much result; then east to Chinle where samples were collected that subsequently played a principal part in building a late prehistoric chronology known as Citadel Dating. The expedition visited Zuni, Chaco Canyon, and several pueblos of the Rio Grande Valley, in New Mexico; the Mesa Verde and other districts in southern Colorado. A section from Chinle, Arizona, later gave the first date to White House ruin and the Mesa Verde pieces lengthened my late prehistoric ring sequence. Additional borings obtained in Chaco Canyon placed Kinbiniyol among the several related ruins of Pueblo Bonito age.

Members of the National Geographic Society and other friends contributed greatly to the results of this initial beam expedition through unfailing hospitality and helpfulness.[1] An even hundred beam specimens were collected. In this, as in other ways, success was largely due to the tactful approach of Mr. Jeançon, who had lived for a time in the Tewa village of Santa Clara in the Rio Grande Valley, and to the knowledge of southwestern travel previously gained by Dr. Ricketson. One of their most interesting experiences was the conference at Walpi for the purpose of gaining permission to make borings in kiva logs, thus referred to by Mr. Jeançon:

"At Walpi we had a council with the two kiva chiefs who appeared the most interested of all of the men with whom we had to deal. I promised them that I would make the necessary medicine to protect them fully against any evil influences that might attempt to injure them. In accordance with this, when we had finished the boring in the beam in the Moen Kiva, I broke up some turquoise and placed it on the end of the plug and after saying some Tewa prayers, I inserted the plug, and they were perfectly satisfied."

At this same conference I promised one of the priests to let him know the age of the log and when his ancestors had cut it, little

[1] Mr. Jeançon's report mentions in this connection Mr. Lorenzo Hubbell, Jr., Mr. Emory Kopta, Dr. F. W. Hodge, Mr. Jesse L. Nusbaum, Mr. and Mrs. Gerald Cassidy, Mr. Herman Switzer, and the Fred Harvey Company; Major Daniels of the Indian Service, Juan Gonzales, and others.



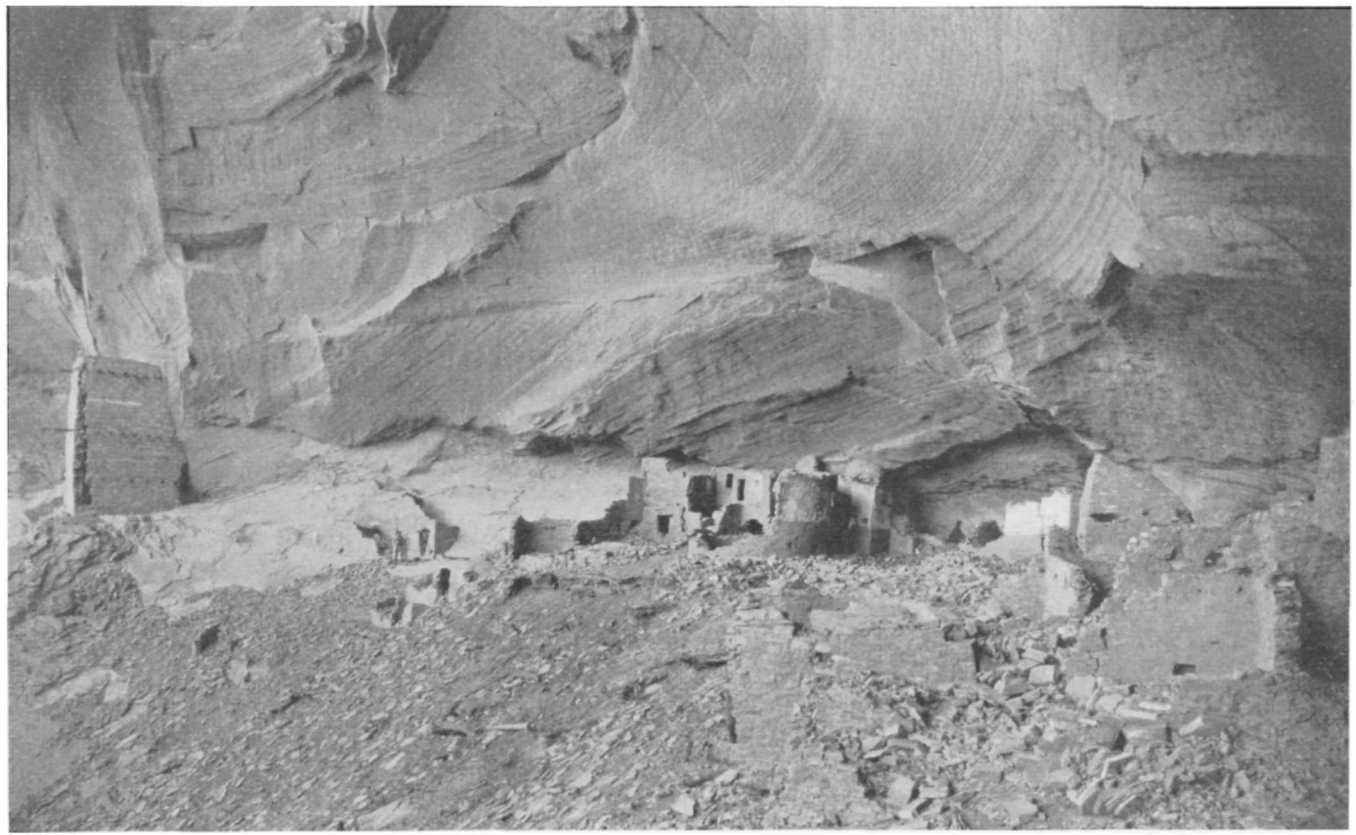
Photograph by A. E. Douglass, 1926

CITADEL RUIN, NORTH WALL; IT WAS BUILT A. D. 1192 (SEE PAGE 21)

thinking it would be years before I could fulfill that promise. It was, however, finally done in 1928. The timber was felled near 1500 A. D. and was one of the largest we encountered that unquestionably dated from before arrival of the Spaniards. It gave a superb series of rings back to 1297. In 1929 we were sorry to learn that this rare old beam had been used for firewood, having been replaced by new spruce logs presented to the Indians by the Government. Many another old log, with its wonderful hidden story, perished at that time.

While it was impossible to complete the necessary microscopic work on these hundred specimens for several years, there was a very important, related study which I pursued intermittently as opportunity offered. This was a comparison of living trees over the Pueblo area. We well knew that building a chronology of such length as that visioned would depend on complete success in a widespread crossdating. At that time we had found satisfactory resemblance between the pines of Flagstaff and those near Prescott on the west, Grand Canyon on the north, Pine and Cibecue on the south, Aztec and Basin Mountain 250 miles to the northeast. Ancient Aztec had been joined to Pueblo Bonito and other Chaco ruins, but the natural question arose: How generally over the whole area will crossdating be found feasible? If it should not prove possible, then we must proceed cautiously before incurring added expense. The answer to our question could easily be ascertained by further comparisons between modern trees.

The result of these tests was very reassuring. We found the entire Pueblo area bound together in a similarity that was astonishing. If we take the Chuska-Lukachukai Mountains district, along the Arizona and New Mexico line north of Gallup, as the central Pueblo area, we find very strong ring agreement with it in some such circuit as the following: Flagstaff area, including Flagstaff, Prescott, and the Grand Canyon, 200 miles to the southwest; Black Mesa, north of the Hopi villages, 80 miles west; the Mesa Verde and Shiprock region, 75 miles northeast; Chaco Canyon, 50 miles east; the Mogollon Rim and Cibecue, 150 miles south and southwest. The Zuni Mountains south of Gallup, the Jemez Mountains 100 miles east, and Santa Fe 200 miles east show long periods of agreement but have slight changes here and there that reflect Rio Grande Valley conditions. Thus the entire area containing the intriguing prehistoric ruins on the Colorado Plateau and west of the Rio Grande acts almost as a climatic unit with regard to its effect on tree growth. The Rio Grande Valley was recognized as needing a special study for the age determination of its ruins. And fortunately that has since been accomplished by the Laboratory of Anthropology at Santa Fe.



Photograph by Edwin L. Wisherd, National Geographic Society

MUMMY CAVE RUINS, SHOWING TOWER AT LEFT WHICH WAS BUILT 1280 TO 1284 (SEE PAGES 21 AND 44)

Results of First Expedition

Direct attack on the dating problem was resumed in the spring of 1927. In April, Wupatki rings in the Flagstaff area were identified as late in the main Pueblo Bonito calendar. Then followed the placing of Kinbiniyol and Solomon ruins (northwestern New Mexico) slightly after the main construction time of Pueblo Bonito. It was found also that White House ruin, in Canyon de Chelly, was built in Bonito times.

The seven months ending with January, 1928, were occupied with a typical experience in the solution of our general problem that deserves mention. It was the construction of a major section of the tree-ring chronology and its insertion in the general calendar. It resembled a picture puzzle. The picture is not always assembled in steady succession from the first piece to the last. Sometimes a large part is put together on the side and inserted as a whole, filling up some major vacant space. And that is exactly what happened when I added my Citadel Dating sequence to our tree-ring calendar.

There were on hand in the summer of 1927 a hundred Beam Expedition specimens and, in addition, a hundred or so from Wupatki (page 15). The Wupatki beams curiously divided themselves into two groups, giving two separate chronologies, which I mentally referred to as the "large beam" sequence and the "small beam" sequence. The former was joined to our Pueblo Bonito series in April, 1927. Then the small beam sequence, not to be outdone, reached out to encompass such readings as we had acquired at Citadel Ruin (10 miles north of Wupatki) and Fewkes' Ruin J (two miles beyond).

But the Wupatki small beam sequence did not stop here. It took to itself three beautiful sections from the Tower in Mummy Cave, northeastern Arizona; then added eight or ten similar sections from Mesa Verde, in southwestern Colorado. That does not mean these several ruins were all built at the same time but rather that definite time intervals were found between them. Wupatki came first, then, 40 years later, came the Mesa Verde cliff-dwellings and, 40 to 45 years later still, the Tower of Mummy Cave (see opposite page). The old ceiling beams that provided these readings altogether gave 140 years of excellent rings in unbroken sequence, but they were yet to be identified with Pueblo Bonito or with modern trees.

On the basis of a comparative study of potsherds from the several sites, Mr. Judd assured me that Mummy Cave, Mesa Verde, Wupatki, and Citadel unquestionably were later, not earlier, than Pueblo Bonito. Thus by the end of July, 1927, my "small beam" sequence at Wupatki had expanded into a very considerable, but

quite independent, tree-ring record which I assumed to belong somewhere in the large gap between Chaco dating and modern trees. I soon found myself identifying this independent sequence as "CD—Citadel Dating" because it alone included the ring record of the single specimen up to that time found at Citadel Ruin. Every other investigator, I suppose, has a similar habit of adopting chance names as convenient laboratory handles to the material under examination. Views of these ruins are shown on pages 15, 18, 20, and 23.

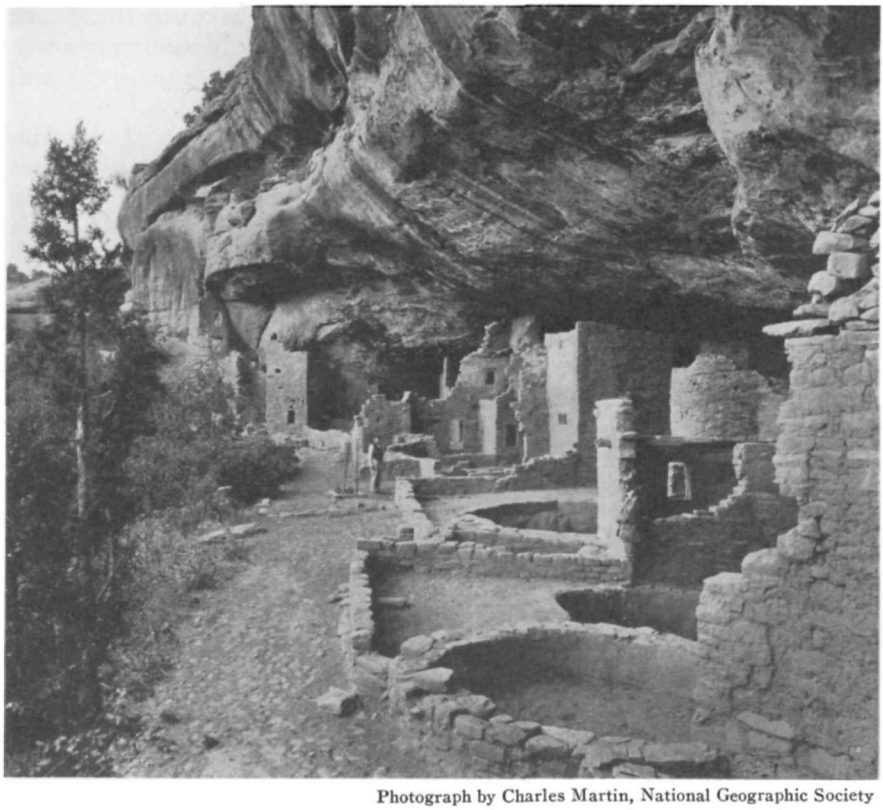
Obviously this new chronology, hanging somewhere between Pueblo Bonito times and the twentieth century, must soon join one or the other. The latter possibility seemed most unlikely and attempts to match it with our Bonito records were delayed several months pending examination of new Pueblo Bonito material. These newly acquired pieces were all found to belong in the early Bonito chronology and then, turning once more to my Citadel sequence, I was considerably surprised to note how readily it fitted into its proper place at the later end of the Bonito series. This happened on February 1, 1928, and then, as a second surprise, it appeared the two distinct chronologies, RD and CD, actually overlapped by nearly 40 years. However, this overlap depended chiefly on one single, reliable specimen of Citadel Dating which extended its ring series back into Chaco times. Thus the entire Citadel series at last found its true place in the prehistoric picture.

By all reasonable expectation the ring records from Wupatki should have formed one continuous sequence without any chance for an interruption in their midst such as had puzzled us. But a special condition was operating there, perhaps related in a distant manner to the last eruption of Sunset Crater near by.[1] Apparently during the building of Wupatki, the neighboring forest was in rapid retreat since the large trees, being older, had good rings deep within their trunks and badly defective rings near the outside due to drying out of the soil (see page 47). This defective portion had been the only part common to both large and small beams and had given an erroneous impression of a gap, or hiatus.

Plans for Second Beam Expedition

By February 1, 1928, most of the results which could be obtained from the First Beam Expedition material had been secured. A long, prehistoric sequence had been assembled extending over an interval of 585 years. To this prehistoric tree-ring chronology something like 30 different ruins had contributed, and thus were bound together in a complex of relative dates. Then followed a gap of unknown duration but supposed to be between 50 and 200 years.

[1] Dr. H. S. Colton, 1932, in bibliography.



Photograph by Charles Martin, National Geographic Society

SPRUCE TREE HOUSE, MESA VERDE, A. D. 1242 (SEE PAGE 21)

At that time my modern tree records extended back from 1929 to 1400, with possible extension to 1300 on some doubtful pieces. A very old tree had been discovered near Flagstaff whose stump showed 640 rings going back to the late 1200's, and actually evidencing a drouth near its center, but its early rings were variable and did not strengthen the chronology before 1400. Therefore every indication pointed to the need for studying early historic material. This could be done at Oraibi, oldest of the Hopi villages (pages 14 and 28).

Oraibi is the only one of the present Hopi towns known to be in its original sixteenth-century location. The others had been moved to their mesa summits after the Pueblo Rebellion of 1680. In 1898, I had visited Oraibi and found a large village with a population of 900. Doors at street level were an innovation and everywhere stone stairways still led from one story to the next; people lived on the lower roofs. Together with perhaps 30 other white guests I

saw the Snake Dance in the small, sloping plaza between the Snake and Antelope kivas shown on page 28. These old remembrances came back to mind on my subsequent visits, in 1923, 1926, and especially in 1928.

In 1906 dissensions arose among the Indians of Oraibi. Although the Indian Bureau attributed this trouble to difficulties connected with school attendance, a highly educated Indian told me it was a religious dispute over methods of bringing rain. And this perhaps suggests an important factor, namely, food supply; for the 10 years preceding 1906 had been severe drouth years, destroying much farm area, and causing crops to fail. Whatever the underlying reason, these difficulties led to a division of the inhabitants of Oraibi; one group migrated and formed a new town called Hotevila. The decision as to which group should go was reached by a tug of war held on the high ground above the town where an inscription in the rock surface still serves to recall the event.

In the meantime, the Government urged the remaining families in Oraibi to move to more favorable locations at the foot of the mesa and many did so. All this reduced the old town, which must once have covered six acres and contained five hundred rooms, to about a hundred people living in the northerly group of houses. This historical change in Oraibi is given in some detail because it supplies a modern picture of a process that has played an important part in the history of Pueblo peoples. Oraibi, oldest continuously occupied settlement in the United States, is now almost wholly abandoned and is rapidly falling into ruin.

Second Beam Expedition, 1928

The first object of The Society's second expedition was to secure samples from a large number of old beams in Oraibi, with the hope some of their inner rings would go beyond the gap and join our prehistoric series. This "gap," it will be recalled, was the unknown interval separating my dated sequence of annual growth rings in pines recently felled in the forests of northern Arizona and a similar, undated, sequence from old ceiling timbers recovered in various Pueblo ruins. The abandoned part of Oraibi offered the most promising place for such search. There houses had been built on the remains of previous houses; beams projected from these old walls and on many of them the unmistakable evidences of stone-ax work indicated great age. (A beam end cut with a stone ax is shown on page 27.)

For reasons every anthropologist will readily understand, samples from these old timbers, if obtainable, must be collected by someone living in Oraibi. On recommendation of Dr. Byron Cum-

mings, Professor of Archeology at the University of Arizona, an advanced student in his department, Mr. Lyndon L. Hargrave, was selected for this responsible task. Mr. Hargrave and I spent six days in old Oraibi during March, 1928, and after I left, he continued there for five weeks. We went first to the old kivas to examine their ceiling beams. From our initial tests we learned that juniper and cottonwood were practically useless at this stage of the search; that pine and Douglas fir were highly valuable and that dried and weathered logs are hard to distinguish as to kind of wood. We found evidence that the desirable kinds of wood ceased to be used in the village after about 1780. Without doubt all such trees within portable distance had by that time been cut down.

We worked upon the best available material in Horn, Antelope, and Snake kivas, securing one-inch cores in nearly every case. Study of these was begun at once and with the result that we soon had two separate series of annual growth rings under way. One series belonged in the 1600's, in perfect agreement with Flagstaff trees, and the other showed some resemblance to rings in the 1500's, but could not be placed there because of disagreement in the 1600's. This brought on a period of most intensive study to find where it really belonged. After returning to Tucson, I devoted every possible moment to this unidentified sequence and after twelve days, through a superb crossdating, finally succeeded in placing it definitely in the fourteenth and fifteenth centuries.

No further serious trouble was experienced with the Oraibi material. Of the samples Hargrave sent in, some 140 pieces were dated with highest certainty. This collection included no beams cut before 1370, but it did give an excellent ring series going back to 1300 and contained at least two individual records which entered the thirteenth century. In one of these specimens, the inner rings were much crowded and difficult to make out, but the other, BE 269, extended back to 1260 A. D. with a very important record.[1]

Mr. Hargrave collected over 200 specimens in Oraibi, 65 in Shongopovi, and perhaps a dozen in Walpi and adjacent villages. Since none of these gave promise of supplying the rings that would unite our historic and prehistoric chronologies, it seemed wise to take advantage of the still early season and secure information regarding those villages from which the Hopi people had migrated to their present location. The beams in such villages would perhaps be old enough to supply ring records through the gap. Accordingly Mr. Hargrave, accompanied by Mr. J. W. Hamilton, was sent out

[1] Shown in National Geographic Magazine, December, 1929, on page 760, lower figure. See also page 36 in this paper.

to look especially for late Hopi ruins which might contribute further toward solution of our problem.

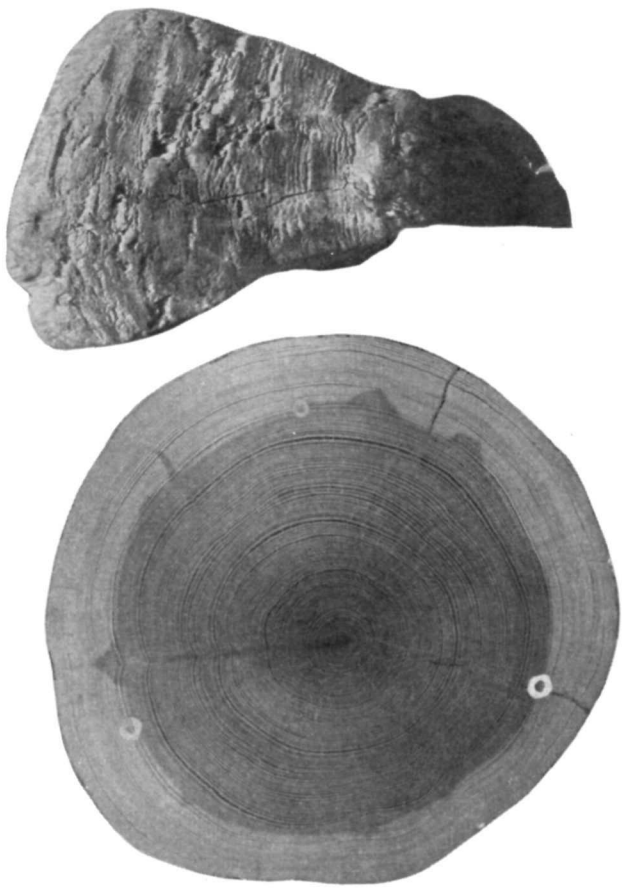
Early in June he returned to Flagstaff from this circuit trip, bringing some 50 specimens of wood from various ruins and many small bags of potsherds which proved of great use in subsequent plans. For immediate operations, he felt that the Jadito area was the region in which search for gap material should next be made.

The First Prehistoric Dates

In early August Mr. Hargrave returned from another visit to the Jadito area. At Kawaika (page 29) on the surface near excavations a few years old, he had found fragments of wood that looked like pine. Many of these were decayed and charred, only an inch or two long, yet contained 50 or more clear-cut and sensitive rings. Again and again these rings were recognized as belonging to the years between 1363 and 1425. While practically convinced, I realized that some of the rings were hard to read and, since so much was at stake, I hesitated to accept the testimony of these small fragments. The better treatment we now give decayed wood and charcoal would perhaps have settled the dating at that time. But it then seemed wise to seek additional evidence.

Later that same month we learned Mr. E. H. Morris was about to make some excavations in these regions for the University of Colorado. We suggested that, if consistent with the objects of his expedition, he do his work at Kawaika and thus aid our search for datable wood. He kindly consented to do this and during the early autumn excavated a number of rooms at points indicated by us. No solid wood was encountered, but, from rooms near the location of the fragments above mentioned, additional pieces of badly decayed pine were recovered. These were treated with preservatives and their rings carefully plotted. Finally, in October, a piece of charcoal the size of one's fist was discovered. It proved to be Douglas fir with a perfect set of rings from 1400 to 1468; our other charred scraps extended this building record to 1357 and to 1495. Thus Kawaika received the distinction of being the first prehistoric ruin of the Southwest to be dated accurately by tree-ring methods. The fragment which made this possible and a comparison piece from Oraibi are shown on page 30. Their agreement in distribution of drouth years is perfect.

This achievement was accomplished at Kawaika while Hargrave and I were guests of Mr. and Mrs. Morris. It was of course noticed how near the last date, 1495, came to the years of Coronado's famous expedition, 1540 and 1541. We surmised that some of his men must have seen this ruin when actually occupied. Hence



Photographed at Steward Observatory

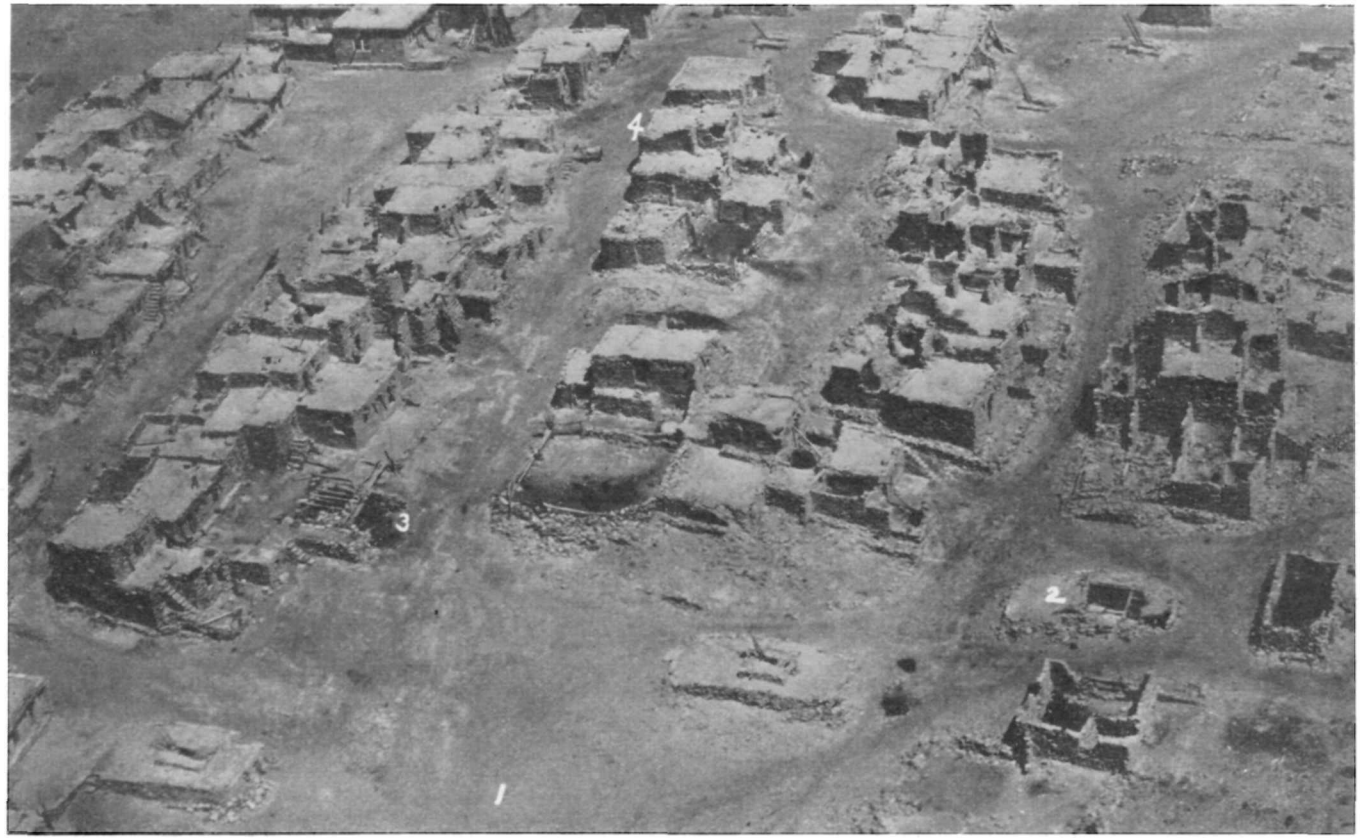
ANCIENT AND MODERN WOOD SPECIMENS

Stone-ax marks appear on the fragment of a beam end shown at the top. At the bottom is a modern Douglas fir, collected by E. H. Morris, showing the sapwood (outer part) and darker heartwood (central). The white circles indicate the outer edge of the heartwood (see pages 24 and 50).

our interest recently in Luxán's diary of 1582, in which reference is made to this pueblo and its identification as one destroyed by Coronado's men in retaliation for injuries inflicted on the Spaniards.

During the summer of 1928, a few other dates were obtained, especially late prehistoric dates from Turkey Hill Pueblo, 12 miles east of Flagstaff, then in process of excavation by Dr. Cummings and his class. A date of 1410 was found on a charred fragment at Kokopki, likewise in the Jadito region, which thus became the second pre-Spanish village to be dated. The ruin at Chaves Pass, 65 miles southeast of Flagstaff, gave 1381 on some of its pine fragments, and thus was the third to be assigned an exact age.

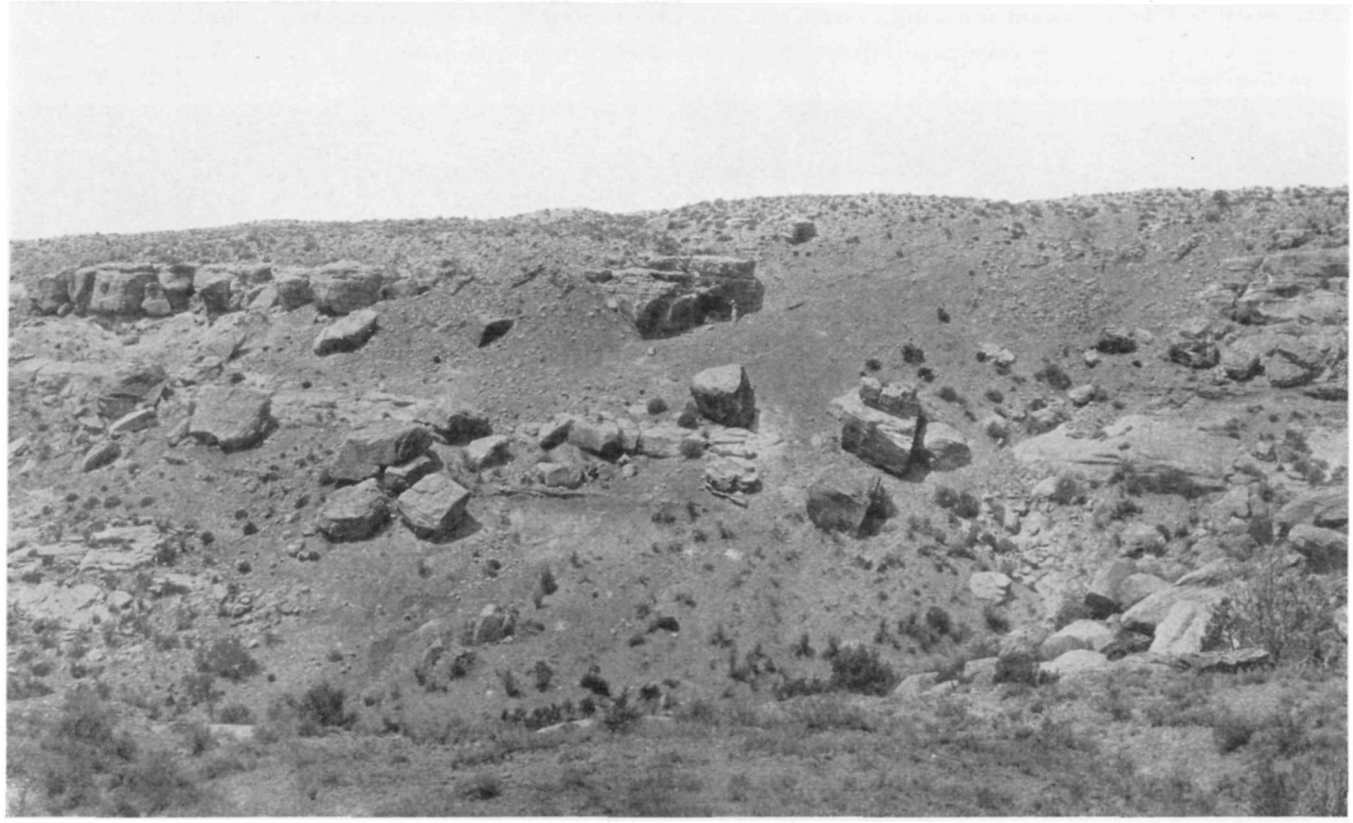
In reviewing the progress made in 1928 it was seen that 52 percent of 830 collected beam samples had been brought into the single sequence of relative dates, covering the classical and late prehistoric periods of Pueblo history. Altogether this gave a floating series 585 years long. Twenty-six large ruins were tied together in this chronological complex. Then came the gap, followed by my



Air photograph by Fred Harvey

THE HEART OF ANCIENT ORAIBI

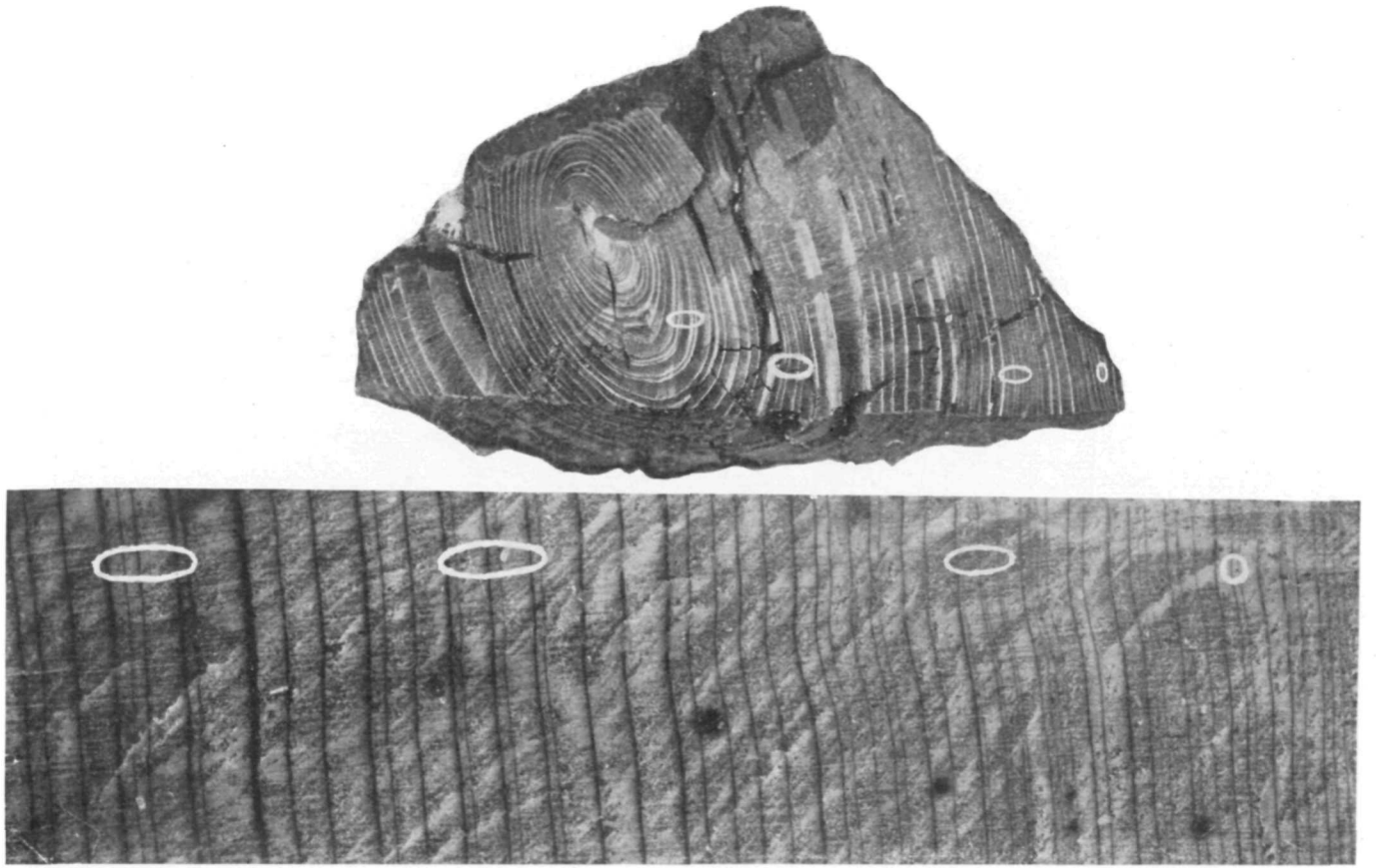
(1) Old Snake Dance Plaza. (2) Snake Kiva, abandoned. (3) Antelope Kiva, abandoned, showing roof logs. (4) Home of the town crier, from which important old timbers were obtained (see illustration, page 14, and text, pages 17 and 23).



Photograph by A. E. Douglass

KAWAIKA, FIRST DATED PREHISTORIC RUIN, COVERS 10 ACRES

The skyline of this picture is made up of fallen walls. Pine fragments dating from 1357 to 1495 were found above the rocks at the extreme left. According to Luxán, the pueblo was destroyed by Coronado's men in 1540 (see page 26).



Photographed at Steward Observatory

THE CROSSDATING THAT GAVE THE FIRST PREHISTORIC DATE

Above is a charcoal fragment from Kawaika, showing rings from 1396 to 1467. Below it is an Oraibi beam covering the same interval. The white circles from left to right give the ideograms, 1410-11-13, 1421-3-5, 1442-4-6, and the small ring 1464. 1455 is absent in each specimen. 1460 is microscopic in the charcoal and absent in the Oraibi specimen below (see page 26).

modern ring sequence. The latter reached as far back as 1300 in reliable form, but extended weakly to 1260.[1] The status of our researches at the close of the Second Beam Expedition is illustrated on page 32. It was felt at the time that this gap we sought to bridge must represent some great crisis in the history of the Pueblo people.

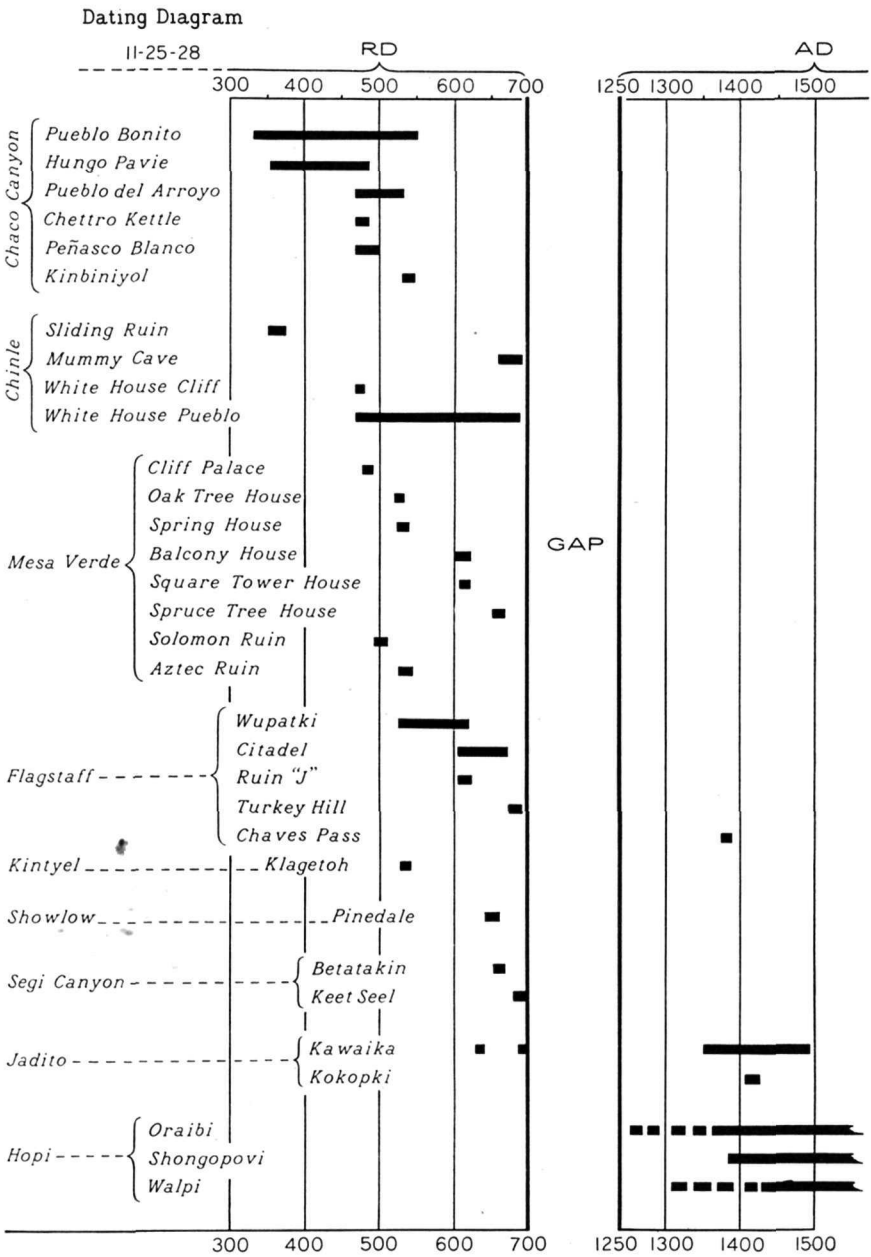
Preparation for 1929

We looked forward to 1929 as a critical year in our tree-ring investigations. Two expeditions had already been sent into the field without attaining our primary objective. We naturally could not anticipate an indefinitely long attack upon the problem. Therefore, in planning for the next field season, we reviewed the dim path along which we had come and focused attention on a few cold footprints. One of these was the type of pottery found at the several ruins.

Following the course charted by Kidder, Mr. Hargrave gave particular attention to the potsherds he had gathered throughout the Hopi area during the preceding summer. The chronological argument hidden in these fragments ran somewhat as follows: Pueblo Bonito at about Relative Dating 475 shows black-on-white and black-on-red types of pottery; Betatakin and Keet Seel in late prehistoric times, 200 years after, show an advance to a red polychrome consisting of a red background with at least two colors painted on it. But the more recent Jadito ruins show not only this late prehistoric, red polychrome but a further advance through orange into yellow and later into the beautiful Sikyatki cream, bromidically called "Jadito black-on-yellow," that was in abundant use at the time the Spaniards arrived.

Reëxamination of this ceramic sequence led to the following deductions: The gap to be closed apparently lies in the transition period between polychrome red and the cream-colored wares. Betatakin and Keet Seel, showing no development beyond polychrome red, barely preceded the gap while the Jadito ruins, showing a close cultural connection with the modern Hopi villages through exquisite cream-colored pottery, had their major building period after the gap. Of course they could, and probably did, precede it also. The crude designs on much of their fine yellow ware were assumed to identify an early form of Jadito yellow from which their improved pottery technique developed very soon after the gap. Finally, there was occasional evidence of an orange-colored pottery in the Pueblo area which, in time as well as in color, obviously stood between the basic reds and the yellows and thus had some connection with the gap. This complex became a guide in selecting locations for special work in 1929.

[1] The early rings in two or more logs extended back to 1300, but only one log had rings reaching 1260.



THE "GAP" AS IT APPEARED IN JANUARY, 1929

Twenty-six ruins contributed to the prehistoric chronology whose later part is here shown at the left and marked 300 to 700 in "RD," or Relative Dating; six supplied the historic part. The gap is the unknown interval that separates the two. Joining them would immediately date the prehistoric ruins. The solid heavy lines show building dates; the dotted lines indicate time covered by central rings in logs from the Hopi villages, collected in 1928 (see page 31). Several other ruins were added to this list in 1929 before the "gap" was closed.

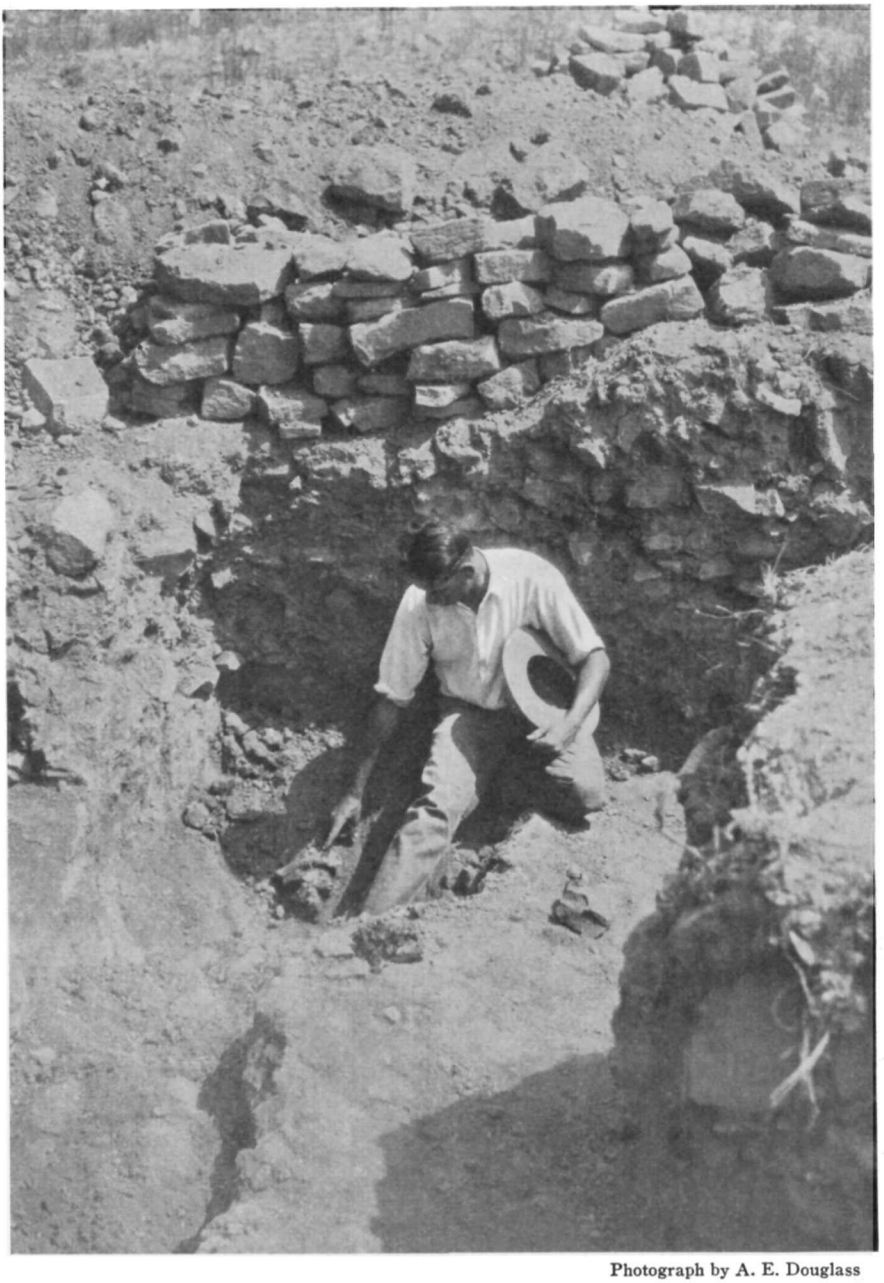
Third Beam Expedition, 1929

Without realizing how close was the solution of the age problem of the Pueblos, we formed detailed plans for the season of 1929. First we must concentrate on a very few specially promising ruins with full permission to make such excavations as seemed necessary. This permission was obtained from the Interior Department and covered all the principal ruins which we had previously investigated. Second, with a more exact knowledge of the pottery sequence, we could concentrate on such ruins as showed presence of the transition orange ware which, in a general way, was presumed to correspond to the gap in age. The presence of charcoal formed a third basis of selection.

There was no doubt that timbers of gap age existed in many of the large Jadito ruins. But these covered from 6 to 10 acres each and no one could tell beforehand just where to dig. It might be necessary to go down 10 feet to find beams in good condition. Only small portions of the Jadito ruins could be depended on to have that depth. Beams near the surface would be thoroughly decayed unless preserved in the form of charcoal. Accordingly, a ruin where charcoal was likely to be found would be preferable. This at once turned our attention to known ruins near the pine forests, where firewood was abundant and house fires necessary in winter. Of these, Showlow and Pinedale, 60 miles south of Holbrook, were already familiar to us. Mr. Hargrave had brought back some small sections from Pinedale which seemed to date in late prehistoric times and he reported large pieces of charred pine accompanying a pottery collection held by Mr. Edson Whipple, who owned the Showlow ruin.

The wood reported at this latter site seemed well worth examination as a preliminary to summer activity. Accordingly, in March, 1929, Mr. Hargrave and I drove to Showlow just in time to enjoy a heavy snow storm. To our disappointment, the pottery collection and the pine fragments had been sold. A few charred scraps I picked up in the empty storeroom showed very sensitive, but unidentifiable, ring sequences. These demonstrated at once the need for tracing the larger pieces. We found them in possession of Mr. Harold S. Gladwin, Director of the Association for Prehistoric Research in the Southwest (now Gila Pueblo), at Globe, Arizona, who kindly permitted me not only to examine the fragments but to take away for my collections a duplicate ring series.

Two months later, this Showlow series was joined to our prehistoric sequence and extended it some years through and beyond an evident great drouth in late prehistoric times. Tracing the ring sequence through this drouth was difficult and very uncertain.



Photograph by A. E. Douglass

MR. E. W. HAURY POINTS OUT ONE OF THE BEST PINEDALE CHARCOAL BEAMS, CUT IN 1286 (SEE PAGE 39)

Photograph by Neil M. Judd

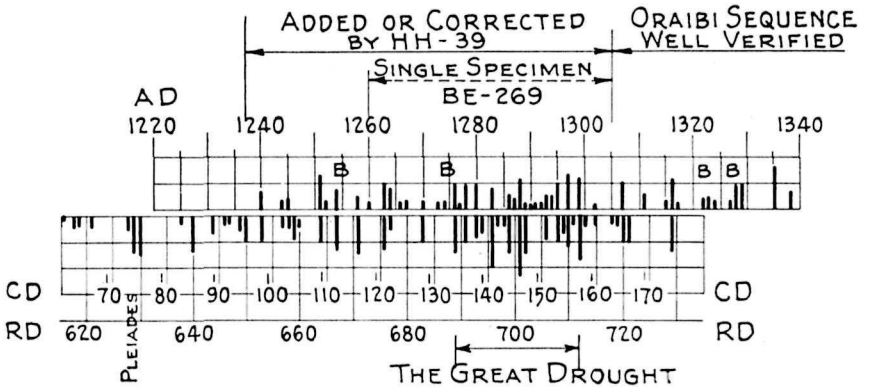
DISCOVERY OF AN IMPORTANT FIRE-SCARRED BEAM AT SHOWLOW

Beam HH 39 is shown in the position in which it was found. It has been carefully wrapped with twine because of its fragility (see page 36).

It was my urgent wish that a group of archeologists should assist in deciding which ruins were likely to provide gap material. The field party finally included Mr. Neil M. Judd, representing the National Geographic Society; Dr. H. S. Colton, Director of the Museum of Northern Arizona; Mr. Lyndon L. Hargrave, Assistant Director of the same, and the writer. Mr. Hargrave's experience in the preceding year made his help very important to the beam researches contemplated for 1929. At inconvenience to the Museum, his services were kindly lent to our expedition for a period of two months.[1]

The appeal of Showlow and Pinedale was so strong that Mr. Hargrave was left at Showlow on May 28 to begin our search.

[1] At this time, as on many other occasions, we were greatly indebted to Dr. and Mrs. Colton for their unvarying hospitality, their assistance in transportation, and their advice concerning the roads and ruins of northern Arizona.



Drawn by A. J. Krutmeyer

"SKELETON PLOTS" LINK KNOWN AND UNKNOWN

They show the overlapping parts of the prehistoric chronology (below) and the historic chronology (above). The coincidences between them are most easily found in small rings. The skeleton plot is so called because it is a part record only; the smaller the ring, the longer the line representing it in the proper date. Note the large number of lines that coincide in the two plots (see page 37).

The point selected for initial excavation was immediately back of Joe Whipple's house, somewhat west of the center of the ruin. Small pieces of charcoal began to appear at once and attempts to date them by the skeleton-plot process promptly followed. A room at the Museum of Northern Arizona was generously placed at our disposal for a laboratory. To speed the work before us, we needed another assistant so that search might go on at a second site. Mr. Emil W. Haury, a student of archeology under Dr. Byron Cummings at the University of Arizona, was selected and sent on to join Mr. Hargrave.

Problem Solved

On Saturday, June 22, 1929, Mr. Judd and I drove out from Flagstaff to Showlow. Hargrave and Haury enthusiastically exhibited some newly exposed fragments of charred beams. Rings of the 1300's were quickly recognized; some specimens showed the drouth year 1316 and nearly all were cut near 1380.

Later we were shown a log still in place at the extreme northern edge of the ruin (page 35). This lay near a stone wall marking the property line and at a point not before excavated although earth had been taken away for grading purposes. The log was scarcely more than a foot below the surface and, because it appeared very fragile, had been bound thoroughly with string. Its diameter of

seven inches made it look like a large beam. However, it broke away from the ground with suspicious ease. We carried it to a nearby shed and there, in the course of handling, it fell apart and disclosed the fact that it was only the remains of a charred shell which had once been the end of a solid log. The wood had decayed entirely except where preserved by its charred state.

I readily identified rings of the fourteenth century; the outside extended to the vicinity of 1380. In a minute microscopic examination of the inner rings the drouth of the late 1200's, beginning in 1276, was very conspicuous. Ring 1270 showed small as always; 1263-4 were very small. Before that, the rings were large except 1258, 1254, 1251, which were very small, and 1247, which was below average.

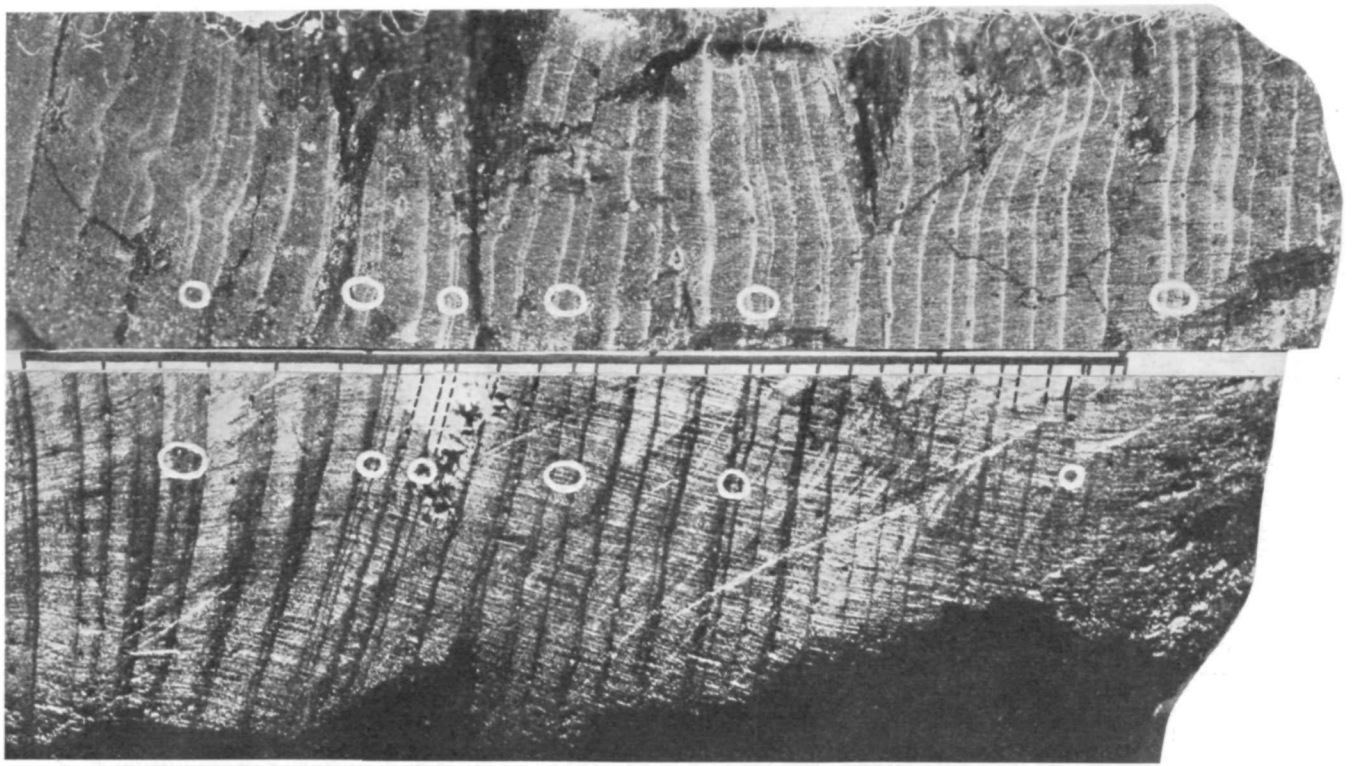
In consequence of the afternoon devoted to study of this precious old log, my skeleton plot of modern drouth years was extended to 1237, as shown in the upper part of the dating chart, opposite page.

That night, as Messrs. Judd, Hargrave, and Haury sat with me under the brilliance of a gasoline lamp in the little living room of the local hotel, Judd suggested, "Maybe the gap is not very big." I immediately ran my skeleton plot of prehistoric rings along the edge of the newly extended, historic sequence and at once noted a position of coincidence, highly attractive though not perfect because of slight disagreement within the drouth period. However, since most trees were defective at that time, there need be no occasion for surprise if some rings were missing in the decayed and charred fragment before us. After carefully checking this apparent correspondence on the original, as well as on the two plots, the agreement seemed more convincing. But, still with natural hesitation, I preferred to think it over and remarked that, while it looked very encouraging, we would try it again in the morning. Examples of the sequences in question are shown on page 38.

On retiring, I found it possible to produce before the mind's eye vivid pictures of all the rings involved. Every one was passed in review and weighed in the matter of identity between its historic and its prehistoric appearance. There could be no doubt of the identity in date for those rings between 1240 and 1300 in both the prehistoric and the historic specimens. Our "gap" was closed.[1]

In this successful conclusion of our work the unexpected feature was that there had been no real gap at all. Rather, our two chronologies already coincided for as much as 25 years, but, owing to the single historic specimen that made this overlap (BE 269) and to the almost universal defects in specimens that lived through the

[1] It was later found that 1283 and 1288 were omitted in almost all trees that lived through the drouth. When these were inserted in the lower skeleton plot of the late prehistoric rings, as on page 36, the agreement shows through the whole length of the overlap.



Photographed at Steward Observatory

THE RINGS THAT SOLVED OUR DATING PROBLEM

At the top is HH 17, a prehistoric sequence in charcoal that later proved to date from 1244 A.D. to 1280. Below it is HH 39, the historic charred beam shown on page 35. The white circles in order, left to right, indicate the following years: 1247, 1251, 1254, 1258, 1263, and 1276. Note that 1250 in HH 17 has a broken surface and appears darker; 1251 in each is double; that is, has an extra ring that is not annual. This is occasionally caused by the double rainy season in this region and this important character is recognized by microscopic examination of the wood. The 1256 ring in each is double; 1261 is double in the lower figure only; 1265 and 1270 are double in the upper figure only (see page 37).

great drouth, it would have been utterly impossible convincingly to join the historic and prehistoric ring sequences without the new material produced by the excavations of the Third Beam Expedition.

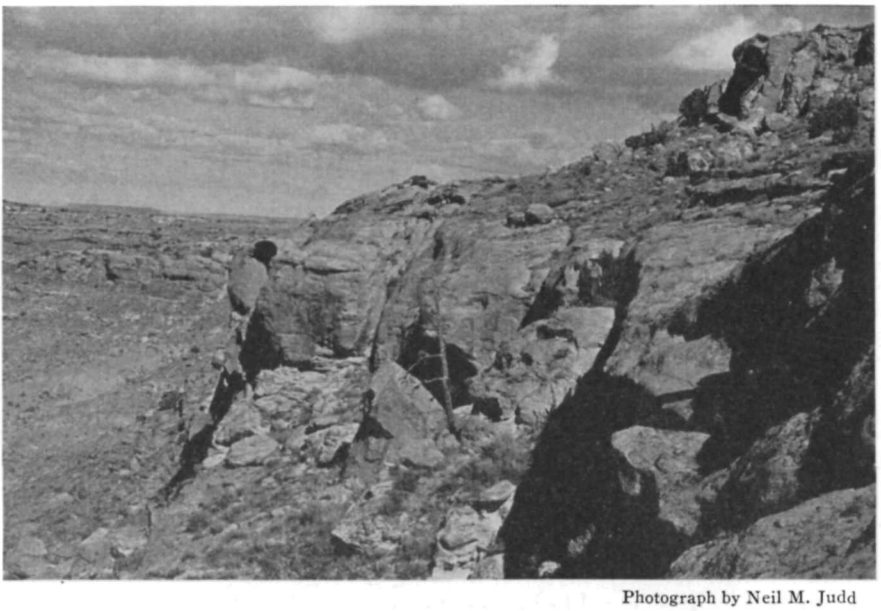
Thus the "gap" was due in part to the greatest drouth evidenced in our tree-ring calendar, now continuous from 700 A. D. to 1929. Our surmise of the preceding year that this hiatus represented some great crisis in the history of the Pueblo people was amply confirmed. The break in the continuity of Pueblo history at the time of the drouth was tremendous and far-reaching; how great it was will sometime be an interesting study for an archeologist. The word "gap" still finds frequent place in our vocabulary, but it no longer means an interruption in our ring sequence—rather, it reminds us of a very difficult problem solved at last.

Though actual dating of prehistoric ruins had been accomplished, the remainder of the summer offered opportunity for seeking additional material to support or modify the results. Mr. Haury continued at Pinedale, making a large collection of charcoal fragments, while Mr. Hargrave, assisted by Mr. Greene, excavated interesting kivas at Kintyel. (See Haury and Hargrave, 1931.) Then followed a period of further observation at Kokopki, near the hospitable home of Mr. and Mrs. W. C. Roberts of Jadito.

In late July our field work was brought to a close. Mr. Hargrave returned to the Museum of Northern Arizona while Mr. Haury undertook thorough reëxamination of the large collections now in hand, with a view toward strengthening the freshly-built bridge across the supposed gap.

Well worthwhile this latter study proved to be, both in supplying great numbers of additional, dated specimens and in extending our methods to pinyon wood, hitherto much neglected. But more important than all was his independent confirmation of the gap closure. It came about in this way.

For purposes of experience in reading tree rings, Haury was assigned the task of reviewing the beam fragments he had collected at Pinedale, some of which I had already dated. He treated them as if entirely new, made skeleton plots, and built a chronology of his own. After becoming in this way familiar with ring counting and crossdating in late prehistoric material, he began work on historic specimens having ring sequences in the middle 1300's. There were many of these, with which he became well acquainted. Gradually I handed him fragments that came earlier and earlier, working into and through the great drouth of which we had by this time four or five very fine tree-ring records (see page 42). In this way, Haury carried his own individual calendar to the rings preceding the drouth. Then he worked on HH 39, the piece that closed the gap, continuing the series back to 1237. Next, I took a bit of charcoal that he had



Photograph by Neil M. Judd

HERE FORESTS GREW AND PREHISTORIC AMERICANS CUT LOGS

Now the only tree to be seen is a single dead pine, standing on a barren talus slope. The scene is in the Chaco Canyon National Monument, New Mexico, about four miles southeast of Pueblo Bonito.

Photograph by Neil M. Judd, 1926

LAST LIVING REMNANT OF THE FOREST ON THE MESA TOPS

This lone pine is three-quarters of a mile southeast of Pueblo Bonito. The view is toward the northwest across Chaco Canyon to the mesas beyond, once probably covered with forest. The cliff wall behind Pueblo Bonito is seen at the left of the center; on the skyline at the right of the tree are the ruins of Pueblo Alto (see page 46).

already dated as late prehistoric and, after removing all identification tags, handed him the piece without comment. He recognized the rings at once as historic and, with great delight and many an exclamation of interest, found he was getting into the 1220's and 1210's. This was exploring a new region. I then said, "Did you ever see that specimen before?" And he knew it was one of those he had already dated as prehistoric. By his own skill in reading rings Haury had crossed the "gap" himself.

III

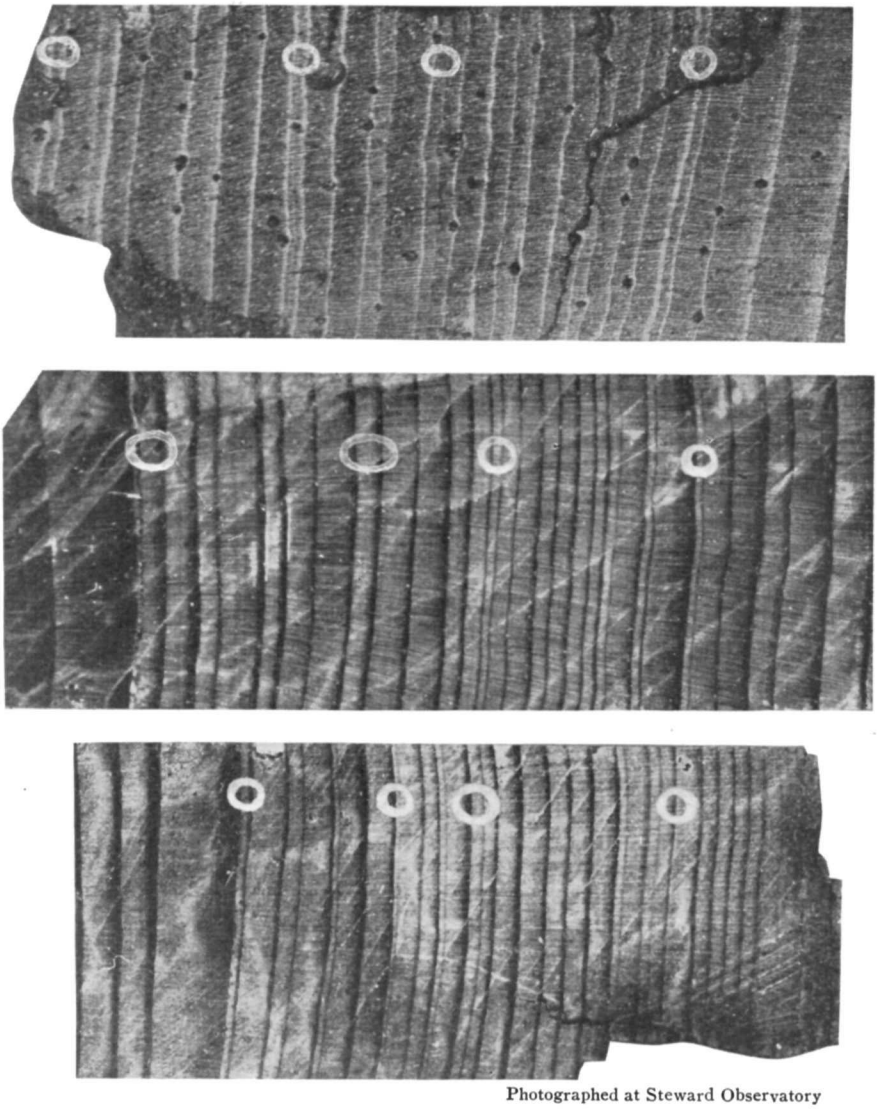
AGE OF SOUTHWESTERN RUINS

After ten years of work we had at last solved the "x" of our time equations. We had learned the true value of the hypothetical date, RD 500, applied in 1919 to a certain ring in Aztec beams in order to express the time relations of the ruins. We had demonstrated that year "x" was, in fact, A. D. 1087. Therefore, 587 years must be added to all our provisional RD figures in order to transpose them into our own system of recording history. Force of habit is so strong that even now, when asked the construction time of an early ruin that I know perfectly, I still think of it in relative dating and have to go through a little mental calculation before giving it in modern terms.

Our tree-ring chronometer had measured time for us through more than a thousand years. The accurate dating of Pueblo villages abandoned prior to arrival of the Spaniards provided a framework for Pueblo prehistory, or the skeleton upon which archeologists, with greater assurance, may henceforth hang the more important, flesh-and-blood details of Pueblo cultures.

Our own historical picture puzzle built of diagrams in tree-rings now had its parts so joined that we could read much of the story in it. We placed the beginning of the beautiful, cream-colored Hopi pottery in the early part of the 14th century; the great drouth formed a dreadful climax for the 13th century; the polychrome red pottery largely filled the 1200's; red pottery was common in the 1100's, at least in the ruins we investigated; black-on-white ware was characteristic of the tenth and eleventh centuries. These statements will be given in much more precise manner by the archeologists.

In more general terms, we could now assign historical dates to some of the recognized Pueblo cultures. Pueblo III, the golden age of southwestern prehistory, took its early form in Chaco Canyon about 919 A. D., reached its local climax in the late 11th century, and probably closed with the great drouth of 1276 to 1299. Pueblo



Photographed at Steward Observatory

THE GREAT DROUTH, 1276 TO 1299

White circles (left to right) indicate 1276, 1283, 1288, and 1299. (Top) Showlow record HH 10, charcoal: 1277 and 1283 are double; that is, they show extra rings that are not annual. This character may be readily identified by microscopic study of the wood. Its occurrence in the Pueblo area is usually due to the double rainy season in that region. (Center) Oraibi beam, BE 269, found in 1928; drouth not so severe as at Showlow, especially in early part. (Bottom) Beam section GP 191, from the Sierra Ancha, 50 miles south of Showlow, collected and dated in 1930 by E. W. Haury for Gila Pueblo (see pages 39 and 49).

IV began in the early 1300's. It is generally believed that these cultures originated in certain localities, perhaps all in one region, and spread out as from a center. Diffusion would scarcely proceed at a uniform rate. So a statement of culture times becomes very complex. Already there is evidence of overlapping of cultures, but the details will be given by others.

But the welcome results of these tree-ring studies gave more definite information than general culture periods. Investigators interested in different ruins had rendered great assistance to a study of climate that, at first thought, had nothing to do with prehistory. Now, with accurate information of building times and of climatic conditions connected with human migrations, we could make some return for the help that had made much of our climatic work possible.

Thus it was an extraordinary pleasure to be able to report to the National Geographic Society and to Mr. Judd that Pueblo Bonito was the oldest ruin yet dated. Seven beams from the western half of this ruin gave A. D. 919 as the building time. The major construction appears to have been in the 1060's, followed by a lesser activity twenty years later. Then it dwindled away, ending, so far as our evidence is concerned, shortly after 1130. These details have all been checked by Mr. Judd who elsewhere will discuss their archeological significance.

We could report that Pueblo del Arroyo, Peñasco Blanco, and Chettro Kettle were building at the same time. So was Hungo Pavie although two of its ancient beams were cut in the middle tenth century. Six cliff ruins on the Mesa Verde were dated between the end of the 11th century and the middle of the 13th.[1] The Segi Canyon ruins, Betatakin and Keet Seel, showed building in the late 1200's, just before the big drouth or in its early years.[2] The Klagetoh ruins we visited in 1928 provided a few pieces of charcoal with rings in the twelfth century. Kintyel was under construction in 1275, as ascertained from pinyon logs, the first deliberate dating in that kind of wood.

We reported that the first of the Hopi dates determined in 1923 showed relation to the Spanish conquest. On our second expedition, in 1928, we found that Oraibi had been continuously inhabited since before 1400. A lessening in the number of dated beams occurred at each major drouth. Diminishing housebuilding when famine and perhaps starvation were prevalent was entirely natural. That the Hopi villages as a whole show less building after 1600 is doubtless connected with arrival of the Spaniards. Walpi and Shongopovi

[1] Mr. H. T. Getty, a student in tree rings, has been carrying on dating work at Mesa Verde National Park for two summers.

[2] Dr. Byron Cummings of the University of Arizona has very kindly sent us modern juniper sections from this region and two borings from ancient Keet Seel logs. But these latter, unfortunately, had ring records too complacant for dating.

had some beams dating in the 1400's, showing that roof logs must have been transported from the old location below to the mesa top after the rebellion in 1680. The Jadito ruins, Kawaika, Kokopki, and Chakpahu, found their greatest development in the fourteenth century. The Showlow ruin was largely built between 1260 and 1382; that at Pinedale, between 1275 and 1300. (See Haury and Hargrave, 1931.)[1]

We have had great satisfaction in telling Dr. Clark Wissler, of the American Museum, and Mr. Earl H. Morris, formerly connected with the same museum but now with the Carnegie Institution of Washington, our results regarding the wonderful old ruin at Aztec. Though it is fairly large, it appears to have been built in the course of some 12 years, 1110 to 1121, judging from our specimens that cover the central portion of the ruin. Although Morris also collected from Grand Gulch, Utah,[2] two specimens dating in the 1130's, his other important contribution toward Pueblo dating is a superb series of beam sections from Mummy Cave Tower, in Canyon del Muerto, and from White House Ruin, in Canyon de Chelly. The Tower was chiefly built between 1280 and 1284, a few logs cut in the preceding 30 years being used. White House Ruin had a splendid series from 1060 to 1096, thus identifying it with late Chaco times; the more recent addition at the east end gave two dates in the thirteenth century. A single specimen from the cliff ruin above gave a reasonably certain date at 1061.

Upon the suggestion of several nationally minded persons, these two Arizona canyons, with their marvelous cliff dwellings, have recently been set aside as a National Monument, a far-reaching act, for they contain perhaps the longest record of ancient habitation to be found in any equally limited area in the Southwest. These remains well merit preservation and protection for the benefit of future generations.

To Dr. H. S. Colton, Director of the Museum of Northern Arizona, who contributed so largely to the success of these researches, it was a special pleasure to report that his beam collections from Medicine Valley and from under the cinders near Sunset Crater have proved an important contribution to southwestern chronology.

Dr. Colton also helped us obtain material from Wupatki, a most interesting ruin 35 miles northeast of Flagstaff. Of the 163 wood samples obtained there in 1927, on trips under the guidance of the late Mr. J. C. Clarke or as guest of Dr. and Mrs. Colton, 69 have given us building years from 1080 to 1205. Citadel Ruin,

[1] At the time this paper goes to press we are able to report the age of a pit house uncovered by Mr. Judd in 1922 in the Chaco Wash, whose beams date A. D. 777 (see Judd, 1922, in bibliography).

[2] Mr. N. C. Nelson of the American Museum had collected three specimens there, which he kindly sent on to me, but their ring records proved too complacent to be dated.

10 miles north, has produced very few beams, but two of them supplied dates at 1192 and 1260 A. D. Ruin J, named by the late Dr. J. W. Fewkes, was dated 1192 from a single specimen, found over a doorway by Mr. Ferrell Colton.

Other southwestern ruins have had varying fortunes in the dating problem. Turkey Hill Pueblo, 12 miles east of Flagstaff, was excavated by Professor Cummings of the University of Arizona. Although the first piece from this site actually dated was submitted by Mr. L. F. Brady, those furnished by Dr. Cummings enabled me to say that building operations were under way here from 1168 to 1278.

Elden Pueblo, six miles east of Flagstaff, was excavated in 1926 and 1927 by Dr. Fewkes. He sent us some pieces of charcoal whose rings were entirely devoid of dating character and whose age, therefore, could not be determined. But on a personal visit to Elden Pueblo about that same time, I picked up a fragment of charcoal showing rings near the outside of a tree. After lying neglected in my collections for several years, and as a result of the progress in our studies meanwhile, it was very easily dated at 1162+ A. D.

Grateful acknowledgment is made to Dr. A. V. Kidder and the Peabody Museum of Phillips Academy, Andover, Massachusetts, for specimens from the historic ruin at Pecos, New Mexico. To my regret, I was unable to date any of these with satisfaction owing to certain recurring differences in tree-ring character between the Rio Grande Valley and the Pueblo areas to the west. However, I am happy to have had a part in instructing Mr. W. S. Stallings who, at the Laboratory of Anthropology in Santa Fe, has since worked out a Rio Grande Chronology by which Dr. Kidder's specimens have been dated (see bibliography, page 73).

I cannot close this chapter without expressing my very sincere thanks to those friends not mentioned in these pages who have aided me at all times with ideas and information, and to my numerous interested students whose patience, skill, and enthusiasm have given encouragement and help beyond measure.

IV

DISCUSSION OF PROBLEMS

Besides dating prehistoric ruins, the building of a basic tree-ring chronology has supplied material for several other interesting problems.

A Prehistoric Forest in Chaco Canyon

The enormous use of good pine timber in the building of the great communal houses in Chaco Canyon and the contrasting absence of timber there today have a meaning for us to decipher. During

explorations by the National Geographic Society at Pueblo Bonito, numbers of ceiling logs were brought to light in perfect condition. Their smooth, unweathered surfaces mean they were cut and peeled and promptly used. There is no scarring by transportation. This suggests an extended forest in the immediate neighborhood of the ruins, without doubt on the mesas above and possibly on the valley floor itself.

The altitude above the sea is sufficient to support a pine forest. Did the original inhabitants who built today's ruins exterminate such a forest? It seems very likely. In 1926 I spent nearly a week at Pueblo Bonito, as guest of The Society, looking into this question. There was at that time a stunted, lone pine on a promontory jutting north from the south mesa (page 40, lower). Samples taken from this tree with a Swedish increment borer showed a compressed and defective growth for so many years that dating the rings was difficult or impossible. A year later this tree was cut by some sheep-herder for firewood.

An inspection was made of a deep ravine entering the south mesa, a mile and a half southeast of Pueblo Bonito. At its upper, south end four dead pine trees were accounted for—one still standing, one lately blown down, and two partly buried in sand that had lodged on a shelf just below the mesa edge.

Later, an Indian guided us to a spot a few miles east of Pueblo Bonito where he remembered having seen a pine growing in the bottom of a side canyon which joins the Chaco from the north. But all trace of this tree had disappeared. So he led us up on the mesa near by to another remembered location and there we found several sets of roots, so arranged that we knew large pine trees had recently stood there. The trees were gone and those roots easily reached had likewise been cut away. Thus the Indian's memory of pines formerly standing was shown to be correct and he was doubtless right in describing one on the floor of the side-canyon.

The best surviving remnant of the ancient Chaco forest is at the head of the canyon, 16 miles east of Pueblo Bonito. Here a total of 25 trees were counted, living and dead—perhaps three in good condition, another standing recently girdled, some logs, and some stumps. One stunted tree had a stem going down to bare ground and then a horizontal root or two, bare for two feet before entering the soil. This seemed plain evidence that the soil was blowing away. The location of this group is quite typical of forest survivals in this country. The south side of the canyon, where the trees have a north exposure, retained sufficient soil to support this remnant of a former forest.

Near Pueblo Bonito there are three types of area in which pine trees could have grown at the time of building. First, in the pro-

tected north-facing rincons, or rocky ravines, where we have actually found old logs and stumps, as described above. Second, the prehistoric forest could have covered the mesas and, in such case, may well have extended down into the valley. Third, it is not unlikely that pines grew on the valley floor near the present ruins. This view is supported by a single example, JPB 99, a great log with parts of the roots still attached, found by Mr. Judd within the westerly plaza, near the south wall of Pueblo Bonito. Its outer parts were badly decayed, but as a living tree it unquestionably had stood somewhere near through the early history of this prehistoric settlement (page 2).

We may assume then that a forest existed in the vicinity of Pueblo Bonito and the other Chaco ruins while they were under construction. This forest played an important part in the conservation of the local water supply. The holding of soil and moisture on the mesas above by tree roots and vegetation was especially vital to the growth of trees and the continuance of springs. Cutting down this forest had an important influence on, if it did not cause, the drying out of the Chaco region with a resultant decrease in its power to support human life. Such changes as this are very real in limited areas and are sometimes called microclimatic changes.

The Possible Use of Dead Timber

At Wupatki, 35 miles northeast of Flagstaff, the forest question again attracted our attention. Many of the larger logs in the ruin were from trees that could have been dead when they were used, probably the only case of that sort encountered in all our far-reaching investigation. Their outer rings showed diminishing size until it was practically impossible to count them. The trees looked as if they had died of starvation. But in both Chaco and Segi Canyons we found roots of pine trees exposed by blowing away of the soil. Their rings showed effects similar to that in the Wupatki beams and thus seemingly identified the cause of the starvation rings in the latter as due to injury to the soil cover. While it is possible some of these Wupatki pines died a number of years before their use by the Indians in house construction, this is rendered improbable by their lack of weathering. The neighboring forest doubtless included both living and dead trees and as the former are much easier to cut, it is considered most likely that all those used were still alive, however close to natural death. The smaller roof poles at Wupatki were certainly growing when cut, for some are found today with the bark intact.

There is no doubt that the larger number of these Wupatki timbers indicate a nearby forest. Judging by our investigations at other

points, one would conclude that the pine forest, now some eight miles distant, extended in the twelfth century to the mesa immediately above the ruin. The retreat of the forest to its present position is probably due to the blowing away of cinders spread over the country at the last eruption of Sunset Crater, as suggested by Dr. Colton in an important paper. (See Colton, 1932; also Haury's discussion in Haury and Hargrave, 1931, p. 13.)

Re-use of Timbers

The study of 200 specimens from Oraibi provided an unusual opportunity for observing on beams the effect of long continued occupation of one site. Chiefly, two such effects were recognized: wear and discoloration. Very old timbers are always worn down on the outside and, if more than 400 years in constant use, the sapwood is usually gone. (For illustration of sapwood, see page 27.) In logs 300 years old, the loss of sapwood is slight; in 200-year logs, scarcely any loss can be detected. Very little impression was made on the heartwood, even in logs used continuously for 500 years.

Discoloration near the outside of a beam also results from long use. Caused largely by smoke in the room, deep-seated discoloration in most cases is proportional to age. Although quite evident in those of the 1700's and 1600's, discoloration is much more apparent in beams of the three preceding centuries. We found ourselves able to estimate the age of some specimens within fifty years by carefully noting the degree of discoloration and wear. Prolonged occupation of a site naturally invites the re-use of timbers, as in modern Zuni and the Hopi villages. The presence of a log of later age in a room built long previously means, presumably, a substitution for a broken piece. From such substitution, as from wear and discoloration, archeologists may roughly estimate the length of occupancy.[1]

Drouth Effects

In this dry Arizona climate, at the border separating forest from desert, available water is a factor of greatest importance. We may safely attribute a succession of small rings in these border trees to drouth, thus using a relationship of tree growth to rainfall that has been verified by tests. It is different in high altitudes and in high latitudes, for diminished ring size there is attributed to intense cold. Long continued "drouth" years in the prehistoric pines may be accepted as evidence that the contemporaneous Pueblo Indians were experiencing economic misfortune. Building activity during such

[1] Reference is made to a fourth, and very promising, method of estimating length of occupation now being developed by Miss Florence M. Hawley, a student of tree-ring dating. It is a study of the dating of charred wood in the rubbish heaps, chiefly charcoal from the daily fires. See Hawley, 1934, in bibliography.

periods appears to have been greatly diminished. Therefore, on account of its interest to archeologists, the following summary is given of the major drouths indicated in our tree calendar, now extending from 1929 back to 700 A. D.

The great drouth from 1276 to 1299 was the most severe of all those represented in this 1200-year record and undoubtedly was connected with extensive disturbances in the welfare of the Pueblo people. Some of its details are shown on page 42. Next in magnitude was the drouth that came just 300 years later, 1573 to 1593. And after another 300 years there was a third major drouth. This latter began, perhaps, in the 1870's and after a few abundant years near 1890 took on a drastic character from 1896 to 1904. It was followed by a series of very favorable years, as in the case of its predecessors. If this sequence constitutes a 300-year cycle, there should have been a great drouth near 1000 A. D., but the tree rings fail to show it. However, the interval from 1005 to 1036, or even to 1044, was distinctly below normal and, like the three instances cited above, was followed by a score of favorable years.

Other drouths that have attracted our attention came in the 790's; 900 to 904, with a return about 20 years later; a severe but short one about 980; another, 1090-1101; possible short ones at 1131 and 1217. 1400 had a severe one, lasting nearly 10 years, as did 1500; 1727 to 1737 was severe; and 1820 to 1823.

Climatic Values

It has long been a maxim with scientists that the value of their work to mankind lies not only in the immediate results attained but in other advances that follow. Each research successfully concluded forms a link in the chain of progress. Our evidence of drouths disclosed by prehistoric ceiling beams is not only important to the archeologist but it is leading to a hitherto impossible historical study of climate and hence is of value to everyone interested in the latter, especially in the Southwest.

Drouths are working havoc today, just as they did in the days of the old Pueblo people. When times are good we forget the discouragement of "dry spells," believing naïvely that we can do nothing about it. True, we cannot change nature's great laws that govern the movement of the earth's atmosphere, but perhaps we can protect our cities and farms to some extent by wise reclamation projects and preservation of the forest cover. And we certainly can attempt to learn the laws of climate and so obtain, if possible, foreknowledge of good and bad years to come. We find presented in the tree-ring calendar a climatic chronology that not only aids the reclamation engineer but supplies to the student of climatology some

of his most fundamental material for the formation of climatic theories. This is one gift to the future that emerges from our prolonged, but finally successful, effort to learn the age of prehistoric Pueblo Bonito.

V

TABLE OF DATES

The following table includes the dates obtained from nearly 1400 specimens recovered at 45 different ruins which here, for convenience, are arranged in ten geographical groups. A very large proportion of these dates are the actual years when the trees were felled and thus give exactly, or very nearly, the years when construction was under way. Consideration of the relationship between the felling of trees and the building of houses must be left to the archeologist.

In explanation of the symbols used: Readings from beams in prime condition are given in ordinary type; italics indicate approximate dates. These approximations, which occur chiefly in the material from Showlow ruin and the Hopi villages, may be considered correct within about ten years, one way or the other. At Showlow, the only surviving timbers had been reduced to charcoal by prehistoric conflagrations; the charcoal beams were usually broken into fragments. But on comparison of their rings these fragments often group themselves in such a way that fairly close dates are indicated. Such approximations are given in italics and the number of fragments stated. The Hopi beams were often in good condition except for wearing of the softer sapwood on the outside. The number of years in complete sapwood may vary from 20 to 100 but the common number is about 45. Therefore, in worn beams the date of beginning of sapwood is taken if possible and 45 years added. I believe most of these "sapwood dates" are correct to within about ten years; they, also, are indicated by italics. As time goes on, the technique of estimating the amount worn from the outside of certain beams will become more and more accurate.

All years given depend on a sequence of carefully dated rings, and give the estimated final growth year of the tree. The sign $\pm$ is used to express an uncertainty of not more than three years but, if an actual estimate was made of possible error in the final growth year due to crowding of rings in the last years of the tree's life, the sign $\pm$ is followed by such estimate. The $+$ sign means a possible addition of one to five rings; it is inserted in cases where the last few rings of a series are too crowded for accurate reading or possibly worn off from long usage of the beam. The number of specimens at each date, if more than one, is given immediately before the date itself.

The figure given in parentheses after each major heading indicates the number of dated specimens listed from that particular geographic district; that appearing after the name of a ruin shows the number of dated specimens included from that ruin. While nearly all the specimens listed were obtained by the several beam expeditions of the National Geographic Society, it should be stated once more that a number of other institutions and individuals have contributed important material, as described in the foregoing paragraphs. The dates here given for the Kintyel and Showlow districts include many determined by Mr. Emil W. Haury.

I. CHACO CANYON (113)

Pueblo Bonito (65)	7— 919	1041	1071	1088
	920	1044	1072	1092
	932	3—1047	2—1073	2—1101
	2— 935	1052	2—1075	1102
	1009± 8	1056	1076	1117
	1010±10	1057	4—1078	1126
	1017±35	3—1061	2—1080	1130
	1033	2—1063	4—1081	
	1034	2—1064	1082±	
	2—1040	4—1065	2—1083	
Pueblo del Arroyo (30)	1052	2—1075	3—1096	1102
	1064	1077	1097±	6—1103
	3—1066	2—1086	1099±1	
	2—1072	1090	2—1100	
	1074	1092±3	1101	
Peñasco Blanco (5)	1056	1069	1084	1087
	1057			
Hungo Pavie (4)	942	943	1057	1077
Chettro Kettle (5)	1053	1069	2—1072	1073
Kinbiniyol (2)	2—1120			
Pit House in Wash (2)	777	777±10 (dated Dec., 1934)		

II. CHINLE DISTRICT (58)

Sliding Ruin [Mindeleff's Ruin 32] (6)	936	944	956	3— 957
Mindeleff's Ruin 15 (1)	1011			
Mummy Cave Tower (36)	1253	1271	2—1277	1282±1
	1266	1272	1279	2—1283
	1267	1276	1280±1	18—1284
	1269	1276±3	3—1281	
White House Ruin (14)	1060±	1072	1082	1219
	1066	1074	1085	1275
	3—1071	2—1075	1096	
White House Cliff Ruin (1) provisional	1061			

III. KINTYEL DISTRICT (215)

Klagetoh, large ruin (1)	1112			
Klagetoh, small ruin (1)	1126			
Rincon Red House (2) (Kin-kle-chee)	1126	1130		
Kintyel (200)	1255	1268	16 fgts.—*1273*	10—1279
	1262	17—1270	139—1275	2—1280
	1264±1	2—1273	9—1276	1285
Kinnazinde (11)	2—1720	2—1755	1758±1	1804
	1742±2	2—1757	2—1763	

IV. FLAGSTAFF DISTRICT (85)

Wupatki (69)	1073	2—1128	2—1153	1178
	1078+	2—1130	4—1155	2—1181
	1083	1134+	1157	2—1183
	3—1088	3—1137	1160	1184
	1090	1138	1164	1186
	1099	1141+	3—1167	2—1191
	1107+	1143	2—1168	1192
	1118	1145	1170	2—1193
	1119+	1147	1171	3—1194
	2—1122	1149	1172	1195+
	1124+	1150	1174	1205
	3—1127	1151	1175±1	
Citadel (3)	2—1192	1260		
Ruin J, near Citadel (1)	1192			
Turkey Hill Pueblo (9)	2—1168	1227	1259	1271
	1203	1246	1262	1278
Chaves Pass (2)	2—1381			
Elden Pueblo (1)	1162+			

V. MESA VERDE DISTRICT (53)

Cliff Palace (1) provisional	1073			
Oak Tree House (1)	1112			
Spring House (1)	1115			
Balcony House (2)	1190	1206		
Square Tower House (1)	1194			
Spruce Tree House (2)	2—1242			
Grand Gulch, Utah (2)	1132	1135		
Solomon Ruin, N. M. (2)	1089	1089±3		
Aztec Ruin, N. M. (41)	3—1110	1114	3—1117	2—1121
	11—1111	16—1115	2—1118	
	1112	1116	1120	

VI. SEGI CANYON (19)

Betatakin (13)	1242	2—1266	1271	1277
	1253	3—1267	1273	
	1260±2	1268	1275	
Keet Seel (5)	1274	1275	2—1284	1286
Rubbish Ruin (1)	1257			

VII. SHOWLOW DISTRICT (541)

Showlow (461)	1174±	1311±	1369	
146 beams	1175	35 fgts.—*1315*	3—1370	
315 fragments	1179	7 " *1330*	3—1370±	
	1188	15 " *1345*	4—1373±	
	1202±	1355±	1374	
	38 fgts.—1205±	1356	4—1375	
	1228	1356±	8—1375±	
	13 fgts.—1230±	1357±	86 fgts.—*1375*	
	12 " *1240*	1360	4—1376	
	24 " *1265*	1362	3—1377	
	1276±	1363±	8—1377±	
	1277	1364±	40—1378	
	1277±	6—1365±	1379±	
	1283±	30 fgts.—*1365*	9—1380	
	1284±	1367	9—1380±	
	42 fgts.—*1285*	1367±	2—1381	
	13 " *1295*	2—1368	1381±	
	1305±	1368±	13—1382	
Pinedale (80)	15 fgts.—*1150*	1285	1298	
21 beams	1155±1	1285±	14 fgts.—*1300*	
59 fragments	27 fgts.—*1210*	5—1286	2—1305	
	1 fgt. —*1235*	1287	2 fgts.—*1325*	
	1273±	1293±1	1331	
	1280	1296±	1373	
	1281	1297	1375	

VIII. JADITO MESA (93)

Kawaika (34)				
(probable date, juniper)	—1217	1368	1440±	
	1357	1380±2	1450±	
	1364±2	1396±	1460+	
	7—1365	1397	2—1468±	
	1365±1	1398	2 fgts.—*1475*	
	1365±2	3 fgts.—*1400*	1480±	
	2—1366	1412	1495	
	1366±	1430+		
Kokopki (43)	2—1269	2—1369	1389	
	1274±	4—1370	1399	
	1275	1371±2	4—1400	
	2 fgts.—*1275*±	15—1380	1416	
	1276	1383	2 fgts.—*1435*	
	2—1368	2 fgts.—*1385*		
Chakpahu (16)	6—1377±	2—1388±	2—1389±	1390±
	5—1378±			

IX. ZUNI DISTRICT (4)

Hawikuh (4)	1381	1391	1405	1480

X. HOPI VILLAGES (191)

Oraibi (131)	2−*1370*	*1520*	*1612*	3−1710±
	1378	2−*1534*	*1613*	1711+
	1408	*1535*	*1616*	2−*1715*
	1412	2−*1540*	*1617*	1719
	1414	*1541*	*1619*	2−1720
	1416	*1544*	2−1619+	3−*1720*
	1428	*1557*	1620+	1722±
	1430	*1562*	1622	*1723*
	1442	*1564*	1624	1724+
	1444	*1566*	*1624*	2−*1725*
	1448	1567±	*1626*	1726±
	1450	*1568*	1629+	1729
	1460	*1569*	1630+	2−1730±
	1470	1570±	1630±10	*1735*
	1471	*1572*	1631	1740±
	1474	*1573*	1631+	1741±
	1478	2−*1576*	2−1634	*1747*
	1479	1582±	3−1635±	1749±
	1487	*1585*	1636	1753
	1490±	*1590*	1638±5	1754
	1501	*1593*	1667±	2−*1755*
	1504	1596	1690±	1756
	1507	*1600*	1691±	2−1759+
	1510	*1601*	1692	1760
	1511	1603+	1696	*1774*
	1512	1605±10	1698±	*1779*
	1515±	*1606*	1700±5	
	1518	*1607*	*1700*	
	1519	*1610*	1703+	
Shongopovi (46)	*1408*	*1455*	2−*1513*	2−*1569*
	1409	*1460*	*1517*	*1581*
	1415	*1465*	*1520*	*1629*
	1428	*1475*	2−*1528*	1641±
	1429	2−*1477*	*1534*	1642±
	1430	*1478*	*1537*	*1648*
	1431	*1483*	*1539*	1656
	1434	*1490*	*1551*	1703
	1440	3−*1502*	*1563*	1728±
	2−*1447*	*1503*	*1564*	
Walpi (12)	*1417*	*1531*	*1587*	*1624*
	1476	1552+	*1589*	1692
	1494±	*1561*	1614±	1712±
Shipaulovi (2)	1550±15	1588±1		

VI

TREE-RING PHOTOGRAPHS, 698 TO 1929 A. D., ANNOTATED

These photographs of tree rings, whose dating was established in 1929 by the closure of the "gap," make use of 31 enlargements from 20 different specimens. The pictures were taken directly from wood at the Steward Observatory (see footnote, page 10). The periods of time represented in the photographs slightly overlap each other so that a continuous ring series may be traced from 698

to 1929 A. D. The dates and other annotations below the photographs aid in establishing connection from one to another, and in identifying the character of ring growth in respective years.

From about 800 A. D. to the present time each ring has been checked in approximately one hundred different specimens. The number decreases to less than a dozen good specimens at 700 A. D.[1] Hence no doubt need be felt of any connection between these pictures, even with those in which the different size and different curvature of the rings make the matching difficult at first sight, such as the one near 1145 A. D. The scale of these photographs is in most cases between three and four times that of the original, but is not perfectly constant.

In studying the original specimens it was found necessary to use pin pricks on the wood to indicate dates of the rings and to call attention to the proper solution of difficult rings. These symbols are continued in these photographs. A single dot stands for a decade number, such as 1810, 1820, etc. Two dots indicate the 50 year rings, 1850, 1750, etc.; three dots give the century rings, 1800, 1900, etc.; and four dots will be found at the year 1000 A. D. Difficult and microscopic rings have a dot on each side, opposite each other. If the ring does not appear on the specimen, but is safely assumed to belong there from a multitude of comparisons with other trees, then a dot is placed on each side of the assumed absent ring, but not opposite each other. In case two difficult or absent rings adjoin each other, two dots instead of one are placed on the side of the smaller ring.

In order to make clear the precision in tree-ring methods of dating, these "annotations" are repeated in the margin below the photograph, and such other data are added in that margin as seem necessary to render evident the identity and condition of each ring. In this margin the rings themselves are indicated when needed by small marks close to the photograph. Doubles are indicated by the letter "d"; microscopic or very difficult rings are indicated by the letter "m" and are usually repeated by date in the annotations below; the ten year dates given in the lower line of the margin correspond to the dots at the lower edge of the photograph.

Attention is called to the occasional "signatures" also marked in the lower part of this margin. A signature is a special group of rings that can be easily remembered, thus aiding very greatly in the dating of specimens.

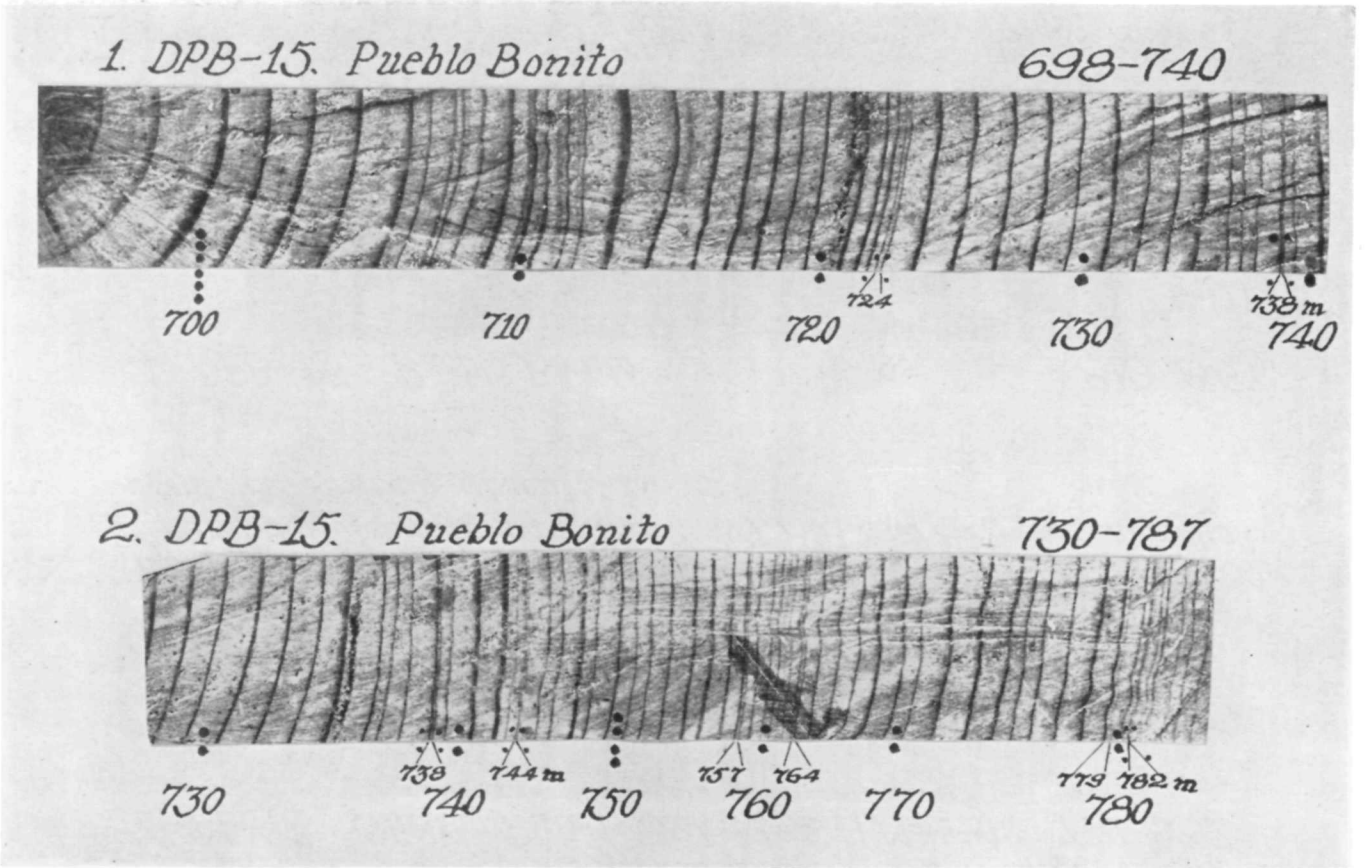
To the student interested in tree-ring details there are other features in this series of photographs worth special attention. Carrying out the continuity from one photograph to the next is a bit of "crossdating," the most fundamental part of tree-ring work.

[1] This number has been greatly increased at the time of going to press.

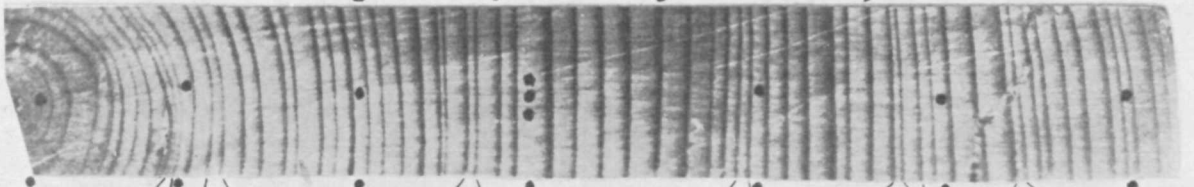
In doing this one finds similarity in successive ring-widths in the two photographs. Between 1083 and 1101 a resemblance may be found between Pueblo Bonito and Betatakin. The interval 1224 to 1251 is shown from Mummy Cave and from Betatakin. Walpi and Oraibi are compared from 1328 to 1361, and give an excellent case of agreement. Widely separated trees near Flagstaff are given at 1845 more or less. Ring records through the great drouth at Showlow, Oraibi, and a ruin in the Sierra Ancha are compared on page 42. In such comparisons one needs to remember that the rings take slightly different forms in different species of trees and even in the central as compared to the outer parts of one tree.

Modern trees from the forests near Flagstaff have ring series such as shown in the photographs from 1710 to 1929. A brief inspection will reveal the difference in style of rings between these from the interior of the forest, somewhat complacent though readily datable, and the entire series before 1710 which has the more highly sensitive type of the forest border, with immense difference between large and small rings.

It is worthwhile to attempt to recognize the long picture here presented of alternating good years and drouth periods in the history thus revealed. Such climatic changes are associated with the varying success of the prehistoric Pueblos. We find favorable or unfavorable climate, indicated by ring size, is followed respectively by increased building, or decreased building and even abandonment. In this way we get a picture of human life and climate through a great length of time.

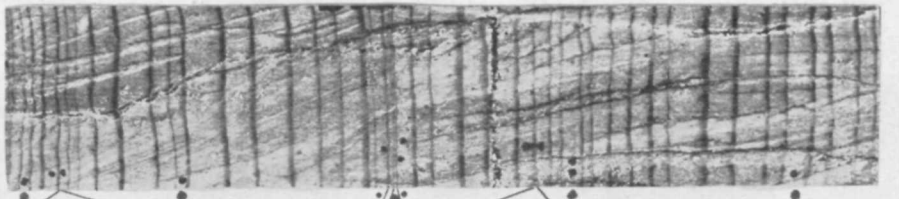

1. DPB-15. Pueblo Bonito
698-740
700
710
720
724
730
738 m
740
2. DPB-15. Pueblo Bonito
730-787
730
738
744 m
750
757
764
760
770
779
782 m
780

3. M-57. Sliding Ruin (collected by E. H. Morris) 770-832

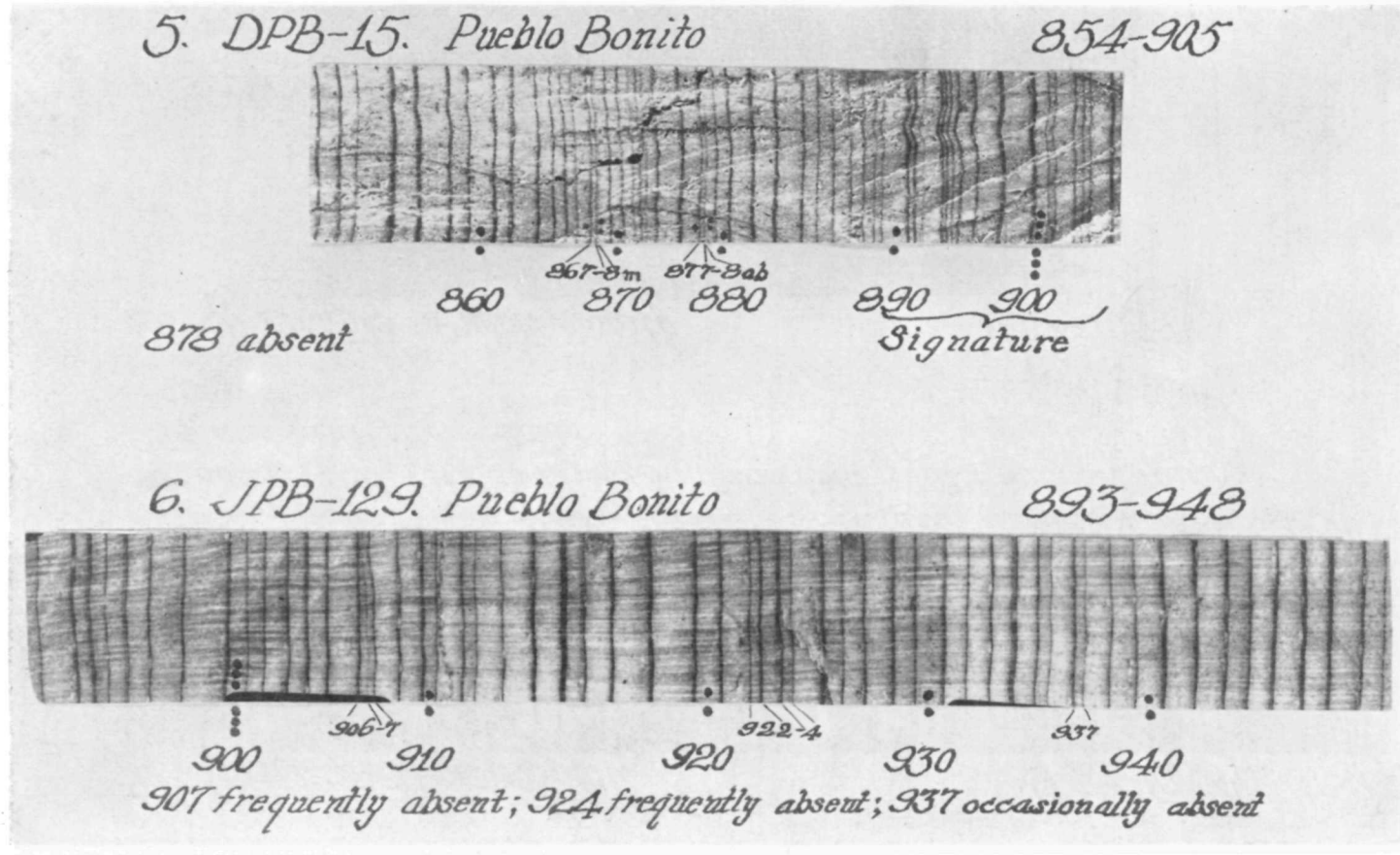


797 and 809 absent in many trees; 817, 818, and 823 occasionally absent; 824 rarely absent

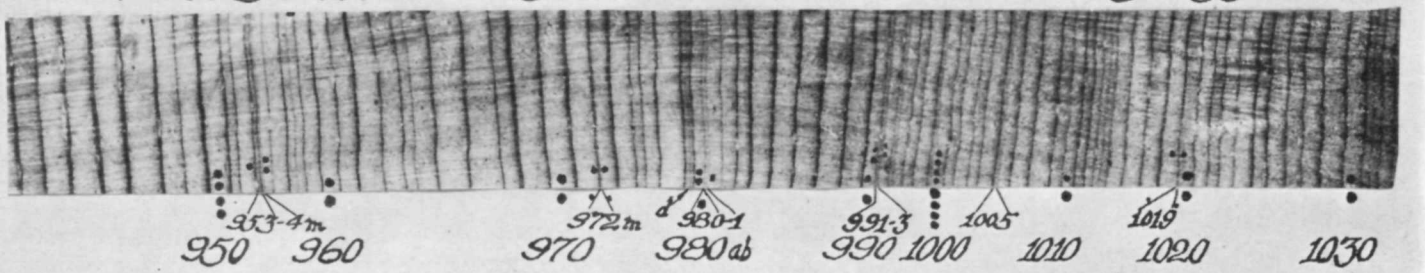
4. DPB-15. Pueblo Bonito 819-863



micro.

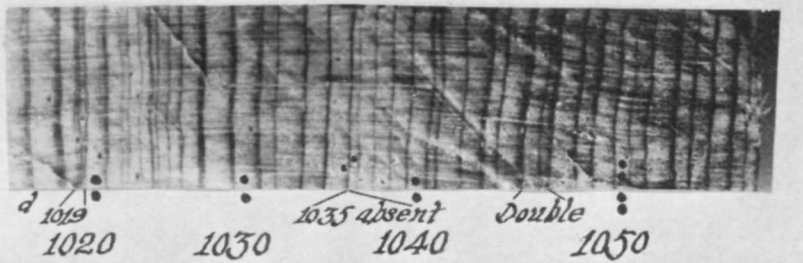

5. DPB-15. Pueblo Bonito
854-905
867-8m
877-8ab
860
870
880
890
900
878 absent
Signature
6. JPB-129. Pueblo Bonito
893-948
906-7
922-4
937
900
910
920
930
940
907 frequently absent; 924 frequently absent; 937 occasionally absent

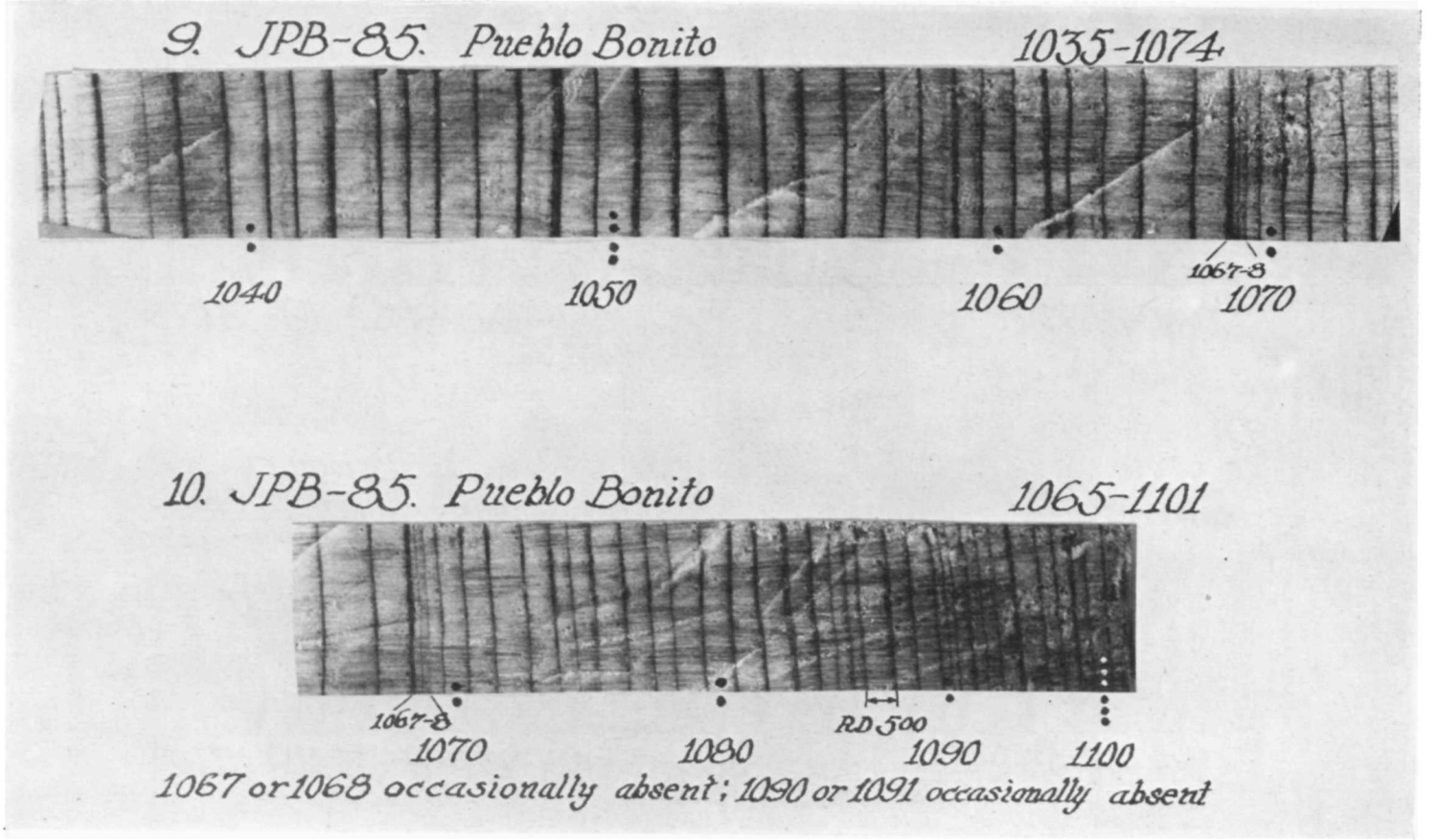
7. JPB-129. Pueblo Bonito 943-1033

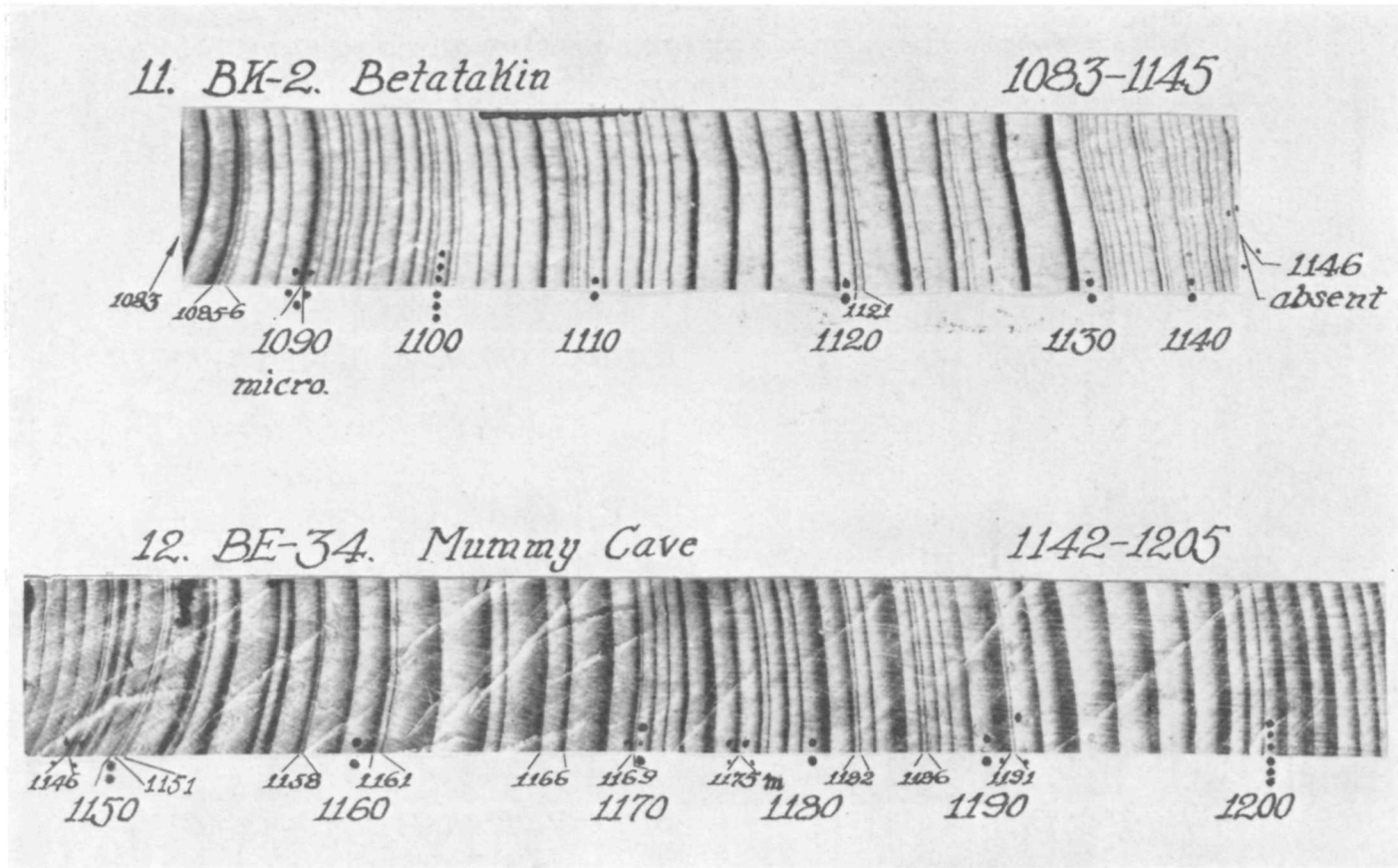


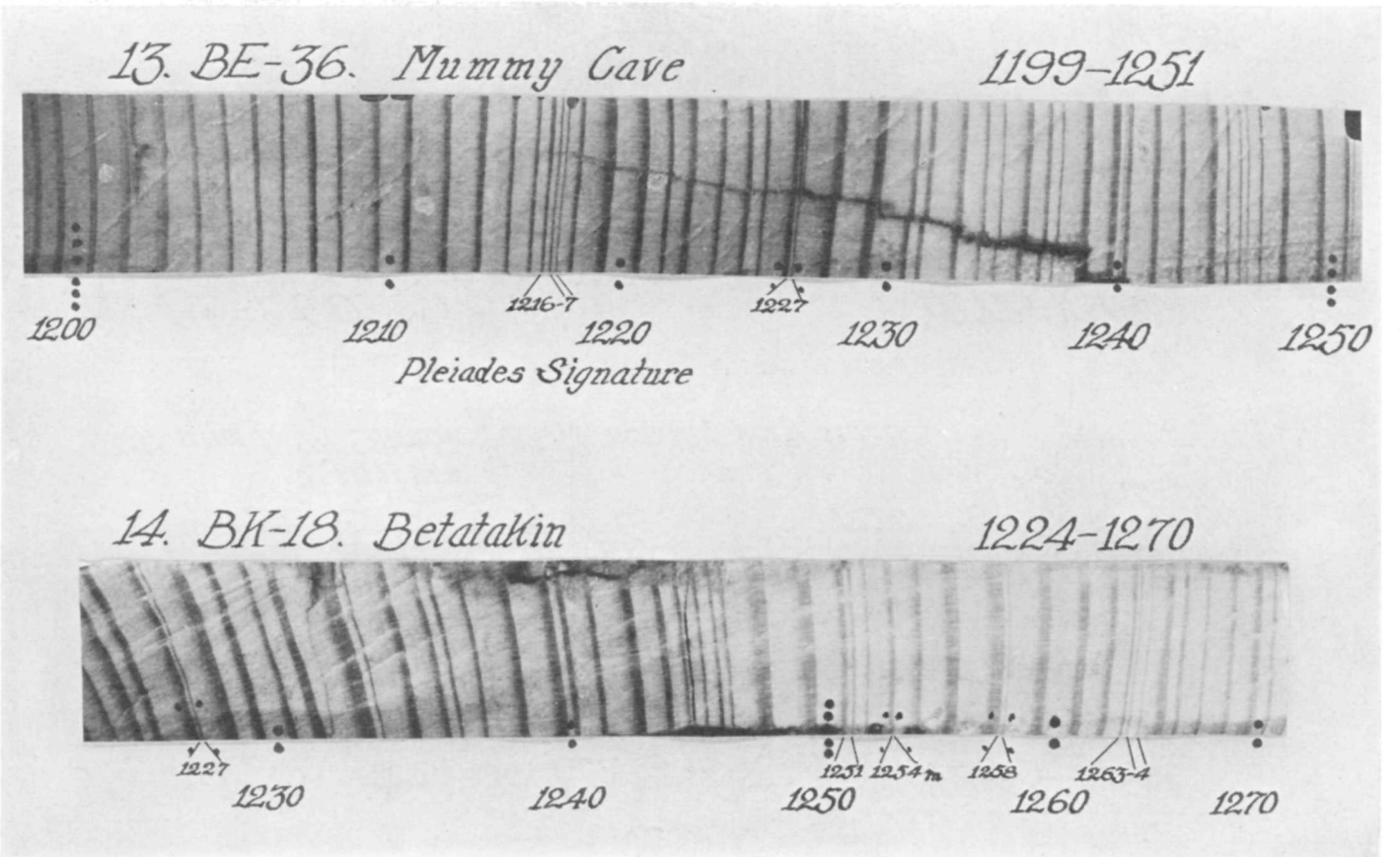
991 absent; 992 very small; 993 microscopic: 1019 microscopic
954 and 980 often absent

8. JPB-156. Pueblo Bonito 1017-1057

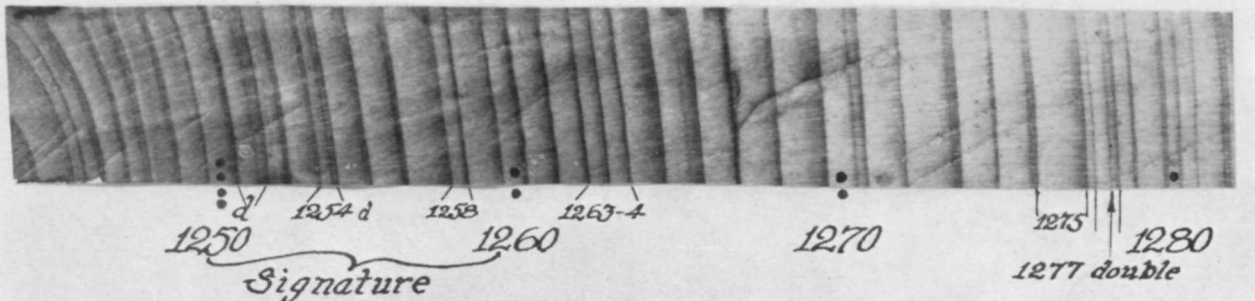



9. JPB-85. Pueblo Bonito
1035-1074
1040
1050
1060
1067-8
1070
10. JPB-85. Pueblo Bonito
1065-1101
1067-8
1070
1080
RD 500
1090
1100
1067 or 1068 occasionally absent; 1090 or 1091 occasionally absent


11. BK-2. Betatakin
1083-1145
1083
1085-6
1090
micro.
1100
1110
1121
1120
1130
1140
1146
absent
12. BE-34. Mummy Cave
1142-1205
1146
1150
1151
1158
1161
1160
1166
1169
1170
1175
m
1180
1192
1186
1191
1190
1200

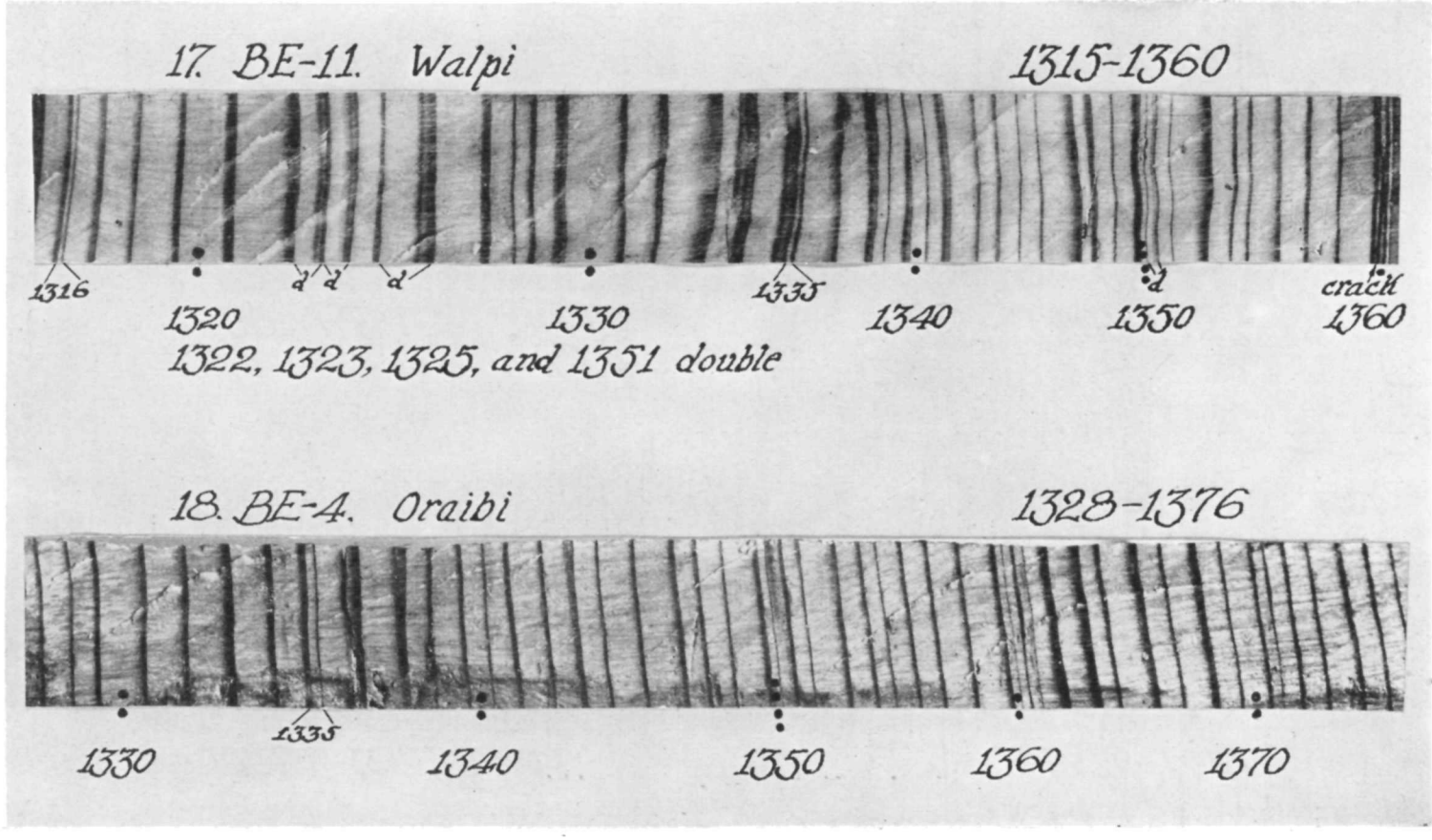

13. BE-36. Mummy Cave
1199–1251
1216-7
1227
1200
1210
1220
1230
1240
1250
Pleiades Signature
14. BK-18. Betatakin
1224–1270
1227
1251
1254 m
1258
1263-4
1230
1240
1250
1260
1270

15. KS-18. Keet Seel 1243-1282



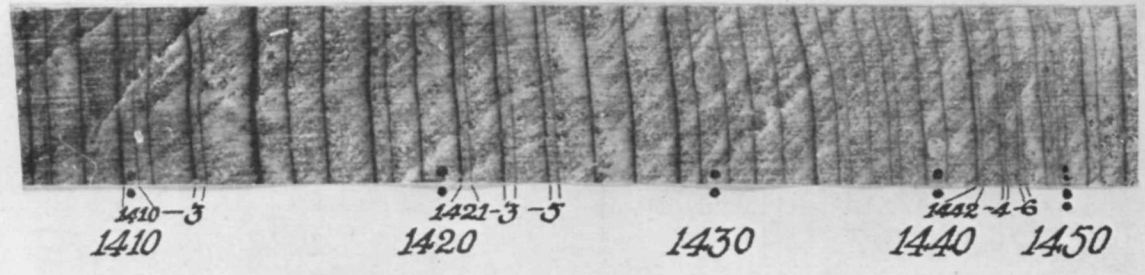
1251 and 1277 double; 1251 usually very small

16. BE-269. Oraibi 1272-1319

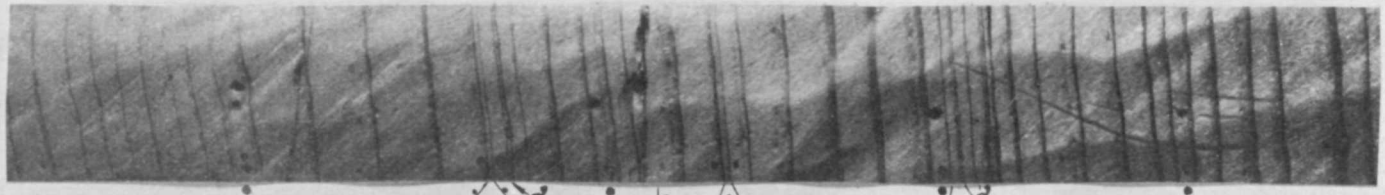

17. BE-11. Walpi
1315-1360
1316
1320
1330
1335
1340
1350
crack
1360
1322, 1323, 1325, and 1351 double
18. BE-4. Oraibi
1328-1376
1330
1335
1340
1350
1360
1370

19. BE-183. Oraibi 1375-1421

20. BE-183. Oraibi 1407-1453

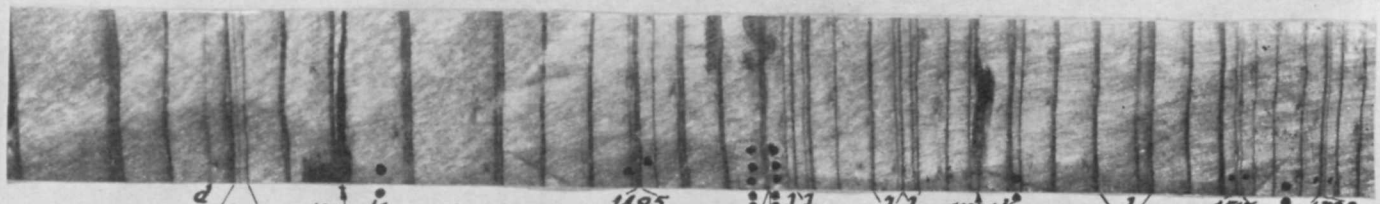


21. BE-10. Oraibi 1442-1485



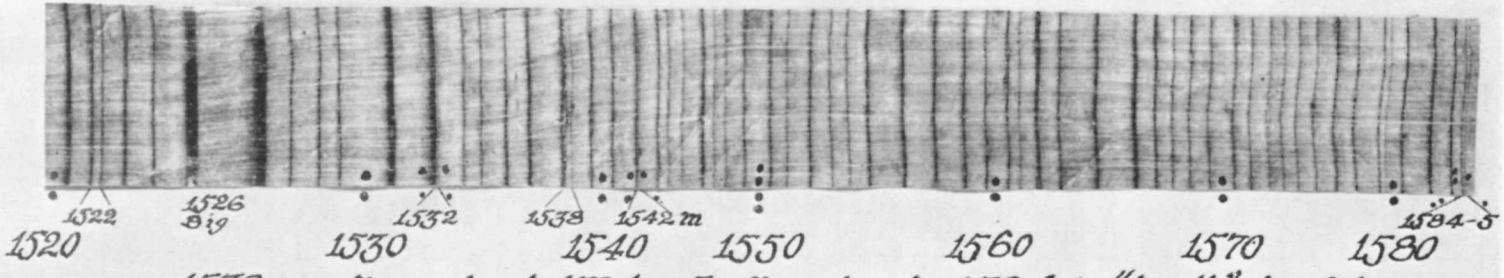
1456, 1460, 1462, 1464, 1465, 1471, and 1473 double
1455, 1464, and 1471 often absent

22. BE-10. Oraibi 1484-1524



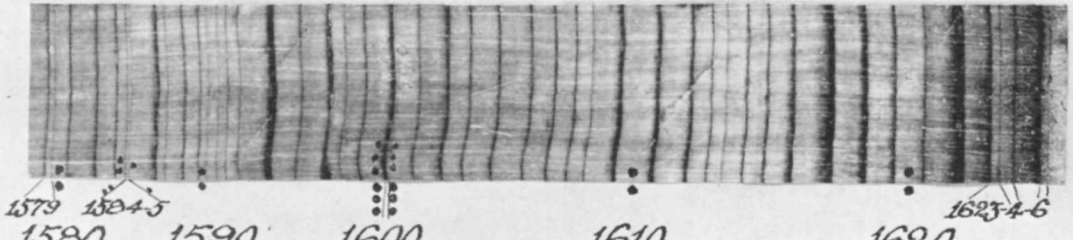
1487, 1501, 1502, 1505, 1506, and 1513 double; 1517 and 1522 always small

23. BE-215. Oraibi 1521-1585



1532 sometimes absent; 1584 or 5 often absent; 1584 is "locally" absent here

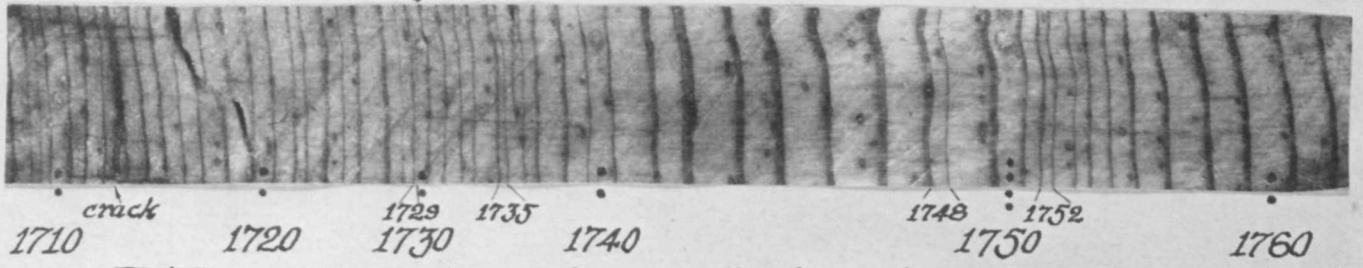
24. BE-215. Oraibi 1579-1626



25. BE-237. Oraibi 1623-1675

26. BE-219. Oraibi 1667-1709

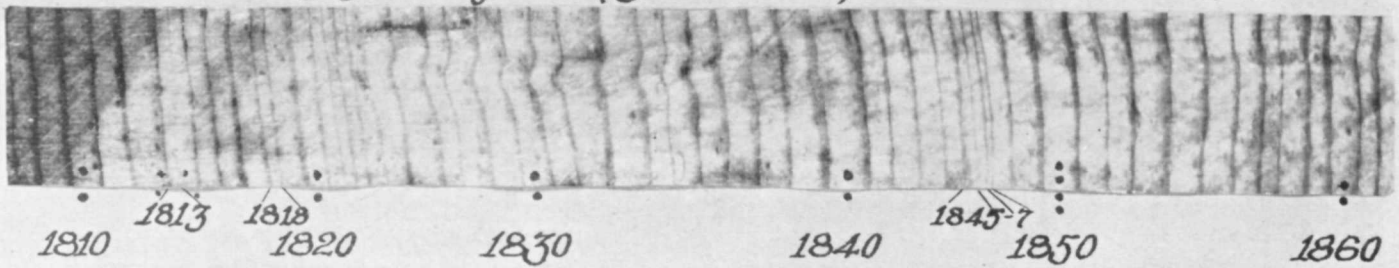
27. FL-33. Flagstaff 1707-1761



FL-33: weathered pine surface; forest interior type of rings; tree cut 1918 near present Fort Tuthill, 5 miles south of Flagstaff

28. FL-33. Flagstaff (5 mi. south) 1759-1809

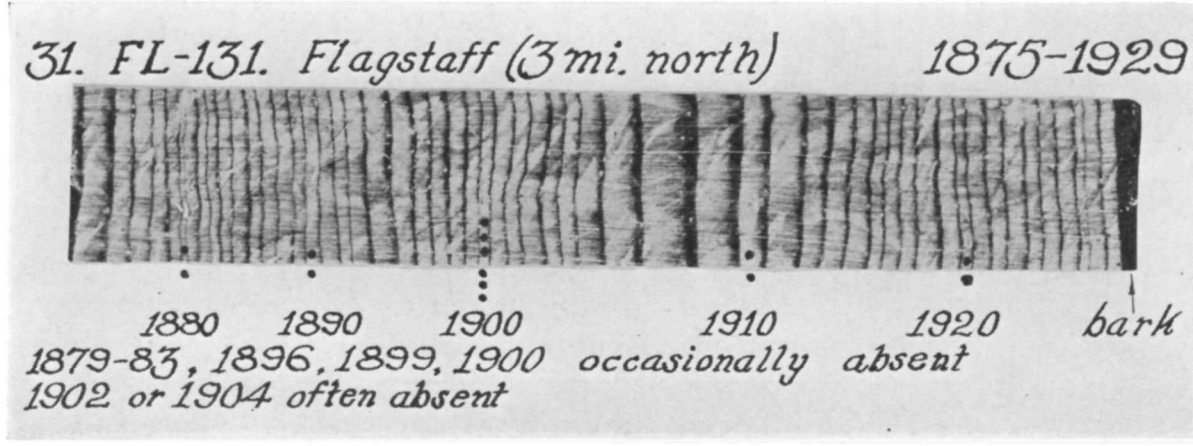
29. FL-33. Flagstaff (5 mi. south) 1808-1861



1820 is usually very small, sometimes absent
1822 is frequently absent. 1847 is occasionally absent

30. FL-131. Flagstaff (3 mi. north) 1834-1891

FL-131: forest interior type of rings, complacent but datable; grew near residence of Dr. H.S. Colton


31. FL-131. Flagstaff (3 mi. north) 1875-1929
1880 1890 1900 1910 1920 bark
1879-83, 1896, 1899, 1900 occasionally absent
1902 or 1904 often absent

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