Annual Subscription, $1.50 Single Copy, 50c

THE TREE-RING BULLETIN
Editor-in-chief.....Dr. A. E. Douglass
Managing Editor..Dr. Edmund Schulman
Associate Editors:
Arctic Studies....Mr. J. L. Giddings, Jr.
Botany.....Dr. Charles J. Lyon
Archaeology....Mr. W. S. Stallings, Jr.

THE TREE-RING SOCIETY
President.....Dr. A. E. Douglass
Secretary.....Mr. Harry T. Getty
Tree-Ring Laboratory
University of Arizona
Tucson, Arizona

DENDROCHRONOLOGY AT MESA VERDE NATIONAL PARK

EDMUND SCHULMAN

This report gives an index of the winter-season storminess at Mesa Verde, in southwestern Colorado, for 1,346 years, the climatic records recently developed in living firs having been extended by the measurement of the longer and more sensitive ring series in archaeological specimens.[1]

CHRONOLOGY IN OLD WOOD

Collections. About a score of specimens, mostly sections, were obtained by A. E. Douglass[2] in 1923 as a result of an expedition of the National Geographic Society. Major collections were made by H. T. Getty[3] in 1932-33; these consist of about 100 cores obtained with the 1-inch tubular borer and many sections and fragments, the latter mostly charcoal from pit houses.

Dates. Statistics on all the longer and more sensitive series in ruin woods from Mesa Verde which have been dated at the Tree-Ring Laboratory are given in Table 1*. Since the quantitative analysis of these ring records represents what is perhaps a type case it is presented here in some detail.

In Table 1, numbers originally dated by Getty may be found in *Bulletin* 1 (3) and 1 (4); all others were first analysed by Douglass—*Bulletin* 1 (3), 5 (2), and unpublished notes—with the exception of numbers 94, 140, 294, and 295, recently dated by the writer. Occasional differences, all trivial, in the data on some specimens in the present table as compared with previous tables are traceable to the use of different radii on these specimens. A few secondary, previously published series—provisionally dated, junipers, complacent pinyons or very short records in young firs—are not included in the present summary, since they represent little of potential value in climatic studies; they will be included in a future supplementary table. The unnumbered charcoal series "Earth Lodge A" at the end of the list was the only one not independently studied by the writer.

Number: Starred specimens were measured; the ring-widths are plotted in Figures 1 and 2. Specimens 294 and 295 represent opposite ends of one beam; no other specimens are paired, as far as could be determined.

Form: F. sec.—full section; Sq. cut—square cut; Fragm.—fragment.

Species: DF—Douglas fir; PNN—Pinyon pine.

Inner Ring: The letter *p* indicates the date as that of the pith-ring, which is present on the specimen.

Heartwood Ends: In older trees the heartwood-sapwood boundary often varies across a number of rings; in such cases an estimate of the mean date was made. Sapwood is probably present on most pinyon specimens, but since the boundary is difficult to determine no estimate for any specimen of this species was made. Some sapwood is probably present in the Douglas fir specimens 23, 184, and 185, but was difficult to determine because of discoloration.

Outer Ring: When the outer ring is constant, *c*, in date everywhere on the outer surface of the specimen, an original cutting date at or very near that of the outer ring is probably indicated, if the evidence based on the number of sapwood rings and on the dates of associated specimens is consistent with such a possibility. A small variation in outer date, noted by *v*, indicates a loss of outer rings, which may range from zero to perhaps as many as ten rings; a very variable outer date, *vv*, indicates a loss of many rings and in the absence of sapwood can give little indication of cutting date. The outer 15-20 rings in specimens 70 and 294 were so compressed that they could not be dated with sureness; the plus sign indicates possible missing rings in these intervals.

Record Quality: This is an estimate, in four grades from poor to excellent, of the climatic-indicator value of the ring series, made when it was checked for

[1] Bull. Amer. Met. Soc. 19:152-4, 1942.
[2] Nat. Geog. Mag. 56:743, 1929; Nat. Geog. Soc. Tech. Paper, p. 52, 1935.
[3] Tree-Ring Bull. 1:21-3, 28-9, 1935.
*The writer is indebted to A. E. Douglass and H. T. Getty for placing the archaeological collections at his disposal.

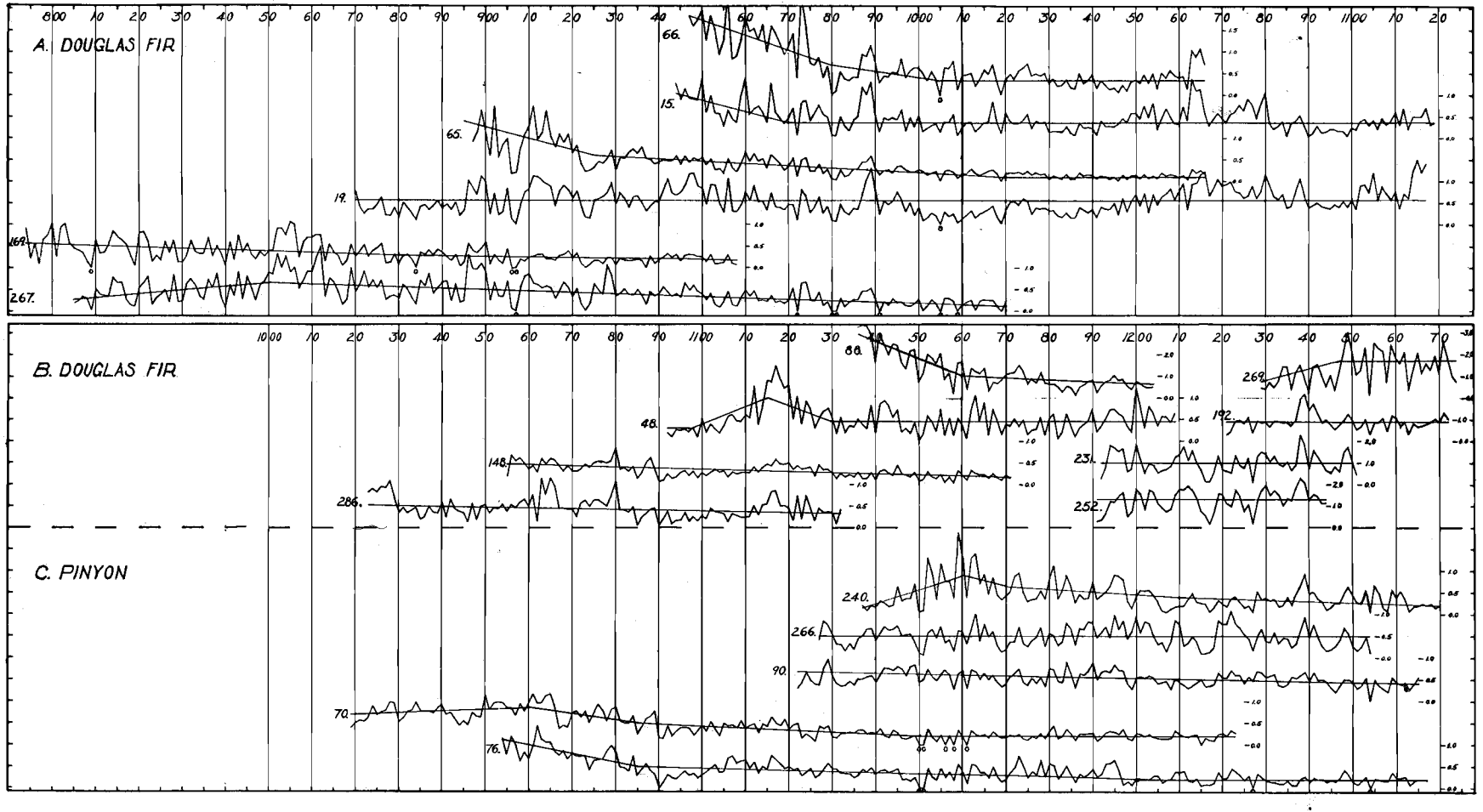


Figure 1. Measured ring-widths in Douglas fir and pinyon trees at Mesa Verde; the vertical scale is in millimeters. Mean trend or standardizing lines are graphically fitted to each curve. Locally-absent rings are noted by zeros below the curve. Average curves for the Douglas fir sets A and B and the pinyon set C are plotted in Figure 2. The coordinate grid may be completed by use of the border divisions.

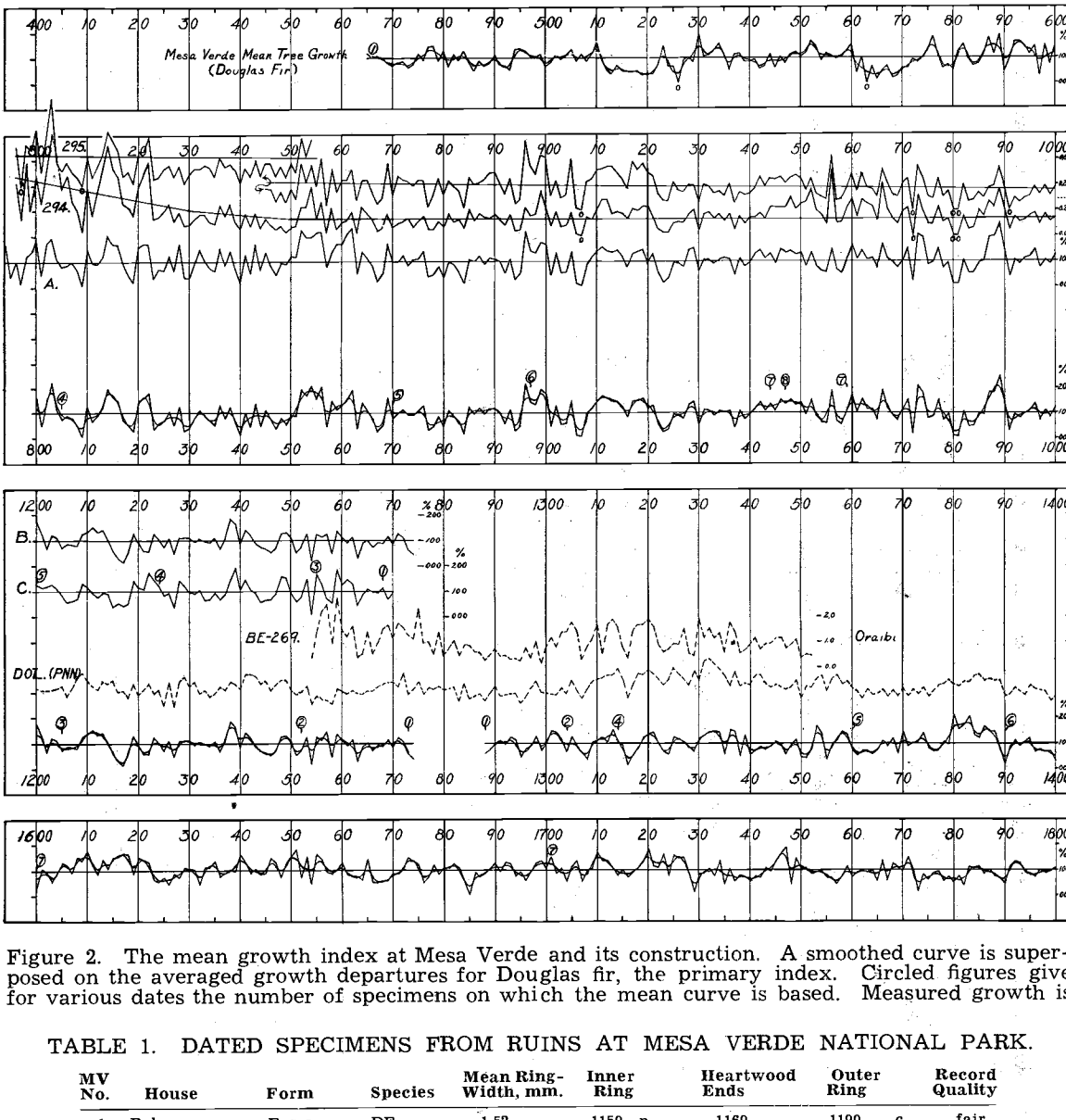
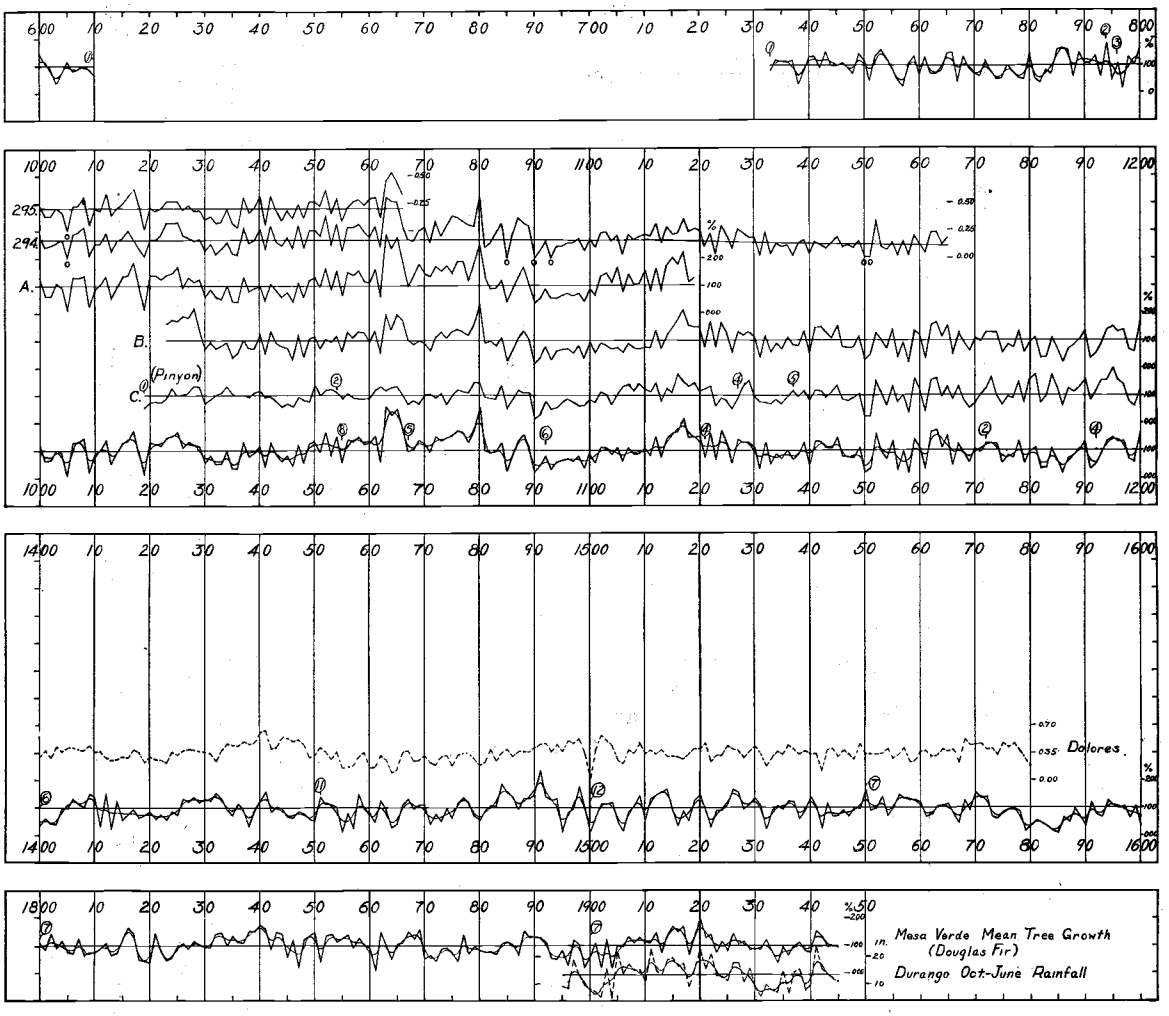


Figure 2. The mean growth index at Mesa Verde and its construction. A smoothed curve is superposed on the averaged growth departures for Douglas fir, the primary index. Circled figures give for various dates the number of specimens on which the mean curve is based. Measured growth is

TABLE 1. DATED SPECIMENS FROM RUINS AT MESA VERDE NATIONAL PARK.

MV No.	House	Form	Species	Mean Ring-Width, mm.	Inner Ring		Heartwood Ends	Outer Ring		Record Quality
1	Balcony	F. sec.	DF	1.52	1159	p	1169	1190	c	fair
2	Balcony	Fragm.	DF	1.22	1149	p	1176	1206	vv	good
15*	Oak Tree	F. sec.	DF	0.43	940	p	1070	1119	vv	exc.
17	Spruce Tree	Sq. cut	DF	2.00	1185		1224	1243	c	good
18	Spruce Tree	F. sec.	DF	1.31	1210	p	1228	1244	c	fair
19*	Spring	F. sec.	DF	0.54	867	p	.....	1117	vv	exc.
23*	Step	F. sec.	DF	0.75	464	p	.....	610	v	exc.
40	Cliff Palace	F. sec.	DF	0.86	1237	p	1244	1264	c	good
48*	Cliff Palace	Core	DF	0.51	1091	p	1176	1210	c	exc.
51	Cliff Palace	Core	PNN	0.37	1105	p	.....	1266	c	poor
52	Cliff Palace	Core	DF	1.38	1220	p	1260	1267	c	fair
53	Cliff Palace	F. sec.	PNN	0.44	1159	p	.....	1273	c	fair
64	Buzzard	F. sec.	PNN	0.75	1174	p	.....	1273	c	fair
65*	Jug	½ sec.	DF	0.37	896	p	1008	1066	v	exc,
66*	Jug	Core	DF	0.68	947		1009	1066	c	exc.
70*	Ruin 16	½ sec.	PNN	0.42	1018	p	.....	1241+	vv	good
74	Ruin 16	F. sec.	PNN	0.75	1210	p	.....	1261	c	fair
76*	Long	Core	PNN	0.39	1052	p	.....	1268	c	exc.
84	Long	Fragm.	DF	0.55	1139		1184	1204	vv	good
85	Long	F. sec.	PNN	0.90	1153	p	.....	1246	vv	fair
86	Long	F. sec.	PNN	0.32	1117	p	.....	1274	c	good
87	Long	F. sec.	PNN	1.09	1207	p	.....	1263	c	fair
88*	Long	¼ sec.	DF	1.17	1132	p	1193	1211	vv	exc.
90*	Long	¼ sec.	PNN	0.53	1121	p	.....	1267	v	good
93	Long	F. sec.	DF	0.56	1148	p	1233	1273	c	good
94	Long	F. sec.	DF	0.47	1080	p	1212	1267	v	poor
140	Hemenway	Fragm.	DF	0.29	994		1139	1174	c	exc.
148*	Hemenway	Fragm.	DF	0.31	1055		1130	1171	v	exc.
160	Bone Awl	Fragm.	DF	0.26	941		.....	1022	vv	exc.
169*	Bone Awl	Fragm.	DF	0.33	794		.....	958	vv	exc.
170	Bone Awl	Fragm.	DF	0.34	900		.....	964	vv	exc.



plotted in millimeters for specimens 294, 295, DOL (Dolores), and BE-269 (Oraibi), and in per cent departures for the mean curves. Trend lines are omitted for the Dolores and Oraibi series, plotted here to show the connection between living and archaeological ring series at Mesa Verde. The primary index in Douglas fir may be compared with the supplementary index C in pinyon.

MV No.	House	Form	Species	Mean Ring-Width, mm.	Inner Ring		Heartwood Ends	Outer Ring		Record Quality
182	Oak Tree	Core	DF	0.47	1114	p	1159	1184	c	good
184	New Fire	Fragm.	DF	1.05	1218		.....	1260	v	fair
185	New Fire	Fragm.	DF	1.16	1229		.....	1259	v	fair
187	Painted Kiva	F. sec.	PNN	0.62	1101		.....	1199	c	good
188	Painted Kiva	F. sec.	PNN	0.42	1126		.....	1202	c	fair
192*	Balcony	Core	DF	0.91	1220	p	1244	1272	c	good
230	Spruce Tree	Core	PNN	0.58	1115		.....	1251	v	poor
231*	Spruce Tree	Core	DF	1.00	1191	p	1219	1251	c	exc.
239	Spruce Tree	Core	PNN	0.41	1149	p	.....	1273	v	fair
240*	Spruce Tree	Core	PNN	0.44	1136	p	.....	1270	v	exc.
243	Spruce Tree	Core	PNN	0.61	1163	p	.....	1250	c	fair
245	Spruce Tree	Core	DF	0.86	1149	p	1211	1230	c	fair
246	Spruce Tree	Core	DF	2.00	1195	p	1212	1230	c	fair
248	Spruce Tree	Core	DF	1.27	1200	p	1214	1240	c	fair
251	Spruce Tree	Core	DF	1.26	1190	p	1210	1235	c	fair
252*	Spruce Tree	Core	DF	1.27	1190	p	1218	1244	c	exc.
256	Spruce Tree	Core	DF	0.78	1189	p	1220	1247	v	good
260	Spruce Tree	Core	PNN	0.79	1162	p	.....	1251	c	poor
261	Spruce Tree	Core	PNN	0.66	1172	p	.....	1251	c	poor
265	Spruce Tree	Core	PNN	0.80	1160	p	.....	1254	c	good
266*	Spruce Tree	Core	PNN	0.49	1121	p	.....	1254	c	exc.
267*	Spruce Tree	Core	DF	0.44	804	p	.....	1020	vv	exc.
269*	Spruce Tree	Core	DF	1.41	1228	p	1255	1274	c	exc.
274	Cliff Palace	Core	PNN	1.08	1200	p	.....	1273	c	fair
282	Sq. Tower	Core	DF	1.20	1167	p	1223	1246	v	poor
284	Sq. Tower	Core	PNN	0.52	1158	p	.....	1243	v	fair
286*	Kodak	Core	DF	0.46	1023		.....	1132	vv	exc.
292	Sq. Tower	Core	PNN	0.44	1149	p	.....	1241	v	fair
293	Sq. Tower	Core	PNN	0.90	1157	p	.....	1242	c	fair
294*	Sq. Tower	Core	DF	0.23	794	p	1149	1181+	vv	exc.
295*	Sq. Tower	Core	DF	0.29	732	p	.....	1066	vv	exc.
Earth Lodge A		.....	.....	.....	.....		.....	612+		

date. It is based on the sensitivity, the crossdating quality, the freedom from major suppression and release effects, and the freedom from compression wood and other erratic growth.

All specimens were freshly surfaced according to modern techniques and a decade-pinhole dating in A.D. dates made. Since the outside rings on all but four of the specimens had been previously identified, no preliminary skeleton-plot dating was needed. Direct and minute cross-comparisons among the Mesa Verde specimens, supplemented by reference to specimens from neighboring areas, resulted in sufficiently numerous verifications of ring characters *forecast* from one specimen to the next to permit an unqualified dating of the ring records from A.D. 733 to A.D. 1274. False rings were relatively rare and easily identified, as is characteristic of slow-growth Douglas fir and pinyon in Colorado. Locally-absent rings could be located with precision in view of the excellent sensitivity and crossdating character of the ring records.

Thus, since the present dating, essentially extended back to successively older specimens from the writer's series in living trees at Mesa Verde, is in general agreement with the master chronology of Douglass for the Pueblo area,[4] it serves both as a check on all specimens in Table 1 previously dated and as an independent check on the master chronology since A.D. 733, in which few Mesa Verde records had been included. The gap of thirteen years, A.D. 1275-87, between the inner ring of the living-tree series and the outer ring of the archaeological series was crossed by means of the records from neighboring areas, especially the 860-year pinyon at Dolores[5] and BE-269 from Oraibi, plotted as broken-line curves in Figure 2.

Age trends and the mean growth-curve. An average growth-curve representing individual tree records of varying length and cutting date—the usual case in archaeological ring series—should be based primarily on relatively long-lived trees if possible, for the elimination of the individual age trend is at best an approximation in a young tree of rapidly changing mean growth-rate. The Mesa Verde series is specially favored in this respect, for the characteristically slow growth in this area results in many long records in small beams.

Twenty-two specimens, representing 3,300 rings, were measured.* Of these, nineteen fell naturally into the three sets plotted in Figure 2. By treating these sets separately, it is possible to make some check comparisons of the means (see below). Crossdating among individual series is obviously extremely high in the firs, but rather moderate in the pinyons.

To derive the mean growth curves, percentage departures of the ring-widths from the age trend of individual trees may be computed and averages taken. Placement of the eye-fitted trend lines shown in Figure 1 was guided by the following desiderata:[6] (1) concavity downward except for growth suppression and release in youth rings, (2) straight lines of as few segments as possible. The trends in concurrent series guided the fitting in some cases. More precise fitting of trend lines, by least squares or other methods, seems undesirable, since, in general, there are inescapable uncertainties in the position of the line at the inner and outer ends of each series, approximations exist in the data themselves, and the fundamentally important use of a large quantity of data might, with excessive statistical work, become impractical. The advantage of long series, in most of which, the trend line has little or no slope, is here apparent. To avoid introducing personal bias, no allowance was made in the trend lines for what seemed to be special growth release or suppression effects in some curves; however, no serious case of such effect in the measured series was observed (a fine example of discontinuity in trend, probably caused by repair of an injury

[4] Tree-Ring Bull. 6:39, 1940.
[5] Journal of Forestry 41:425, 1943.
*The measured ring series are now being photographed and, it is hoped, will be made available on microfilm. Circumstances did not permit, at this time, complete reduction of the remaining dated series, mostly the shorter and less sensitive records.
[6] Carnegie Inst. Wash. Pub. 289, III, pp. 25-6, 1936.

on a nearby radius, is shown in the July, 1945 *Bulletin* on the increment core for tree 828 at A.D. 1829 *et seq.*)

The three sets of single-tree series in Figure 1 have been averaged into the three mean growth-curves A, B, and C plotted in Figure 2. The overlap between A and B from A.D. 1023 to A.D. 1119 is obviously very strong, as one would expect in correctly dated series in which some of the local imperfections in chronology have been removed by the averaging process. These two series, properly weighted, have been averaged with specimens 294 and 295 to form the final mean growth-curve in Douglas fir at Mesa Verde from A.D. 733 to A.D. 1274, plotted as the lowermost curve in the panels of Figure 2; the superposed smooth curve, which displays more clearly the long-period fluctuations in chronology, is of the usual type in these studies—$b' = (a+2b+c)/4$. The Douglas fir mean series from A.D. 465 to A.D. 610, plotted in the uppermost panel, is based on specimen number 23 only; the interval A.D. 733-93 is based on number 295 only.

Comparison in Figure 2 of the pinyon series C with the general mean in Douglas fir indicates that, as averages of several trees are used, much of the difference in chronology noted in individual pinyons as compared with firs disappears.

Specimens 294 and 295. These two series are characteristic of over-age drought conifers (see below), a class of trees which yield excellent ring records of rainfall. Locally-absent rings are very numerous so that dating often requires extended effort, but the sensitivity and crossdating are so high that unqualified placement of these absent rings is usually possible. In specimen 294, for example, the average ring-width in the outer 300 years is about 0.16 mm and there are ten absent rings and numerous microscopic rings, yet Figure 2 shows that the growth-curve for this specimen is almost perfectly parallel to those of concurrent series.

It was learned after dating these series that they came from opposite ends of the same log, perhaps ten feet apart. This height growth in sixty-two years, the difference in pith dates, is by no means unusual in trees of this category. The single-tree record, measured from A.D. 733 to A.D. 1165, is specially valuable because its supersensitivity is associated with great length.

Age of standing snags. The chronology in living trees might conceivably be extended backwards in time by the record in standing dead trees. Only one such tree at Mesa Verde, a promising Douglas fir, was examined, in late August, 1945. This tree grew, with its roots along cracks, on a bare ledge of limestone east of the Lower Well in Prater Canyon. It was about ten feet high and some ten inches in lower stem diameter; all branches had been eroded from the strongly spiralled stem. Toppled with some effort, sectioned, and dated, it proved to be only 350 years in age, about half that of the oldest living firs at Mesa Verde. But it had died in A.D. 1819, and was still well braced 126 years later. (Its death could be related to the extremely severe dry interval at Mesa Verde in 1818-1820).

THE CHRONOLOGY IN LIVING TREES*

Tree ages and chronology. The rainfall chronology in living trees here presented is based on increment cores from Douglas firs of the category called over-age drought conifers, extremely slow-growing individuals, which are somehow able to maintain themselves on severely dry sites and seem thereby to be endowed with extraordinary longevity. Four canyons on the Mesa Verde were searched for such trees by the writer, during July 19-21, 1941 and August 28-31, 1945. Little attention was paid to the trees in the characteristic pinyon-juniper woodland of the mesa top, since field experience has shown them to be of secondary chronology value.

A fine example of the range in growth characters of Douglas fir with local variations in available moisture is found near the head of shallow

*For aid in the field work at Mesa Verde the writer is greatly indebted to Superintendent Jesse L. Nusbaum, Jack Wade, Don Watson, Kenny Ross, and Ted Smiley.

Spruce Tree Canyon, close to Spruce Tree House and the Park headquarters. Of the several large firs growing on the canyon floor in front of the ruins the tallest (100 feet?) and largest, well over three feet in lower stem diameter, was shown by an increment boring to have been just five feet high and about five years old in A.D. 1720; the others in the grove are much younger still. All showed readable chronologies, complacent to moderately sensitive, with no locally absent rings. But a few score yards distant, along the upper slope at the base of the cap-rock cliff, are many stunted old firs; the oldest, perhaps 100 yards south of Spruce Tree House, is eleven inches in stem diameter, twenty feet tall, and began growing about A.D. 1390. Several hundred yards south, along the Pictograph Trail, is an even older, though comparatively large fir, the inner ring on whose core sample, which missed the tree center by at least a decade, dating at A.D. 1312.

Perhaps the most severe site of all for Douglas fir thus far found at Mesa Verde was near the Prater Canyon Lower Well already mentioned; one fir, less than six feet high and about two inches in stem diameter, proved to be about 135 years old.

The crossdating quality and sensitivity is a maximum in the over-age drought conifers. Seven firs, ranging from 486 to 542 years in length of ring record, obtained in 1941 from Spruce Tree, Spruce, and Fewkes Canyons within about two miles of Park headquarters, were averaged to form the basic Mesa Verde climatic index. In 1945 numerous additional firs, the oldest carrying 657 years of ring record, were found in a tributary of Navajo Canyon, about four miles north of Fewkes Canyon; these served to extend the record into the late 1200's. There is little doubt that living trees will be found which will close the 13-year gap, A.D. 1275-87, in Mesa Verde climatic history.

A number of old pinyon pines were sampled in the northern portion of the Park. Two, near Hill's Cabin, proved to be about 550 and 600 years of age; of some ten pinyons sampled on Wetherill Mesa the oldest did not exceed 500 years. Although datable, the chronologies are far more complacent and erratic than in the Douglas firs.

Of the fine stand of large ponderosa pines in the Morefield Well area, the oldest proved to be about 355 years of age. All were complacent and somewhat erratic in chronology.

Construction of the growth index. The elimination of trend and averaging of individual trees into a group mean has already been treated above. Since only the oldest trees were used in deriving the index, mean growth rates were constant in the outer centuries and trend lines were therefore horizontal. Thus, the average growth curve from A.D. 1288 to A.D. 1945, given in Figure 2 in per cent of the mean, is for the outer centuries essentially a plot of the raw data. There is some evidence that the assumed trend lines were in error in the earliest decade or two, so that the per cent departures computed for this interval may be too high and thus mask the outer portion of the "Great Drouth" of the late 1200's in the Pueblo area.

Climatic history at Mesa Verde. The analysis of this and other indices in the Colorado River Basin is being published elsewhere;[7] only a few notes are given here.

Comparison of the outer part of the Mesa Verde tree index with the October-June rainfall at Durango, Colorado, indicates a close parallelism; the trees also give a fairly faithful record of the runoff of the Animas River at Durango. Numerous minor sources of error, in all variables concerned, do not permit perfect correlation.[7]

Winters of extreme drought, such as that of 1903-04, characterized by tree growth less than 50% of normal, may be read off the mean curve; they occurred on the average about twelve times per century. The most severe drought interval since A.D. 1300 seems to have occurred in 1573-93; only with the collection of additional applicable specimens will it be possible to decide whether the dry interval 1276-99 was more intense in this area.

[7] University of Arizona Bull. 16 (4), in press.