

Tree-rings and Medieval Archaeology

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INTRODUCTION

MEDIEVAL timber, preserved in old churches or in waterlogged archaeological sites, can often be dated by tree-ring analysis, and, in favourable circumstances, the date of felling can be determined with precision.

Tree-ring analysis was first applied to chronology in the American Southwest (cf. Schulman, 1956, pp. 35-9),* where the science of 'dendrochronology', as it was called, made it possible to establish a *relative* dating of 'medieval' beams from Pueblo ruins. The *absolute* dating of living trees was meanwhile examined, and, in 1929, the ring pattern of a thirteenth-century beam was found to match both the 'floating' chronology of the building timber and the exact chronology of the living trees. The relative dates could therefore be converted to absolute dates, and the oldest ring then known was thereby dated as A.D. 697. 'Dendro-archaeology' in America has now extended its time-range back as far as the first century A.D. The tree-rings of the semi-arid Southwest are particularly suitable for dendrochronology—their width in any year depends almost entirely upon the available moisture, and, stunted, drought-sensitive trees have now been found which are four thousand years old and still living.

Dendrochronology was at first unsuccessful in Europe. There were no very old trees and the climatic factors were very complex. These initial difficulties have now been overcome; indeed, the existence of medieval documentary information of the dates both of building construction and of the occurrence of droughts often provides additional evidence of a kind not available on the other side of the Atlantic.

In Scandinavia, except in the drier areas, tree-rings often reflect the summer temperature (especially near the timber-line), and it has been possible to use the data accumulated as clues to the climate of individual summers since at least the year 1461 (Schove, 1950a, 1954). Additional studies in Norway, under the guidance of Professor Høeg (1956), have extended the dating back in some cases to 1383, and Eidem has published (1953) a relative 'floating' chronology which is expected to overlap with the absolute chronology, as in America, so that, once it is fixed, the time-range will extend back to the tenth century. It is hoped that it

* For details of this and other works cited see Bibliography, p. 94 f.

may be possible to date the medieval wooden churches (*stavkirker*) and eventually to obtain an absolute date for some of the Viking ship-burials.¹

In Germany, Professor Huber (1956) and his co-workers, especially Dr. W. von Jazewitsch, have systematically prepared chronologies for various species of tree, and have successfully obtained a curve for oak which is nearly a thousand years in length. This was initially based on present-day specimens of the famous Spessart oaks, which themselves are nearly four hundred years old, but it has now been extended, with the aid of plots from medieval church timber, to the twelfth century. About 100 oak beams have thus been dated from the medieval town of Ziegenhain, near Kassel.

In England, Lowther (1949, 1951) has worked in the opposite time direction; he has selected specimens of drought-sensitive oak from both the Roman and medieval periods and has prepared two floating chronologies for the periods *c.* 160 B.C.-A.D. 320 and *c.* 850-1500 respectively. An additional chronology for the intervening Anglo-Saxon period, tentatively dated *c.* 714-835, has been published by Schove (1955).

There are seven methods by which the dating of the floating tree-ring chronologies can be tested:

- (1) *Independent dating evidence.* Coins, pottery, or documentary evidence of building construction. Such evidence should be associated with timber in which the *sapwood* or the *outermost rings* (the *waney edge*, see p. 91) can be traced.
- (2) *Meteorological evidence.* The correlation of maxima and minima on the tree-ring chart with weather peculiarities.
- (3) *Other documentary evidence.* Information relating to trees themselves is sometimes recorded by chroniclers. In particular, years are sometimes noted in which the acorn crop was abundant.
- (4) *Teleconnections.* The correlation of maxima and minima on the tree-ring chart with dated maxima and minima in other parts of Europe.
- (5) *Overlap with modern trees.*
- (6) *Qualitative characteristics of rings at particular dates.*
- (7) *Correlation with varve-chronologies.*

Besides these, tree-ring analysis for the period 1500-1957 can be checked with reference to trees with known dates of felling or planting.

ROMAN FLOATING CHRONOLOGY

The plots prepared by Lowther were dated approximately by the first method. The floating Roman chronology was anchored within a decade by the evidence of pottery, but the precise date will not be known until timbers are available to bridge the gap between the years 320 and 714.

¹ Oak has also been measured in Denmark for the period 1815-1949 (Holmsgaard, 1955, p. 101, fig. iii) and, nearer this country, in Holland, pioneer work was done about 1880 by J. C. Kapteyn on very old drought-sensitive oaks, but this work has not been followed up. Pines have been measured in various countries and recent measurements in Scotland have been made by Miss A. M. Frewer but, archaeological timber is normally oak, and in this paper we are concerned only with oak, probably *Quercus robur* (rather than *Quercus petraea*, characteristic of the Highlands).

ANGLO-SAXON FLOATING CHRONOLOGY

The second (meteorological) method was used (Schove, 1955) for the dating of the Anglo-Saxon curve presented here as FIG. 19.

Eleven specimens of timber from the Saxon site at Hamwih, the Saxon town beneath present-day Southampton, were studied by one of us (A.W.G.L.), who prepared curves from timbers kindly provided by the excavators. Four of the curves could be cross-dated at identical points by each of us using independent methods. Possibly two of these timbers had originally belonged to the same tree, but in any case the agreement of the four plots provided an encouraging basis. The mean of these four curves was then plotted as a preliminary master-curve, and this was next used to test the agreement of each of the remainder.

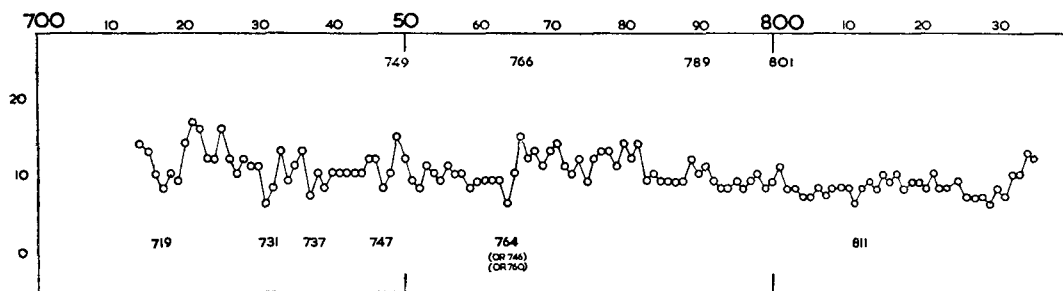


FIG. 19

The simplest method by which an independent curve can be tested is by a 'sign-agreement test'. Such a test (slightly modified from Schove, 1955) is illustrated in Table I (p. 81).

The year-to-year tendency of the plot being investigated is checked with the master-plot. Where both curves go up or both go down the letter o (for 'agreement') is entered in the table. Cases of disagreement are indicated by a cross, and cases with no change in either curve were ignored. In the modified form of Table I now presented, such cases should be counted as halves or (as when electronic computers are used) counted alternately. The percentage of crosses gives the measure of disagreement and for Table I this is exactly 25 per cent. Perfect cross-dating would give a value of zero per cent. and erroneous dating—or pure statistical chance—a value of 50 per cent.; the 'disagreement' for this plot over the whole sixty years was 35 per cent. This was considered just satisfactory, particularly because the agreement was consistent in different parts of the curve and because the skeleton plots agreed in their main features.

One more curve was also accepted in the same way; in this case there were 86 circles and 39 crosses in the analysis, that is, the disagreement percentage was down to 31 per cent. in 125 rings. These two plots were thus incorporated in a revised master curve.

In an ideal case the same procedure could be applied to each of the remaining curves, but in practice, especially with 'archaeological' timber, there are invariably

TABLE I

Illustration of a sign-agreement test applied between a provisional master-plot and an independent timber specimen

Year No.	Mean Ring-width (Four Plots) Tenth-mm.	Signs of Differences		Sign-agreement	
		(Four Plots)	(Fifth Plot)	Like	Unlike
50	11	—	—	0	.
51	8	+	+	0	.
52	11	+	+	0	.
53	17	—	—	0	.
54	15	+	+	0	.
55	16	—	+	.	×
56	13	+	—	.	×
57	15	0	+	$\frac{1}{2}$	$\frac{1}{2}$
58	15	—	—	0	.
59	14	—	—	0	.
60	12				

plots which (for various reasons) fail to cross-date. In the present instance the cross-dating could be guessed for some curves, but the sign-agreement tests were not sufficiently conclusive to allow their use statistically. FIG. 1 is based therefore, only on the six 'consistent' plots.

Annual rings are thicker for the first 150 years of the life of an oak, but the tendency for the ring-width to become thinner with time continues until the old age of the tree. Although all the rings considered evidently belonged to the *outer* timber of very large oak trees (about 300 years old), the consistently narrow 'complacent' rings from the year no. 70 to the year no. 117 are explained by the age of the trees and not by any long period of drought. This chart represents what is known as an *unstandardized floating* chronology.

The correspondence between years of minimum growth and years of drought has already been mentioned. In connexion with the so-called Spectrum of Time project (Schove, 1950b, 1951, 1954-5, 1959), the meteorological evidence in many European chronicles had already been assembled, and it was possible to make certain predictions about the rings at certain dates.

The most notorious year in the period 700-900 was undoubtedly 764, when—after a long and remarkably severe winter throughout Europe—there was an extensive summer drought. Simeon of Durham records as follows:

'In the same year (764) many towns, monasteries and villages in various districts and kingdoms were suddenly devastated by fire; for instance, the calamity struck Stretburg (=?), Winchester, Southampton (Hamwih itself), the city of London, the city of York, Doncaster, and many other places. . . .'

The epidemic of fires was caused by what, even in Ireland, was termed in the *Annals of Tighernac* 'a great drought beyond measure', and it is probable that timber will be found with the scars caused by the bark-burning forest fires.

It was argued that the tree-ring for 764 should have been very narrow on account of the drought, but only one of the various alternatives (assuming a terminal date of the timber somewhere between 771 and 850) showed any satisfactory agreement with the dates of other known droughts. The dates suggested fit the dry summer recorded in Ireland for 719, the drought in Northumbria in 737 and a very hot summer recorded abroad in the *Annals of Lorsch* in 783.

A date of 835/840 was accordingly suggested (by D.J.S.) as the date of the timber of the pits. It was then noticed (by A.W.G.L.) that a well-preserved coin of Berhtwulf, king of Mercia (839-852) 'by his moneyer Burnwald' had been found in the upper part of the filling in one of the pits. This coin was in good condition and M. R. Maitland Muller (1951) used it as the only dating evidence available. A hoard, and not a single coin, is necessary for satisfactory numismatic dating. The coin was presumably already in the material thrown into the pit to fill it, so that the settlement could have been later.²

If we suppose that for some reason the tree-ring of 764 was *not* particularly narrow, alternative datings, notably 696-817 and 710-831, would still provide a good fit with the meteorological evidence, which in this early period is too fragmentary to be decisive. Moreover, if we suppose that a date after 850 is possible, still other alternatives arise. Timber recently excavated by B. Hope-Taylor at Old Windsor is being investigated, and it is hoped that, with the aid of further Saxon specimens of this kind, some of these various alternatives will be eliminated.

LATER MEDIEVAL CHRONOLOGY

Medieval timbers have already been dated by tree-ring analysis by Lowther (1951), who published some of the relevant curves for the period *c.* 1230-1360. The plots in question were compared with one another and found to match visually; a provisional master-plot was thereby established. The absolute dates of some of the timbers were in some cases already known approximately, so that the dating of the master-plot was determined with an error of 'between two and five years'.

The visual matching of curves in dendrochronology is not generally acceptable, and, indeed, it is often regarded as an art rather than a science. Provisional dates which are readily determined by this means, can nevertheless be checked by more rigorous analysis. The agreement between the original plots (prepared by Lowther) as indicated below³ was found (by Schove) to be correct if more laborious mathematical tests were applied. Indeed, the curves were found to match, at the dates suggested, by several independent methods. Such methods include the correlation of first or second differences, or cross-dating both by

² Saxon timber pits of this kind are unlikely to have lasted long. The contents of the pits suggested that they had been used in tanning or in preparing hides.

³ The dating of one published curve (WA/5 in Lowther, 1951, p. 133) had been subsequently amended from 1244-1361 to 1246-1363.

three-year overlapping curves and by annual *deviations* from such curves. In such ways, the visual matching of curves can be subjected to scientific principles, but it is now possible to measure and locate the disagreement percentage by an electronic computer (von Jazewitsch, *et alii*, 1957). The outstanding features of the curves dated objectively were accordingly analysed so that the precision of the provisional chronology could be tested by the various methods listed.

TIMBERS USED AND SKELETON PLOT

Oak chests in Westminster Abbey and Winchester College and the details of their ring-structure recorded by Mr. John Harvey form the basis of the

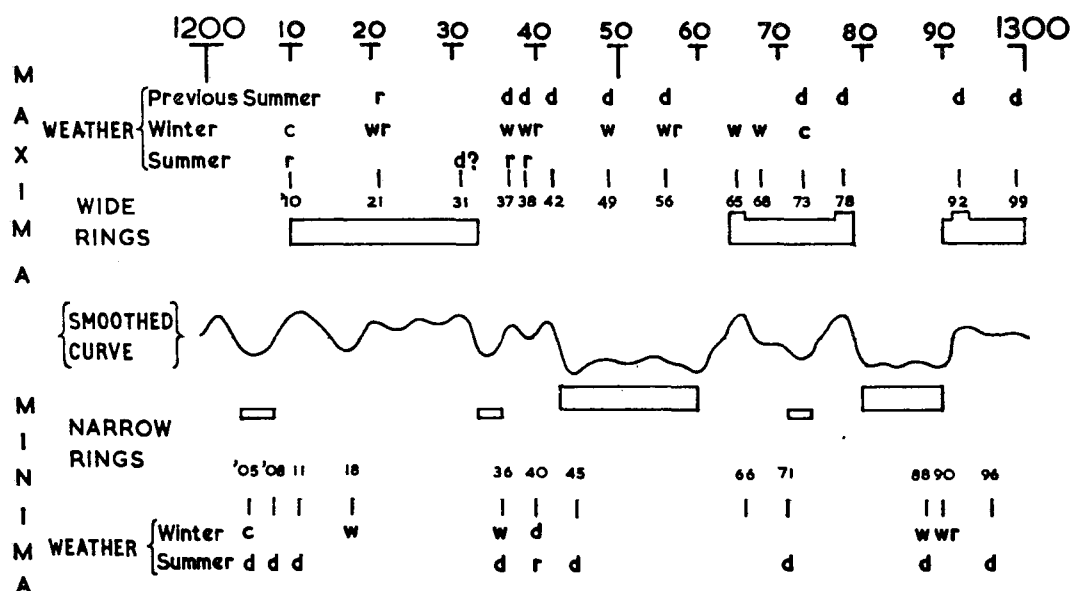


FIG. 20
Skeleton plot for the 13th century.
Oak found at Westminster or in Hampshire.

medieval chronology, and the Westminster (WA) and Hampshire (H) plots cross-date well with one another. Some of these timbers have already been described (Lowther, 1951, p. 132); curves for additional timbers were prepared by one of us (A.W.G.L.) and both series were utilized by the other (D.J.S.) as the basis for the conclusions that follow:

1188-1363	WA/5	Westminster Abbey	Pyx chapel. East and front plank c. 1490 (127 outer rings missing)
1292-1480	WA/4	" "	Top of east style at front of same chest
1193-1327	WA/3	" "	14th-century chest, c. 1330
1054-1261	WA/2	" "	13th-century chest in Muniment Room
c. 850-1138	WA/1	" "	'Late 12th-century' chest, lid
1104-1362	H/2	Winchester College	Old chest in Muniment Room (no. 2 front plank) c. 1370
c. 1329-1389	H/1	" " (Old Brewery)	Oak wall-plate c. 1395
c. 1260-1353	H/5	River Hamble	Timber from hulk of wreck. Outer rings missing.

The agreement between interlocking plots is readily checked, and the cross-dating was accordingly tested by independent methods. In the period 1188 to 1363, each year was represented on three or more specimens, and the cross-dating could be proved rigorously. The examples that follow have therefore been selected mainly from this period, although some features from other centuries will be mentioned. In particular, the plot for WA/4 was used to date a 'floating' chronology for the fifteenth century based on timbers from Cocking church in Sussex and reference was also made to results obtained from living trees also in Sussex. These two series of plots were kindly sent (to D.J.S.) by Mr. G. P. Elphick.

A 'skeleton plot', as it was termed, based on the above timbers is presented as FIG. 20.

THE THIRTEENTH CENTURY

The thirteenth century is suitable for special investigation partly because the seasons are better documented meteorologically than in other centuries of the middle ages and partly because of the anomalous climatic patterns ascribed to this period.

The thirteenth century is especially interesting in American dendrochronology, as the period 1215-1299 marks a long drought, which appears to have had serious demographic consequences and to have been responsible for the desertion of many sites, at least after *c.* 1260. In Europe and in northern Asia the period is commonly supposed to have been wet (cf. Schove, 1949a).

The thirteenth century is a significant century climatically because the climate was 1°-2°F warmer than in the nineteenth century. The melting of the glaciers and perhaps of Antarctic Ice is thought to have been responsible for the rise in ocean levels known to have begun before 1000 (Evans, 1955) and to have culminated shortly before 1300. The oceans may, therefore, have been higher than in later centuries; at Lubeck the storm-flood of 1291 has been identified as the only dated tidal surge to leave its mark in a pollen-diagram covering over 2000 years (Schmitz, 1951).

The date '1200' marks a conventional date for what in peat bogs is known as a recurrence surface (RY I), and this has hitherto been thought to mark a change of climate from dry to wet. There certainly was such a change about 1195, and the weather of successive decades as presented in a thesis (Schove, 1953) suggests that the period 1195-1240 was wet in N.-W. Europe. However, this wet phase was one of several, and radio-carbon evidence now makes it clear that recurrence surfaces were formed at various dates (e.g. Mitchell, 1956, for Ireland, J. Lundqvist, 1957, for Sweden, Münnich, 1957, for Germany) and that such a surface is not necessarily synchronous even within a single bog (van Zeist, 1955, pp. 49-52).⁴

⁴ The following three phases in a typical high moor in north Germany have been dated approximately (Overbeck *et alii*, 1957) by C-14 methods as follows:

1. *Corylus* (Hazel) again reaches 10%. High crops. *c.* 1200
2. Rising *Betula* (Birch) curve, and falling *Fagus* (Beech) curve. High crops. *c.* 1270
3. *Corylus* maximum of RY I. Minimum crops. *c.* 1470

The correct determination in English pollen-diagrams of the level dated 1200 will depend not on any recurrence-horizon but on the effects of the introduction of the rabbit (Veale, 1957) on the pollens of different plants. The effects of myxomatosis in the last year or so has caused systematic changes in pollen-composition and it is probable that characteristic changes in reverse occurred about this date. The new technique of pollen-analysis of buried soils (Dimbleby, 1955) may prove significant if it can be applied to soils buried beneath thirteenth-century rubble.

MAJOR TRENDS

Consistent characteristics in the major features of different plots can only be expected when the original timbers are representative of the main trunk of the tree, and are not unduly affected by nearness to branches or roots. In the thirteenth century the following 'long waves' appear to be common to timber from Hampshire and Westminster:

<i>c.</i> 1211-1233	wide rings	1243-1260	narrow rings without important maxima
1264-1278	" "	1280's	ditto
<i>c.</i> 1290-1310	" "		

Such long waves may be associated with changes in rainfall, and they may be common to many parts of N.-W. Europe, but further evidence on these points is required.

In nineteenth-century Sussex narrow rings characterize the period from 1812-25 and wide rings occur from 1829-39, but the meteorological reason for this is not yet clear. In Denmark, the decadal fluctuations of beech-rings are found to mirror the decadal fluctuations in the rainfall of May, June and July (Holmsgaard, 1955, figs. 39-42).

The meteorological significance of major trends in tree-ring chronologies is likely to become clear as soon as drought-sensitive chronologies become available for different parts of N.-W. Europe.

MAJOR MAXIMA AND MINIMA

Curves of three-year overlapping means and 'Antevs' curves (where the middle year is given a weight equal to the other two) show characteristic maxima and minima. Maxima *c.* 1264/6, *c.* 1276/9, *c.* 1291/4 are noteworthy, and, in the fifteenth century, there is an outstanding maximum in the period 1446-50. Minima such as *c.* 1204-8, 1233/6, 1271/4, 1356/9 may be noted, and, in the fifteenth century, a minimum of this kind occurs *c.* 1425/8. In nineteenth-century Sussex a similar maximum (1871/6) and similar minima (*c.* 1811/14, 1861/4) were observed, and they correspond roughly to wet and dry periods.

METEOROLOGICAL CORRELATIONS

(a) *General.* The outstanding maxima and minima in the tree-ring plots were first compared with *all* evidence of abnormal seasons (1180-1320) within five years of the dates provisionally indicated by Lowther. Abnormalities in the weather were more frequent (by ten per cent.) in the actual year of the abnormal

tree-ring and in the year immediately preceding. This could hardly be due to chance and confirmed the exactness of the chronology in the period in question.

(b) *Very narrow rings*. A comparison of a list of outstanding minima with an independent list of dated droughts confirmed in a more striking manner the exactness of the chronology which had been used tentatively by Lowther. Years in which the narrowness of the rings were probably caused by drought are 1205, 1208, 1211, 1236, 1245, 1271, 1288, 1296, 1319, 1333, 1371, 1375, 1390 and 1404. Other characteristic narrow rings include 1218, 1266, 1290, 1320 and 1420.

The dryness of the summer of 1236 at St. Albans was described by Matthew Paris as follows:

‘Also in the same summer, as people remarked, after an unusually wet winter, there was a continual drought with an almost intolerable heat continuing four or more months. So much so that deep pools and ponds were dried up, water mills stood useless and profitless, and, the water being dried up, the earth gaped into cracks. Also the seed corn in many places barely grew as high as two feet.’

In 1245, the Oseney Annals state that ‘there was a dry summer this year in Wales’, and in Liège on June 29 there was a procession to obtain rain. The same (Oseney) Annals describe the drought of 1288:

‘In the same year in the beginning of July, that is to say, on the feast of SS. Processus and Martinian, there began an intolerable heat and an increasing great drought, which endured continually for five weeks, namely, to the feast of St. Oswald, so that in the interval it did not rain at all.’

In the nineteenth century in Sussex, when rain-gauge information provides a continuous record, narrow rings are usually associated with droughts, as in 1836, 1840 and 1862/3, but there are occasional narrow rings in other years, such as 1856 and 1874.

The frequency of fires can sometimes be used to indicate the years of drought, and a documentary chronology of fires is being assembled, as a correlation would be expected between years of fires and years of narrow tree-rings. Information is not yet sufficient to apply this method to the medieval period.

It is nevertheless interesting to note that the 1211 drought was associated not merely with a narrow ring but also with fires which led to an early attempt at fire-precautions in London building-legislation (cf. Salzman, 1952, p. 222), which came into effect in the following year. Roofs of reeds, rushes, straw or stubble were forbidden. Likewise the fires of the 1375 drought probably explain the further regulations of 1376 which commanded that a vessel or tub was to be set outside every house.

One unexpected feature appeared in these medieval plots. Droughts were certainly associated with minima in the years concerned, but they were still more clearly associated with maxima in the year that followed the drought, evidently on account of the physiological response of the individual trees. This rule, provisionally termed the $d+1$ rule, was especially surprising, as it had been supposed that oaks with deep roots would suffer most from the effects of a drought

in the succeeding year, when the water-table in the subsoil would be at its lowest. It would seem that the tree-rings are narrow in the same year as the *foliage* is affected by drought; the water-table is less important.

(c) *Very wide rings.* Years of outstanding maxima, therefore, often occurred when the previous summer had been dry and the intervening winter warm. Maxima such as 1237, 1249, 1278, 1292, 1299 and 1405 appear to be explained in this way. Other maxima include 1309, 1396, and 1399.

The maximum of 1249 can be considered as a typical example of the $d+1$ rule. The previous year, 1248, was described by Matthew Paris as follows (*Transl.*, V, 30):

'This year passed temperate and calm, filling the barns with abundance of corn, and making the presses flow with wine; so much so that a measure of corn fell in price to two shillings, and a cask of choice wine was freely sold for two marks; the orchard fruit was very abundant in some places, but scanty in others; but the gourd-worms entirely destroyed everything green, when the disease made its way into the shrubs.'

The dryness of the summer and autumn in Frisia was recorded in the chronicle of Menko, and the dryness of the summer in Hampshire was noted in the account roll of Sutton manor⁵ as follows:

'Steel bought for two ploughs for the year, 5s. 5d., by reason of the dry summer.'

The mildness of the winter 1248/9 was noted by Matthew Paris:

'The whole weather of winter was changed into spring so that neither snow nor frost covered the face of the earth, nor bound it in their customary manner, for two days together; trees were seen to be sprouting in February and young birds singing and sporting as though it were April.'

It was also noted in Cologne, where (in the *Annales S. Pantaleonis Coloniensis*) the winter was described as both mild and wet so that the seeds promised to be good, and (in the *Annales Egmondani*) at Egmond, in North Holland, where the very mild period is stated to have lasted from 18 October 1247 to 14 February 1248.

(d) *An apparent anomaly.* In chart 2 a drought was indicated for 1231 because of the statement in MS. C. of the Welsh *Annales Cambriae*, which refers (cf. Britton, 1937, p. 88) to a drought in 'all England . . . from March to October'. The wide tree-ring for this year however seemed to suggest that the printed evidence might be incorrect so that the doubtful sign was added. Since this diagram was completed, we consulted Professor J. G. Edwards, Director of the Institute of Historical Research, who kindly examined the manuscript at the British Museum, and writes:

'The Rolls Series edition of *Annales Cambriae* is quite unreliable in the sense that it has conflated distinct, though related, texts in a way that is very unscientific. For instance, the editor has put your passage about the drought under the annal 1231. It seems to me perfectly clear that it cannot be under

⁵ *The Crondal Records*, ed. F. J. Baigent (Hampshire Record Society, 1891), p. 80.

1231. Unfortunately MS. C. at that stage is purely annalistic, that is to say it simply says *annus* followed by the entry without giving the *annus* a number. But the *annus* in which the drought passage occurs in MS. C. contains two other events, a fight at Carmarthen and the death of "Resus Creg", both of which undoubtedly happened in 1233. So I think there can be no doubt that so far as MS. C. goes, it ascribes the drought to 1233.

'It is also quite clear, however, that the *annus* entries in MS. C. at that point are somewhat muddled, because the *annus* entry corresponding to 1233 is followed by another *annus* entry which is blank, and that is followed by another *annus* entry which refers to something which really belongs to the *annus* entry corresponding to 1233. Evidently then the scribe was in a muddle, and it is unsafe to assume that the drought passage is necessarily in the right annal when associated with events which happened in 1233. But so far as MS. C. goes, there is certainly no authority for associating the drought with 1231, but rather with 1233.'

The tree-ring for 1233 is narrower, but there is still no indication of a *severe* drought in the trees so far examined. The chronicler may have exaggerated a minor drought, or possibly the statement was added about 1287 from an English source that really referred to 1236 (cf. p. 86). Whatever the interpretation the exception helps to confirm the rule. A conflict between tree-ring and documentary evidence has in this way led to the discovery of a chronological error in a printed chronicle.

TELECONNECTIONS

Tree-rings in California were formerly supposed to be a guide to the dating of tree-ring plots in Europe. This belief is now known to be unfounded (cf. however, a stimulating paper by Hustich, 1956, on Arctic correlations). In each country, and, indeed, in each type of habitat, the tree-ring patterns are different. Nevertheless, some small correspondences may be noted, and the correlation between drought-sensitive trees in Germany and drought-sensitive trees in England is usually sufficient to detect any chronological displacement of a year or so between master-plots of the two countries. Unpublished tree-ring curves from Germany were kindly lent by Professor Huber and it was found that, between 1221 and 1260, the principal maxima occurred at the same dates in S.-E. England and in Germany (1221, 27, 31, 38, 49/50, 56, 60). The German maxima for the period 1351/1450, that is, 1359, 76/7, 89, 98/9, 1406, 10, 15/16, 21, 24, 27/8, 33, 35/7, 40/1, 45 and 49 (according to von Jazewitsch *et alii*, 1956, fig. 10) were thus used as a rough check on the maxima of the single fifteenth-century beam (WA/4) and the general agreement suggested that errors of one to five years were less likely than exact synchronism.

German oaks, especially in valleys, are sensitive to severe winters; however, in England, cold winters are not infrequently followed by wide rings, so that the agreement shown in the period 1221-60 is not found generally, and, indeed, different sites in both countries can behave quite differently. Thus, the same check

was applied to the dating of the Sussex (Cocking) master-plot for the fifteenth century, but the correspondence was inverse. The years of maxima in Germany were precisely those years in which maxima were *least* likely in the 'Cocking' timber; nevertheless this again confirmed the *exactness* of the chronology, as neighbouring years showed no correlation either way.

Further investigations are needed before checks of this kind can be considered as scientific proofs.

OVERLAP WITH LIVING TREES

The direct method of checking the medieval chronology by providing an extension to overlap with living trees has not so far been successful, although a series of plots covering the later period has been collected and it is hoped to bridge the gap very soon.

ACORN YEARS

The third method of testing the precision of an approximate chronology utilizes documentary evidence relating to trees and their fruit.

In the early medieval period the most useful references are to years of abundant acorn harvests, such as are recorded in the Irish Annals for 935, 950, 956, 981, 986, 1011, 1057, 1066, 1087, 1091, 1093, 1095, 1097, 1108, 1112, 1151, 1152, etc. The period 900-1130 was fully represented by only a single beam among the plots examined, but ring-minima were more frequent than maxima in years of good acorn harvests and ring-maxima than ring-minima in neighbouring years. No tendencies either way were noted in years 2 to 6 years on either side. This is consistent with the belief of foresters that the rings of the oak, like those of the beech, are narrower when the acorn crop is abundant. The reasons for an abundant crop have not been fully investigated, but it is generally supposed that the oak, again like the beech, needs adequate summer warmth in the *preceding* year. (Cf. Matthews, 1955.)

Thus, Mr. M. V. Laurie, Chief Research Officer of the Forestry Commission at Alice Holt, writes:

'There is little doubt that a heavy mast usually results in reduced vegetative growth in that year and possibly also in the following year, and this will of course affect the width of the annual ring.'

These results are not inconsistent with the dating of the beam (WA/1) covering the early period, and indeed they suggest that an error of one or two years is unlikely; however, this method should be regarded as a supplementary check on the results indicated by other methods. Results based on a single beam and a few instances cannot constitute a proof.

QUALITATIVE CHARACTERISTICS

The quantitative measurement of ring widths alone is not sufficient. Special characteristics of individual rings and of the darker latewood lines separating the rings are occasionally found. Peculiar colours, scars or fractures should be noted,

and, when microscopic analysis is possible, the relative width of the latewood itself should be measured. This is now the regular procedure in Sweden (Eklund, 1957). In such ways, the effects of long and severe frosts, which sometimes cause the bark to split (as noted in 1685 by Evelyn), can be determined. Scars left by forest-fires of the seventeenth century have been found and dated in the white oaks of central New Jersey (Buell *et alii*, 1954); and even in England years of extensive forest fires were formerly not unknown. It would be premature to mention some of the particular items which have been noted (e.g. on furniture timber at the Victoria and Albert Museum), but, as and when sufficient information of this kind is available, there is no doubt that it will prove chronologically significant. An instance of this in Alaska is the 'faint red' ring of the year 1783; the colour of the ring can be attributed to the volcanic dust-haze of that year (Schove, 1954, pp. 77-8).

CYCLE ANALYSIS

It is often supposed that tree-rings reflect the 11-year sunspot cycle. The years of sunspot maxima (e.g. 511, 522, 531, 542 . . .) have been recently determined (Schove, 1950b, 1951, 1955), but no significant correlation with European tree-ring width is expected. On the other hand, cycles do occur in tree-growth as a result of the interaction of physiological and climatic factors. Such cycles are not persistent, but their appearance in a plot of unknown date can help to date the plot. An 8-year cycle characterizes the period 1065-1110, an 11-year cycle the period 1430-80 (a period, incidentally, when the sunspot cycle itself is weak and irregular).

VARVES

Varves have been counted in Switzerland and Sweden, and in Russia annual measurements have been made. Varves are not necessarily annual and the errors in the current varve-chronologies are still of the order of a century or so; radio-carbon dating (e.g. in Sweden; cf. G. Lundqvist, 1957), and palaeomagnetic studies now being undertaken by D. H. Griffiths will soon allow more precision. However, at present tree-rings are likely to be more useful for the dating of varves, although where varve-measurements are made in association with pollen- and sediment-analyses, as in the well-known Faulensee study of Welten, the climatic correlations should prove significant in the future.

SELECTION OF TIMBER AND METHODS OF WORKING

Specimens of timber suitable for tree-ring analysis need to be carefully selected as follows:

(a) '*Water-logged*' oak found in a wet or boggy site. This should either be examined when first found, and before it has dried out, or else kept wet until it has been examined. Otherwise the outer, more decayed 'sap-wood' (in the case of logs) or the exposed portions of the 'heart-wood' (in the case of squared timbers) collapse and the remainder of the specimen becomes cracked and distorted.

The slice cut and sent for examination need only be of sufficient thickness for it to hold together (two or three inches at most) but it should be from the main trunk of the tree, i.e. cut from above the root-stock and below the branching upper-part of the tree, as the formation either of roots or branches produces irregularities in the growth of the rings. Cutting should be done with a fine-toothed saw—a power-driven saw, when possible—as the striations caused by the saw-teeth can obscure the rings and are difficult to eradicate in the case of soft, semi-decayed timber.

(b) *Sound 'seasoned' timber.* Specimens of squared timbers (beams, joists or large planks) should include the outer sap-wood and what is known as the waney edge. The 'waney edge' is the rounded edge which was originally immediately beneath the bark of the living tree and which can often be detected as an edge which is not square. Such a waney edge represents the date of felling, and, as the time left for seasoning in the middle ages (cf. Salzman, 1952)⁶ was usually short, this date is usually close to the date of construction. Wherever timber is affected by rot, it should of course be appropriately treated before it is transported from the site.

For both types of timber it is best to look for wood containing 100 to 300 rings, but much depends on the importance of the specimen and the extent to which an approximate date can be determined by other means. Timber, or carbonized timber, found in a potentially datable level during excavations, should be measured and recorded even if there are only 20 to 30 consecutive rings. If the number of rings seems inadequate, as many specimens as possible should be measured; specimens which cross-date should then be combined before dating is attempted.

The timbers which have been studied so far are timbers whose annual rings show even growth around the heart in circular or elliptical form, and some of which are consistently narrow in certain years. Such timbers are usually drought-sensitive. Trees which grew originally in sites subject to flooding produce rings which individually are irregular and wavy and which are almost equally wide—often very wide—every year. Timbers from sites of this kind are probably temperature-sensitive, but so far it has not been possible to date them, and at present only specimens with over 200 rings would be worth investigation.

In order to eliminate saw-marks and to bring out the rings clearly it may be advisable to use a sharp chisel to produce a clean cut along the radii. Various methods of polishing can be used.

Measurements have often been made along a straight radius from the pith of the heartwood to the outer sapwood, although the natural radii of the oak are the medullary rays and these are not normally straight. The machine used by von Jazewitsch and his collaborators (1957) measures along these rays. It is preferable in some other cases to diverge from the medullary rays, but corrections may have to be made to the measurements.

It is convenient to start with long strips of paper or card and pencils (both

⁶ Cf. *ibid.*, pp. 237, 490: an occasional contract might stipulate for wood that was seasoned (*siccatus et induratus*), but it was often used green.

soft and coloured), a supply of tacks or pins and some stamp-paper. The soft pencil can be used to make rubbings and pins can be inserted after every tenth ring. Provided that the pins along different radii are consistent, coloured marks can be added to the paper after every fifth ring. Stamp-paper can be coloured and stuck to indicate the position of very narrow rings which might otherwise be missed, or to indicate rings with any qualitative features which should be recorded. When timber cannot be cut for removal and investigation, the rings can be recorded either photographically or by 'ticking them off' with a sharp point on a thin card (or stout paper) 'straight edge'.

The measurements can be made with an ordinary mm. ruler and estimated—even without a microscope—to the nearest fifth of a mm. The actual distance on the ruler of each winter line (i.e. the outer edge of the autumn latewood) should be noted and should be checked every five years against the sum of the five ring-widths. The plots from several radii or several slices are checked with one another.

The means of at least two consistent series of measurements should then be plotted. Squared paper divided into half inch and tenths should be used with an inch equal to 1.0 mm. on the vertical or ring-width scale and 10 years on the horizontal or time scale. The pith (i.e. year 0) is on the left.

Several associated plots should be cross-dated with one another and a master-plot obtained. The way in which this can be done has been already indicated (p. 80), but, in the combination of several plots, correction factors (cf. Høeg, 1956) may have to be introduced.

Cottages in medieval times were normally taken apart and re-erected with many of the same timbers, and the dendrochronological date of re-used timbers will not be the date required by the archaeologist. In later historical times, the evidence of manorial accounts or building accounts may occasionally conflict with the date indicated by the tree-rings. In a set of associated plots of building timber, some will almost invariably have to be discarded for this or other reasons.

FUTURE DEVELOPMENTS

(a) *Automatic machines.* It is to be hoped that our tree-ring studies in this country will soon be facilitated by the introduction of the machines developed by von Jazewitsch and his collaborators (1956, 1957). They are designed to cope with the surface of a flat cross-section slice of timber and they are therefore useful for archaeological oak timbers. Increment-corers yield flattened pencils of wood but they cannot be used on tough English oak.

(b) *Watch to be kept on demolition-work.* When early structures undergo demolition or repair, many oak timbers are likely to become available. It is to be hoped that wherever possible slices may be cut from such timbers and the necessary plots made of their rings.

(c) *Collaboration in different counties.* As a result of a previous appeal for collaborators (Schove, 1955), the measurement of rings of recently-felled trees has been initiated, and it is to be hoped that separate master-curves will soon be prepared for different situations in various counties. Measurement sheets are

available, on request, for those who are willing to take a more active part in dendrochronology.

(d) *Tree-rings and radiocarbon studies.* The combination of tree-ring dates and radio-carbon dating at the Heidelberg radio-carbon laboratory (Münnich, 1957) is a very encouraging feature for medieval archaeology. Most A.D. radio-carbon dates published hitherto have been too vague for the medievalist, although future dates from Groningen (cf. de Vries *et alii*, 1954 and 1958), Copenhagen (Tauber 1956, Troels-Smith 1956) and Stockholm (cf. Lundqvist 1957, Ostlund 1957) are likely to be of considerable interest. Characteristic small discrepancies between tree-ring dates and C-14 dates have been found by Hl. de Vries (1958), who notes that initial radio-activity was less in the three phases of the little Ice Age (cf. Schove 1949b) *c.* 1600, *c.* 1750 and *c.* 1850 and was greater *c.* 1500 and *c.* 1700.

(e) *The historical geography of building construction.* Salzman (1952) has illustrated the potentialities of the documentary evidence for the chronology of medieval architecture and Harvey has published a recent chronology in his *English Medieval Architecture* (London, 1954). The study of masons' marks (Davis, 1956) and the realization that many of the architects are no longer anonymous now makes it possible to be more precise. In this field tree-ring analysis has an important part to play. It is even anticipated that the periods of architectural activity (e.g. 1288-1308) will be associated with the periods of good harvests (especially when, as from 1170 to 1190, the building activity occurs in the wetter parts of the British Isles) and that these periods, like the tree-rings themselves, will reflect the vagaries of medieval weather. The historical geography of architecture has yet to be written; the documentary evidence is intermittent, and the possibilities offered by an independent dating technique would seem to be important in the study of medieval civilization.

SUMMARY

Medieval tree-rings are now being studied in England as well as in America, Scandinavia and Germany. In England 'floating chronologies' have been dated approximately by associated finds such as coins; and the evidence of chronicles now makes it possible to obtain exact dates. Moreover, the *thin* rings can often be attributed to known droughts or known *acorn-years*, and the *wide* rings often occur when the previous summer had been *dry* and the intervening winter *warm*. A plot tentatively dated 714-835 and an exact analysis of precisely dated thirteenth-century material are presented. In one case the absence of a narrow tree-ring led to the discovery that the printed date for a drought (1231) was incorrect. Suggestions for the measurement of rings in archaeological timber and for future research are given.⁷

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BIBLIOGRAPHY

- Britton, C. E. 1937 *A Meteorological Chronology . . . to 1450* (London).
- Davis, R. H. C. 1934 'Catalogue of Masons' Marks as an aid to Architectural History', *J. Brit. Archaeol. Assoc.*, 3 ser., XVII, 43-76.
- de Vries, Hl., and Barendsen, G. W. 1954 'Measurements of age by the Carbon-14 technique', *Nature* (London), CLXXIV, 1138.
- de Vries, Hl., Barendsen, G. W., and Waterbolk, H. Tj. 1958 'Groningen Radiocarbon Dates II' (in the press).
- de Vries, Hl. 1958 *Proc. Kon. Nederl. Akad. v. Wetenschappen* (Amsterdam), ser. B, LXI, no. 2.
- Dimbleby, G. W. 1955 'The Ecological Study of Buried Soils', *Advancement of Science*, XII (1955), 11-16.
- Eidem, P. 1953 'On variations in the annual ring widths in Norway Spruce and Scots Pine in Trøndelag' (Norwegian, English summary), *Medd. fra Det Norske Skogsforsøksvesen*, (Bergen) no. 41, vol. XII, pt. i.
- 1956 'Dendrochronological Dating of Building Material from Flesburg in Numedal, Eastern Norway', *Tidsskrift for Skogbruk* (Oslo), no. 2, 96-116.
- Eklund, B. 1954 'Variation in the Widths of the Annual Rings in Pine and Spruce due to Climatic Conditions in Northern Sweden during the years 1900-1944' (Swedish, English summary), *Med. Fran Statens Skogsforskningsinstitut* (Stockholm), XLIV, no. 8.
- 1957 'The Annual Ring Variations in Spruce in the Centre of Northern Sweden and their Relation to the Climatic Conditions', *Med. Fran Statens Skogsforskningsinstitut* (Stockholm), XLVII, no. 1.
- Evans, J. H. c. 1955 'Archaeological Horizons in the North Kent Marshes', *Archaeol. Cantiana*, LXVI, 103-46.
- Høeg, O. A. 1956 'Growth-ring research in Norway', *Tree-Ring Bulletin*, XXI, 2-15.
- Holmsgaard, E. 1955 'Tree-ring Analyses of Danish Forest Trees' (Danish with English summary), *Det Forstlige Forsøgsvæsen i Danmark*, XXII, pt. i, 1-246.
- Huber, B., and W. v. Jazewitsch 1956 'Tree-ring Studies of the Forestry Botany Institutes of Tharandt and Munich', *Tree-ring Bulletin*, XXI, 28-30.
- Hustich, I. 1956 'Correlation of tree-ring chronologies of Alaska, Labrador and Northern Europe', *Acta Geographica* (Helsinki), XV, no. 3.
- v. Jazewitsch, W. 1954/5 'Jahrringchronologie von Ziegenhainer Eichengebalken', *Zeitschrift des Vereins für Hessische Geschichte und Landeskunde* (Kassel), LXV/LXVI.
- 1956 'Synchronisiermaschine zum Vergleich von Jahrringkurven', *Ber. der Deutschen Botanischen Gesellschaft*, LXIX, pt. iii, 128-42.
- v. Jazewitsch, W., Bettag, G., Siebenlist, H. 1957 'Eine neue Jahrringmessmaschine mit elektrischer Messwertregistrierung', *Holz als Roh- und Werkstoff* (Berlin), XV, 241-44.
- Lowther, A. W. G. 1949 'Dendrochronology', *Archaeological News Letter*, I, no. 11, March 1949, 1-3.
- 1951 'The date of timbers from the spire of Chilcomb church and from the wreck in the river Hamble: Some evidence from dendrochronology', *Proc. Hampshire Field Club and Archaeol. Soc.*, XVII, pt. ii, 129-33.
- Lundqvist, G. 1957 'C14-Analyser i Svensk Kvartärgeologi 1955-57', *Sveriges Geologiska Undersökning*, ser. C, Årsbok, LI, no. 8.
- Lundqvist, J. 1957 'C14-Datering av Rekurrensytor Varmland', *Sver. Geol. Undersökning*, ser. C, Årsbok, LI, no. 5.
- Matthews, J. D. 1955 'The influence of weather on the frequency of beechmast years in England', *Forestry*, XXVIII, no. 2, 107-16.
- Mitchell, G. F. 1956 'Post-boreal pollen diagrams from Irish raised bogs', *Proc. Roy. Irish Acad.* (Dublin), LVII, B 14, 219-21.
- Münnich, K. O. 1957 'Heidelberg Natural Radiocarbon Measurements I', *Science*, CXXVI (2 Aug. 1957), 194-99.
- Ostlund, H. G. 1957 'Stockholm Natural Radiocarbon Measurements I', *Science*, CXXVI, 493-7.
- Overbeck, F., Münnich, K. O., Aletsee, L., and Averdjeck, F. R. 1957 in *Flora* (Jena), CXLV, 37-72.
- Salzman, L. F. 1952 *Building in England to 1540* (Oxford).
- Schmitz, H. 1951 'Die Zeitstellung der Buchenausbreitung in Schleswig-Holstein', *Forstwissenschaftl. Centralblatt*, LXX, pt. iv, 193-203.

- Schove, D. J. 1949a 'Chinese "Raininess" through the Centuries', *Meteorol. Mag.* (London), LXXVIII, 11-16.
- 1949b 'European Temperatures since A.D. 1500', *Quart. J. Roy. Met. Soc.* (London), LXXV, 175-9.
- 1950a 'Tree-Rings and Summer Temperatures, A.D. 1501-1930', *Scott. Geogr. Mag.*, LXVI (1), 37-42.
- Schove, D. J. 1950b 'Visions in North-west Europe and dated Auroral Displays (A.D. 400-600)', *J. Brit. Archaeol. Assoc.*, 3 ser., XIII, 34-49.
- 1951 'Sunspots, Aurorae and Blood Rain: The Spectrum of Time', *Isis*, XLII, 133-8.
- 1953 M.Sc. Thesis in Geography, University of London: *Climatic Fluctuations in Europe in the Late Historical Period (esp. A.D. 800-1700)* (Microfilm copy in Florida State University).
- 1954 'Summer Temperatures and Tree-rings in North-Scandinavia, A.D. 1461-1950', *Geografiska Annaler* (Stockholm), XXXVI, pts. i-ii, 40-80.
- 1955a 'Droughts of the Dark Ages and Tree-rings (A.D. 714-835)', *Weather*, X, 368-371, 395.
- 1955b 'The Sunspot Cycle, 649 B.C. to A.D. 2000', *J. Geophys. Res.*, LX, 127-46.
- 1959 *The Spectrum of Time* (in preparation).
- Schulman, E. 1956 *Dendroclimatic changes in Semi-arid America* (Univ. of Arizona Press).
- Tauber, H. 1956 'Copenhagen Natural Radiocarbon Measurements II', *Science*, CXXIV, 879-81.
- Troels-Smith, J. 1956 'Neolithic Period in Switzerland and Denmark', *Science*, CXXIV, 876-9.
- Veale, E. M. 1957 'The Rabbit in England', *Agric. Hist. Rev.* (London), V, 85-90.
- Zeist, W. van. 1955 *Pollen Analytical Investigations in the Northern Netherlands with special reference to archaeology* (Amsterdam, North-Holland Publishing Company). With English summary.