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Ancient Monuments Laboratory
Report 72/98

TREE-RING ANALYSIS OF OAK TIMBERS FROM ELMS FARM, HEYBRIDGE, ESSEX

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Summary

Despite the shortness of most of the ring patterns, tree-ring dates were obtained for the Roman oak timbers from Elms Farm. Felling dates in the second century AD were obtained for timbers from four wells, whilst a timber from a timber-lined ditch was felled after AD 215 and probably before AD 251. The study also produced a tree-ring chronology for the period AD 27-205.

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TREE-RING ANALYSIS OF OAK TIMBERS FROM ELMS FARM, HEYBRIDGE, ESSEX

INTRODUCTION

This document is a technical archive report on the tree-ring analysis of oak timbers from Elms Farm, Heybridge (NGR TL847082). It is beyond the dendrochronological brief to describe the site in detail or to undertake the production of detailed drawings. As part of a multifaceted and multidisciplinary study of the site, elements of this report are being combined with detailed descriptions, drawings, and other technical reports produced elsewhere to form a comprehensive publication. The conclusions presented here may therefore have to be modified in the light of subsequent work.

The remains of the Romano-British town at Heybridge lies on the north bank of the River Blackwater opposite the Saxon town of Maldon (Atkinson 1995). Excavations in 1994 revealed a temple complex and other associated buildings (Figs 1 and 2). Around these were the remains of several roads and a metalled surface area which could have been a marketplace. Although timber buildings would have been present, the only timbers preserved on the site were found in a series of wells and ditches.

Most of the tree-ring samples came from four Roman wells (Table 1), all of which had wooden box linings of similar construction (Fig 3):

- Well 6280 was a substantial structure with a wooden box lining about 1m square. It survived to a maximum height of 1.18m with six planks on each side, although the uppermost planks were not complete. Most of the measured tree-ring samples were planks from the lining; the exceptions (16083, 16117, 16144, and 16146) came from the fill. Archaeological evidence suggested that the well was constructed in the second half of the second century AD.
- The well lining in oval construction cut 8188 was roughly 1.15m square and survived to a height of three planks which were dovetailed together at the corners. All the tree-ring samples came from these planks. The well had a suggested construction date in the second century AD.
- The timber-box lining in construction cut 9421 was a relatively simple structure just under 1m square. The boards were joined with single dovetails and survived to a height of five courses. All the tree-ring samples came from these boards. A late first- or second-century date was suggested for the well on the basis of stratigraphy and other archaeological evidence.
- Well 14984 consists of a deep cut with a clay lining and a timber box shaft which survived to a height of four courses. It had dovetailed joints and corner braces, and was surrounded on the outside by a series of stakes. The measured tree-ring samples were mostly either from the timber lining or the stakes; the exception was 14971 which was thought to be from the fill. A first- or second-century AD date was postulated for construction and a fourth-century date for the fill. A possible early Saxon date was suggested for the stakes based on the shapes of their pointed ends. However, the

relationship between the box lining and the stakes, and indeed the whole construction process, was not clear during excavation.

- The remaining tree-ring samples were planks from the lining of ditch 12046 (samples 12130 and 12143) and a post from posthole 6027 (sample 6066).

Analysis was undertaken to provide precise dates for the timbers, and hence for the construction of the wells. It would also provide non-chronological data with which to augment the information collected from the wood technology studies. Finally the tree-ring data themselves were seen as important. Most existing Roman chronologies are either from the central London area or Carlisle, and the majority are made up from first- or second-century timbers. The Heybridge timbers therefore had the potential to extend the tree-ring databank, both geographically and temporally.

METHODS

The samples were first frozen for at least 48 hours to consolidate the wood; they were then cleaned with a Surform plane which highlights the boundaries of the annual growth rings. If the cross-sections were still not clear, an edge was pared with a Stanley knife.

Samples unsuitable for dating purposes were rejected at this stage. These included non-oak samples, samples with unmeasurable ring patterns due to knots or narrow rings, and those with less than 30 rings. Normally samples with less than 50 rings are rejected because their ring patterns may not be unique (Hillam 1998; Hillam *et al* 1987). However, analysis of Iron Age timbers from Fiskerton in Lincolnshire had showed that samples with 30-50 rings can sometimes be dated reliably provided that longer ring sequences are available from the site and that there are several timbers per structure (Hillam 1998). In addition, some of the tangential planks from Elms Farm were clearly from the same tree (see below). Some were from the centre of the tree and therefore had more rings at the inside of the ring sequence, whilst others were from the outer part of the tree and had more rings at the outside. If all the samples with 30 or more rings were measured, some might be combined into ring sequences from the same tree with more than 50 rings.

The ring widths were measured to an accuracy of 0.01mm on a travelling stage connected to a microcomputer which uses a suite of dendrochronology programs written by Ian Tyers (1997). The ring width data were plotted as graphs. Crossmatching was carried out visually by comparing the graphs on a light box. A computer program was then used to measure the amount of correlation between the two ring sequences at the position of match found visually. The program uses crossmatching routines which are based on the Belfast CROS program (Baillie and Pilcher 1973; Munro 1984). Generally *t*-values of 3.5, or above, indicate a match, provided that the visual match between the tree-ring graphs is acceptable (Baillie 1982, 82-5). *t*-values over *c* 10 usually indicate an origin in the same tree, although *t*-values less

than 10 may be produced when different radii are measured on the same trunk. Visual matching and examination of the timbers themselves can sometimes aid the decision as to whether timbers come from the same tree but inevitably some same tree samples will go undetected by dendrochronology. When samples are thought to derive from the same tree, their ring widths are averaged to form a single sequence so as not to bias the site master curve.

The samples were examined structure by structure. Crossmatching was carried out visually by comparing the graphs from each well. Once visual crossmatching was complete, the matches were checked on the computer and *t*-values produced. The data from the matching sequences were then averaged to produce a master curve for each structure. When all the ring sequences had been crossmatched, the structure masters were compared against each other visually and by computer. They were also tested for similarity against dated reference chronologies using the computer. Any unmatched sequences were tested individually against the reference chronologies.

Once tree-ring dates have been obtained, calendar dates can be assigned to each of the annual rings within the sample, but the date of the outer ring is not necessarily equivalent to the year of felling. If a sample has bark or bark edge, the date of the last measured ring is the date in which the tree was felled. This can sometimes be refined even further (Fig 4):

1. A complete outer ring indicates that the tree was felled between autumn and early spring when it was dormant (herewith referred to as "winter felled").
2. A partially formed ring indicates that the tree died in late spring or summer (known as "summer felled").
3. If the springwood is <u>just</u> beginning to form, the tree was felled in April or May just before the opening of the leaves ("spring felled").

The onset of wood formation each year varies within and between trees according to their genetic make-up and their environment. Trees which were actually felled at the same time therefore could appear from the tree-rings to be felled in "winter" or "spring" (Fig 4).

Partially formed rings are not measured so, for spring- and summer-felled trees, there will be a one-year discrepancy between the date of the last measured ring and the felling date. It is not always possible to distinguish between an incomplete ring and a complete narrow ring and therefore the season of felling is often indistinguishable. Sometimes the outer edge of a sample may be damaged because of the delicate nature of sapwood and, whilst it is known that bark edge was originally present, a few outer rings may have been lost. In cases such as these, the felling dates are precise to within a few years. Where bark edge is absent, felling dates are calculated using a sapwood estimate of 10-46 rings (Hillam 1998; see also Miles 1997). This is the range of the 95% confidence limits for the number of sapwood rings which best fits tree-ring data currently available at Sheffield (Tyers pers comm). It replaces the previously used

estimate of 10-55 rings (Hillam *et al* 1987). Where sapwood is absent, felling dates are given as *termini post quem* (*tpq*) by adding 10 years, the minimum number of missing sapwood rings, to the date of the last measured heartwood ring. This is the earliest possible felling date but the actual felling date could be much later depending on how many heartwood rings have been removed during conversion of the trunk into its component timbers.

The estimation of felling date ranges gives some indication of when a tree was felled. This information must then be related to the date that the timber was used. At this stage, factors such as seasoning, reuse, and/or stockpiling have to be considered. Seasoning is unlikely to have had an impact since timber was usually felled and used green until relatively recently. Examples of the use of green timber during the Roman period are given in Hollstein (1980). The reuse of timber has been a common practice since prehistoric times and stockpiling may also occur. Therefore, although the production of tree-ring dates is an independent process, the interpretation of these dates can sometimes be improved by drawing on other archaeological evidence such as that provided by the wood technologist.

The above gives a brief introduction to dendrochronology. Further information about the history, principles, and methodology of dendrochronology can be found in Baillie (1982) and Hillam (1998).

RESULTS

Initially 24 timbers were selected as being suitable for dendrochronology by Richard Darrah. Samples from these were analysed at Sheffield in 1996. These included plank 12030 which had 179 rings and dated easily. Most of the remaining samples initially appeared unsuitable for dating as they had less than 50 rings. Closer examination of the ring sequences from well 6280 showed that many were almost identical and obviously came from the same tree (Figs 5 and 6). The ring widths were therefore measured and matched together visually to produce an overall ring sequence which was over 50 years long. This proved datable since it matched both 12030 and reference chronologies from other sites.

The results from this pilot study were so encouraging that the remaining timbers stored in Essex were assessed by members of the Sheffield laboratory and a further 77 samples sent for analysis, a few of which were samples from the same timber. A total of 60 timbers, including those analysed in the pilot study, contained more than 30 rings and therefore for the purposes of this study were considered suitable for dating purposes (Table 1). Those which were assessed in Sheffield and found to be unsuitable are listed in Appendix 1. The results are described for the assemblage as a whole, feature by feature; *t*-values for matches within and between structures, and against master chronologies, are listed in Tables 2-7. Where more than one sample was taken from a timber, each sample was measured and the ring widths combined to produce a single sequence. This proved useful because multiple sampling,

presumably from different ends of the timber, often increased the length of the ring sequence for the timber.

Most of the timbers were tangential planks (Fig 7). Exceptions were the stakes from well 14984, which were shaped from halved or quartered trunks, and the timbers from posthole 6027 and ditch 12046 (Table 1). 6066 was a halved timber, 12030 was a radial plank, and 12143 was an almost complete trunk. With the exception of the radial plank 12030, which had 179 rings, most of the timbers were from young trees, probably less than 70 years old when felled. Average ring widths were usually over 2.0mm, and often over 3.0mm, indicating that the timbers came from trees subject to favourable conditions of growth.

Posthole 6027

Post 6066 had 45 heartwood rings, but its ring sequence could not be dated.

Ditch 12046

12143 could not be dated. It contained 32 rings, including 14 sapwood rings and bark edge; it was felled in winter. 12030, by contrast, was the key to dating all the timbers from Elms Farm. It had 179 rings and possible heartwood-sapwood boundary. Its ring sequence was dated to AD 27-205 by comparison to dated reference chronologies (Table 7).

Well 6280

Timbers 16083, 16144, and 16146 from the fill had 32, 39, and 47 heartwood rings respectively; none of their ring sequences were datable. The top two layers of planks from the lining had almost identical ring patterns and were probably from the same tree (Figs 4 and 5). These were combined to produce a single sequence of 71 rings. This matched the ring sequence from plank 16117, a broken plank from the fill, with a *t*-value of 6.0. The *t*-values for all the matches are set out in Table 2. A master, 6280-T2, of 79 years was produced for the structure. This was dated by comparison with other structure masters and dated reference chronologies to AD 83-161 (Tables 6 and 7). The remaining samples from the lower layers of the lining failed to date either against other Elms Farm sequences or dated reference chronologies. Timber 16132, which bore the stamp "SV", had only 27 rings and was unsuitable for dating purposes.

Well 8188

The eleven measured timbers from the lining of this well crossmatched to give a structure master of 68 rings (8188-T7), which dated to AD 92-159 (Tables 3, 6, and 7). Five timbers probably derive from a single tree: 8199, 8201, 8217, 8218, and 8219.

Well 9421

The eleven measured timbers from the lining of this well crossmatched to give a structure master of 69 rings (9421-T9), which dated to AD 67-135 (Tables 4, 6, and 7). Two pairs of timbers were thought to derive each from single trees: 9066/9901 and 9886/9907. Although the *t*-values for this structure are not very high, the visual matching was good. The fact that the ring patterns from 9421 are shorter than those from other features probably contributes to the lower *t*-values.

Well 14984

Fourteen ring sequences crossmatched from this structure (Table 5). Correlation between the ring patterns was acceptable but generally less good than for the other wells. This may be partly due to the fact that the 14984 timbers had fewer rings; it may also indicate that they are a more disparate group of timbers. The 50-year structure master, 14984-T11, was dated to AD104-153 by comparison with other structure masters and dated reference chronologies (Tables 6 and 7). Amongst the dated timbers were one from the fill, 8 from the lining, and 5 stakes. Two groups of same trees were identified:

1. stakes 20242/20245 and
2. lining timbers 14971/14974/20051

It is possible that stake 20247 belongs to the first group whilst lining timber 20076 may belong to the second, but given the uncertainty, they will be treated as different trees. 14971 from the second group was thought during excavation to be from the fourth-century fill but these results indicate that it comes from the well lining instead. The interpretation of the tree-ring dates from the stakes and the lining will be discussed below.

The matches between the structure masters are illustrated in Fig 8. In view of the shortness of some of the ring patterns, each structure master was tested against all reference data from 400 BC to the present. No alternative dates were indicated. Data from the structure masters and 12130 were therefore combined to produce an Elms Farm site chronology which dates to AD 27-205 (Table 8). Although represented by only a single sample over much of its length (Fig 9), it is valuable reference data. Levels of crossmatching between it and other reference chronologies are shown in Table 7.

INTERPRETATION

The tree-ring dates are summarised in Fig 10 and Table 1. The resulting felling dates or felling date ranges from each dated timber can then be used to obtain the date of use of the timbers. Since none of the timbers showed any signs of reuse and the heartwood-sapwood boundaries are consistent with an assemblage felled at one time, these can be used as construction dates for the structures.

Ditch 12046

The date of the possible heartwood-sapwood boundary on lining timber 12030 is AD 205. If a sapwood estimate of 10-46 rings is applied, a felling date after AD 215 and probably before AD 251 is obtained.

Well 6280

Plank 16117 from the fill, which was possibly from the above-ground superstructure, has a last measured heartwood ring of AD 129 and was therefore felled some time after AD 139. The remaining timbers, which comprise the top two layers of planks from the lining, are probably all from the same tree. They have a combined felling date range of AD 161-188. However, timber 161096, which has an outer sapwood ring dating to AD 161, appears to be from the outside of the trunk. It is therefore possible that felling was soon after AD 161.

Well 8188

Four of the dated samples, three from the same tree, had bark edge and were felled in the winter of AD 159/60. Two others, 8199 and 8201, are probably from the same tree and therefore also felled at this time. 8194 and 8198 contained some sapwood rings and were both felled during the period AD 153-189. The other three samples, 8200, 8215, and 8216, had no sapwood and were felled after AD 146, AD 138, and AD 152 respectively. The closeness in date of the heartwood-sapwood boundaries suggests that the timbers were felled at the same time (Baillie 1982, 57) or within a few years of each other. Since the use of green timber was known to occur in the Roman period, a construction date of AD 159/60 or soon after is obtained for the wooden box lining of well 8188.

Well 9421

The dates of the heartwood-sapwood boundaries or the last measured heartwood rings range from AD 114 for 9902 to AD 126 for 9891, which suggests a group of timbers felled at the same time or within a few years of each other. The outer rings of 9899 and 9901 (and by inference 9066, which is probably from the same tree as 9901) were thought to be bark edge. The timbers were therefore probably felled in AD 135/6. 9891 does not have sapwood, but has an estimated *terminus post quem* for felling of AD 136. This is based on a sapwood estimate with 95% confidence limits so there is a 1 in 20 chance that a timber might have less than 10 rings or more than 46. A construction date of AD 135/6 or just after is therefore suggested for the lining of this well.

Well 14984

Two distinct phases are identified for this well. The stakes, 20055, 20242, 20245, and 20247, were all felled in the winter of AD 153/4. The lining timbers, however, seem to have been felled a few years earlier. 14971, 14973, 14974, 20051, and 20052 were felled either in the winter of AD 150/1 or the spring of AD 151. Since this could be the same time (see above), felling in April/May of AD 151 is

postulated for these timbers. 20076 could have been felled at the same time since it may be from the same tree as 14971/14974/20051. The remaining dated timbers do not have full sapwood and so it is not possible to assign them to either of these phases.

The tree-ring results can be summarised to produce the following chronology for the site:

AD 135/6 or just after.....box lining of well 9421 constructed

AD 151, spring .....box lining of well 14984 constructed

AD 153/4 or just after.....stakes added to well 14984

AD 159/60 or just after.....box lining of well 8188 constructed

AD 161-89 (?nearer AD 161).....box lining of well 6280 constructed

AD 215-?251 .....ditch 12046 lined with timber

DISCUSSION

The construction of the wooden box linings appears to be a single phase of construction in each case with timbers felled at the same time for each well or within a few years of each other. Well 14984 is more complex. The lining was made of timbers felled in the spring of AD 151 but was surrounded by stakes felled in the winter of AD 153/4. Two explanations are possible. The first is that the box lining was built in AD 151 or just after but proved to be unsteady and was therefore strengthened with stakes felled in AD 153/4. The alternative is that at least some of the timbers were felled and stockpiled for a few years. The lining and stakes would then have been inserted some time in or just after AD 153/4. There is no archaeological evidence to help resolve this problem since conditions were too wet during excavation to allow a detailed examination of the stratigraphy. However, since there is no obvious evidence of stockpiling of timbers for the other wells, the first explanation seems to be more likely, particularly as the *t*-values within and between the two groups suggest that the lining timbers and stakes may have come from different sources (Table 5).

The only other Roman well in the region which has produced timbers for dendrochronology is well 567 from Great Holts Farm, Boreham. Only four timbers were salvaged, the others being removed by machinery before they could be excavated. The timbers, probably two pairs from two trees, were felled after AD 188 (Groves pers comm). The well lining is therefore probably later than those at Elms Farm; no details of its construction are available.

CONCLUSION

Tree-ring dates were obtained for all the main timber-producing features. Presence of bark edge on many of the timbers resulted in the production of precise felling dates which indicated that the wells - or at least their box linings - were constructed in the second century AD. The stakes around well 14984 were not Saxon but were felled in winter AD 153/4, a few years after the trees which were used for the

lining planks. Ditch 12046 was lined in the third century AD, probably in the first half. The study illustrates the value of using timbers with fewer rings than is usual in British dendrochronology and proves that, provided there are several timbers per structure and that at least one has more than 100 rings, it is possible to date timbers with 30-50 rings. The resulting site chronology from Elms Farm spans the period AD 27-205.

ACKNOWLEDGEMENTS

The analysis was funded by English Heritage. I am also grateful to Mark Atkinson and Richard Darrah for information about the site and the timbers, and to Cathy Groves and Ian Tyers, who assessed the timbers in Essex and provided helpful comments about the timbers and the tree-ring results.

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Fig 1: Elms Farm, Heybridge, showing the approximate location of the main features with timbers; the area is shown in more detail in Fig 2 (drawing by Essex County Council Field Archaeology Unit).

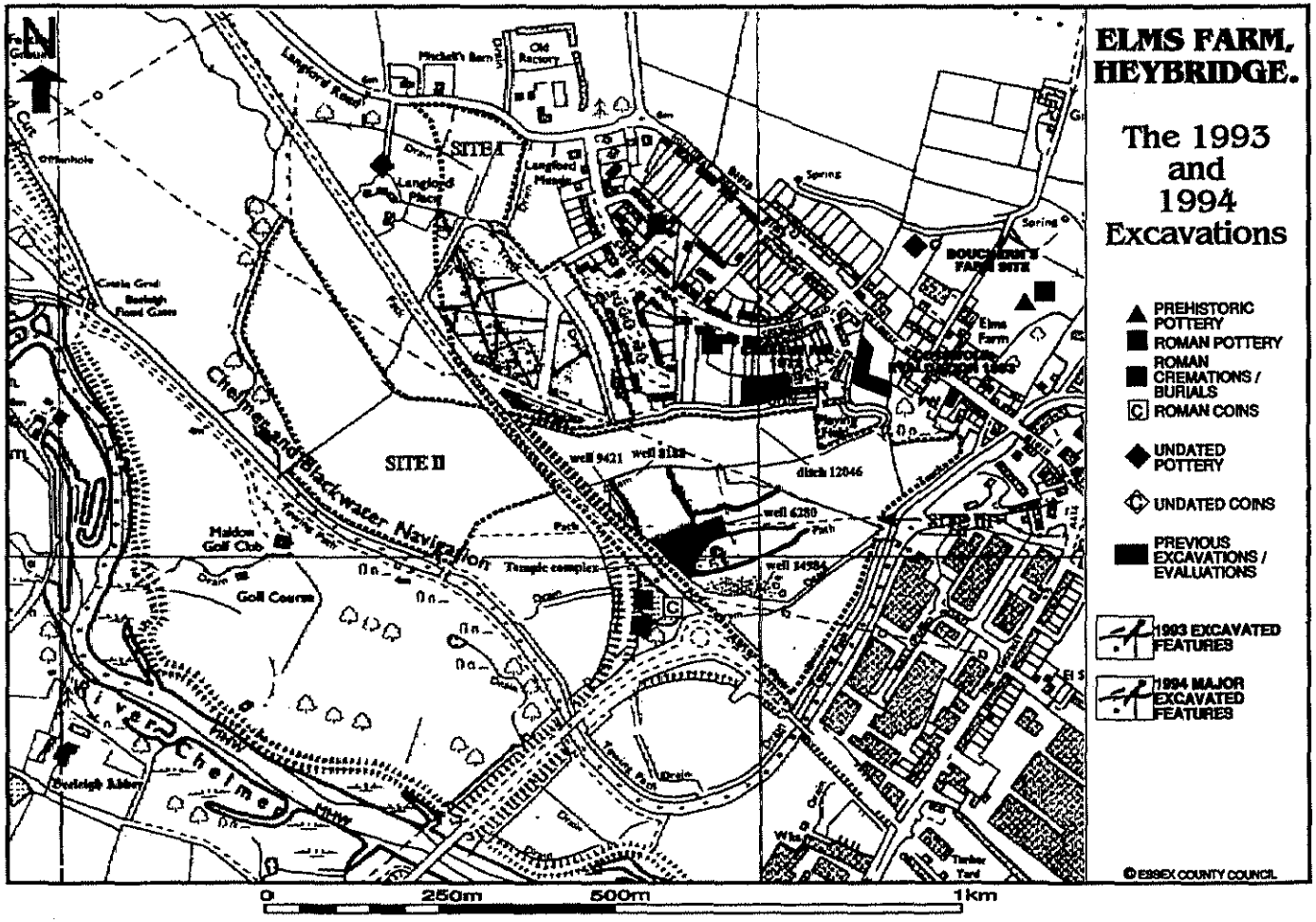

Fig 2: The site in detail; the drawing was made available by Essex County Council Field Archaeology Unit.

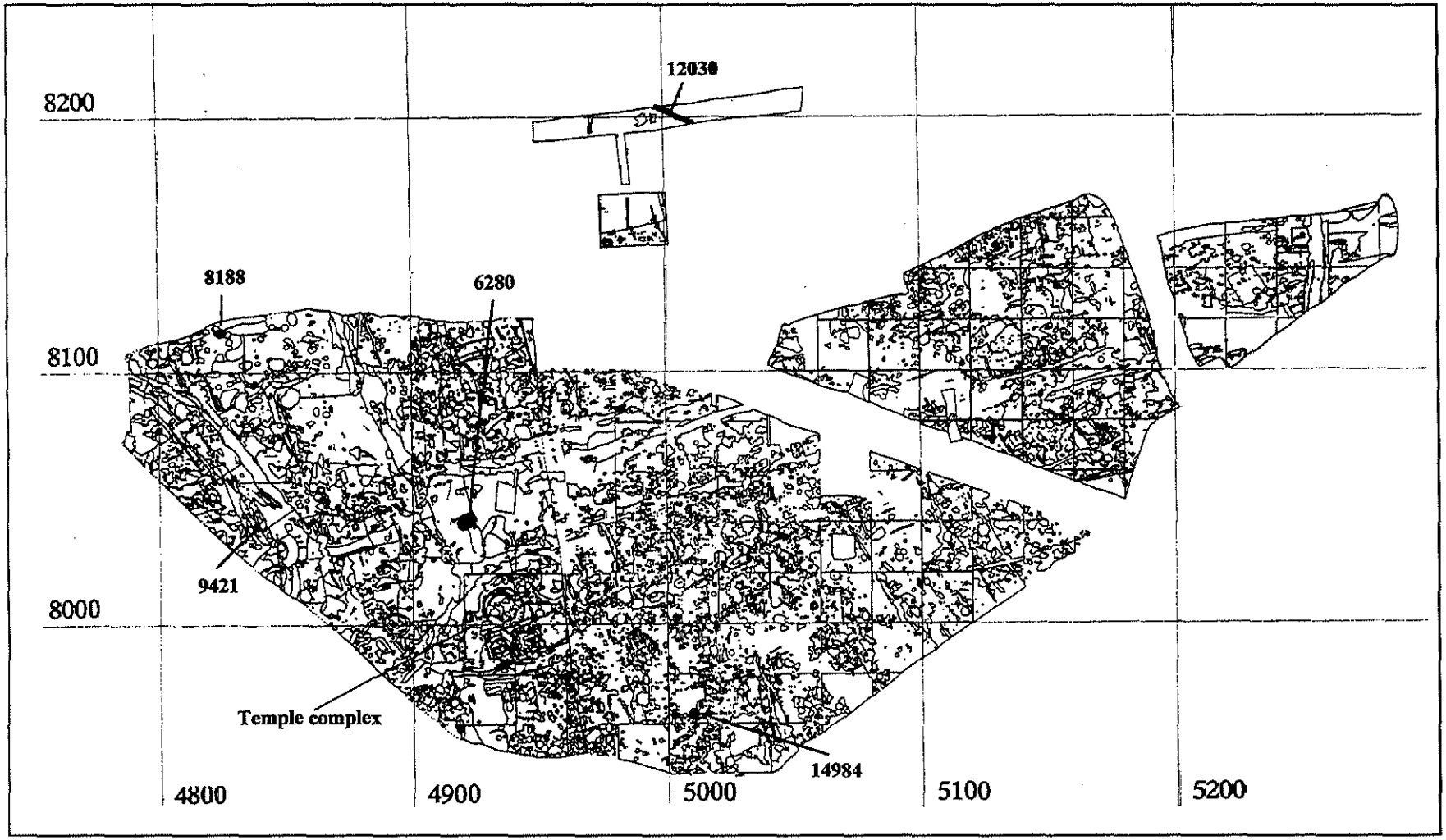

Fig 3: Typical construction of the wells at Elms Farm as shown here by well 6280; the sketch was made available by Essex County Council Field Archaeology Unit.

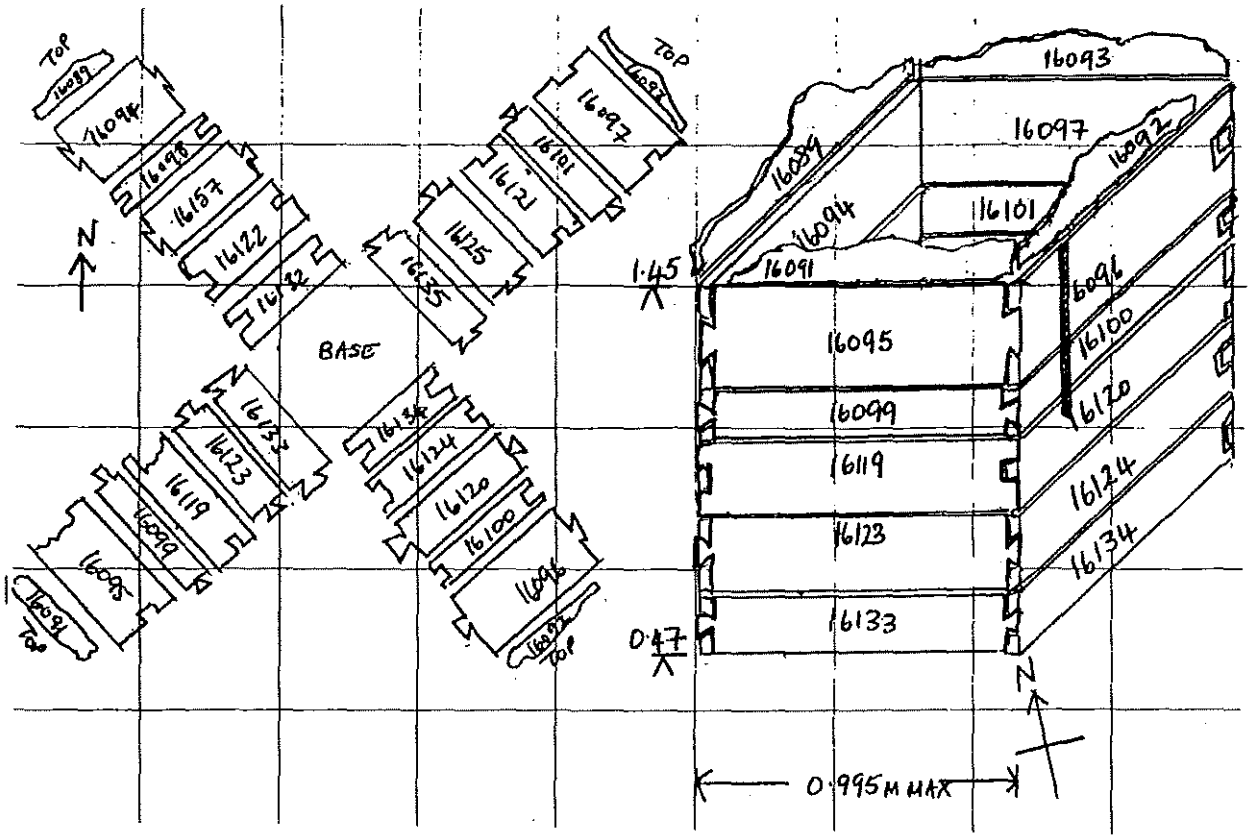

Fig 4: The formation of an oak tree-ring (after Varley and Gradwell 1962).

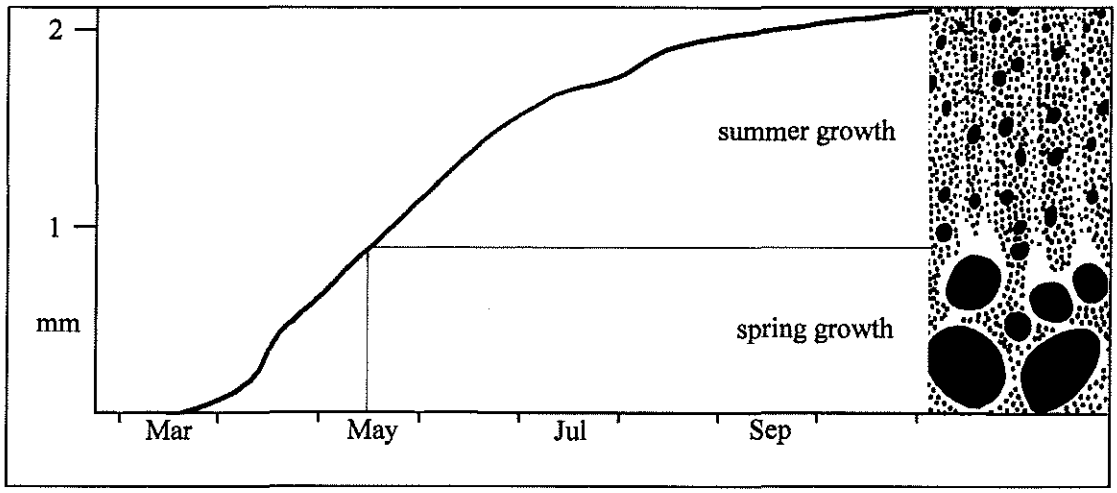

Fig 5: Drawing of the ring patterns from timbers in well 6280. Some of the corresponding narrow rings are highlighted.

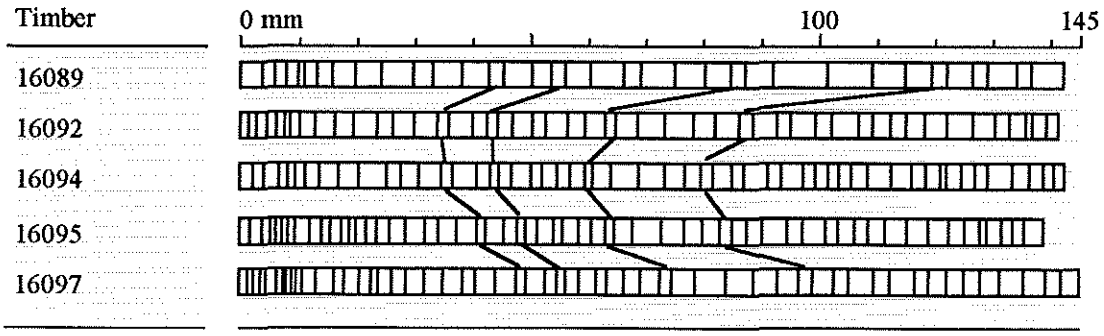

Fig 6: Actual ring patterns from the timbers as in Fig 5; the same narrow rings are highlighted. Vertical scale is logarithmic.

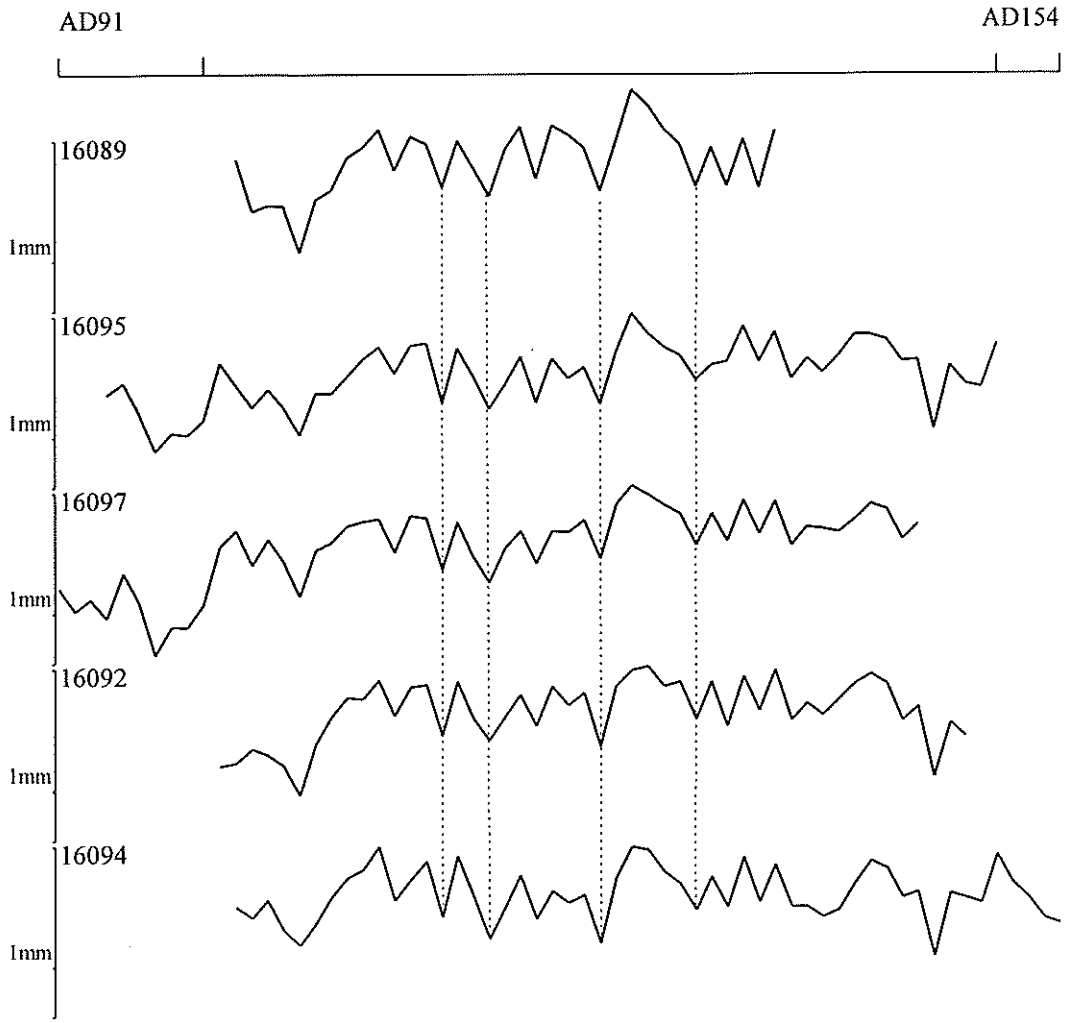

Fig 7: Timber conversion types represented by the Elms Farm tree-ring samples.

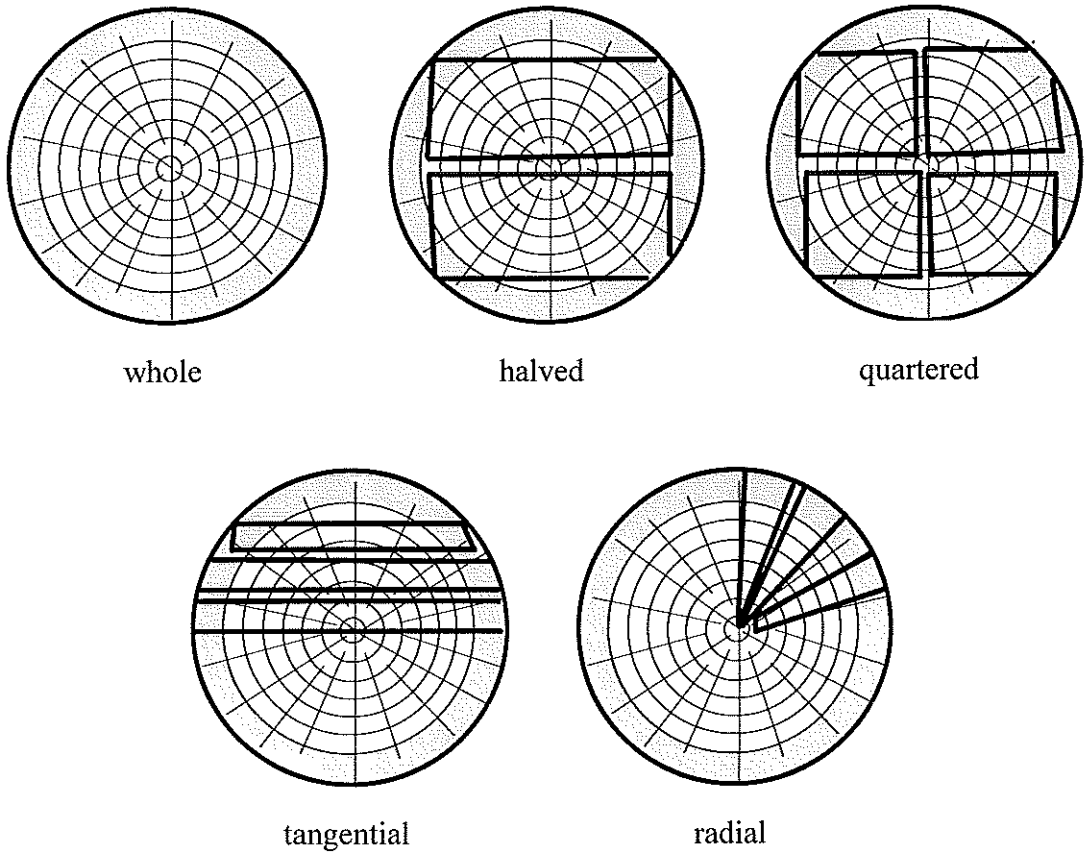

Fig 8: Visual matches between the masters from the four wells. Vertical scale is logarithmic.

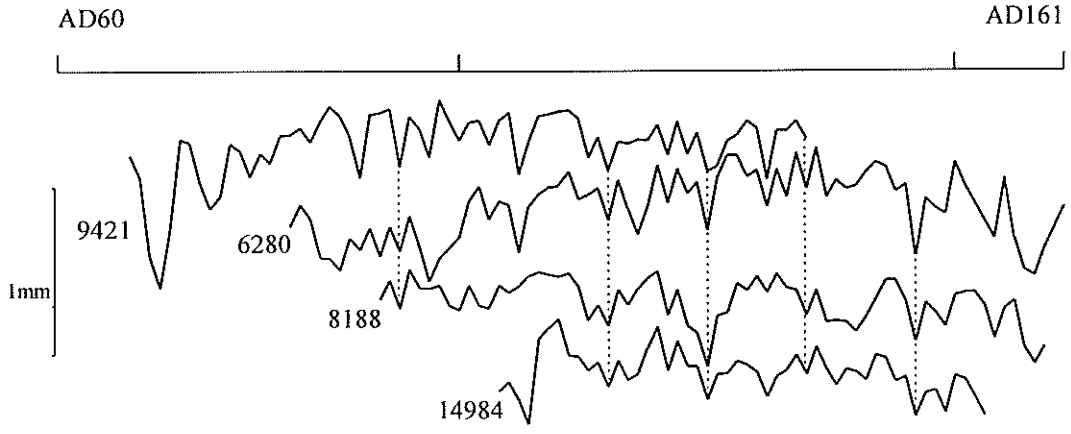

Fig 9: Histogram showing the distribution of data, as measured by the number of trees, in the Elms Farm chronology.

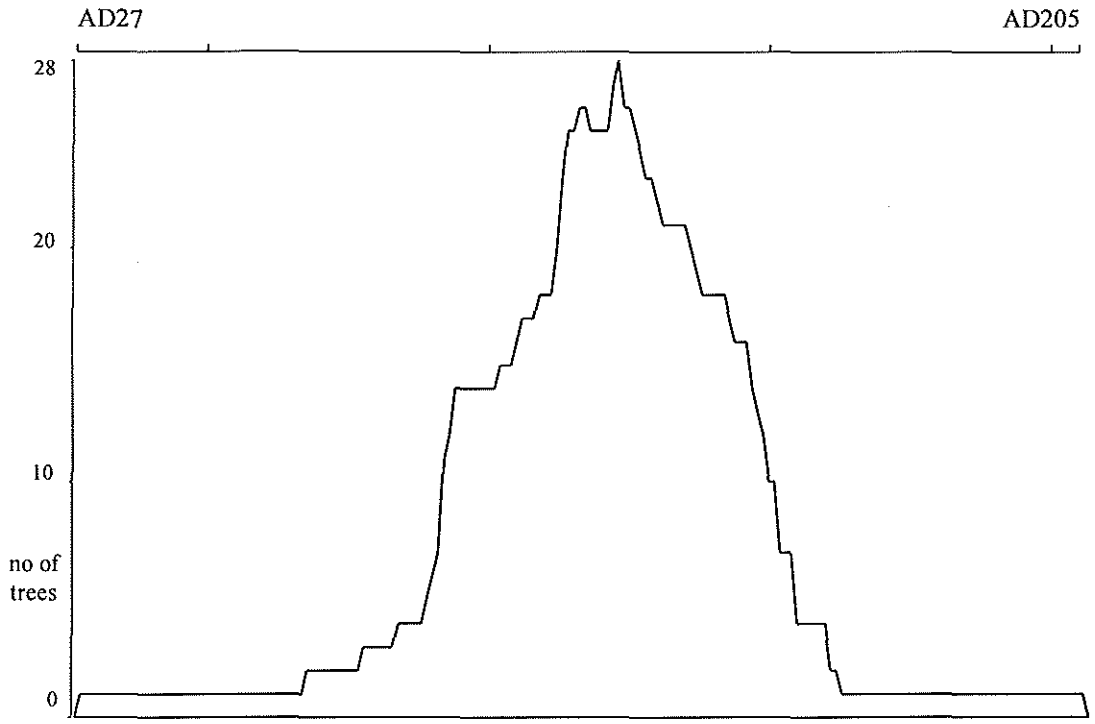

Fig 10: Bar diagram showing the relative positions of the dated ring sequences from Elms Farm. White bars - heartwood rings; hatching - sapwood; narrow bars - unmeasured rings; C - pith present.

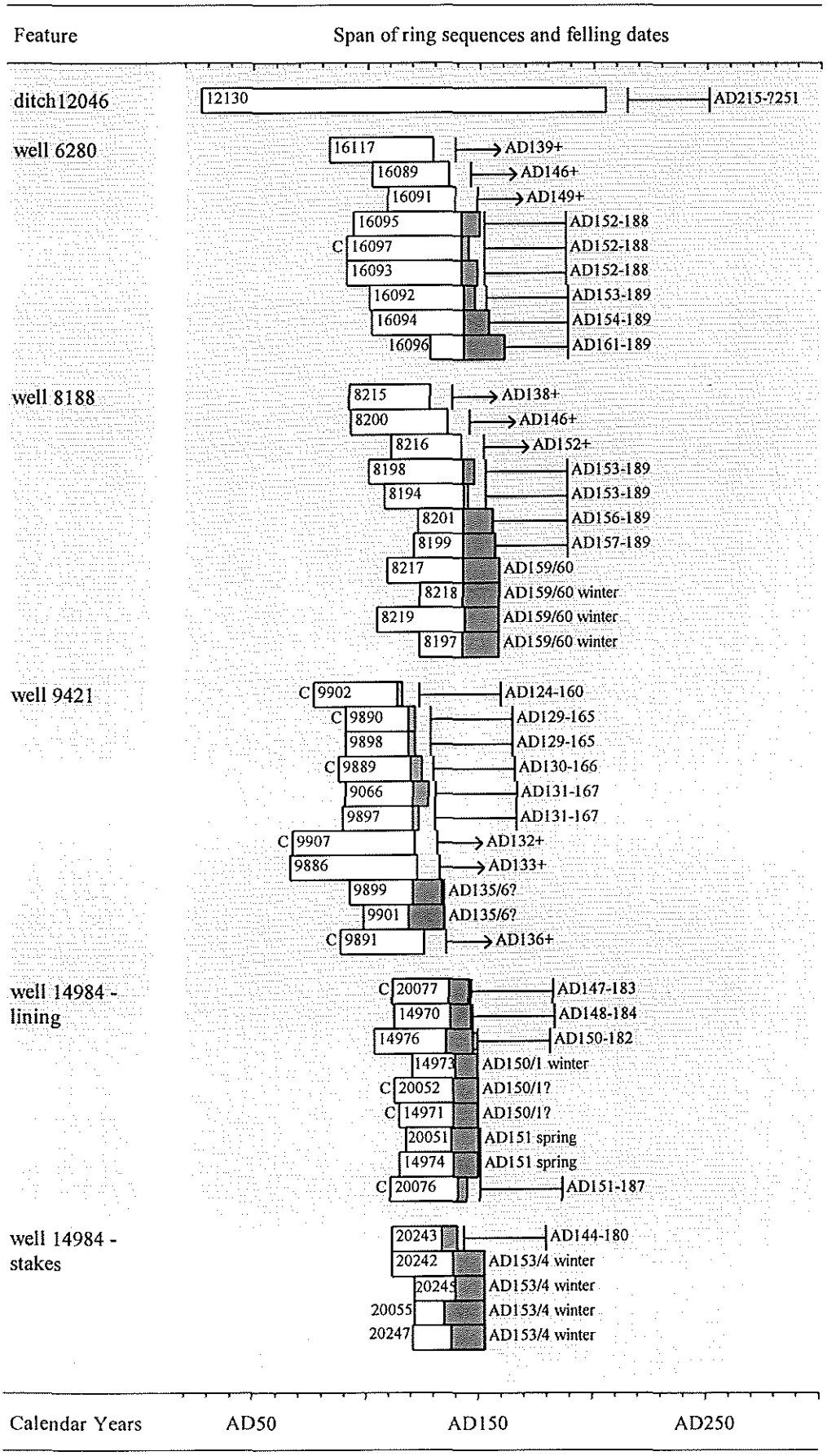

Table 1: Details of the measured tree-ring samples. Timbers sampled more than once are marked with an asterisk; details of the combined ring sequences are given.

Sapwood details: HS - heartwood-sapwood transition; BW - bark edge with complete outer ring; +sprB - bark edge with spring wood just forming; B - bark edge, season of felling indeterminable; + - unmeasured rings present.

Pith details: C - centre or pith present; V - within 5 rings of pith; F - within 5-10 rings of pith; G - more than 10 rings from pith.

Sample no	Feature	Function	Total no of rings	Sapwood rings	Timber conversion	Pith	Dimensions (mm)	ARW (mm)	Date span (AD)	Felled (AD)
06066	posthole 6027	post	45	-	halved	G	255x90	2.6	-	-
12130	ditch 12046	lining	179	HS?	radial	G	215x45	1.2	27-205	215-?251
12143		lining	32	14BW	whole	C	105x85	2.0	-	-
16083	well 6280	fill	32	-	tangential	G	140x25	3.0	-	-
16089		lining	35	-	tangential	G	175x30	4.1	102-136	after 146
16091		lining	31	-	tangential	G	170x35	4.2	109-139	after 149
16092		lining	48	5	tangential	G	145x35	2.9	101-148	153-189
16093*		lining	59	7	tangential	F	165x35	2.6	91-149	152-188
16094		lining	53	11	tangential	G	290x35	2.7	102-154	154-189
16095*		lining	57	8	tangential	V	290x35	2.4	94-150	152-188
16096		lining	34	18	tangential	G	280x35	2.9	128-161	161-189
16097*		lining	55	3	tangential	C	185x35	2.6	91-145	152-188
16098		lining	40	10	tangential	V	155x70	2.0	-	-
16117		fill (plank)	47	-	tangential	F	170x35	2.1	83-129	after 139
16119		lining	34	2	tangential	C	200x40	3.0	-	-
16120		lining	31	14B?	tangential	G	115x60	2.7	-	-
16121*		lining	35	3	tangential	C	205x50	3.7	-	-
16133		lining	30	-	tangential	C	165x30	3.1	-	-
16144		fill	39	-	tangential	G	205x45	5.1	-	-
16146		plank	47	-	tangential	C	310x85	3.5	-	-

16157*		lining	35	HS	tangential	C	200x45	3.3	-	-
08194	well 8188	lining	38	2	tangential	G	265x45	3.2	108-145	153-189
08197		lining	36	16BW	tangential	G	305x45	2.7	124-159	159/60 winter
08198		lining	48	5	tangential	G	190x45	2.9	101-148	153-189
08199		lining	37	14	tangential	G	265x40	2.8	121-157	157-189
08200		lining	44	-	tangential	F	275x40	3.7	93-136	after 146
08201		lining	34	13	tangential	G	270x60	3.1	123-156	156-189
08215		lining	37	-	tangential	F	140x45	3.6	92-128	after 138
08216		lining	32	-	tangential	G	270x45	2.8	111-142	after 152
08217		lining	51	16B	tangential	G	330x65	2.9	109-159	159/60
08218		lining	36	16BW	tangential	G	315x60	2.9	124-159	159/60 winter
08219		lining	55	15BW	tangential	G	315x70	3.2	105-159	159/60 winter
09066	well 9421	lining	38	7	tangential	G	210x35	2.3	91-128	131-167
09886		lining	57	-	tangential	V	190x45	1.9	67-123	after 133
09889		lining	38	5	tangential	C	160x40	2.4	88-125	130-166
09890		lining	32	3	tangential	C	160x30	2.5	91-122	129-165
09891		lining	38	-	tangential	C	160x45	2.4	89-126	after 136
09897		lining	35	3	tangential	F	150x40	2.1	90-124	131-167
09898		lining	32	3	tangential	V	150x40	2.5	91-122	129-165
09899		lining	42+	13+1 to B?	tangential	G	200x50	2.2	93-134	135/6?
09901		lining	37	16B?	tangential	G	195x50	2.1	99-135	135/6?
09902		lining	40	2	tangential	C	195x50	2.5	77-116	124-160
09907		lining	55	-	tangential	C	200x35	1.4	68-122	after 132
14970	well 14984	lining	35	9	tangential	V	210x45	3.2	113-147	148-184
14971		fill	36	11B?	tangential	C	165x55	2.9	115-150	150/1?
14973		lining	30	10BW	tangential	G	170x60	2.5	121-150	150/1 winter
14974*		lining	36	11+sprB	tangential	G	190x65	2.9	115-150	151 spring
14976		lining	45+	12+2	halved	V	240x130	3.0	104-148	150-182
20051		lining	33	12+sprB	tangential	G	180x65	2.5	118-150	151 spring

20052*	lining	38	11B?	tangential	C	210x35	2.8	113-150	150/1?
20055	stake	32	18BW	halved	V	170x105	3.3	122-153	153/4 winter
20076*	lining	35	4	tangential	C	170x55	3.0	111-145	151-187
20077	lining	35	9	tangential	C	210x40	3.4	112-146	147-183
20113*	stake	34	21+sprB	quartered	G	65x45	1.3	-	-
20238	stake	46	25B	halved	V	85x70	1.4	-	-
20242	stake	42	14BW	halved	V	200x135	3.4	112-153	153/4 winter
20243	stake	30	7	halved	G	205x90	3.1	112-141	144-180
20245	stake	32	13BW	quartered	G	120x100	3.3	122-153	153/4 winter
20246	stake	45	22	halved	C	100x60	1.1	-	-
20247	stake	33	15BW	tangential	G	185x65	3.6	121-153	153/4 winter

Table 2: *t*-value matrix for matching ring sequences from well 6280. Note that all but 16117 are probably from the same tree. *t*-values are given for two samples from timber 16093 to show the level of correlation between pieces from the same timber. \ - overlap less than 15 years.

		16089	**16091**	**16092**	**16093a**	**16093b**	**16094**	**16095**	**16096**	**16097**	**16117**
	Date span (AD)	102-136	109-139	101-148	91-140	115-149	102-154	94-150	128-161	91-145	83-129
16089	102-136	*	10.96	12.81	13.51	10.74	11.43	12.28	\	13.59	4.18
16091	109-139	*	*	10.65	15.30	9.49	11.67	9.47	\	10.15	3.72
16092	101-148	*	*	*	12.49	13.64	17.47	12.54	7.09	15.09	4.38
16093a	91-140	*	*	*	*	11.47	14.04	12.50	\	17.51	5.77
16093b	115-149	*	*	*	*	*	14.49	17.07	9.02	14.83	5.20
16094	102-154	*	*	*	*	*	*	15.28	8.13	14.46	4.70
16095	94-150	*	*	*	*	*	*	*	5.20	15.49	5.31
16096	128-161	*	*	*	*	*	*	*	*	6.17	\
16097	91-145	*	*	*	*	*	*	*	*	*	5.94
16117	83-129	*	*	*	*	*	*	*	*	*	*

Table 3: *t*-value matrix for matching ring sequences from well 8188. Probable same tree matches are highlighted in bold. Values less than 3.0 are not printed; \ - overlap less than 15 years.

		08194	**08197**	**08198**	**08199**	**08200**	**08201**	**08215**	**08216**	**08217**	**08218**	**08219**
	Date span (AD)	108-145	124-159	101-148	121-157	93-136	123-156	92-128	111-142	109-159	124-159	105-158
08194	108-145	*	3.74	7.44	6.28	5.94	7.23	5.50	8.09	6.40	-	5.95
08197	124-159	*	*	5.82	6.47	\	5.68	\	3.13	6.38	5.72	7.00
08198	101-148	*	*	*	6.59	6.04	5.41	5.90	6.93	6.81	3.94	7.48
08199	121-157	*	*	*	*	5.62	**14.56**	\	4.49	**10.80**	8.41	**10.42**
08200	93-136	*	*	*	*	*	\	6.18	4.69	4.98	\	7.02
08201	123-156	*	*	*	*	*	*	\	5.37	**9.23**	5.92	**8.89**
08215	92-128	*	*	*	*	*	*	*	7.48	5.43	\	6.34
08216	111-142	*	*	*	*	*	*	*	*	4.97	3.47	6.56
08217	109-159	*	*	*	*	*	*	*	*	*	**10.79**	**13.93**
08218	124-159	*	*	*	*	*	*	*	*	*	*	**9.12**
08219	105-158	*	*	*	*	*	*	*	*	*	*	*

Table 4: *t*-value matrix for matching ring sequences from well 9421. Probable same tree matches are highlighted in bold. Values less than 3.0 are not printed.

		09066	**09886**	**09889**	**09890**	**09891**	**09897**	**09898**	**09899**	**09901**	**09902**	**09907**
	date span (AD)	91-128	67-123	88-125	91-122	89-126	90-124	91-122	93-134	99-135	77-116	68-122
09066	91-128	*	4.10	5.03	6.31	6.37	5.44	4.82	8.04	**11.97**	4.16	3.21
09886	67-123	*	*	4.61	7.87	8.03	5.84	6.29	5.13	4.35	5.47	**12.17**
09889	88-125	*	*	*	5.61	4.70	5.81	4.62	-	-	4.02	3.30
09890	91-122	*	*	*	*	6.90	7.82	9.44	6.24	6.32	5.52	7.14
09891	89-126	*	*	*	*	*	5.90	6.19	5.33	5.08	4.50	6.63
09897	90-124	*	*	*	*	*	*	9.30	4.84	3.83	5.61	5.11
09898	91-122	*	*	*	*	*	*	*	3.94	4.63	5.42	6.31
09899	93-134	*	*	*	*	*	*	*	*	8.93	-	3.86
09901	99-135	*	*	*	*	*	*	*	*	*	3.18	5.80
09902	77-116	*	*	*	*	*	*	*	*	*	*	5.19
09907	68-122	*	*	*	*	*	*	*	*	*	*	*

Table 5: *t*-value matrix for matching ring sequences from well 14984. Probable same tree matches are highlighted in bold. Values less than 3.0 are not printed.

		Lining timbers									Stakes				
		14970	**14971**	**14973**	**14974**	**14976**	**20051**	**20052**	**20076**	**20077**	**20055**	**20242**	**20243**	**20245**	**20247**
	Date span (AD)	113-147	115-150	121-150	115-150	104-148	118-150	113-150	111-145	112-146	122-153	112-153	112-141	122-153	121-153
14970	113-147	*	3.20	3.16	3.70	-	3.82	6.06	4.03	7.59	3.83	5.21	-	-	-
14971	115-150	*	*	6.57	**11.90**	-	**10.11**	-	9.32	3.18	3.58	-	4.24	-	-
14973	121-150	*	*	*	6.27	-	6.24	-	5.49	-	4.50	4.01	-	3.56	-
14974	115-150	*	*	*	*	-	**12.27**	3.12	7.59	3.40	3.30	-	4.73	-	-
14976	104-148	*	*	*	*	*	-	4.02	-	-	-	-	4.76	-	-
20051	118-150	*	*	*	*	*	*	-	7.30	-	-	3.32	5.29	-	-
20052	113-150	*	*	*	*	*	*	*	3.07	5.56	4.26	4.15	3.38	-	-
20076	111-145	*	*	*	*	*	*	*	*	3.22	3.16	3.69	4.74	-	-
20077	112-146	*	*	*	*	*	*	*	*	*	-	3.91	-	-	-
20055	122-153	*	*	*	*	*	*	*	*	*	*	3.90	-	3.84	3.25
20242	112-153	*	*	*	*	*	*	*	*	*	*	*	-	**11.33**	7.46
20243	112-141	*	*	*	*	*	*	*	*	*	*	*	*	-	-
20245	122-153	*	*	*	*	*	*	*	*	*	*	*	*	*	8.31
20247	121-153	*	*	*	*	*	*	*	*	*	*	*	*	*	*

Table 6: *t*-value matrix for the master sequences from each feature. Values less than 3.0 are not printed.

		12130	**6280 T2**	**8188 T7**	**9421 T9**	**14984 T11**
	Date span (AD)	27-205	83-161	92-159	67-135	104-153
12130	27-205	*	4.09	5.60	-	4.57
6280 T2	83-161	*	*	6.61	3.96	5.37
8188 T7	92-159	*	*	*	4.21	4.17
9421 T9	67-135	*	*	*	*	3.45
14984 T11	104-153	*	*	*	*	*

Table 7: Dating the Elms Farm masters. *t*-values for independent reference chronologies. Values less than 3.0 are not printed; \ - overlap less than 15 years; SDL - Sheffield Dendrochronology Laboratory.

Chronology	Date span	**Elms Farm** AD27-205	**12130** AD27-205	**6280 T2** AD83-161	**8188 T7** AD92-159	**9421 T9** AD67-135	**14984 T11** AD104-153
Canterbury, Rosemary Lane (Hillam 1978)	AD38-129	3.56	3.83	-	3.32	-	-
Great Holts Farm (Groves unpubl)	AD66-178	5.00	3.81	3.79	5.05	3.45	4.82
London, Baynards Castle (SDL unpubl)	AD140-249	5.24	4.85	4.35	-	\	\
London, Billingsgate (Hillam 1990)	AD24-239	4.76	5.19	4.27	5.26	-	3.23
London, County Hall Wreck (Tyers pers comm)	AD95-277	5.76	5.21	3.02	4.56	3.72	3.16
London, Guys Hospital W9 (Tyers pers comm)	AD86-163	4.79	4.46	4.58	5.13	-	4.18
London, New Fresh Wharf (Hillam 1990)	53BC-AD241	5.44	7.00	4.94	5.65	-	3.51
Pevensey Castle, East Sussex (Tyers 1994)	AD131-270	4.55	-	-	-	\	-
Scole, Norfolk (Tyers and Groves 1996)	71BC-AD171	4.31	5.64	3.73	5.90	-	3.00

Table 8: Elms Farm tree-ring chronology, AD 27-205.

Year	Ring widths (0.01mm)										No of trees (approximate)									
AD 27							380	426	351	323							1	1	1	1
-	299	317	249	203	255	284	260	304	229	206	1	1	1	1	1	1	1	1	1	1
-	305	268	126	193	226	222	214	199	184	152	1	1	1	1	1	1	1	1	1	1
AD 51	167	144	123	106	146	123	117	90	80	86	1	1	1	1	1	1	1	1	1	1
-	109	122	165	133	152	148	145	123	75	58	1	1	1	1	1	1	2	2	2	2
-	84	162	153	114	105	113	163	152	116	139	2	2	2	2	2	2	3	3	3	3
-	142	171	172	193	156	171	206	204	183	121	3	3	4	4	4	4	4	5	6	7
-	244	246	284	152	279	227	175	295	238	199	11	12	14	14	14	14	14	14	14	14
AD 101	265	261	202	270	284	188	246	321	330	336	15	15	15	16	17	17	17	18	18	18
-	344	307	225	266	185	278	234	254	311	397	20	23	25	25	26	26	25	25	25	25
-	236	355	252	259	167	259	280	349	319	323	27	28	26	26	25	24	23	23	22	21
-	235	321	302	350	263	384	276	237	268	263	21	21	21	21	20	19	18	18	18	18
-	262	342	362	291	276	155	233	226	173	283	18	17	16	16	16	14	13	12	10	10
AD 151	261	235	185	142	241	205	123	109	126	113	7	7	7	4	4	4	4	4	4	2
-	142	75	66	71	68	54	75	119	82	50	2	1	1	1	1	1	1	1	1	1
-	76	104	70	108	62	93	108	127	88	136	1	1	1	1	1	1	1	1	1	1
-	94	115	122	151	128	106	90	111	78	111	1	1	1	1	1	1	1	1	1	1
-	104	70	79	124	106	140	85	68	69	91	1	1	1	1	1	1	1	1	1	1
AD 201	133	70	107	52	88						1	1	1	1	1					

Appendix 1: List of samples which were assessed in Sheffield and proved unsuitable for dating purposes.

Sample no	Context	Details
12117	river channel	21 rings, including 11 sapwood; felled winter
12131	12046	15+ heartwood rings, remainder unmeasurable
12134	12046	16 sapwood rings, felled winter
14967	14984	23 heartwood rings
14969	14984	25 rings, including 13 sapwood
14972	14984	22 rings, including 6 sapwood
14975	14984	23 rings, including 5 sapwood
16099	6280	22 rings, including 15 sapwood
16100	6280	23 heartwood rings
16106	6280	9 sapwood rings, felled winter
16116	6280	26 heartwood rings
16125	6280	23 rings, including 14 sapwood
16132	6280	27 rings, including 14 sapwood
16135	6280	19 rings, sapwood boundary
16145	6280	26 heartwood rings
16396	6280	10 sapwood rings, felled winter
20078	14984	19 rings, including 9 sapwood
20244	14984	28 rings, including 11 sapwood