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**Tree-Ring Analysis of Timbers from Hubbards Farm,
West Drayton Road, Hillingdon, Middlesex**

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Summary

Thirty-six timbers from a wide range of locations in this barn were cored for tree-ring analysis, this coring being undertaken in two stages of sampling. The analysis of these cores produced a single site chronology consisting of ten samples, being of combined length 233 rings. Although cross-matches with a number of relevant reference chronologies, particularly those from southern England, were possibly originally indicated, subsequent and further analysis indicated the t-values to be too low for reliable cross-matching and the building must therefore remain undated.

Keywords

Dendrochronology
Standing Building

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Introduction

Hubbards Farm (TQ 077813; Fig 1) is situated at West Drayton, near Uxbridge, in the London borough of Hillingdon on the west side of London. The building is a timber-framed structure of six bays, and forms part of a late medieval farmstead group that also includes two timber-framed barns and a small timber-framed granary. The smaller of the barns was recently destroyed by fire and the remaining buildings are all in urgent need of repair. The group of buildings now sits uncomfortably between a main road and a modern housing estate, parts of which are still under construction. There is currently a proposal to convert the six-bay structure (the subject of this report) to modern residential accommodation.

The building is aligned north-south, and has been built in three distinct stages, see Figure 2. Bays 1 to 3 (numbering from the north end) represent an original three-bay timber-framed structure. Bays 1 and 2 are (and always have been) open from ground to roof and some of the roof timbers in this area are smoke-blackened. There is evidence for the existence of a former loft or platform at first-floor level in bay 1, however it is possible that this was a secondary feature. Bay 3 was storied from the outset with its first floor open to the roof; it was separated from bays 1 and 2 by a closed cross frame partition wall (truss 3). What type of building is indicated by this initial three-bay structure is not known. Conceivably, the building was built as a house and was the home of a poor farmer and his family. Certainly the two-unit house (comprising an open hall at one end and a service bay with chamber above at the other end) was a common type in and around London in the late fifteenth and early sixteenth centuries.

If the structure was not a house, then perhaps it was used to house livestock (there is clear evidence that the ground floor of bay 3 was used as a stable in the last century). Alternatively, the building may have been built as a forge (perhaps accounting for the presence of smoke blackening over the central and northern bays) or was designed with some other semi-industrial or small scale manufacturing function in mind. One other possibility, although so far without any firm archaeological or historical support, is that the building may have been some sort of detached kitchen building serving a former nearby grand house.

Probably within fifty years or so of the first building being constructed it was extended by a further two bays at its southern end. This additional section was also a timber-framed structure. It was built in-line with the earlier building and its roof followed the same ridge line and roof pitch as the original roof. Just as the original building had terminated in a half-hip at its southern end (ie bay 3) so this later extension also terminated in a half-hip at its southern end (bay 5). Whereas the function of the earlier building is unknown, it seems fairly certain that the additional two-bay structure was used as stabling from the outset.

Beyond the southern end of the two-bay extension is a final timber-framed bay (bay 6). This bay was probably added in the eighteenth or nineteenth century and served as a loose box. As in the case of the period II building, the period III building was constructed so that its side walls and roof followed the lines of the original period I building. In addition, just like the periods I and II building the roof of the period III building terminated in a half-hip at its southern end.

The east and north exterior walls have been rebuilt in yellow stock brick and the south and west walls have later weatherboarding over the original timber framing. The roof is of clasped-purlin construction throughout, with diminished principal rafters. The only real difference between the roof construction of the period I structure (bays 1 to 3) and the period II extension (bays 4 and 5) is that in the period II extension the common rafters are pegged through to the purlins; in the period I building, by contrast, the rafters simply rest over them. Spanning the centre of the two-bay addition

is an arch-braced collar truss, the timbers of which have failed and been given further support by an inserted truss comprising a tie beam with struts to the purlins. The cross frame dividing the single storey section at the northern end of the building (truss 2) features diminutive curved braces between the wall posts and the tie beam. The wall posts of this cross frame have empty mortices in their inner faces for a beam spanning between the wall posts at first-floor level. This evidence and the presence of a window opening at first-floor level in the north gable (now blocked) points to there having once been a loft of some kind over the northernmost bay.

The first-floor frames in bays 3, 4, and 5 have all been raised by approximately 1ft (300mm). The upper parts of the wall frames generally preserve much of their original lath and plaster infilling. The wooden laths are mostly held together with ties made from strands of hazel or willow.

A dendrochronological analysis of the timber frame unfortunately failed to date any of the timbers in the building, however from the style of its carpentry it seems likely that the period I structure was built in the late fifteenth or sixteenth century. Given the degree of similarity between the carpentry of the period I and period II structures, and the minimal amount of weathering on the (formerly external) timbers of truss 4, it seems likely that the period II extension was added quite soon after the period I building was first constructed.

Sampling

Sampling and analysis by tree-ring dating of Hubbards Farm were commissioned by English Heritage. The purpose of this was to inform a spot-listing request and proposal for conversion to residential use by establishing dates for a number of elements in the building. In particular this was to establish whether both ends of the building, including the hipped south gable roof and first-floor frame, were all of the same date and whether or not there was a sequential development of the site.

Thus, after discussion with Richard Bond, of English Heritage, and in conjunction with the English Heritage brief a total of eighteen core samples was initially taken. The analysis of these initial samples proved inconclusive (see analysis below) and a further eighteen samples were subsequently obtained, making a total of thirty-six samples. Each sample was given the code WDR-A (for West Drayton, site "A"), and numbered 01 – 36. The positions of these samples are marked on drawings and elevations adapted by Richard Bond from a set of measured drawings of the building made by Jon Lowe of CgMs Ltd, and provided by English Heritage These are reproduced here as Figures 3a-e. Details of the samples are given in Table 1.

The Laboratory would like to take this opportunity to thank Shaun Andrews of OTM Architectural of High Wycombe, for helping with access, and for useful on-site discussions. We would also like to thank Richard Bond for providing much helpful input on the interpretation of possible phasing and for providing drawings for locating sample positions. Richard Bond also provided the site description used in the introduction above.

The Laboratory would also like to thank Cathy Groves of the University of Sheffield Dendrochronology Laboratory for her efforts and help in analysing this site.

Analysis

The eighteen cores obtained in the initial stage of sampling were prepared by sanding and polishing. It was seen at this stage that three of them had fewer than 54 rings, the minimum number for

satisfactory analysis, and the annual growth-ring widths of these were not measured. The data of the fifteen measured samples are given at the end of the report. The annual growth-ring widths of the fifteen measured samples were then compared with each other by the Litton/Zainodin grouping procedure (see appendix). At a minimum value of $t=4.5$ two groups of samples could be formed.

The two samples of the first group cross-match with each other, as shown in the bar diagram Figure 4, to form a site chronology, WDRASQ01, of length 75 rings. Site chronology WDRASQ01 was then compared with a series of relevant reference chronologies for oak. There was, however, no satisfactory cross-matching and this site chronology remains undated.

The two samples of the second group cross-match with each other, as shown in the bar diagram Figure 5, to form a site chronology, WDRASQ02, of length 169 rings. Site chronology WDRASQ02 was also compared with a series of relevant reference chronologies for oak, indicating cross-matches, with low t -values, at two different positions. The earlier of these indicates a possible last measured ring date of AD 1567, the later position indicates a possible last measured ring date of AD 1579. The t -values of these cross-matches are given in Tables 2 and 3.

Because of the inconclusive nature of these results a second batch of eighteen samples was obtained. These were taken not only from the additional areas of interest, but also from the same parts of the building as the earlier group of eighteen samples. Thus a total of 36 samples was obtained.

Each of the additional eighteen samples was prepared by sanding and polishing. It was seen at this stage that, while some of these had sufficient rings for satisfactory analysis, a good number of samples did not. This was particularly so of the six samples, WDR-A26 – A31, from the first-floor joists in bay 4, and the five samples, WDR-A32 – A36, from the timbers of the northern-most truss, truss 1. Because of the way these timbers were either covered in heavy layers of paint or lime wash, and, or, because they were buried deeply in the walls of the structure, it was not immediately apparent that they were often of a small scantling, producing very short cores, and having wide rings. It was felt, however, that an attempt at obtaining a few satisfactory cores should be made. In any case, such samples, having only 15 – 25 rings, were not measured. The data of the six measured additional samples are also given at the end of the report.

The annual growth-ring widths of all twenty-one samples that were measured were then compared with each other by the Litton/Zainodin grouping procedure (see appendix). At a minimum value of $t=4.5$ a single site chronology could be formed. This consisted of the four samples in the site chronologies WDRASQ01 and WDRASQ02 from the initial analysis, plus all six of the additional measured samples. The relative off-sets of the ten samples are shown in the bar diagram, Figure 6. These ten samples were combined to make a final site chronology WDRASQ03, being 233 rings long.

Site chronology WDRASQ03 was then compared with a series of relevant reference chronologies for oak, this indicating a possible cross-match and date at only one position. However, although the number of cross-matches and the t -values for the earlier date were largely eliminated, those for the later, with a possible last ring date of AD 1579 were still not high enough for reliable dating. The t -values for this possible date are given in Table 4.

Site chronology WDRASQ03 was compared with the remaining eleven measured but ungrouped samples. There was no satisfactory cross-matching. Each of the eleven ungrouped samples was then compared individually against the reference chronologies. Once again there was no satisfactory cross-matching or dating.

Given the constraints of dendrochronology and that no truly reliable cross-match or *t*-values can be indicated it is felt advisable not to confirm the possible tentative date and to declare the building undated.

This may be particularly advisable in this unusual situation. As will be seen from the bar diagrams, and from Table 1, the site chronologies, and some of the individual samples, have high numbers of rings. The growth, however, are not unduly distorted but the rings are in many cases very tight and show evidence of compaction. It is felt possible that it is because of this high number of rings that the samples are undateable. The trees the sample represent may have been growing under adverse or stressed conditions producing very narrow rings which are not truly representative of the climatic conditions during their period of growth, and thus any cross-matching and apparent dating may be spurious and incorrect. The growth patterns of the samples are not represented by any available reference chronology including those held by other tree-ring dating laboratories.

Conclusion

Despite an apparently satisfactory site chronology having been created with the material from this site, and having individual samples with high numbers of rings no satisfactory dates have been obtained. This site must therefore remain undated.

However, though no absolute dating is available it appears that there is very little, if indeed any, time gap between the felling date of the timbers in the period 1 building and those used in the period 2 building. This similarity of phasing may be seen by the fact that some of the samples from each of these buildings in site chronology WDRASQ03 (bar diagram Fig 6) have identical last measured complete sapwood ring positions. While it is of course possible that some timbers might have been stored and used later than others it is certain that trees used in both parts were cut at the same time. Thus, while there is certainly a structural break in the building it is possible that construction of the phase 2 part followed on very shortly from that of phase 1.

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Table 1: Details of samples from Hubbards Farm, West Drayton, Middlesex

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
WDR-A01	Tiebeam, truss 3	74	30C	-----	-----	-----
WDR-A02	West upper stud post, truss 3	76	21C	-----	-----	-----
WDR-A03	West main stud post, truss 3	97	19C	-----	-----	-----
WDR-A04	Stave, west bay 3	60	h/s	-----	-----	-----
WDR-A05	East main wall post, truss 4	66	h/s	-----	-----	-----
WDR-A06	West main wall post, truss 4	55	10	-----	-----	-----
WDR-A07	Tiebeam, truss 4	67	26C	-----	-----	-----
WDR-A08	Collar, truss 4	nm	--	-----	-----	-----
WDR-A09	West brace, tiebeam to post, truss 4	54	no h/s	-----	-----	-----
WDR-A10	West main wall post, truss 5	nm	--	-----	-----	-----
WDR-A11	East brace, post to tiebeam, truss 5	57	5	-----	-----	-----
WDR-A12	West intermediate stud post, bay 5	168	30C	-----	-----	-----
WDR-A13	East principal rafter, truss 6	128	25C	-----	-----	-----
WDR-A14	Tiebeam, truss 6	69	10	-----	-----	-----
WDR-A15	East brace, post to tiebeam, truss 6	nm	--	-----	-----	-----
WDR-A16	Central lower stud post, truss 6	65	17C	-----	-----	-----
WDR-A17	West upper stud post, truss 6	65	15C	-----	-----	-----
WDR-A18	East wall plate, truss 4 - 6	54	h/s	-----	-----	-----
WDR-A19	East joist 8, first-floor frame, bay 3	nm	--	-----	-----	-----
WDR-A20	West joist 2, first-floor frame, bay 3	77	h/s	-----	-----	-----
WDR-A21	West joist 6, first-floor frame, bay 3	61	no h/s	-----	-----	-----
WDR-A22	West joist 7, first-floor frame, bay 3	92	h/s	-----	-----	-----
WDR-A23	West joist 10, first-floor frame, bay 3	69	2	-----	-----	-----
WDR-A24	East rail, truss 6	180	no h/s	-----	-----	-----
WDR-A25	West rail, truss 6	196	32C	-----	-----	-----
WDR-A26	East joist 11, first-floor frame, bay 4	nm	--	-----	-----	-----

Table 1: continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
WDR-A27	West joist 8, first-floor frame, bay 4	nm	--	-----	-----	-----
WDR-A28	West joist 9, first-floor frame, bay 4	nm	--	-----	-----	-----
WDR-A29	West joist 12, first-floor frame, bay 4	nm	--	-----	-----	-----
WDR-A30	West joist 11, first-floor frame, bay 4	nm	--	-----	-----	-----
WDR-A31	West joist 10, first-floor frame, bay 4	nm	--	-----	-----	-----
WDR-A32	West stud post, truss 1	nm	--	-----	-----	-----
WDR-A33	East stud post, truss 1	nm	--	-----	-----	-----
WDR-A34	East cross-rail, truss 1	nm	--	-----	-----	-----
WDR-A35	West main wall-post, truss 1	nm	--	-----	-----	-----
WDR-A36	Tiebeam, truss 1	nm	--	-----	-----	-----

*h/s = the heartwood/sapwood boundary is the last ring on the sample
 C = complete sapwood retained on sample
 nm = sample not measured

Table 2: Results of the possible cross-matching of site chronology WDRASQ02 and relevant reference chronologies when first ring date is AD 1399 and last ring date is AD 1567

Reference chronology	Span of chronology	<i>t</i> -value	
JMF-100	AD 1467 - 1557	5.2	(Fletcher 1978 unpubl)
Pye Corner, Moulsoford, Oxon	AD 1340 - 1558	4.3	(Alcock <i>et al</i> 1991)
England London	AD 413 - 1728	4.2	(Tyers and Groves 1999 unpubl)
Sinai Park, Burton on Trent, Staffs	AD 1227 - 1750	4.1	(Tyers 1997)
White House, Blyth, Notts	AD 1453 - 1595	4.0	(Howard <i>et al</i> 1994)
Southern England	AD 1083 - 1589	4.0	(Bridge 1988)
Manor Road, Didcot, Oxon	AD 1415 - 1509	3.8	(Alcock <i>et al</i> 1989)
High Street, Kinver, Staffs	AD 1431 - 1562	3.7	(Howard <i>et al</i> 1995)
Folly House, Steventon, Oxon	AD 1437 - 1542	3.6	(Alcock <i>et al</i> 1989)
Cobham, Kent	AD 1317 - 1662	3.6	(Howard <i>et al</i> forthcoming)
Kent-88	AD 1158 - 1540	3.5	(Laxton and Litton 1989)

Table 3: Results of the possible cross-matching of site chronology WDRASQ02 and relevant reference chronologies when first ring date is AD 1411 and last ring date is AD 1579

Reference chronology	Span of chronology	<i>t</i> -value	
East range, Ighthan Mote, Kent	AD 1393 - 1468	5.1	(Howard <i>et al</i> 1995)
Cottage range, Ightam Mote, Kent	AD 1392 - 1463	4.7	(Howard <i>et al</i> 1994)
Chilton Manor, Sittingbourne, Kent	AD 1368 - 1520	4.0	(Howard <i>et al</i> 1988)
Hagworthingham Church, Lincs	AD 1336 - 1533	3.8	(Laxton <i>et al</i> 1984)
Old Queens Head, Sheffield	AD 1370 - 1498	3.7	(Howard <i>et al</i> 1992)
Wicham, Hants	AD 1373 - 1503	3.7	(Esling <i>et al</i> 1990 unpubl)
Coat's Barn, Cosby, Leics	AD 1426 - 1562	3.7	(Alcock <i>et al</i> 1991)
New Chapel, Ightham Mote, Kent	AD 1394 - 1465	3.6	(Howard <i>et al</i> 1994)
Kent-88	AD 1158 - 1540	3.6	(Laxton and Litton 1989)
Lacock Abbey, Wilts	AD 1395 - 1546	3.5	(Esling <i>et al</i> 1990)
Cobham, Kent	AD 1317 - 1662	3.5	(Howard <i>et al</i> forthcoming)

Table 4: Results of the possible cross-matching of site chronology WDRASQ03 and relevant reference chronologies when first ring date is AD 1411 and last ring date is AD 1579

Reference chronology	Span of chronology	<i>t</i> -value	
Bremhill Farm, Calne, Wilts	AD 1353 - 1484	4.8	(Alcock <i>et al</i> 1991)
Rectory Farm, Weston on Trent, Derbys	AD 1362 - 1503	4.5	(Howard <i>et al</i> 1996 unpubl)
Chicksands Priory, Beds	AD 1200 - 1541	4.1	(Howard <i>et al</i> 1998)
Lacock Abbey, Wilts	AD 1395 - 1546	4.0	(Esling <i>et al</i> 1990)
Eckington, Derbys	AD 1365 - 1480	3.9	(Howard <i>et al</i> 1992)
Church Cottage, Cadeby, Leics	AD 1362 - 1472	3.7	(Alcock <i>et al</i> 1991)
Kent-88	AD 1158 - 1540	3.7	(Laxton and Litton 1989)
Trentham's Barn, Purley, Berks	AD 1404 - 1512	3.6	(Howard <i>et al</i> 1996)
Restoration House, Rochester, Kent	AD 1378 - 1505	3.6	(Howard <i>et al</i> 1997)

Figure 1: Map to show specific location of Hubards Farm

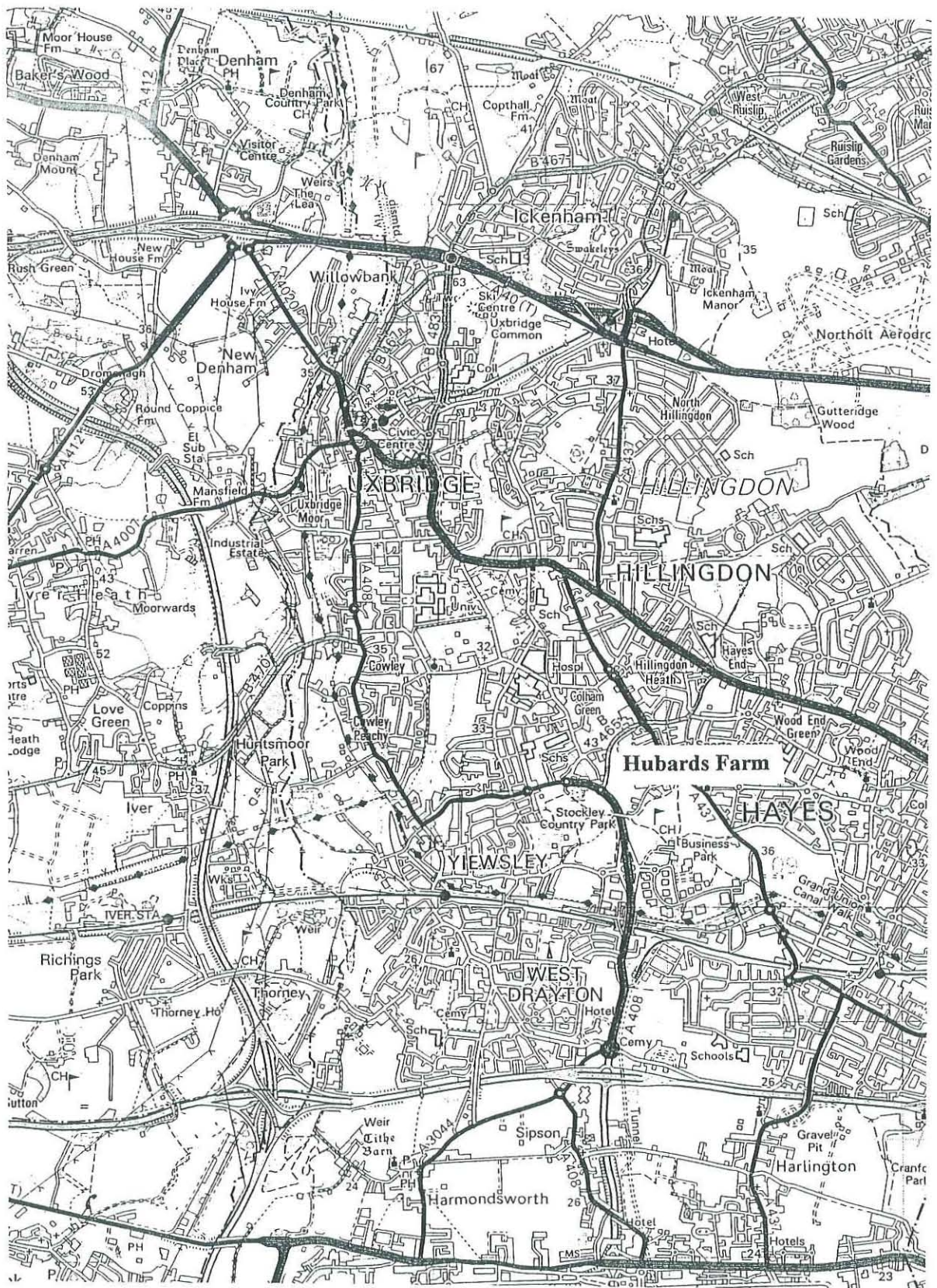


Figure 2: Plan at ground-floor level to show phases of construction

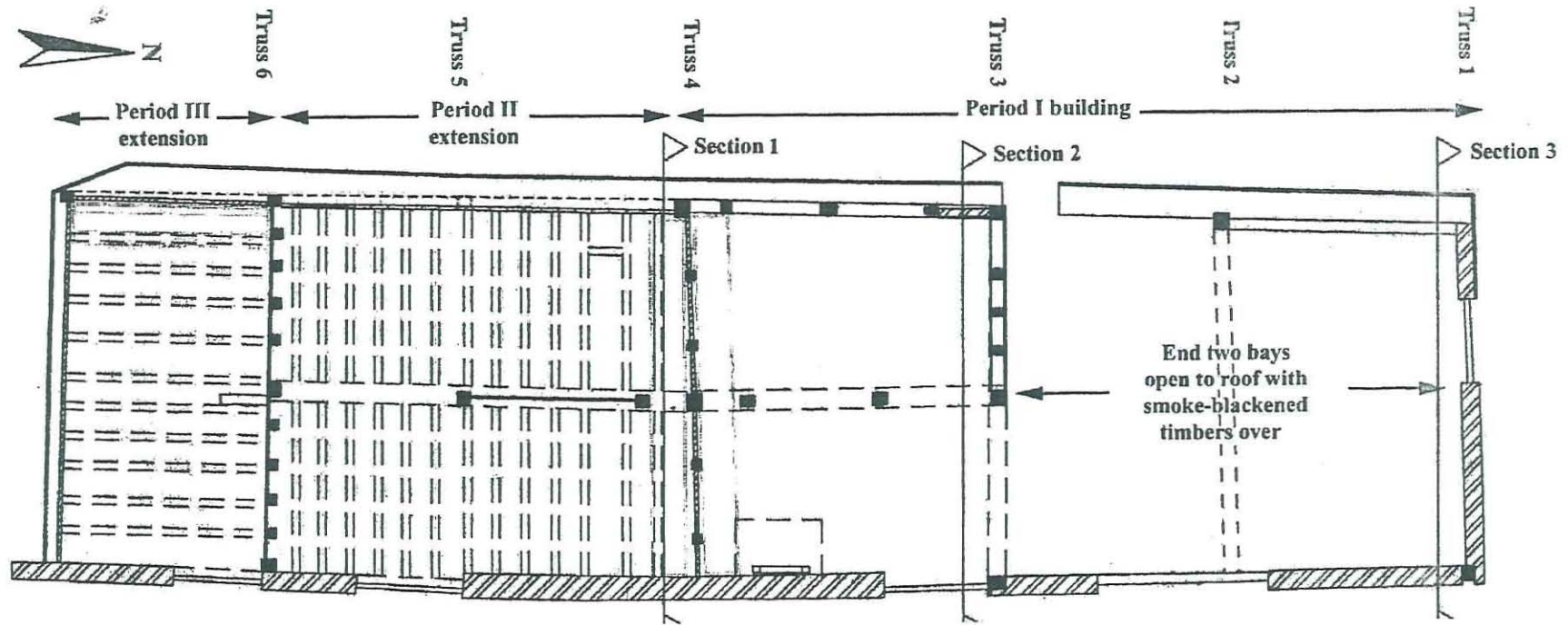


Figure 3a: Drawing of truss 3 to show timbers sampled
(viewed from the south)

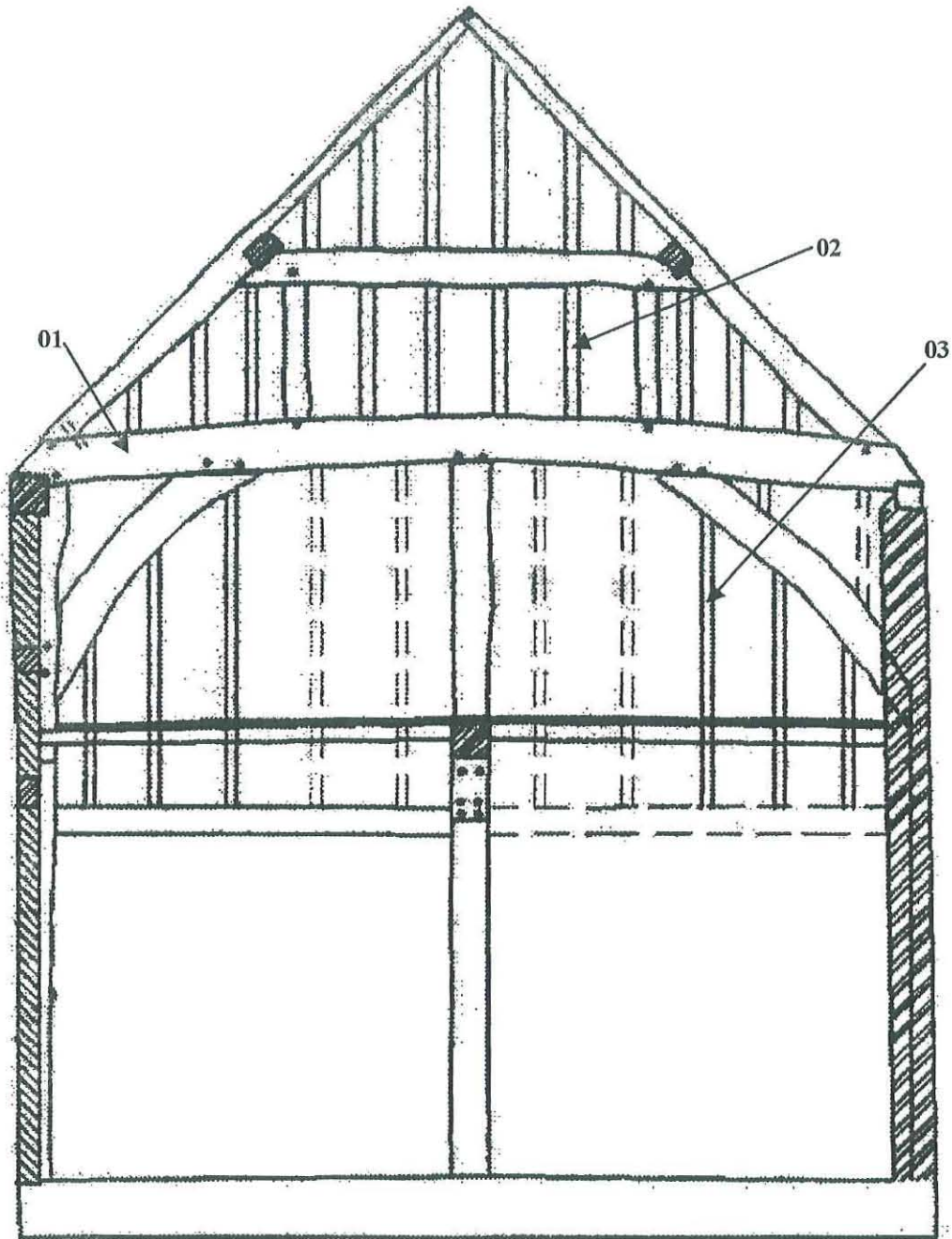


Figure 3b: Drawing of truss 4 to show timbers sampled
(viewed from the south)

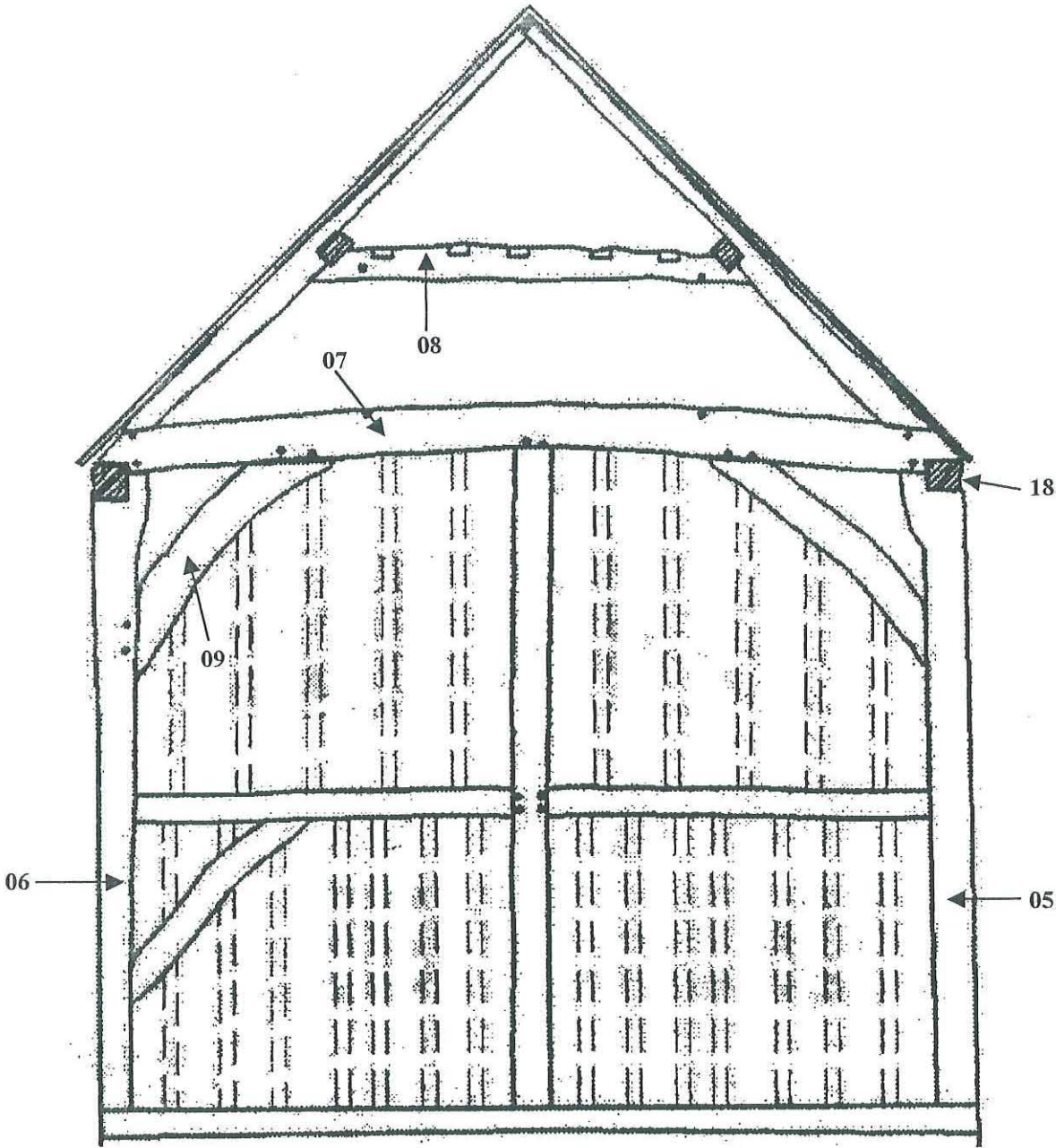


Figure 3c: Drawing of bay 3 to show timber sampled
(viewed from the east)

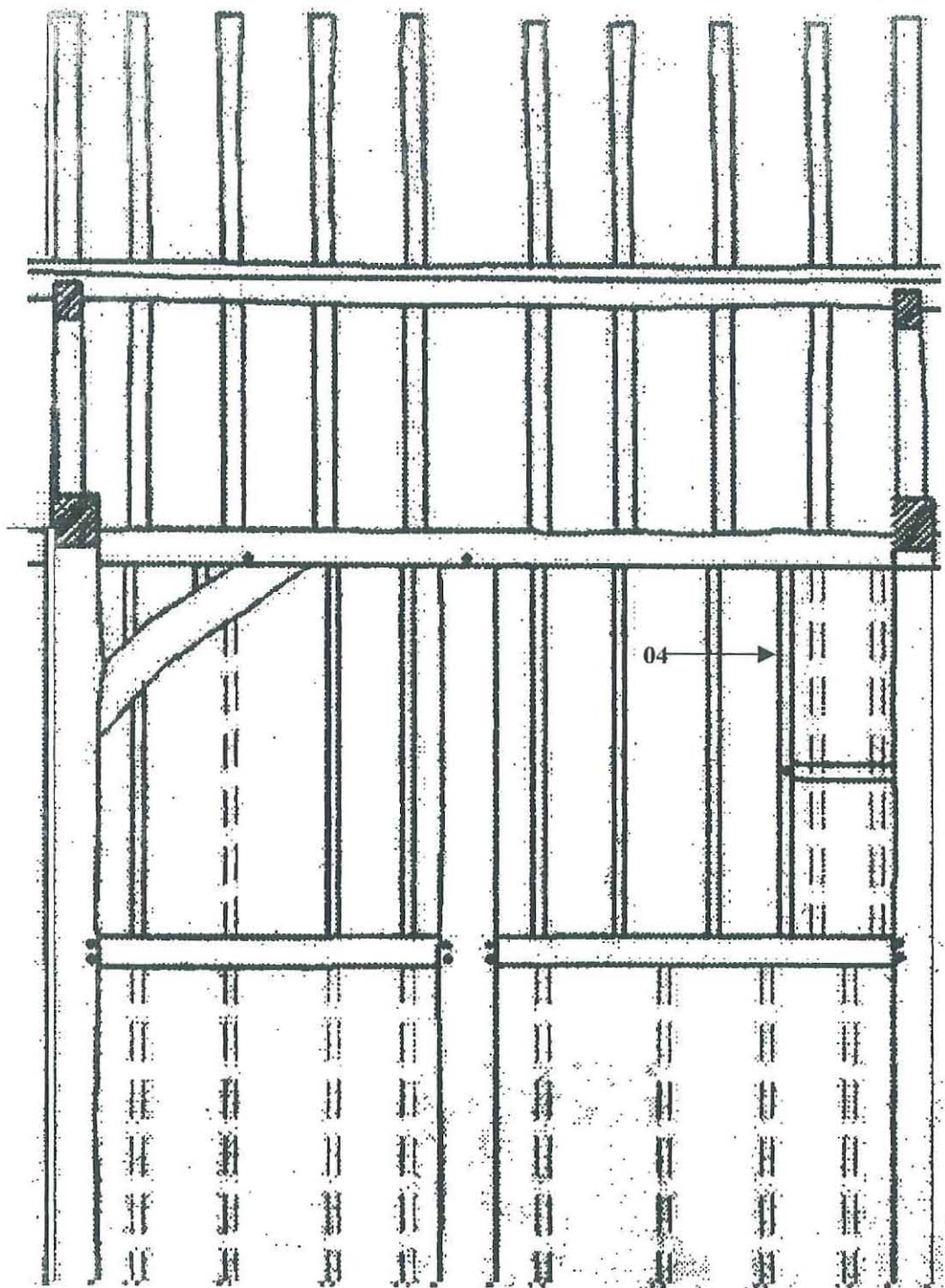


Figure 3d: Plan to show timbers sampled

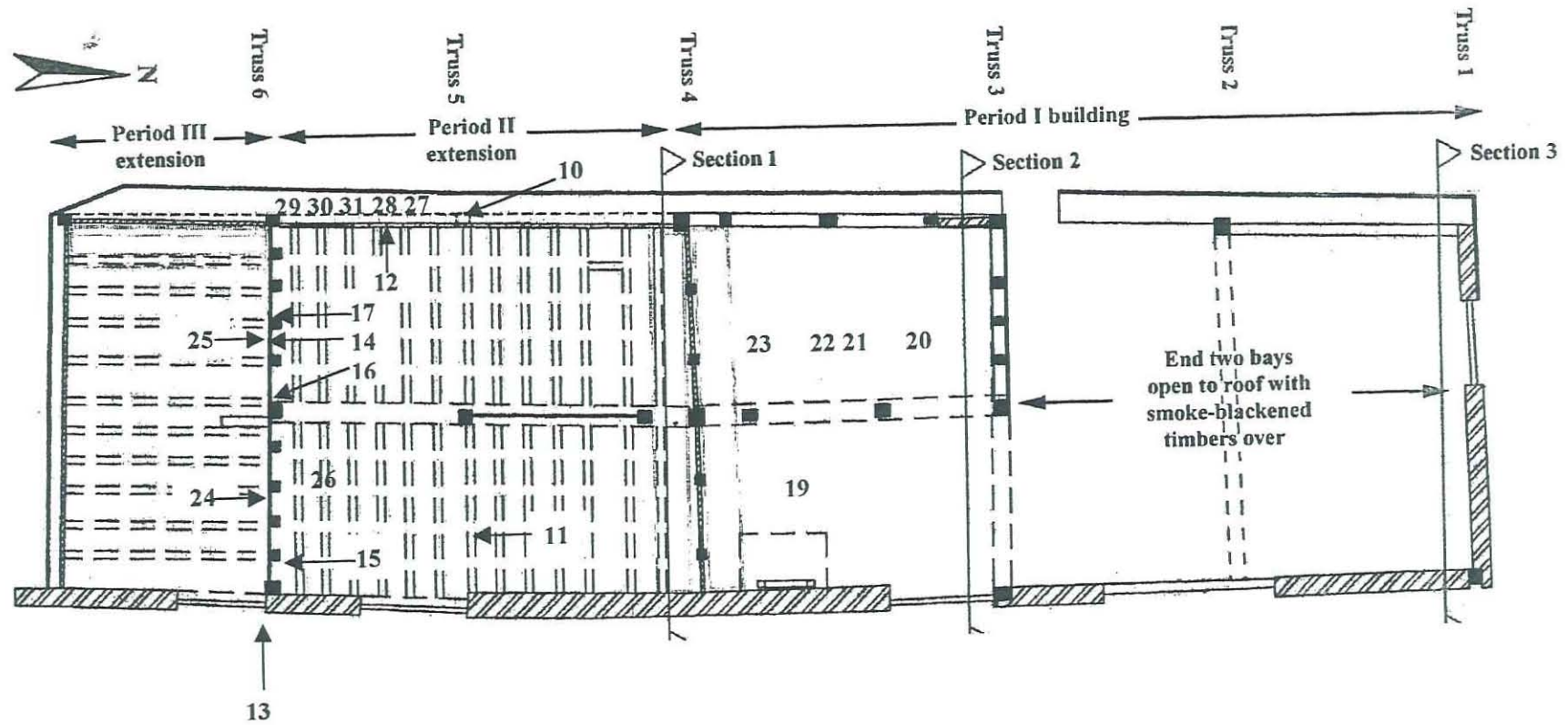


Figure 3e: Drawing of truss 1 to show timbers sampled
(viewed from the south)

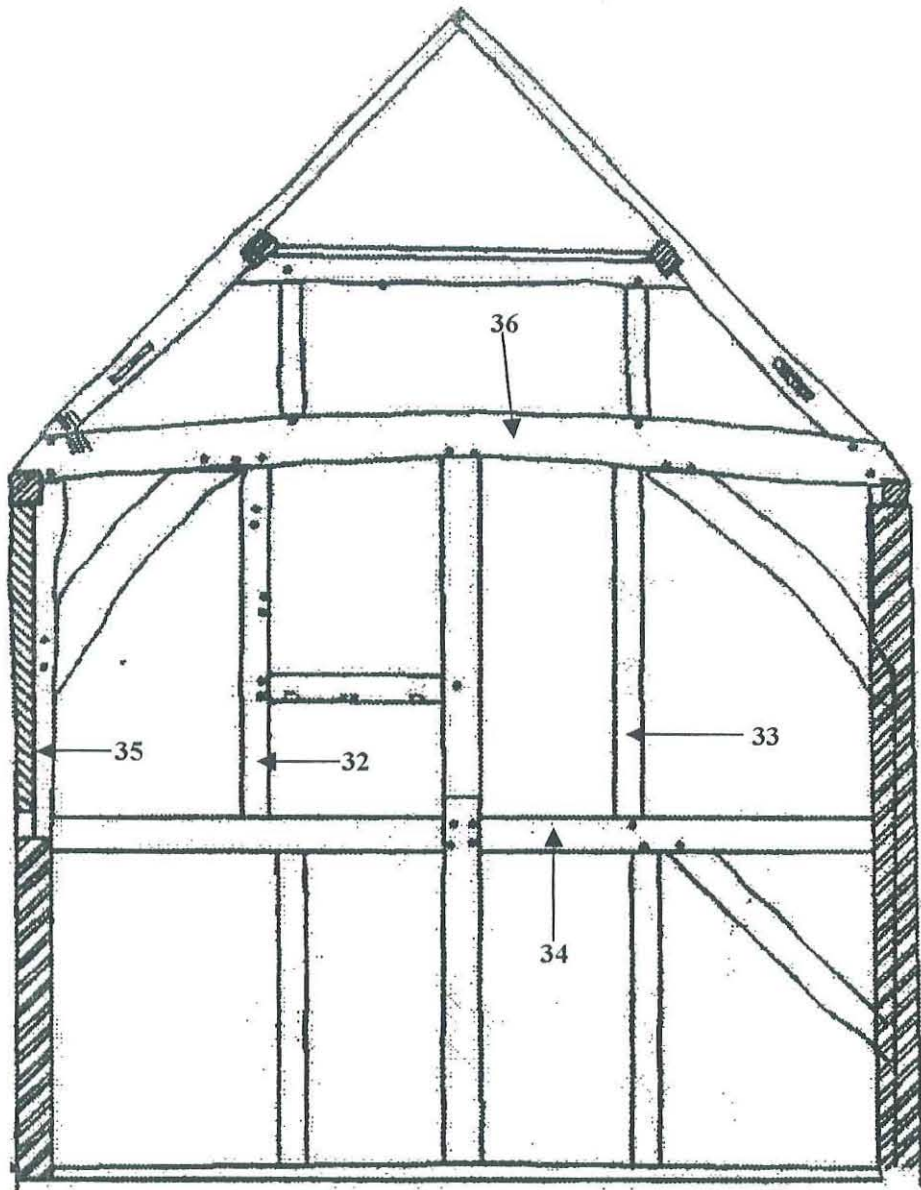


Figure 4: Bar diagram of the samples in site chronology WDRASQ01

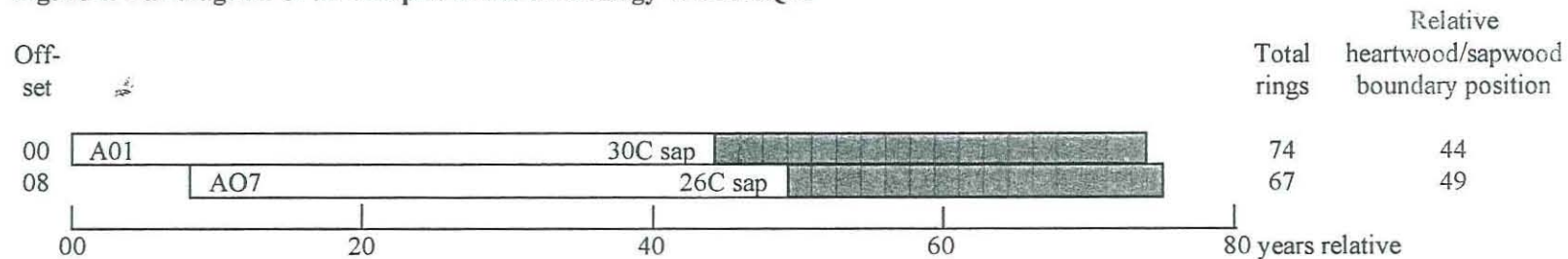
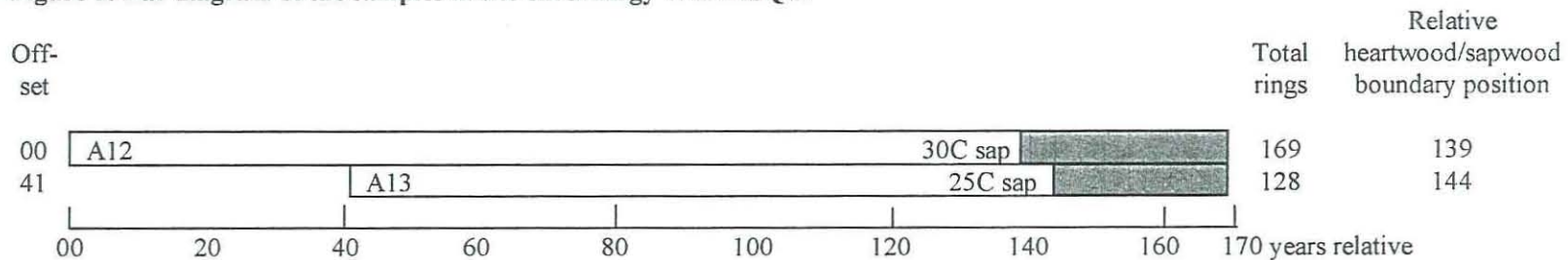
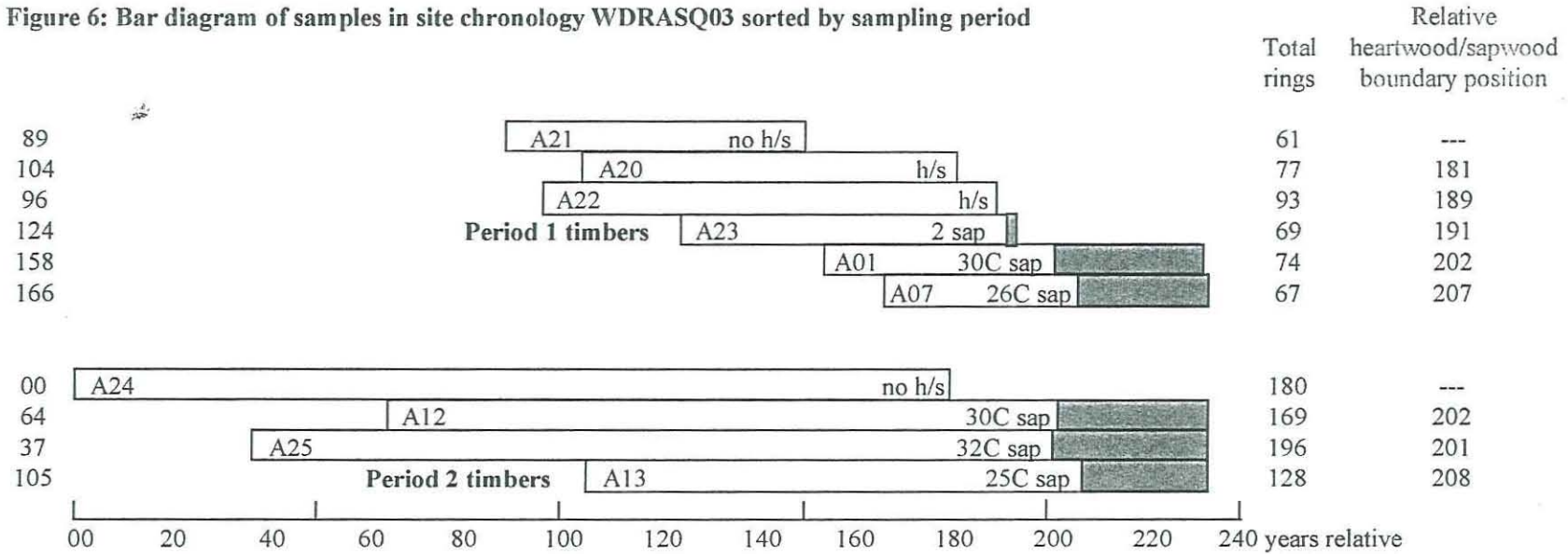


Figure 5: Bar diagram of the samples in site chronology WDRASQ02



white bars = heartwood rings, shaded area = sapwood rings
 h/s = heartwood/sapwood boundary is last ring on sample
 C = complete sapwood retained on sample

Figure 6: Bar diagram of samples in site chronology WDRASQ03 sorted by sampling period



white bars = heartwood rings, shaded area = sapwood rings
 h/s = heartwood/sapwood boundary is last ring on sample
 C = complete sapwood retained on sample

Data of measured samples – data in 0.01mm units

WDR-A01A 74

178 250 334 396 311 315 458 468 352 458 581 521 395 217 171 161 214 244 352 374
302 363 220 93 73 78 120 160 135 152 176 199 162 179 294 227 296 249 205 104
53 49 64 69 98 89 101 110 121 112 108 125 120 160 153 75 85 120 67 77
87 97 128 103 124 109 150 83 77 57 85 64 89 130

WDR-A01B 74

184 239 339 365 321 313 459 463 354 460 558 519 384 222 163 170 209 249 321 375
312 356 198 94 66 80 133 170 140 151 187 197 155 170 289 234 289 248 199 114
56 41 54 83 98 95 87 119 113 125 86 127 110 155 143 161 81 78 65 75
90 90 100 115 126 104 151 75 73 54 72 78 84 126

WDR-A02A 76

256 337 274 150 182 266 240 174 224 315 233 206 224 162 207 244 221 184 324 361
305 310 233 257 240 281 64 75 88 132 112 108 138 212 169 153 145 201 260 229
285 189 251 304 214 246 230 213 243 249 206 236 103 46 52 34 38 50 69 90
87 89 100 75 38 39 43 46 65 76 86 106 138 157 67 67

WDR-A02B 76

227 329 287 143 166 264 264 163 245 325 269 200 211 176 200 226 210 175 303 364
290 334 226 254 244 261 59 68 98 123 134 94 140 197 170 144 137 199 256 247
277 188 260 294 202 247 225 207 247 243 196 241 102 41 32 58 53 49 54 87
84 96 110 73 44 38 43 42 67 78 80 99 109 113 166 103

WDR-A03A 97

260 449 328 176 164 252 256 286 267 260 150 152 151 150 151 144 158 157 186 246
243 295 217 189 275 256 191 137 124 172 233 197 82 58 79 68 130 141 104 80
92 115 155 223 170 203 93 70 93 146 197 208 163 177 215 186 78 64 62 90
71 116 115 144 162 131 177 195 136 151 76 96 90 114 156 164 162 150 141 195
157 217 188 157 157 95 55 93 54 61 88 60 63 89 91 105 131

WDR-A03B 97

194 458 295 193 176 241 249 284 268 247 158 141 148 159 148 147 157 143 191 227
243 293 212 191 270 259 191 127 118 176 233 190 88 66 82 67 123 148 99 87
88 123 156 211 173 199 86 79 96 126 198 191 167 180 218 174 92 75 49 87
74 110 119 145 167 130 170 192 135 159 87 92 86 113 154 166 151 174 116 201
165 193 156 182 157 96 49 91 60 60 81 70 77 76 88 98 143

WDR-A04A 60

458 336 317 237 233 305 309 276 161 183 188 120 166 176 124 129 161 115 96 136
121 153 111 85 98 77 91 84 110 99 126 72 60 108 95 128 100 84 135 116
85 175 174 144 133 117 80 104 53 63 86 75 76 106 121 69 102 85 53 108

WDR-A04B 60

479 324 328 212 231 295 292 279 172 179 189 129 175 165 120 127 149 110 93 132
123 143 113 78 90 80 84 88 110 106 122 68 60 103 94 131 103 97 118 123
121 168 189 139 142 121 79 83 57 53 74 74 63 100 97 70 89 90 82 86

WDR-A05A 66

21 59 61 72 137 184 255 314 414 229 175 172 168 138 213 168 154 173 149 173
188 186 138 189 233 270 148 181 125 138 94 86 84 97 83 96 146 132 109 105
105 118 99 113 105 96 86 131 124 111 93 104 103 100 100 110 100 88 107 87
109 77 105 94 81 93

WDR-A05B 66

37 66 97 84 124 173 267 306 322 165 167 179 164 145 213 170 148 171 152 186
182 178 139 185 245 281 157 184 114 140 94 77 88 100 79 105 132 145 93 108
113 108 109 114 105 99 88 124 110 111 78 94 101 98 101 104 117 75 107 94
100 88 96 88 84 102

WDR-A06A 55

358 323 377 318 444 247 226 232 176 158 164 164 216 172 224 277 444 338 207 321
236 260 278 246 195 191 215 192 184 148 155 112 135 124 125 140 101 140 135 129
126 141 117 106 154 114 113 155 92 97 77 68 84 81 108

WDR-A06B 55

315 322 353 283 455 234 251 171 160 149 141 156 220 183 214 254 413 292 234 325
265 280 283 241 229 187 234 180 161 142 139 120 139 115 123 151 100 127 135 112
128 151 126 99 164 101 107 74 123 84 81 73 81 108 104

WDR-A07A 67

295 248 432 312 291 297 262 303 240 302 293 300 289 260 173 76 71 81 130 208
162 153 182 185 213 203 213 221 255 237 128 99 77 77 89 120 152 126 120 142
132 172 180 238 169 170 88 109 79 72 74 97 91 99 107 142 116 150 128 137
114 67 63 92 97 107 139

WDR-A07B 67

298 263 415 301 294 310 257 277 215 297 296 267 303 266 192 90 63 78 128 198
148 159 151 184 201 195 205 205 254 255 111 90 60 81 101 138 160 136 136 166
148 161 216 210 182 156 102 129 73 65 62 84 90 94 97 142 130 144 128 150
100 69 69 105 83 116 146

WDR-A08A 46

302 462 298 233 266 224 198 253 255 283 256 224 193 164 232 213 218 116 134 159
91 76 229 272 212 196 180 141 161 114 129 146 150 183 195 253 178 178 138 157
222 141 168 106 125 179

WDR-A08B 46

306 467 286 202 274 216 213 235 248 283 257 238 194 191 198 191 206 135 124 174
92 110 216 266 202 190 201 131 158 116 132 140 160 165 179 257 183 168 136 135
227 132 103 235 133 205

WDR-A09A 54

77 72 101 131 55 96 119 234 162 191 149 162 204 245 349 210 201 183 222 345
279 272 220 220 253 334 396 274 347 364 315 399 558 433 480 402 282 330 284 174
278 305 361 414 473 340 313 438 403 479 541 389 354 227

WDR-A09B 54

54 60 104 130 51 94 118 251 180 214 155 176 198 233 282 240 198 178 233 370
278 301 211 229 246 334 392 281 331 367 329 402 537 474 476 417 273 328 296 160
279 306 349 416 472 369 320 431 394 503 539 403 368 222

WDR-A10A 39

626 631 704 646 382 600 554 713 277 632 425 666 597 804 470 713 613 498 151 167
140 198 151 159 228 235 106 85 45 46 45 115 124 252 163 166 194 201 160

WDR-A10B 39

658 633 763 584 414 586 547 708 274 623 436 616 614 786 490 715 626 484 157 174
128 156 145 185 251 196 106 48 44 48 47 110 135 235 159 196 201 178 161

WDR-A11A 57

115 121 134 127 97 55 123 214 116 95 230 171 127 116 109 155 179 97 60 84
49 50 36 62 63 81 73 103 181 156 124 120 201 361 235 184 218 167 138 139
97 153 139 173 152 158 96 130 243 208 392 258 256 161 143 127 162

132 127 137 130 84 70 117 223 110 104 273 109 123 119 123 102 84 32 34
47 46 40 59 68 84 72 104 179 155 128 113 186 333 215 208 235 181 123 156
106 151 161 183 157 167 99 154 243 212 366 267 257 183 120 185 156

WDR-A12A 169

63 53 62 62 68 59 57 90 73 78 80 67 85 95 67 67 45 75 62 68
64 50 42 45 73 63 75 51 74 76 86 118 102 136 87 112 99 114 146 129
156 111 99 119 99 132 187 150 88 111 122 119 112 84 110 142 111 120 100 119
122 122 139 114 126 146 112 136 165 133 150 160 158 157 106 143 161 64 35 40
44 55 57 80 92 93 91 80 91 71 96 103 90 74 86 98 84 75 66 65
70 87 70 85 89 79 59 119 103 103 125 145 107 149 102 170 73 49 28 34
68 52 63 98 107 74 102 112 123 103 89 91 81 71 53 83 46 56 64 66
76 117 93 104 109 72 62 45 42 79 59 72 98 71 70 91 89 91 45 59
81 73 60 76 69 75 68 62 92

WDR-A12B 169

81 58 57 67 68 53 59 85 67 81 71 78 84 81 70 64 57 69 75 67
65 49 45 45 77 60 68 56 75 86 83 123 103 134 75 117 94 129 159 132
150 117 101 120 99 137 185 160 88 113 122 119 118 85 105 148 106 122 114 115
119 125 149 113 120 135 112 140 159 154 160 161 151 157 105 144 163 68 35 40
49 67 58 89 81 86 93 76 91 74 97 94 80 79 81 95 89 70 59 72
55 93 70 83 94 76 73 128 99 94 112 139 109 151 104 173 70 44 30 34
55 67 99 107 74 111 101 123 103 93 82 83 88 51 52 46 66 57 68 65
68 120 94 105 97 90 73 41 60 55 63 70 94 67 80 86 105 86 33 58
87 77 60 72 69 74 76 70 99

WDR-A13A 128

86 114 112 120 138 166 145 115 128 135 130 142 109 124 136 115 151 148 167 178
147 155 150 156 153 116 151 147 127 192 155 194 175 138 150 185 107 75 47 64
56 63 79 85 107 111 89 87 81 117 126 103 78 101 97 100 102 73 79 90
111 78 101 99 109 77 106 111 124 119 163 126 141 107 172 84 41 30 42 69
40 83 106 85 77 94 131 91 100 91 86 87 43 37 59 61 82 74 73 65
75 115 107 121 78 87 79 59 56 66 50 63 62 54 58 70 70 49 59 65
70 54 67 53 60 60 67 83

WDR-A13B 128

72 102 113 107 150 163 145 119 131 122 140 138 107 124 136 110 160 142 172 176
166 158 150 144 153 131 149 150 120 184 141 184 176 136 152 187 105 68 54 57
54 48 73 93 116 115 100 84 85 117 112 98 83 101 95 95 100 78 74 97
106 80 103 100 110 83 97 118 121 125 160 126 128 112 180 83 44 34 43 66
32 76 100 89 91 85 130 89 98 91 84 87 42 52 47 64 78 73 71 68
72 120 109 128 68 89 74 65 65 56 81 61 50 55 67 63 48 65 33 49
65 48 66 55 61 61 62 78

WDR-A14A 69

283 180 342 158 115 96 92 66 94 101 117 281 384 266 131 322 365 275 351 306
263 208 126 139 239 334 310 297 383 212 169 196 273 287 189 237 305 241 216 208
150 144 145 164 207 281 301 314 232 232 272 332 229 178 139 122 129 154 237 178
144 104 63 86 45 87 112 192 244

WDR-A14B 69

293 176 348 171 114 83 104 64 98 96 124 285 394 274 127 307 370 279 386 298
241 204 124 156 234 345 301 296 373 217 163 198 272 302 207 234 303 233 220 211
91 48 139 160 163 216 288 290 324 232 252 285 351 235 182 129 136 173 160 205
173 157 180 62 88 121 80 182 256

WDR-A21B 61

226 346 247 193 266 371 376 412 302 299 379 376 259 215 203 350 303 199 358 241
282 248 137 94 110 158 203 120 254 169 270 341 224 272 307 352 352 272 248 128
57 52 85 138 134 151 151 151 104 159 246 260 96 54 68 116 100 138 109 134
158

WDR-A22A 93

215 350 280 352 446 280 275 160 306 252 249 268 272 350 327 209 135 208 204 158
170 146 154 178 219 231 273 308 303 310 277 189 150 78 111 141 149 157 202 218
216 145 161 165 147 101 103 118 134 147 141 154 150 59 70 109 130 147 130 196
190 185 183 221 198 173 265 228 202 159 230 200 187 60 50 51 59 83 130 125
216 181 209 262 176 83 49 67 70 108 152 128 119

WDR-A22B 93

309 347 282 369 435 280 280 162 309 256 242 268 259 355 334 215 135 207 198 154
171 144 164 168 215 230 272 321 294 316 283 193 148 82 105 140 151 158 207 224
221 149 161 160 159 106 98 113 140 145 156 149 141 55 60 113 121 138 134 186
215 187 173 225 192 189 262 229 213 153 230 206 181 63 53 58 47 86 140 120
210 165 215 282 185 74 51 51 85 103 152 138 133

WDR-A23A 69

423 574 568 512 149 110 58 91 149 117 200 143 169 158 158 228 249 69 76 144
147 143 140 109 147 156 75 67 86 152 190 159 132 207 202 156 318 309 443 415
489 449 361 349 374 370 126 45 58 95 166 144 211 260 274 298 347 106 29 39
79 92 137 181 111 161 144 224 240

WDR-A23B 69

594 562 265 225 150 122 61 93 136 119 201 168 184 139 163 242 251 71 74 144
137 153 135 104 146 160 73 65 78 170 202 174 149 251 184 149 300 297 433 397
464 443 346 339 390 383 122 55 56 94 158 138 218 261 273 268 334 66 27 37
57 89 158 166 113 156 138 234 249

WDR-A24A 180

164 136 118 94 151 109 145 146 162 168 179 105 145 544 280 255 231 196 139 167
117 180 173 140 57 87 78 105 126 108 99 67 88 70 111 73 45 38 50 60
59 92 51 63 69 47 54 50 52 53 64 104 87 100 84 55 69 89 84 77
84 68 74 43 43 49 71 56 68 53 52 83 80 78 66 62 60 66 63 61
40 68 68 64 73 56 43 60 81 62 63 63 69 69 79 109 73 87 67 103
80 88 93 119 112 99 95 91 80 104 132 95 68 100 103 123 102 84 109 102
95 102 87 103 104 117 115 105 99 96 69 108 118 90 139 114 117 126 87 115
116 72 41 32 37 48 52 45 51 60 45 52 59 61 87 91 91 91 86 64
47 48 37 40 39 61 46 73 88 87 49 110 111 106 141 173 116 219 107 155

WDR-A24B 180

111 133 118 98 119 110 151 149 156 179 167 129 118 543 279 241 241 197 129 166
114 186 212 142 60 90 78 102 125 114 87 65 81 78 94 82 44 38 48 66
47 90 51 59 66 56 52 49 47 52 68 95 98 89 80 57 71 92 90 70
84 60 74 49 36 56 71 59 59 55 51 87 74 83 64 61 66 64 63 58
43 67 68 70 67 53 44 52 84 63 57 66 66 69 77 103 82 82 76 109
74 80 96 103 115 102 88 94 76 114 133 97 60 98 97 127 104 91 101 112
97 101 94 106 95 126 113 99 103 82 72 114 121 87 137 119 126 119 88 112
131 62 48 27 46 45 44 51 54 54 47 46 68 56 84 82 95 94 77 54
56 39 43 34 50 59 45 65 87 93 46 106 101 122 139 166 106 199 103 128

WDR-A25A 133

73 78 60 58 62 61 63 54 42 63 58 62 56 46 26 56 77 52 57 64
80 72 67 95 69 63 67 84 58 68 72 73 102 86 84 85 65 101 104 87
63 75 84 78 70 69 87 100 76 87 78 80 90 89 109 90 79 67 62 99

89 75 98 96 101 89 81 95 100 65 37 36 32 38 51 49 61 54 75 64
58 58 73 61 64 70 52 77 70 55 57 53 60 64 61 64 79 76 43 78
90 88 95 107 102 115 74 99 61 31 45 44 53 80 75 72 79 83 125 98
86 77 57 53 55 47 45 40 59 49 54 62 76

WDR-A25B 196

102 87 117 98 109 90 165 143 131 147 128 88 123 130 88 87 123 75 65 62
83 80 95 104 94 92 63 64 60 73 61 75 39 52 77 68 62 55 58 66
67 69 64 47 68 62 50 56 46 47 43 62 50 63 56 81 83 72 99 94
112 80 118 88 108 126 136 130 98 97 88 82 94 113 88 78 93 105 110 108
76 85 105 90 90 78 71 80 78 79 72 76 92 52 91 119 72 94 79 78
73 54 78 91 74 31 22 36 41 48 55 42 57 71 74 76 63 72 64 61
45 52 74 80 60 62 70 68 93 78 88 88 93 62 83 115 90 112 113 94
133 94 143 64 40 30 42 80 69 83 87 73 87 83 93 79 91 85 81 69
61 52 57 50 68 76 66 61 92 105 92 82 66 40 55 60 49 64 58 67
78 75 68 82 58 54 48 50 80 51 53 68 83 52 76 81

APPENDIX

Tree-Ring Dating

The Principles of Tree-Ring Dating

Tree-ring dating, or *dendrochronology* as it is known, is discussed in some detail in the Laboratory's Monograph, '*An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Buildings*' (Laxton and Litton 1988b) and, for example, in *Tree-Ring Dating and Archaeology* (Baillie 1982) or *A Slice Through Time* (Baillie 1995). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The *width* of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure 1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring.

If the bark is still on the sample, as in Figure 1, then the date of the last ring will be the date of felling of the oak from which it was cut. There is much evidence that in medieval times oaks cut down for building purposes were used almost immediately, usually within the year or so (Rackham 1976). Hence if bark is present on several main timbers in a building, none of which appear reused or are later insertions, and if they all have the same date for their last ring, then we can be quite confident that this is the date of construction. If there is no bark on the sample, then we have to make an estimate of the felling date; how this is done is explained below.

The Practice of Tree-Ring Dating at the University of Nottingham Tree-Ring dating Laboratory

1. *Inspecting the Building and Sampling the Timbers.* Together with a building historian we inspect the timbers in a building to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can sample *in situ* timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer rings than this, 50 for example, sequences of widths become difficult to match to a unique position within a master sequence of ring widths and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure 2 has about 120 rings; about 20 of which are sapwood rings. Similarly the core has just over 100 rings.

To ensure that we are getting the date of the building as a whole, or the whole of a phase of construction if there is more than one, about 8 to 10 samples per phase are usually taken. Sometimes we take many more, especially if the construction is complicated. One reason for taking so many samples is that, in general, some will fail to give a date. There may be many reasons why a particular sequence of ring widths from a sample of timber fails to give a date even though others from the same building do. For example, a particular tree may have grown in an odd ecological niche, so odd indeed that the widths of its rings were determined by factors other than the local climate! In such circumstances it will be impossible to date a timber from this tree using the master sequence whose widths, we can assume, were predominantly determined by the local climate at the time.

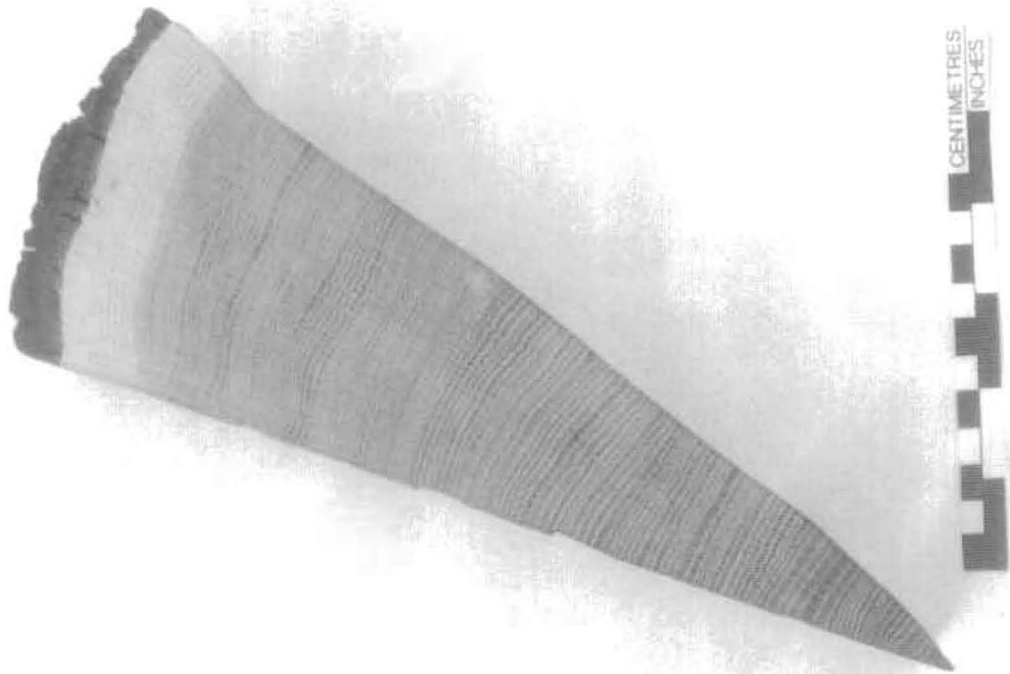


Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

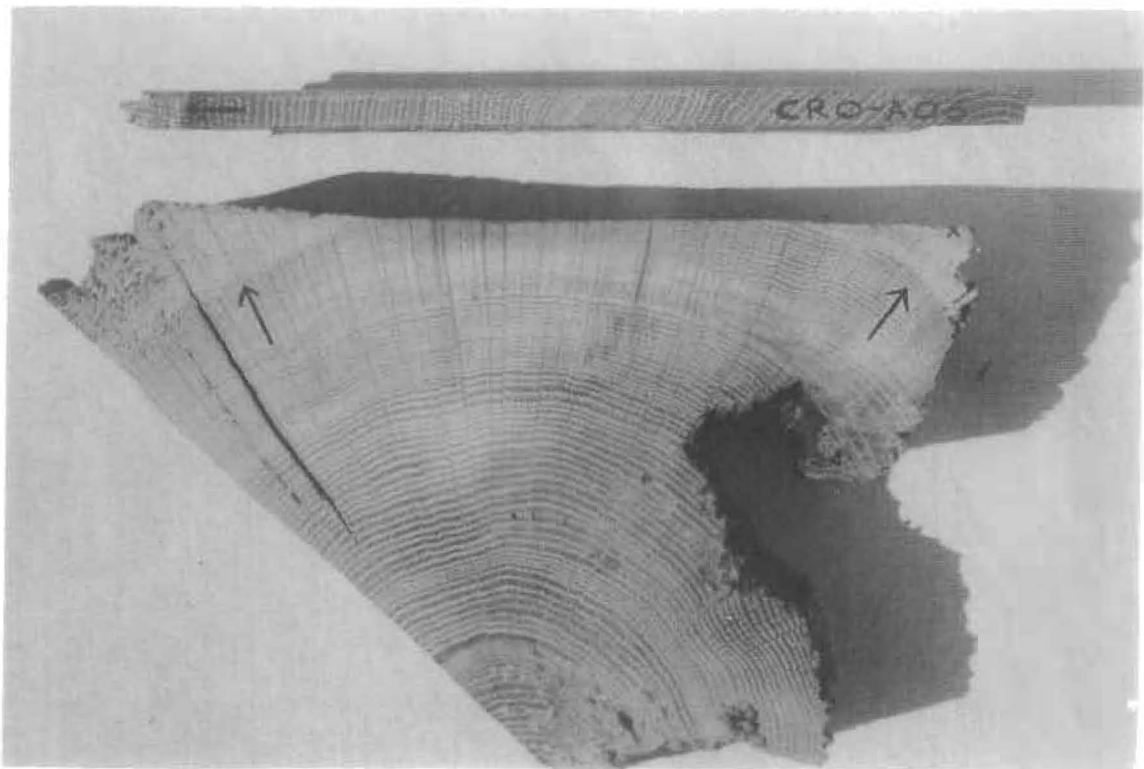


Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.



Fig 3. Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measured twice to ensure that an error has not been made. This type of apparatus is needed to process a large number of samples on a regular basis.

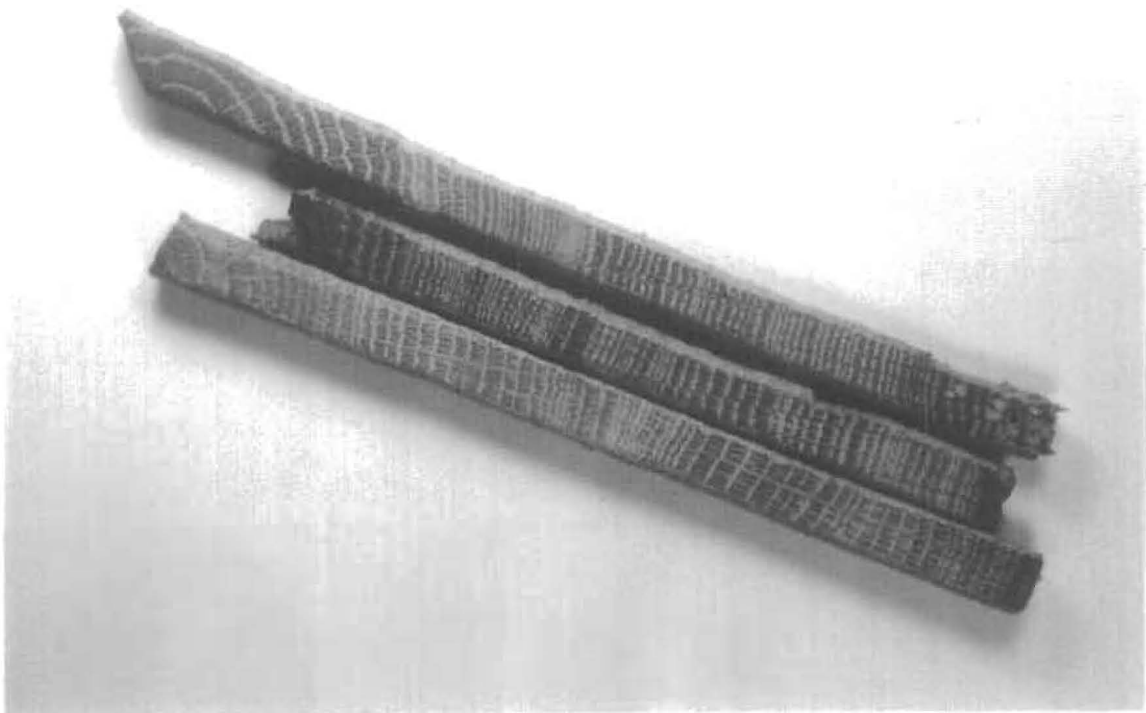


Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

Sampling is done by coring into the timber with a hollow corer attached to an electric drill and usually from its outer rings inwards towards where the centre of the tree, the pith, is judged to be. An illustration of a core is shown in Figure 2; it is about 15cm long and 1cm diameter. Great care has to be taken to ensure that as few as possible of the outer rings are lost. This can be difficult as these outer rings are often very soft (see below on sapwood). Each sample is given a code which identifies uniquely which timber it comes from, which building it is from and where the building is located. For example, CRO-A06 is the sixth core taken from the first building (A) sampled by the Laboratory in Cropwell Bishop. Where it came from in that building will be shown in the sampling records and drawings. No structural damage is done to any timbers by coring, nor does it weaken them.

During the initial inspection of the building and its timbers the dendrochronologist may come to the conclusion that, as far as can be judged, none of the timbers have sufficient rings in them for dating purposes and may advise against sampling to save further unwarranted expense.

All sampling by the Laboratory is undertaken according to current Health and Safety Standards. The Laboratory is insured with the CBA.

2. **Measuring Ring Widths.** Each core is sanded down with a belt sander using medium-grit paper and then finished by hand with flourgrade-grit paper. The rings are then clearly visible and differentiated from each other with a result very much like that shown in Figure 2. The core is then mounted on a movable table below a microscope and the ring-widths measured individually from the innermost ring to the outermost. The widths are automatically recorded in a computer file as they are measured (see Fig 3).
3. **Cross-matching and Dating the Samples.** Because of the factors besides the local climate which may determine the annual widths of a tree's rings, no two sequences of ring widths from different oaks growing at the same time are exactly alike (Fig 4). Indeed, the sequences may not be exactly alike even when the trees are growing near to each other. Consequently, in the Laboratory we do not attempt to match two sequences of ring widths by eye, or graphically, or by any other subjective method. Instead, it is done objectively (ie statistically) on a computer by a process called cross-matching. The output from the computer tells us the extent of correlation between two sample sequences of widths or, if we are dating, between a sample sequence of widths and the master, at each relative position of one to the other (offsets). The extent of the correlation at an offset is determined by the *t-value* (defined in almost any introductory book on statistics). That offset with the maximum *t-value* among the *t-values* at all the offsets will be the best candidate for dating one sequence relative to the other. If one of these is a master chronology, then this will date the other. Experiments carried out in the past with sequences from oaks of known date suggest that a *t-value* of at least 4.5, and preferably 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton *et al* 1988a,b; Howard *et al* 1984 - 1995).

This is illustrated in Fig 5 with timbers from one of the roofs of Lincoln Cathedral. Here four sequences of ring widths, LIN- C04, 05, 08, and 45, have been cross-matched with each other. The ring widths themselves have been omitted in the *bar-diagram*, as is usual, but the offsets at which they best cross-match each other are shown; eg. C08 matches C45 best when it is at a position starting 20 rings after the first ring of 45, and similarly for the others. The actual *t-values* between the four at these offsets of best correlations are in the matrix. Thus at the offset of +20 rings, the *t-value* between C45 and C08 is 5.6 and is the maximum between these two whatever the position of one sequence relative to the other.

It is standard practice in our Laboratory first to cross-match as many as possible of the sequences of the samples in a building and then to form an average from them. This average is called a site sequence of the building being dated and is illustrated in Fig 5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences from four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

This straightforward method of cross-matching several sample sequences with each other one at a time is called the 'maximal t-value' method. The actual method of cross-matching a group of sequences of ring-widths used in the Laboratory involves grouping and averaging the ring-width sequences and is called the 'Litton-Zainodin Grouping Procedure'. This was developed and tested in the Laboratory and has been published (Litton and Zainodin 1991; Laxton *et al* 1988a). To illustrate the difference between the two approaches with the above example, consider sequences C08 and C05. They are the most similar pair with a t-value of 10.4. Therefore, these two are first averaged with the first ring of C05 at +17 rings relative to C08 (the offset at which they match each other). This average sequence is then used in place of the individual sequences C08 and C05. The cross-matching continues in this way gradually building up averages at each stage eventually to form the site sequence.

4. ***Estimating the Felling Date.*** If the bark is present on a sample, then the date of its last ring is the date of the felling of its tree. Actually it could be the year after if it had been felled in the first three months before any new growth had started, but this is not too important a consideration in most cases. The actual bark may not be present on a timber in a building, though the dendrochronologist who is sampling can often see from its surface that only the bark is missing. In these cases the date of the last ring is still the date of felling.

Quite often some, though not all, of the original outer rings are missing on a timber. The outer rings on an oak, called sapwood rings, are usually lighter than the inner rings, the heartwood, and so are relatively easy to identify. For example, they can be seen in two upper corners of the rafter and at the outer end of the core in Figure 2. More importantly for dendrochronology, the sapwood is relatively soft and so liable to insect attack and wear and tear. The builder, therefore, may remove some of the sapwood for precisely for these reasons. Nevertheless, if at least some of the sapwood rings are left on a sample, we will know that not too many rings have been lost since felling. Thus in these circumstances the date of the present last ring is at least close to the date of the original last ring on the tree, and so to the date of felling.

Various estimates have been made for the average number of sapwood rings in a mature oak. One estimate is 30 rings, based on data from living oaks. So, in the case of the core in Figure 2 where 9 sapwood rings remain, this would give an estimate for the felling date of 21 ($= 30 - 9$) years later than of the date of the last ring on the core. Actually, it is better in these situations to give an estimated range for the felling date. Another estimate is that in 95% of mature oaks there are between 15 and 50 sapwood rings. So in this example this would mean that the felling took place between 6 ($= 15 - 9$) and 41 ($= 50 - 9$) years after the date of the last ring on the core and is expected to be right in at least 95% of the cases (Hughes *et al* 1981; see also Hillam *et al* 1987).

Data from the Laboratory has shown that when sequences are considered together in groups, rather than separately, the estimates for the number of sapwood can be put at between 15 and 40 rings in 95% of the cases with the expected number being 25 rings. We would use these estimates, for example, in calculating the range for the common felling date of the four sequences from Lincoln Cathedral using the average position of the heartwood/sapwood boundary (Fig 5). These new estimates are now used by us in all our publications except for timbers from Kent and Nottinghamshire where 25 and between 15 to 35 sapwood rings, respectively, is used instead (Pearson 1995).

More precise estimates of the felling date and range can often be obtained using knowledge of a particular case and information gathered at the time of sampling. For example, at the time of sampling the dendrochronologist may have noted that the timber from which the core of Figure 2 was taken still had complete sapwood. Sapwood rings were only lost in coring, because of their softness. By measuring in the timber the depth of sapwood lost, say 2 cm., a reasonable estimate can be made of the number of sapwood rings missing from the core, say 12 to 15 rings in this case. By adding on 12 to 15 years to the date of the last ring on the sample a good tight estimate for the range of the felling date can be obtained, which is often better than the 15 to 40 years later we would have estimated without this observation.

T-value/Offset Matrix

	C45	C08	C05	C04
C45		+20	+37	+47
C08	5.6		+17	+27
C05	5.2	10.4		+10
C04	5.9	3.7	5.1	

Bar Diagram

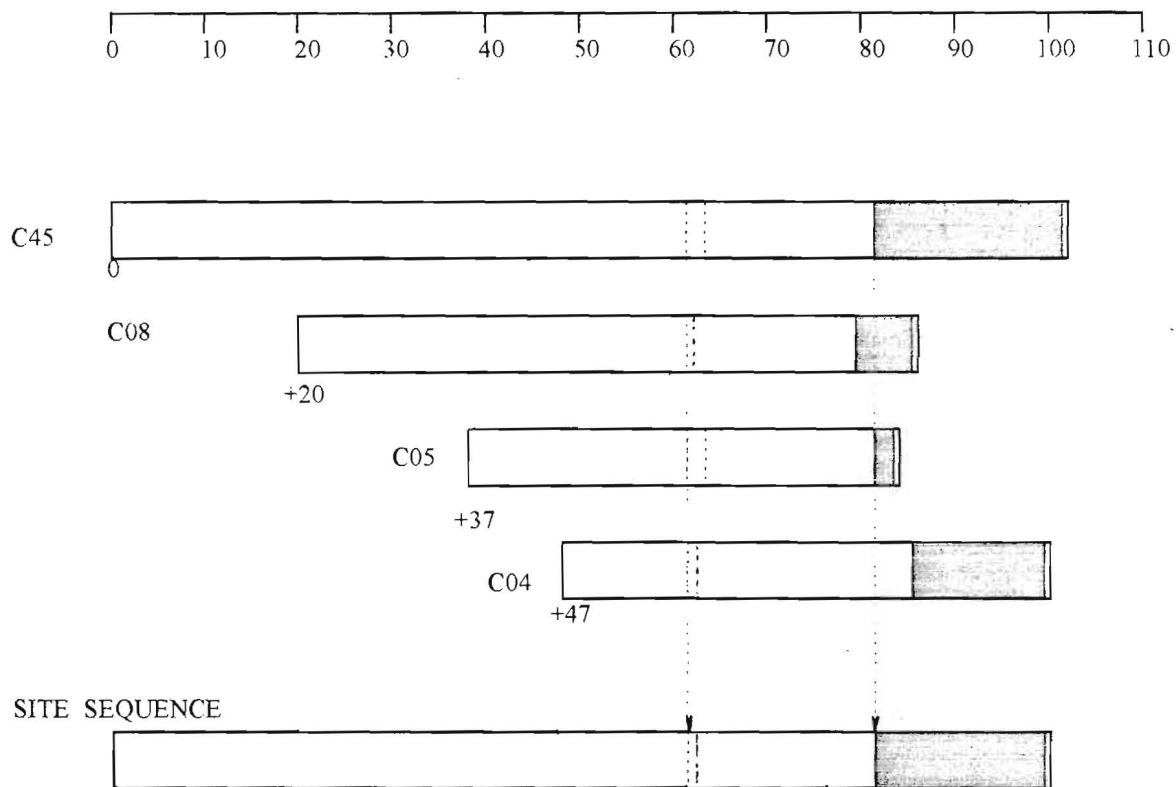


Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set at relative positions (*offsets*) to each other at which they have maximum correlation as measured by the *t-values*.

The *t-value offset* matrix contains the maximum t-values below the diagonal and the offsets above it.

Thus, the maximum t-value between C08 and C45 occurs at the offset of +20 rings and the t-value is then 5.6.

The *site sequence* is composed of the average of the corresponding widths, as illustrated with one width.

Even if all the sapwood rings are missing on all the timbers sampled, an estimate of the felling date is still possible in certain cases. For provided the original last heartwood ring of the tree, called the heartwood/sapwood boundary (H/S), is still on some of the samples, an estimate for the felling date of the group of trees can be obtained by adding on the full 25 years, or 15 to 40 for the range of felling dates.

If none of the timbers have their heartwood/sapwood boundaries, then only a *post quem* date for felling is possible.

5. **Estimating the Date of Construction.** There is a considerable body of evidence in the data collected by the Laboratory that the oak timbers used in vernacular buildings, at least, were used 'green' (see also Rackham (1976)). Hence provided the samples are taken *in situ*, and several dated with the same estimated common felling date, then this felling date will give an estimated date for the construction of the building, or for the phase of construction. If for some reason or other we are rather restricted in what samples we can take, then an estimated common felling date may not be such a precise estimate of the date of construction. More sampling may be needed for this.
6. **Master Chronological Sequences.** Ultimately, to date a sequence of ring widths, or a site sequence, we need a master sequence of dated ring widths with which to cross-match it, a Master Chronology. To construct such a sequence we have to start with a sequence of widths whose dates are known and this means beginning with a sequence from an oak tree whose date of felling is known. In Fig 6 such a sequence is SHE-T, which came from a tree in Sherwood Forest which was blown down in a recent gale. After this other sequences which cross-match with it are added and gradually the sequence is 'pushed back in time' as far as the age of samples will allow. This process is illustrated in Fig 6. We have a master chronological sequence of widths for Nottinghamshire and East Midlands oak for each year from AD 882 to 1981. It is described in great detail in Laxton and Litton 1988b, but the components it contains are shown here in the form of a bar diagram. As can be seen, it is well replicated in that for each year in this period there are several sample sequences having widths for that year. The master is the average of these. This master can now be used to date oak from this area and from the surrounding areas where the climate is very similar to that in the East Midlands. The Laboratory has also constructed a master for Kent (Laxton and Litton 1989). The method the Laboratory uses to construct a master sequence, such as the East Midlands and Kent, is completely objective and uses the Litton-Zainodin grouping procedure (Laxton *et al* 1988a). Other laboratories and individuals have constructed masters for other areas and have made them available. As well as these masters, local (dated) site chronologies can be used to date other buildings from nearby. The Laboratory has hundreds of these site sequences from many parts of England and Wales covering many short periods.
7. **Ring-width Indices.** Tree-ring dating can be done by cross-matching the ring widths themselves, as described above. However, it is advantageous to modify the widths first. Because different trees grow at different rates and because a young oak grows in a different way from an older oak, irrespective of the climate, the widths are first standardized before any matching between them is attempted. These standard widths are known as ring-width indices and were first used in dendrochronology by Baillie and Pilcher (1973). The exact form they take is explained in this paper and in the appendix of Laxton and Litton (1988b) and is illustrated in the graphs in Fig 7. Here ring-widths are plotted vertically, one for each year of growth. In the upper sequence (a), the generally large early growth after 1810 is very apparent as is the smaller generally later growth from about 1900 onwards. A similar difference can be observed in the lower sequence starting in 1835. In both the widths are also changing rapidly from year to year. The peaks are the wide rings and the troughs are the narrow rings, hopefully corresponding to good and poor growing seasons, respectively. The two corresponding sequences of Baillie-Pilcher indices are plotted in (b) where the differences in the early and late growths have been removed and only the rapidly changing peaks and troughs remain only associated with the common climatic signal and so make cross-matching easier.

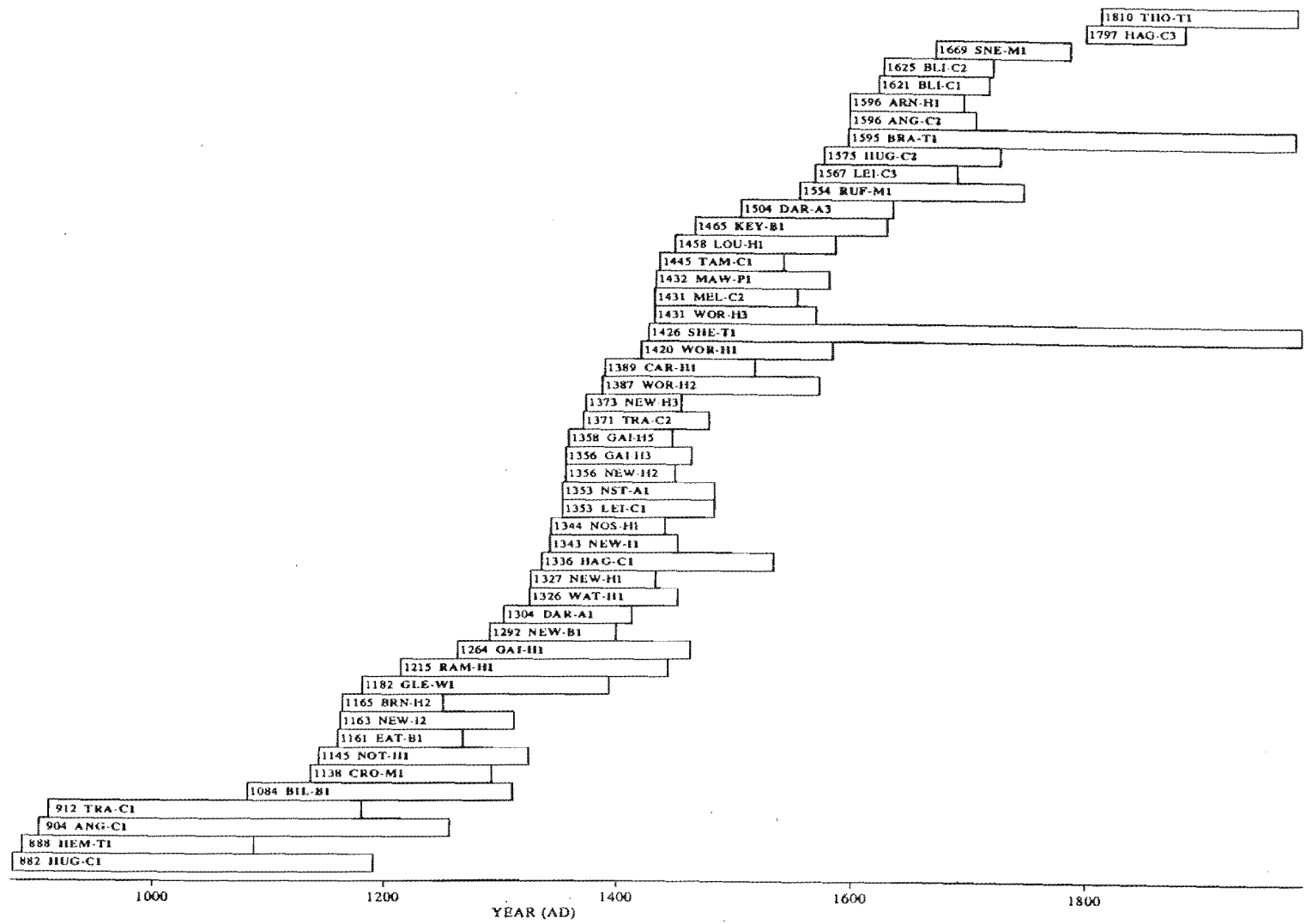


Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

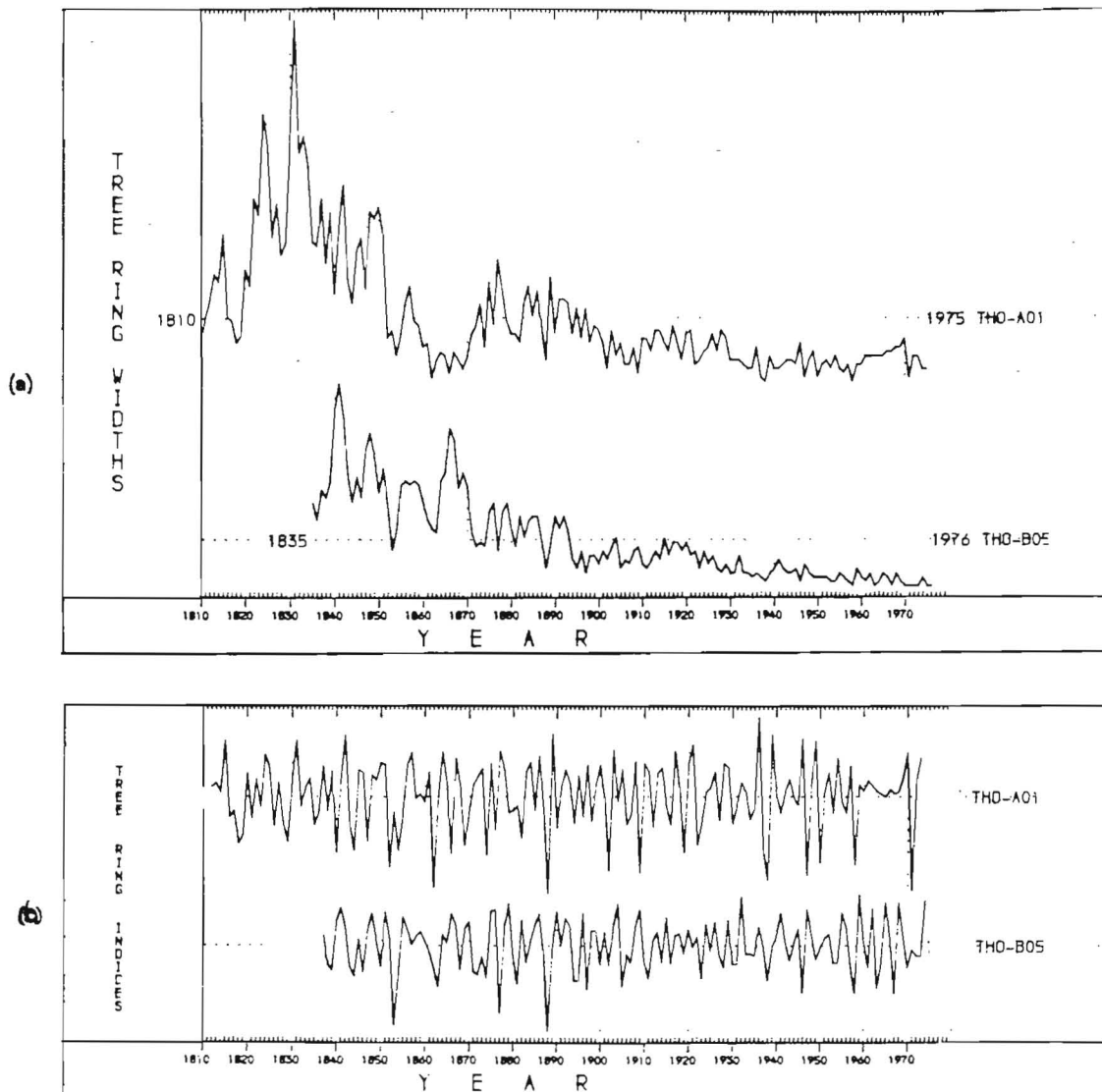


Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree are wider than the later ones of the older tree in both sequences.

(b) The *Baillie-Pitche indices* of the above widths. The growth-trends have been removed completely.

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