Centre for Archaeology Report 63/2003

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ISSN 1473-9224

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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, bay3	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	*t*-value	
JMF-100	AD 1467 - 1557	5.2	(Fletcher 1978 unpubl)
Pye Corner, Moulsford, Oxon	AD 1340 - 1558	4.3	(Alcock *et al* 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 *et al* 1994)
Southern England	AD 1083 - 1589	4.0	(Bridge 1988)
Manor Road, Didcot, Oxon	AD 1415 - 1509	3.8	(Alcock *et al* 1989)
High Street, Kinver, Staffs	AD 1431 - 1562	3.7	(Howard *et al* 1995)
Folly House, Steventon, Oxon	AD 1437 - 1542	3.6	(Alcock *et al* 1989)
Cobham, Kent	AD 1317 - 1662	3.6	(Howard *et al* 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	*t*-value	
East range, Ighthan Mote, Kent	AD 1393 - 1468	5.1	(Howard *et al* 1995)
Cottage range, Ightam Mote, Kent	AD 1392 - 1463	4.7	(Howard *et al* 1994)
Chilton Manor, Sittingbourne, Kent	AD 1368 - 1520	4.0	(Howard *et al* 1988)
Hagworthingham Church, Lincs	AD 1336 - 1533	3.8	(Laxton *et al* 1984)
Old Queens Head, Sheffield	AD 1370 - 1498	3.7	(Howard *et al* 1992)
Wicham, Hants	AD 1373 - 1503	3.7	(Esling *et al* 1990 unpubl)
Coat's Barn, Cosby, Leics	AD 1426 - 1562	3.7	(Alcock *et al* 1991)
New Chapel, Ightham Mote, Kent	AD 1394 - 1465	3.6	(Howard *et al* 1994)
Kent-88	AD 1158 - 1540	3.6	(Laxton and Litton 1989)
Lacock Abbey, Wilts	AD 1395 - 1546	3.5	(Esling *et al* 1990)
Cobham, Kent	AD 1317 - 1662	3.5	(Howard *et al* 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	*t*-value	
Bremhill Farm, Calne, Wilts	AD 1353 - 1484	4.8	(Alcock *et al* 1991)
Rectory Farm, Weston on Trent, Derbys	AD 1362 - 1503	4.5	(Howard *et al* 1996 unpubl)
Chicksands Priory, Beds	AD 1200 - 1541	4.1	(Howard *et al* 1998)
Lacock Abbey, Wilts	AD 1395 - 1546	4.0	(Esling *et al* 1990)
Eckington, Derbys	AD 1365 - 1480	3.9	(Howard *et al* 1992)
Church Cottage, Cadeby, Leics	AD 1362 - 1472	3.7	(Alcock *et al* 1991)
Kent-88	AD 1158 - 1540	3.7	(Laxton and Litton 1989)
Trentham's Barn, Purley, Berks	AD 1404 - 1512	3.6	(Howard *et al* 1996)
Restoration House, Rochester, Kent	AD 1378 - 1505	3.6	(Howard *et al* 1997)

Figure 1: Map to show specific location of Hubards Farm

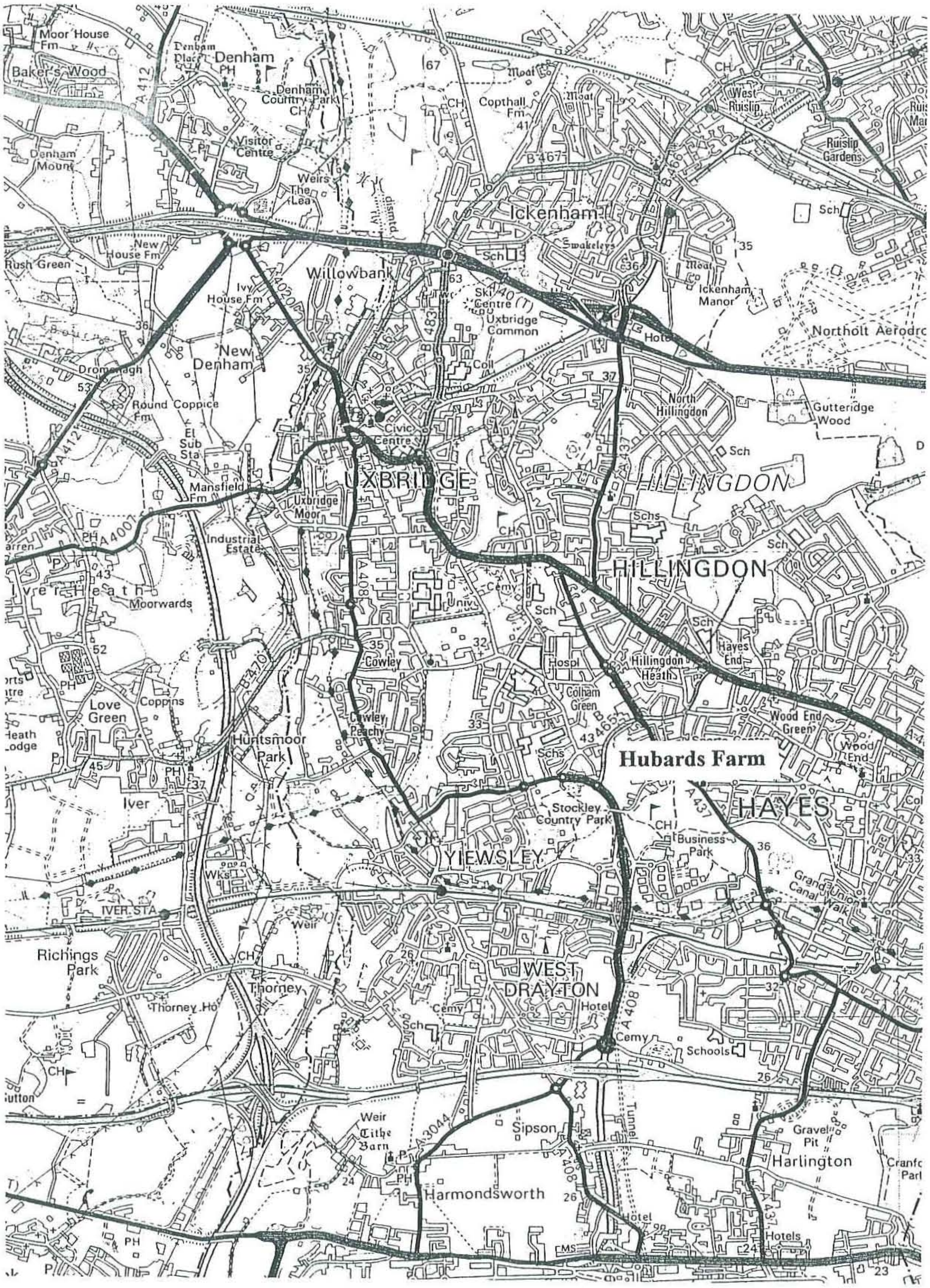


Figure 2: Plan at ground-floor level to show phases of construction

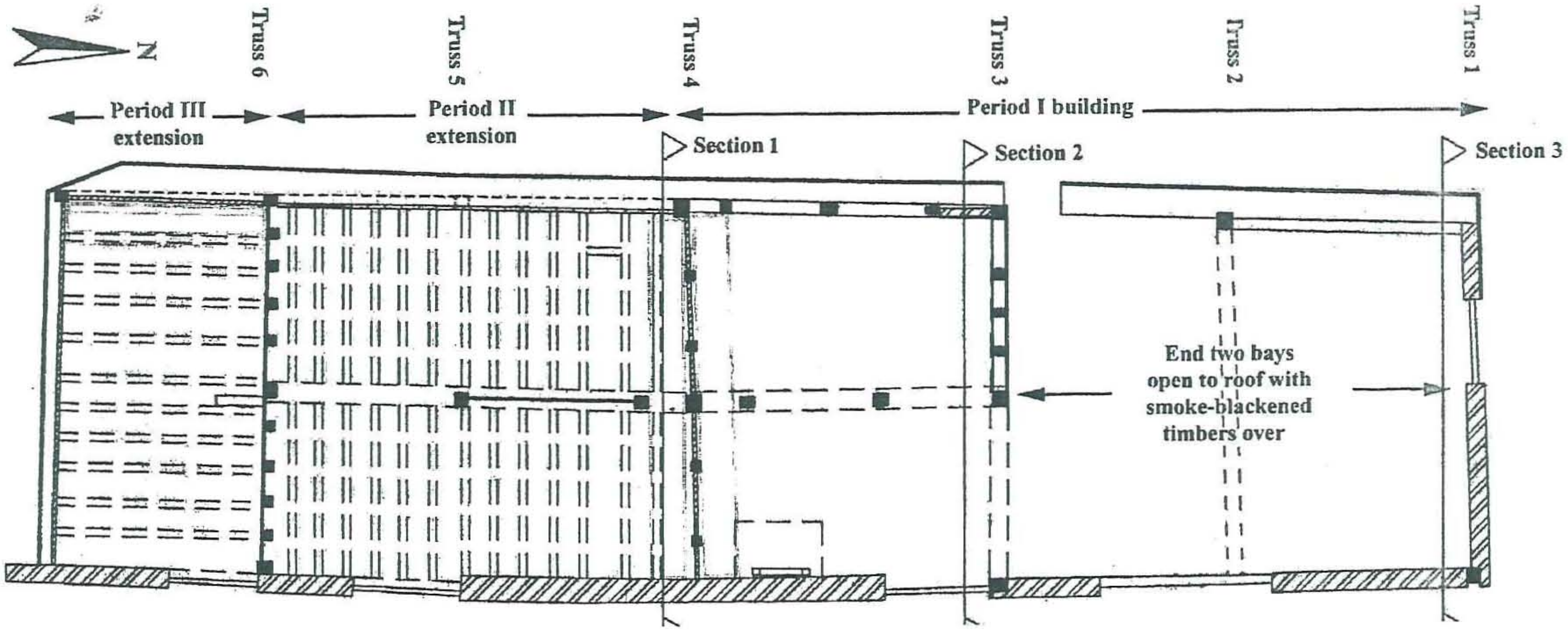


Figure 3a: Drawing of truss 3 to show timbers sampled (viewed from the south)

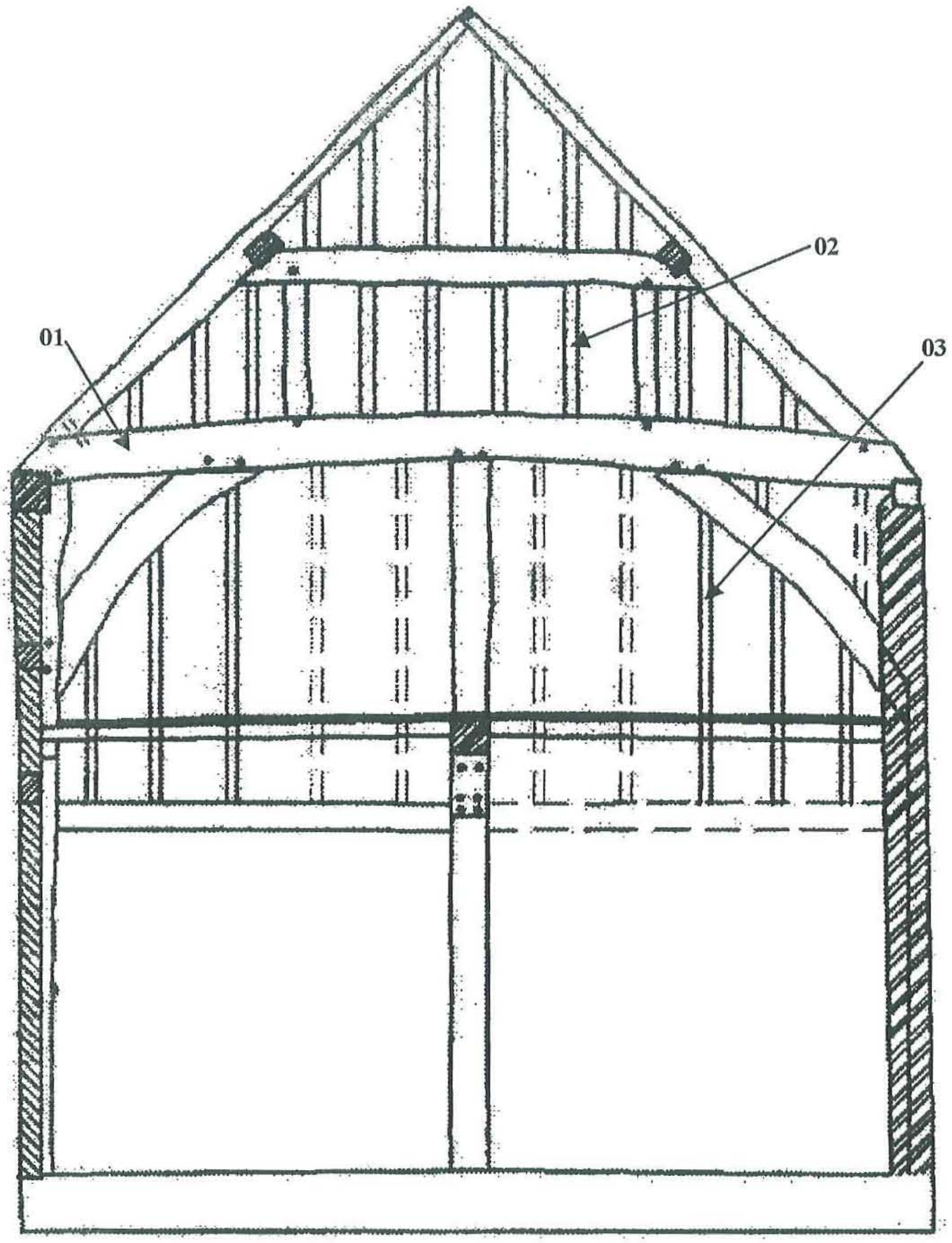


Figure 3b: Drawing of truss 4 to show timbers sampled (viewed from the south)

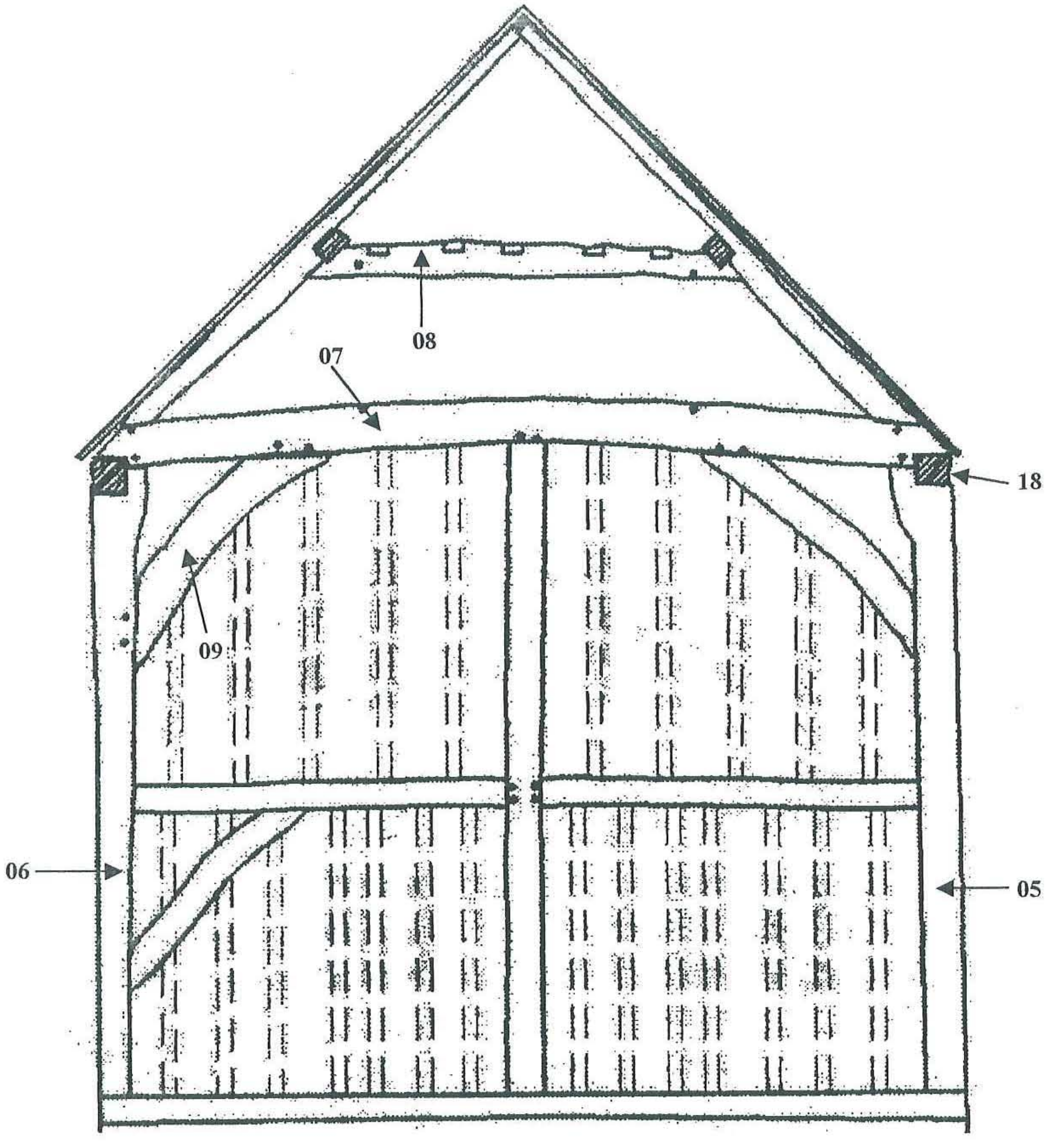


Figure 3c: Drawing of bay 3 to show timber sampled
(viewed from the east)

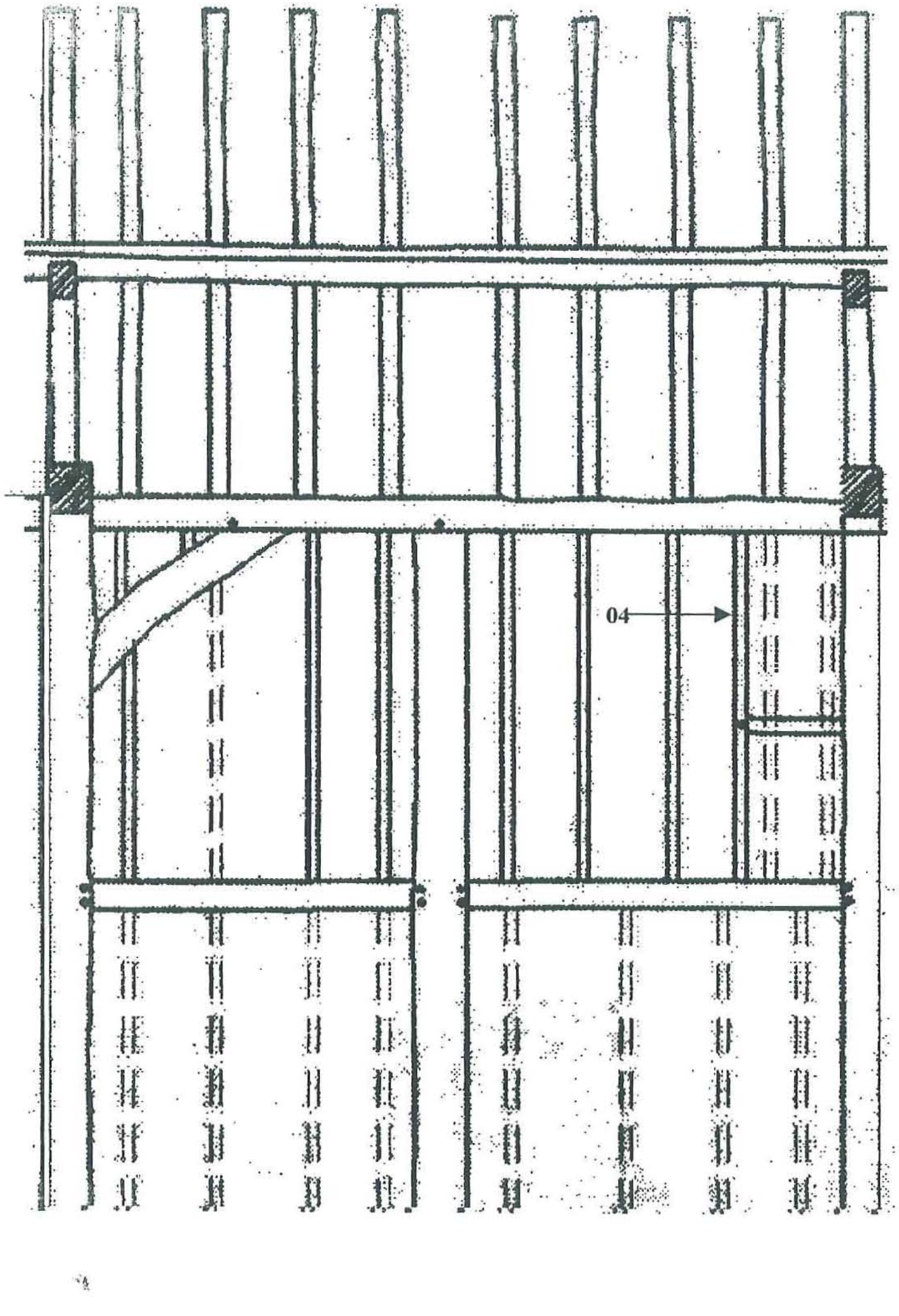


Figure 3d: Plan to show timbers sampled

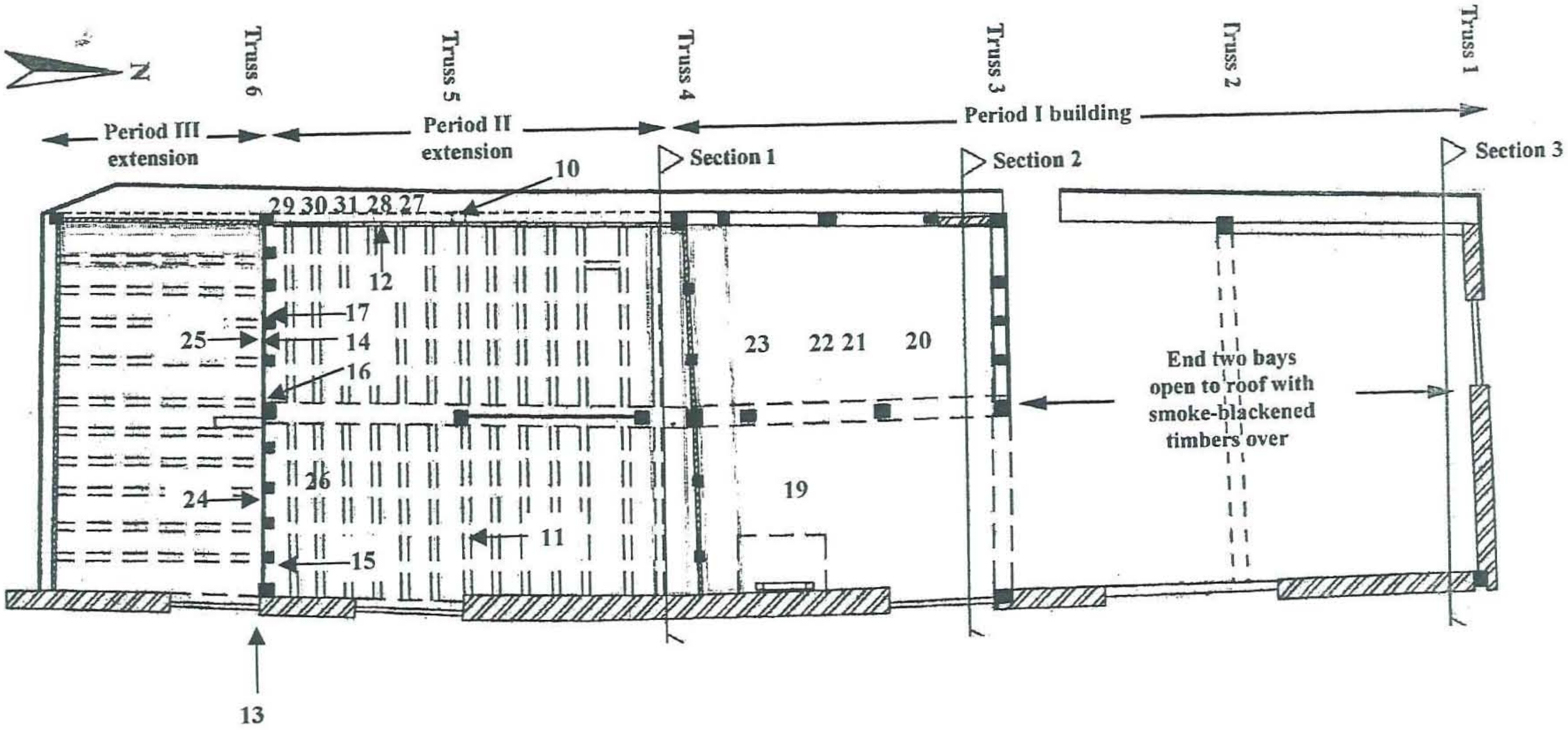


Figure 3e: Drawing of truss 1 to show timbers sampled
(viewed from the south)

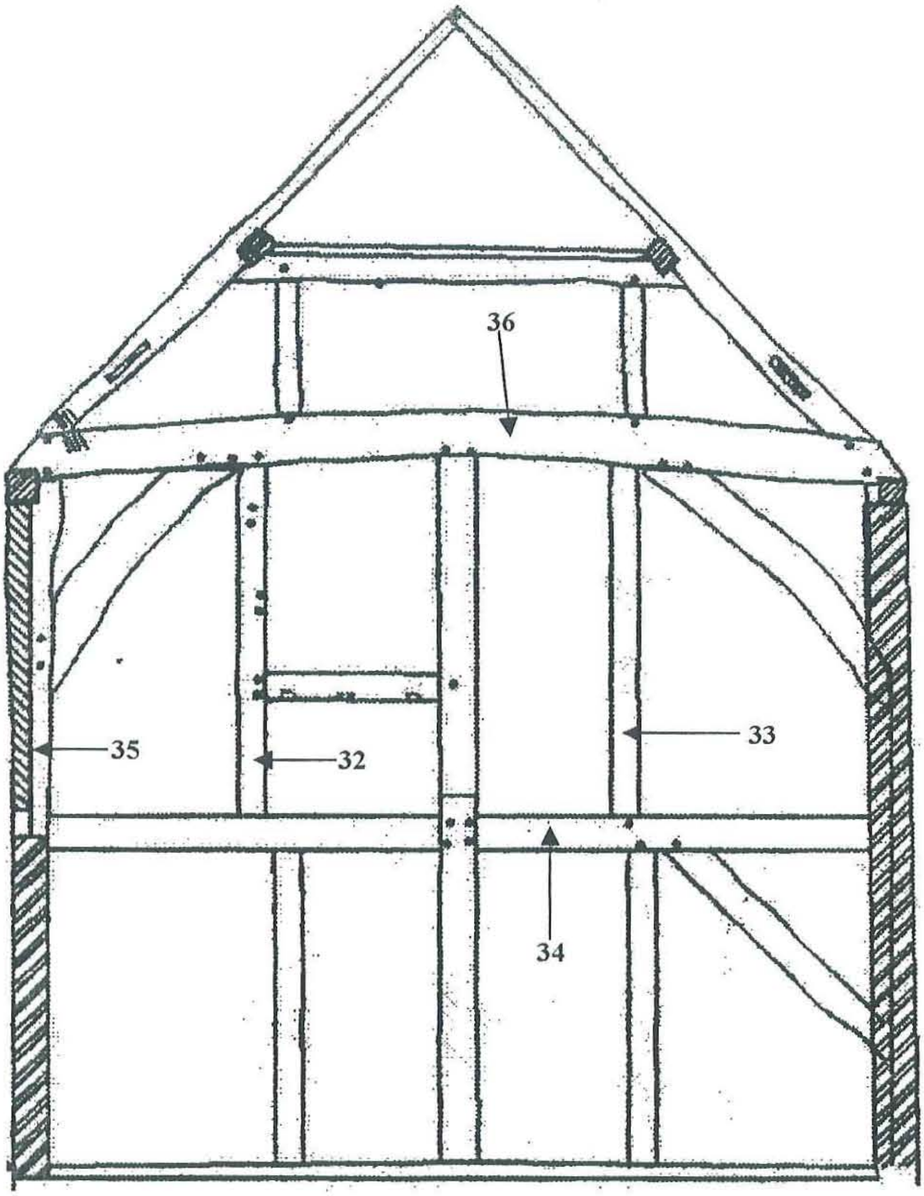


Figure 4: Bar diagram of the samples in site chronology WDRASQ01

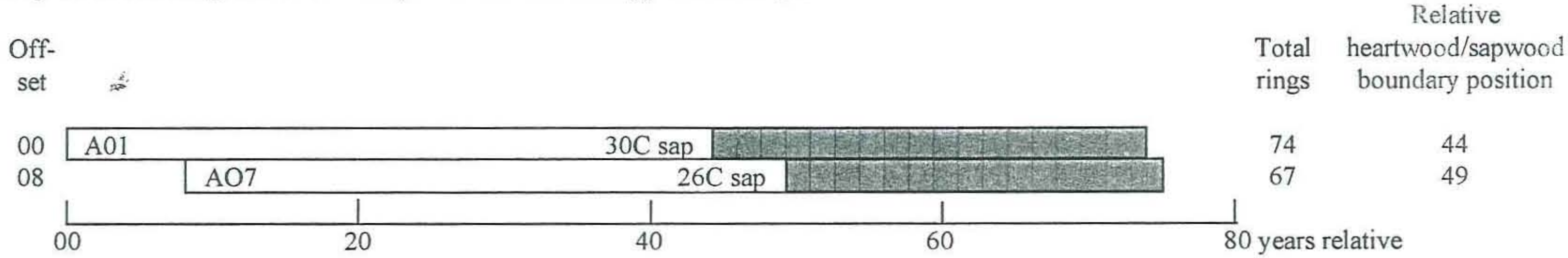
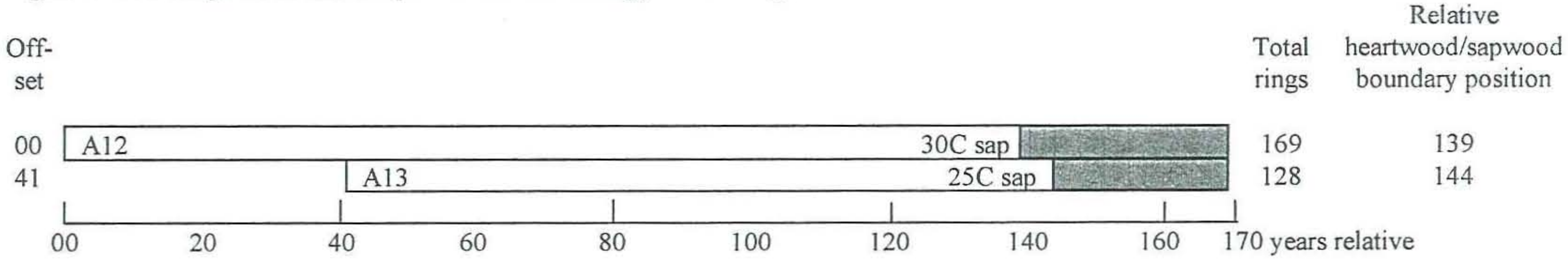
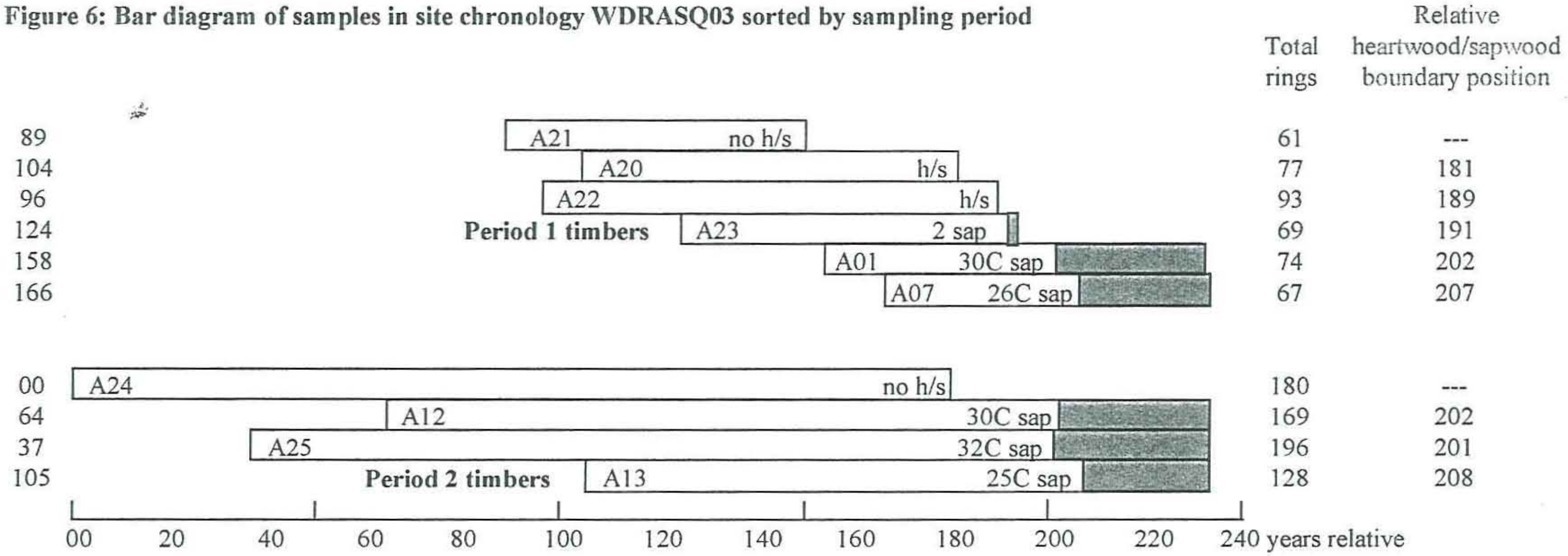


Figure 5: Bar diagram of the samples in site chronology WDRASQ02



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
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 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
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 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
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 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
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 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
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 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
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WDR-A05B 66
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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
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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
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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
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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
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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
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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
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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

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106 151 161 183 157 167  99 154 243 212 366 267 257 183 120 185 156
WDR-A12A 169
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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
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 76 117  93 104 109  72  62  45  42  79  59  72  98  71  70  91  89  91  45  59
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166 158 150 144 153 131 149 150 120 184 141 184 176 136 152 187 105  68  54  57
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106  80 103 100 110  83  97 118 121 125 160 126 128 112 180  83  44  34  43  66
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WDR-A23B 69
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 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
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  95 102  87 103 104 117 115 105  99  96  69 108 118  90 139 114 117 126  87 115
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WDR-A24B 180
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  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
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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
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86 77 57 53 55 47 45 40 59 49 54 62 76
WDR-A25B 196
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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
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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
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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 Figure1 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.

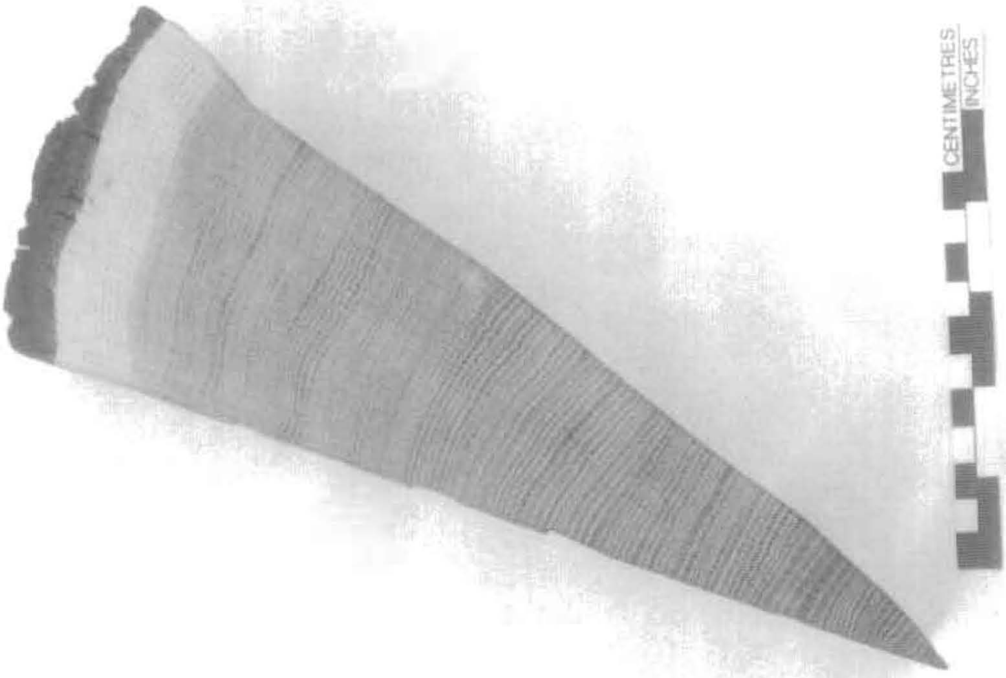

Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

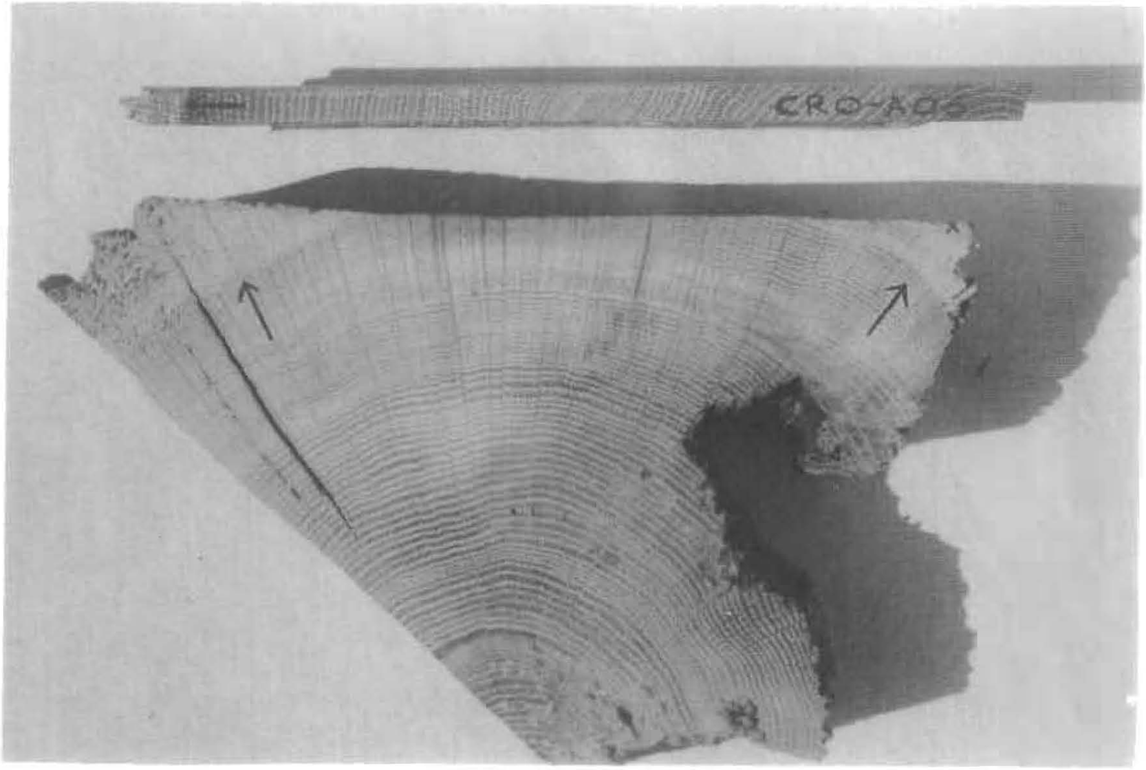

Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

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.

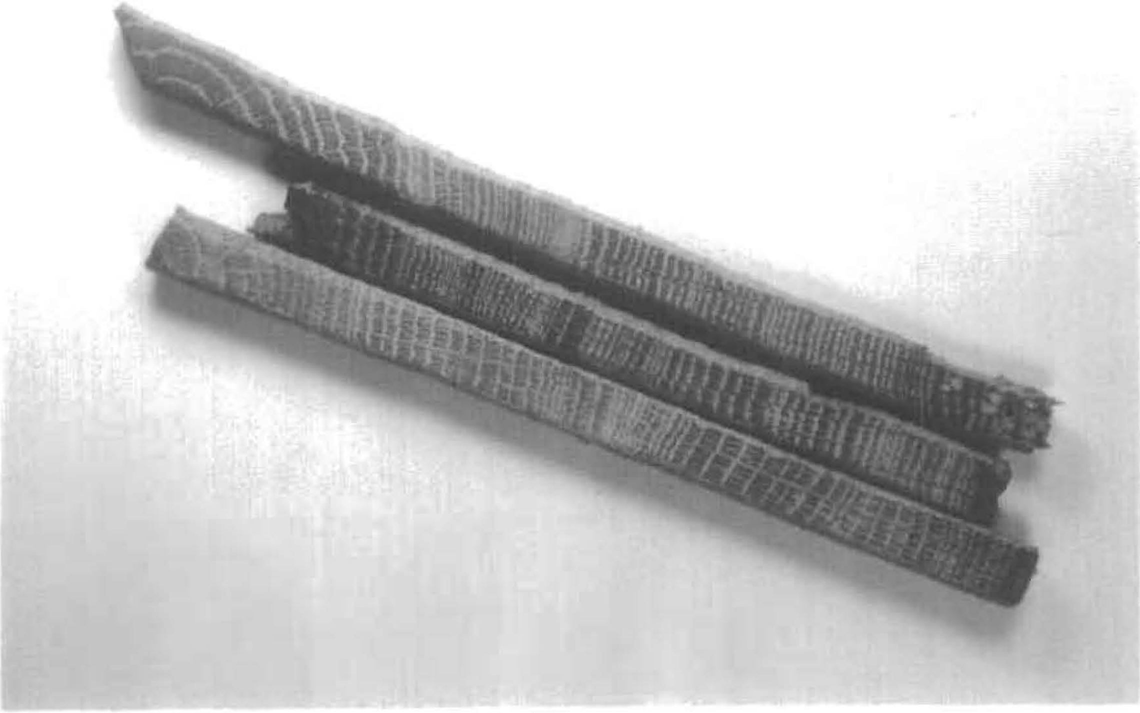

Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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 inspecton 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

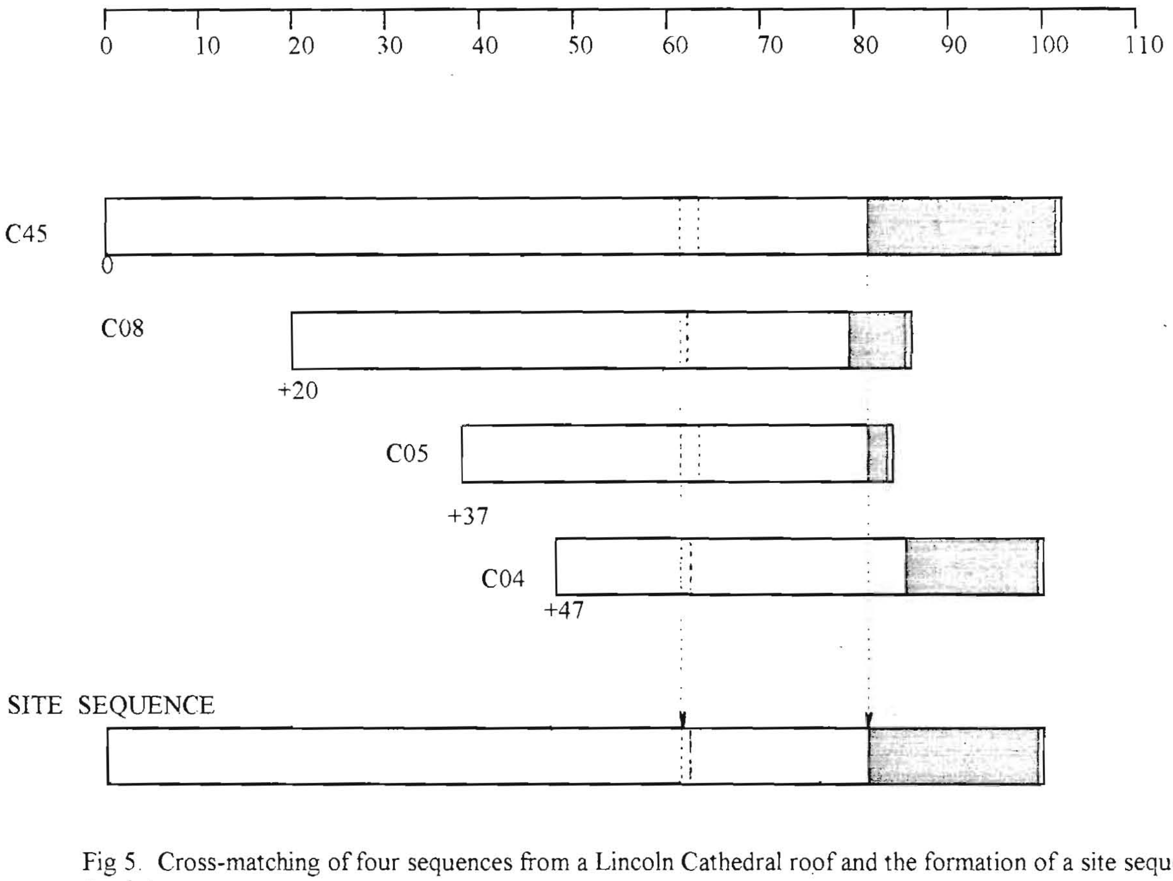

Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.
The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set 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.

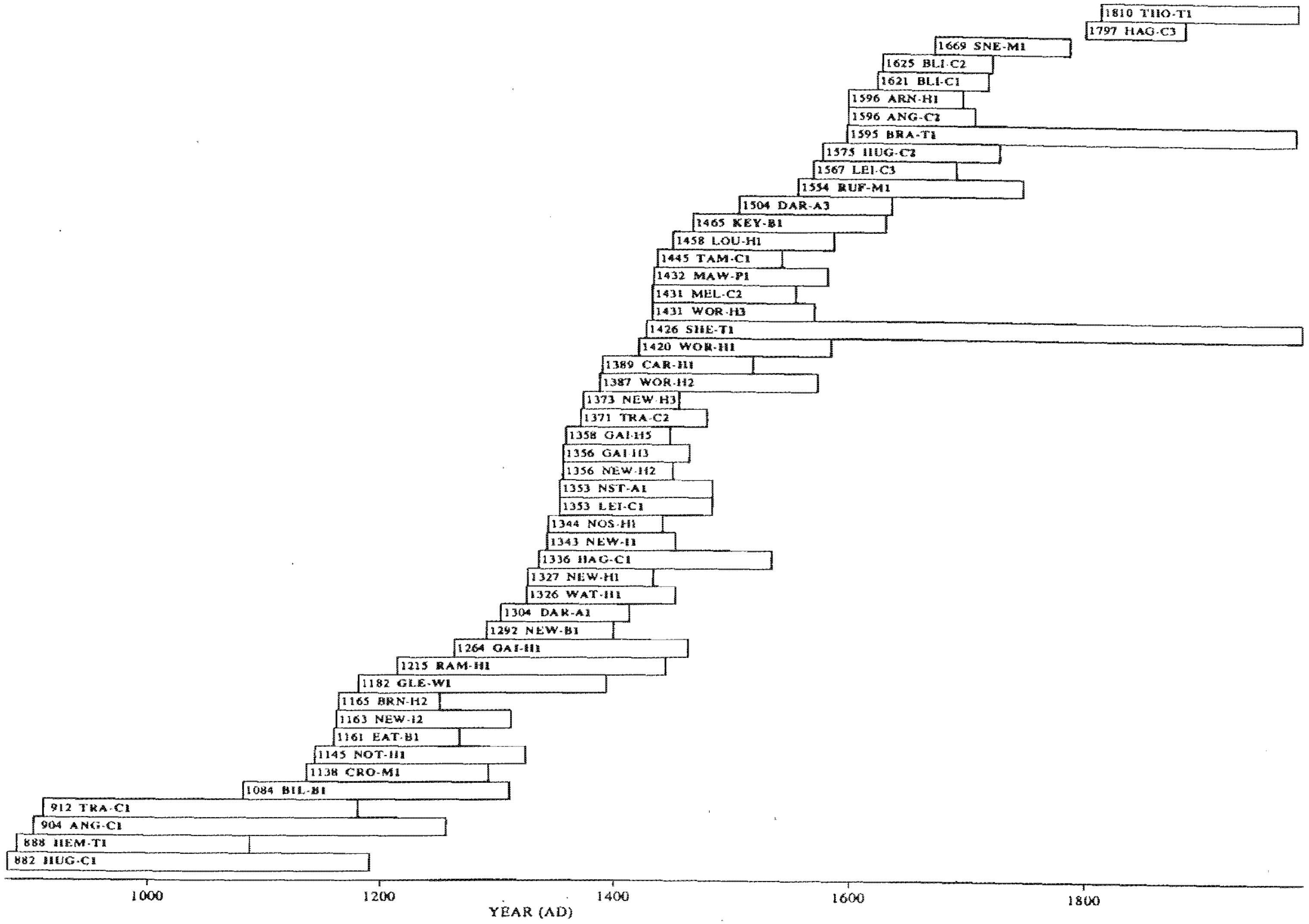

Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

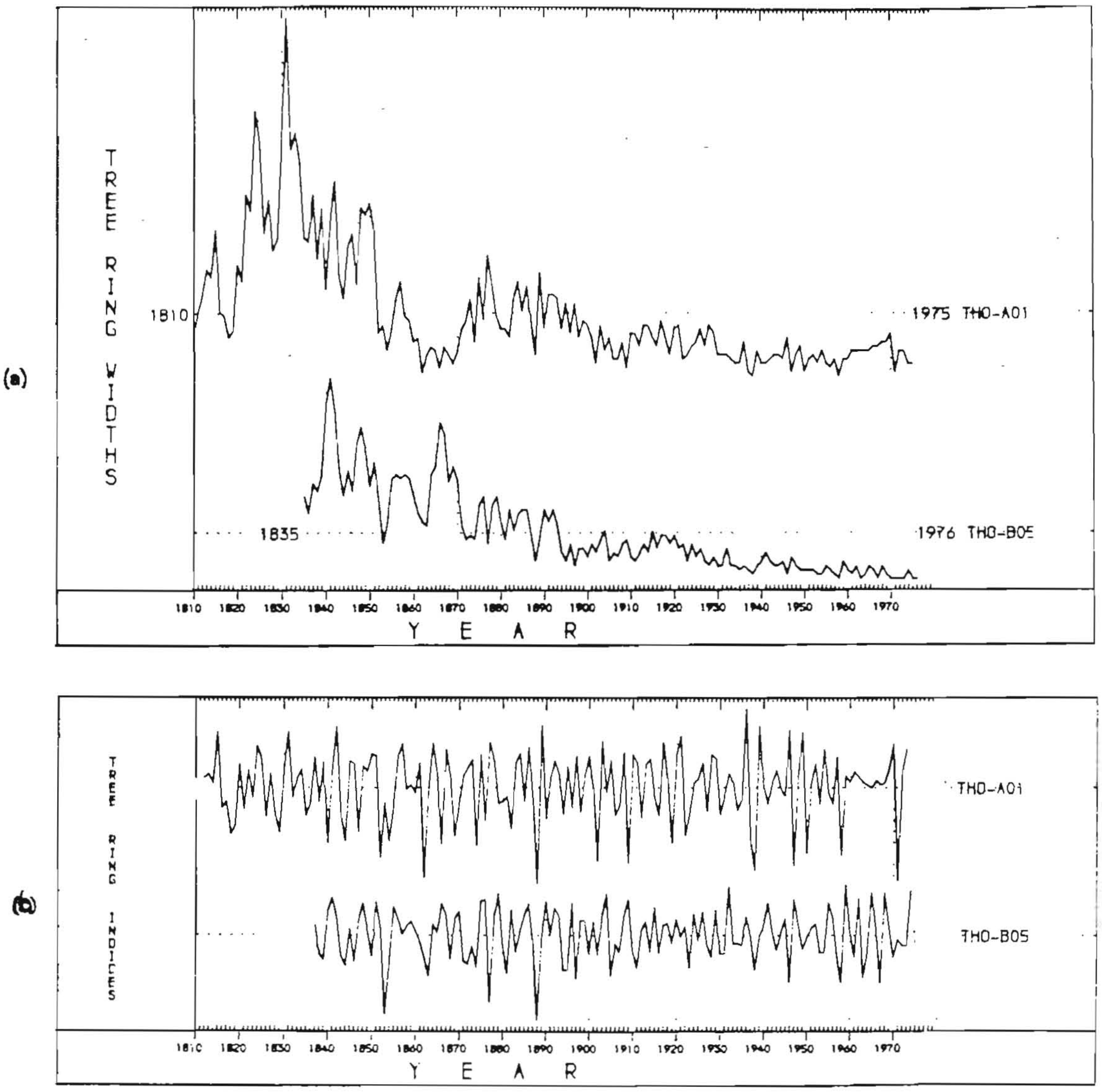

Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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

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

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