Ancient Monuments Laboratory
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TREE-RING ANALYSIS OF TIMBERS FROM THE FLOOR AND ROOF OF THE GREAT CHAMBER, THE DEANERY, CATHEDRAL CLOSE, EXETER, DEVON

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Summary

Thirty samples from the floor and roof of the Great Chamber of the Deanery, in the Cathedral Close, at Exeter were analysed by tree-ring dating. This analysis produced four site chronologies. The first, consisting of six samples, has 171 rings spanning the period AD 1233 - AD 1403. The second site chronology, composed of eight samples, has 120 rings but failed to cross-match with any reference chronologies and is thus undated. The third site chronology, consisting of three samples and having 121 rings, also failed to date. The fourth site chronology, consisting of two samples and having 85 rings, indicated a match with a first ring date of AD 1322 and a last measured ring date of AD 1406. A further single sample was dated as spanning the years AD 1314-99. Interpretation of the sapwood on all the dated samples suggest that there may be two phases of felling represented. It is estimated that the timbers of the Great Chamber floor have a felling date in the range AD 1400-35 whilst those of the Great Chamber roof have an estimated felling date in the range AD 1418-53. However, it is possible that all timbers were felled at the same time in the period AD 1413-48.

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Introduction

The Deanery is a multi-phase building on a large plot between the west front of the Cathedral and South Street, Exeter (SX 920925; Figs 1 and 2). The building has a complex structural history, possibly dating from the early-thirteenth century, or at least from AD 1301 when it was described as "much improved", to the present day. Little of the earliest construction is now recognisable. It currently consists of four blocks laid out in an irregular line running north-east to south-west, with a westward projecting block. These comprise the Great Hall, believed to contain remnants from the thirteenth century as well as later material and now divided up, the Parlour with Great Chamber over believed to be of early sixteenth-century date, and two domestic wings beyond.

A plan of the building, made by Stuart Blaylock of Exeter Archaeology and provided by English Heritage, is given in Figure 3. For ease of description a "site north" was imposed on the plan, although the building is actually orientated north-east to south-west; north-east becomes "north" and south-west becomes "south".

The roof of the Great Chamber is made up of five bays with seven trusses. The trusses are made up of principal rafters and collars, with arch-braces composed of an upper and a lower segment. Between the main trusses are intermediate trusses composed of common backing rafters faced with ribs, each of which carries a pendant boss close to the ashlars. The ribs rise from the ashlars to short hammer beams. Above the hammer beams short cove rafters rise to short collars close to the apices of the common rafters. Ilustrative examples of these trusses are given in Figure 4.

The floor of the Great Chamber is carried on four main beams running north to south forming five bays (Fig 6). Beams 1, 2, and 3 are of a similar scantling and bear on offsets in the north and south walls. Beam 4 is scarf jointed in the centre, is of smaller scantling, and is entirely supported by a stone wall that marks the west end of the parlour on the ground floor below. There are two layers of joists, the lower layer of which supports the parlour ceiling and is therefore absent in bay 5. Whether the lower layer of joists is present in bay 1 is not known. Most of these lower layer joists are reused and are thought likely have been derived from an earlier roof structure. The upper layer of joists consists of two types of which those in bays 2-4 are less substantial than in bay 5. The only exceptions being the northern and southernmost joists in bays 2-4 which are also of larger scantling. The less substantial joists in bays 2-4 are secured to the beams using open mortises and projecting spurs. Those in bay 2 have survived in position whereas those in bays 3 and 4 have been reset at some stage. In bay 5 the larger scantling joists bear on the stone wall and are not jointed to beam 4.

Sampling and analysis by tree-ring dating of timbers from the floor and roof of the Great Chamber were commissioned by English Heritage. It is believed that this two-storey block was added to the west of the Great Hall in the early-sixteenth century, possibly under John Veysey, Dean from AD 1509 – 19 and Bishop thereafter. The purpose of analysis was to confirm the dating of the Great Chamber and to more accurately place its roof, for comparative purposes, within a group of similar type in Exeter. These include other buildings which the Nottingham Laboratory has analysed by dendrochronology, such as Exeter Guildhall, the Law Library, the Archdeacon of Exeter's House (Howard *et al* forthcoming). The research into the group of roofs in Exeter is being undertaken in connection with a major programme of recording and repair at Bowhill in Devon (Blaylock forthcoming), which is being funded by English Heritage (Groves forthcoming).

A further purpose of sampling was to obtain additional tree-ring data for this region. Exeter, and the southwest in general, have relatively few dated reference chronologies. This is in part due to the slightly short growth-ring sequences found on samples in this area caused by the wide rings found on many trees and timber, and in part due to the complacency of the growth-ring patterns. It was believed that the Deanery would provide a substantial amount of timber with longer growth-ring sequences capable of providing a well replicated site chronology with a distinctive regional climatic signature.

The Laboratory would like to take this opportunity to thank all those who assisted with the sampling of the timbers. In particular thanks are due to the Dean, the Very Reverend and Mrs K Jones, for allowing sampling, for putting up with the disruption caused, for their interest in the project, and their hospitality. We would also like to thank Colonel Woodcock of the Cathedral Office and John Allen of the Royal Albert Memorial Museum, Exeter, for their assistance in facilitating sampling. The Laboratory would also like to take this opportunity to thank Stuart Blaylock of Exeter Archaeology for his help in assessing the phasing of the building, his assistance during sampling, and for his help with the introductory paragraphs describing the site.

The Laboratory would also like to thank Cathy Groves of the Dendrochronology Laboratory in the Research School of Archaeology and Archaeological Science at the University of Sheffield. Samples obtained by Cathy Groves but not yet analysed were made available to the Nottingham University Laboratory. Additional cross-matching and dating of site chronologies was also undertaken at the Sheffield Laboratory with much assistance in the interpretation being provided too.

Sampling

A total of thirty different oak timbers was sampled by coring, or in one case, by slicing. Each sample was given the code EXT-B (for Exeter, site "B") and numbered 01–30. Thirteen samples, EXT-B01-13, were obtained from timbers of the roof, with the remaining seventeen samples, EXT-B14-30, being provided by Cathy Groves of the Sheffield Dendrochronology Laboratory.

In the case of the thirteen samples from the roof timbers, the positions of these were recorded at the time of sampling on plans made by Stuart Blaylock, see Figure 5a/b. On these plans the trusses have been numbered from east to west. Only a small portion of the roof, between trusses 1-2 (bay 1), was uncovered and accessible from an inserted floor without the use of a scaffolding tower. However, from this inserted floor a substantial number of timbers were available. The height of the roof timbers elsewhere in the Hall would have required access from a scaffolding tower for fully accessible sampling, but this could not be arranged at the time of coring due to area being in use for meetings etc. Furthermore, the underside of the roof elsewhere in the Great Chamber had been boarded and plastered so that only the timbers of the main trusses were visible. A close inspection of these timbers from a ladder showed most of them to have very wide rings making them less suitable for analysis by dendrochronology, and only two of these were sampled.

The position of the sixteen samples cored by Cathy Groves, EXT-BI4-29, were marked at the time of sampling on draft plans provided by Richard Parker, see Figure 6. In these the floor space has been divided up into bays formed by the main north-south crossbeams. The bays have been numbered 1-5 from east to west. Bay 1 is taken up with the modern stairs and lobbies and was not exposed. The individual joists, including the larger east-west timbers at the southern edge of the floor which may be part of the frame, have been numbered from south to north. Access for sampling at this time was made difficult by floorboards being re-laid as coring was in progress. Access to the northern end of bay 5 and all but the southern edge of bay 2 was therefore not possible. Nor was it possible to sample the lower layer of reused joists beneath those in bays 2-4 as the upper layer of joists prevented suitable access angles being achieved.

A sliced sample, EXT-B30, was also provided by John Allen of the Royal Albert memorial Museum, Exeter. This slice was obtained at an earlier instance by contractors working on site. Its position was not recorded and the exact location of the timber from which it came is unknown. Details of all the samples are given in Table 1.

Analysis

Each sample was prepared by sanding and polishing. One sample, EXT-B29, was found to have too few rings for satisfactory analysis, and it was not measured. The growth-ring widths of all remaining twenty nine samples were measured and their growth-ring widths compared with each other by the Litton/Zainodin grouping procedure (see appendix). The data of these measurements are given at the end of the report. At a minimum t-value of 4.5 four groups of samples formed.

The six samples of the first group cross-matched with each other at relative positions as shown in the bar diagram Figure 7. The growth-ring widths of the six samples were combined at these relative off-set positions to form EXTBSQ01, a site chronology of 171 rings. Site chronology EXTBSQ01 was compared with a series of relevant reference chronologies for oak, giving it a first ring date of AD 1233 and a last measured ring date of AD 1403. Evidence for this dating is given in the t-values of Table 2.

The eight samples of the second group to form cross-matched with each other at relative positions as shown in the bar diagram Figure 8. The growth-ring widths of these eight samples were combined at these relative off-set positions to form EXTBSQ02, a site chronology of 120 rings. Site chronology EXTBSQ02 was compared with a series of relevant reference chronologies for oak, but there was no satisfactory cross-matching

The three samples of the third group to form cross-matched with each other at relative positions as shown in the bar diagram Figure 9. The growth-ring widths of these three samples were combined at these relative off-set positions to form EXTBSQ03, a site chronology of 121 rings. Site chronology EXTBSQ03 was compared with a series of relevant reference chronologies for oak, but again there was no satisfactory cross-matching.

The two samples of the fourth and final grouped to form cross-matched with each other at relative positions as shown in the bar diagram Figure 10. The growth-ring widths of these two samples were combined at these relative off-set positions to form EXTBSQ04, a site chronology of 85 rings. Site chronology EXTBSQ04 was compared with a series of relevant reference chronologies for oak, giving it a first ring date of AD 1322 and a last measured ring date of AD 1406. Evidence for this dating is given in the t-values of Table 3.

The four site chronologies thus created, EXTBSQ01-04, were then compared with each other. There was, however, no further truly satisfactory cross-matching between them. Each of the four site chronologies was then compared with the remaining eleven ungrouped samples. Again there was no satisfactory cross-matching.

Each of the eleven ungrouped samples was then compared individually with a full range of reference chronologies. This indicated a cross-match for sample EXT-B20 only with a first ring date of AD 1314 and a last measured ring date of AD 1399. Evidence for this date is given in the t-values of Table 4.

Interpretation

It will be seen from the bar diagram of Figure 7 that the relative positions of the heartwood/sapwood boundaries on the six samples in site chronology EXTBSQ01 are not particularly consistent with a group of timbers having a single felling date. Rather, the relative positions of the heartwood/sapwood boundaries are more indicative of timbers with two distinct felling phases, it being much earlier on samples EXT-B23 and B24, from the Great Chamber floor, than it is on samples EXT-B01, B04, B10, and B13, all from the Great Chamber roof.

The average last heartwood ring date of only those samples from the Great Chamber floor is AD 1385, whilst the average on those only from the roof is AD 1402. This variation in the average is slightly larger than might be found in a group of timbers with a single felling date, though it is not an impossibility. Using 15 – 50 rings as the 95% confidence limit for the amount of sapwood would give the timbers of the floor an estimated felling date in the range AD 1400 – 35, and those of the roof an estimated felling date in the range AD 1417 – 52.

Taking the other dated samples from the roof into account (EXT-B11 and B12 in site chronology EXTBSQ04 with heartwood/sapwood transition dates of AD 1405 and AD 1406 respectively) would push the average last heartwood ring date of the timbers from the roof up to AD 1403. The estimated felling date would then be in the range AD 1418 – 53. It is probable that these two samples represent timbers from the same tree, cross-matching with each other as they do, with a t-value of 16.7.

The relative position of the heartwood/sapwood boundaries on the samples in site chronology EXTBSQ02 appears to be consistent with a group of timbers having a single felling date. The exception to this is possibly sample EXT-B18, although the relative position of the heartwood/sapwood boundary on this sample is not unduly at odds with the others. It would appear from the cross-matching between the individual samples of this group, that the timbers they represent are from trees which were all growing close to each other, with some timbers possibly being from the same tree, samples EXT-B14, B17, and B18 for example. This observation might strengthen the supposition that the timbers used were all felled at the same time.

Because none of the three samples in site chronology EXTBSQ03 have a heartwood/sapwood boundary it is not possible to say whether or not they are of the same felling date as each other, each one could have been felled at quite different times.

Sample EXT-B20, from crossbeam 4 of the Great Chamber floor, has a heartwood/sapwood transition date of AD 1399. Using the same sapwood estimate of 15 – 50 rings would give this timber an estimated felling date in the range AD 1414 – 49.

Conclusion

In conclusion it would appear possible that two of the more substantial joists from bays 3 and 4 are of one felling phase (samples EXT-B23 and B24), while those of the Great Chamber roof and beam 4 (samples EXT-B01, B04, B10, B11, B12, B13, and B20) are slightly later. Beam 4 is the smaller scantling crossbeam. Both fellings took place in the early-fifteenth century and as their felling date ranges overlap it remains a possibility that they could be the product of a single felling phase.

Thus, tree-ring analysis has shown that the construction date of the Great Chamber is somewhat earlier than expected, being early- to mid-fifteenth century rather than early- to mid-sixteenth century. Its construction can no longer be associated with John Veysey, Dean from AD 1509 – 19 and Bishop thereafter.

Many joists from the Great Chamber floor cannot be dated, though those of larger scantling in bay 5 have been shown to be contemporary with those of smaller scantling in bays 3 and 4 that have clearly been reset at some point. Those joists in bay 2, also of small scantling but thought to be *in situ*, could not be sampled due to access difficulties so it has not been possible to demonstrate that they are part of the same group of joists used in bays 3-5.

Only nine of the twenty-nine samples measured have been dated. Twenty remain undated, although twelve of these are in one of three groups. Many of the undated samples are of suitable length for analysis by dendrochronology, and none of them show stresses or complacent rings that might make dating difficult. It appears possible that many of the undated longer samples, particularly those in site chronology EXTBSQ02, are of a different date or from a different source, or both, to those found in site chronology EXTBSQ01. It is possible that this period or source is not represented in any of the current reference material, but that they could be dated if suitable temporal or geographic material, or both, were available. This is only likely to be the case with further sampling from Exeter and the surrounding area.

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Table 1: Details of samples from floor and roof of the Great Chamber, The Deanery, Exeter

Sample no.	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Great Chamber roof					
EXT-B01	South principal rafter, truss 2	144	h/s	AD 1260	1403	1403
EXT-B02	South arch-brace, truss 2	100	no h/s	------	------	------
EXT-B03	South cove rafter, frame 5, bay 1	54	no h/s	------	------	------
EXT-B04	South intermediate rib, bay 1 (midrib)	104	no h/s	AD 1279	------	1382
EXT-B05	South common rafter 1, bay 1	75	no h/s	------	------	------
EXT-B06	North common rafter 1, bay 1	75	no h/s	------	------	------
EXT-B07	North midrib frame 3	57	no h/s	------	------	------
EXT-B08	North common rafter, frame 3, bay 1	62	no h/s	------	------	------
EXT-B09	Collar, frame 2	71	no h/s	------	------	------
EXT-B10	North arch-brace, truss 2	85	h/s	AD 1316	1400	1400
EXT-B11	South principal rafter, truss 6	84	h/s	AD 1322	1405	1405
EXT-B12	South principal rafter, truss 4	83	h/s	AD 1324	1406	1406
EXT-B13	North post, truss 2	55	h/s	AD 1348	1402	1402
	Great Chamber floor					
EXT-B14	Joist 5, bay 5	95	h/s	------	------	------
EXT-B15	Joist 6, bay 5	77	h/s	------	------	------
EXT-B16	Joist 4, bay 5	72	6	------	------	------
EXT-B17	Joist 3, bay 5	76	2	------	------	------
EXT-B18	Joist 2, bay 5	70	h/s	------	------	------
EXT-B19	Joist 1, bay 5	65	h/s?	------	------	------
EXT-B20	Crossbeam 4	86	h/s?	AD 1314	1399	1399

Table 1: continued

Sample no.	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Great Chamber floor					
EXT-B21	Joist 4, bay 4	110	no h/s	------	------	------
EXT-B22	Joist 2, bay 4	97	no h/s	------	------	------
EXT-B23	Joist 1, bay 4	152	6c	AD 1233	1378	1384
EXT-B24	Joist 1, bay 3	106	h/sc	AD 1287	1392	1392
EXT-B25	Joist 2, bay 3	85	no h/s	------	------	------
EXT-B26	Joist 9, bay 3	95	4	------	------	------
EXT-B27	Joist 12, bay 3	60	h/s	------	------	------
EXT-B28	Crossbeam 3	74	3	------	------	------
EXT-B29	Joist 1, bay 4	nm	---	------	------	------
EXT-B30	Not known	76	h/s	------	------	-----

*h/s = the heartwood/sapwood boundary is the last ring on the sample
c = complete sapwood on timber, all or part lost on sampling

Table 2: Results of the cross-matching of site chronology EXTBSQ01 and relevant reference chronologies when first ring date is AD 1233 and last ring date is AD 1403

Reference chronology	Span of chronology	t-value	
East Midlands	AD 882 – 1981	5.6	(Laxton and Litton 1988)
England	AD 401 – 1981	5.1	(Baillie and Pilcher 1982 unpubl)
Southern England	AD 1083 – 1589	7.2	(Bridge 1988)
Kent-88	AD 1158 – 1540	3.8	(Laxton and Litton 1989)
Reading Waterfront, Berks	AD 1160 – 1407	5.6	(Groves *et al* 1997)
Chichester Cathedral, Hants	AD 1173 – 1295	5.2	(Howard *et al* 1992)
Ware Priory, Ware, Herts	AD 1223 – 1416	5.6	(Howard *et al* forthcoming)
Chicksands Priory, Beds	AD 1200 – 1541	4.3	(Howard *et al* forthcoming)
Daneway House, Sapperton, Glos	AD 1201 – 1315	5.1	(Howard *et al* 1995)

Table 3: Results of the cross-matching of site chronology EXTBSQ04 and relevant reference chronologies when first ring date is AD 1322 and last ring date is AD 1406

Reference chronology	Span of chronology	t-value	
England Mid-west	AD 860 – 1753	5.4	(Tyers and Groves 1999a unpubl)
England South-east	AD 435 – 1790	4.6	(Tyers and Groves 1999b unpubl)
England South-west	AD 770 – 1798	5.3	(Tyers and Groves 1999c unpubl)
Harmondsworth, Middx	AD 1262 – 1425	4.5	(Tyers and Hibberd 1993)
St Mary's Guildhall, Coventry, W Mids	AD 1316 – 1422	4.6	(Tyers 1995)
Hereford City	AD 915 – 1617	5.9	(Tyers 1996a)
St Cuthberts, Wick, Worcs	AD 1257 – 1496	5.0	(Bridge 1988)
Mercers Hall, Gloucester	AD 1289 – 1541	4.8	(Howard *et al* 1997)
Lower Chilverton, Devon	AD 1315 – 1488	5.3	(Groves forthcoming)
Archdeacon's House, Exeter	AD 1186 – 1404	5.8	(Howard *et al* forthcoming)

Table 4: Results of the cross-matching of sample EXT-B20 and relevant reference chronologies when first ring date is AD 1314 and last ring date is AD 1399

Reference chronology	Span of chronology	t-value	
England South east	AD 435 – 1790	7.1	(Tyers and Groves 1999b unpubl)
England South west	AD 770 – 1798	6.9	(Tyers and Groves 1999c unpubl)
England East Anglia	AD 781 – 1899	6.4	(Tyers and Groves 1999d unpubl)
England London	AD 413 – 1728	5.1	(Tyers and Groves 1999e unpubl)
Upminster, Greater London	AD 1276 – 1414	6.5	(Tyers 1997a)
Netteswellbury, Essex	AD 1245 – 1439	7.2	(Tyers 1997b)
St Aylotts, Essesx	AD 1281 – 1500	5.0	(Tyers 1996b)
High Halden, Kent	AD 1299 – 1462	6.2	(Bridge 1987)
Reading Waterfront, Berks	AD 1168 – 1407	5.9	(Groves *et al* 1997)

Figure 1: Map to show general location of Exeter

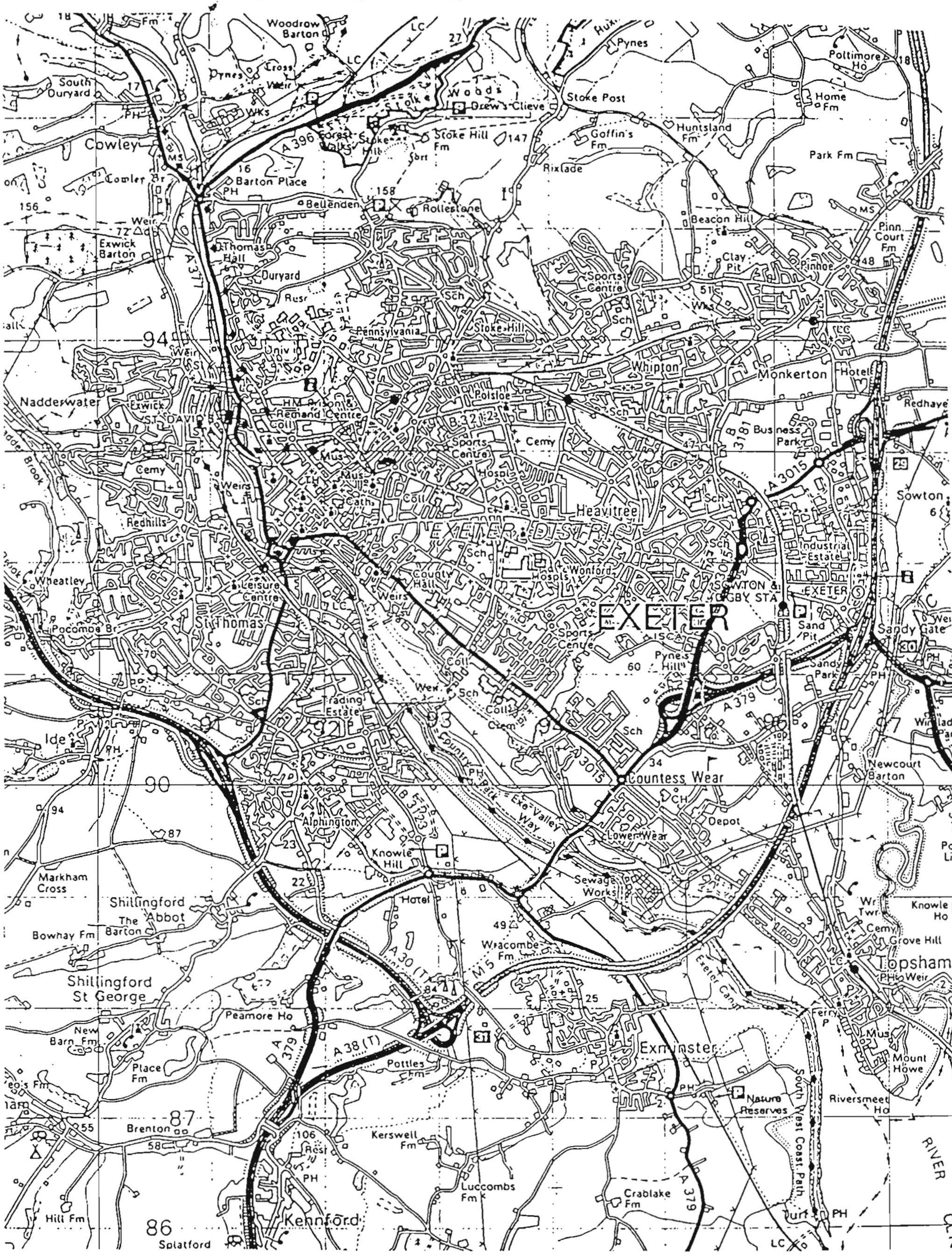


Figure 2: Map to show location of the Deanery, Exeter

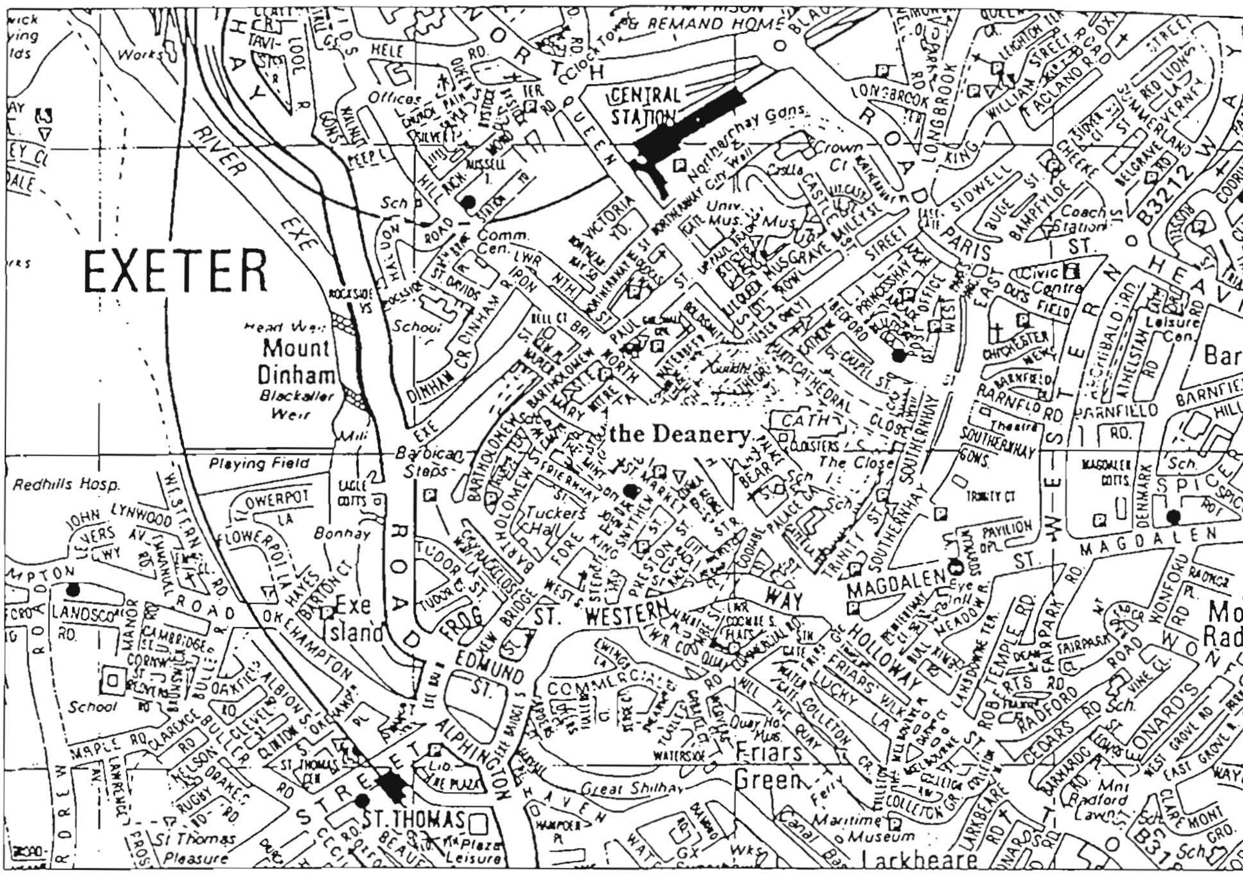


Figure 3: Plan of the Deanery, Exeter

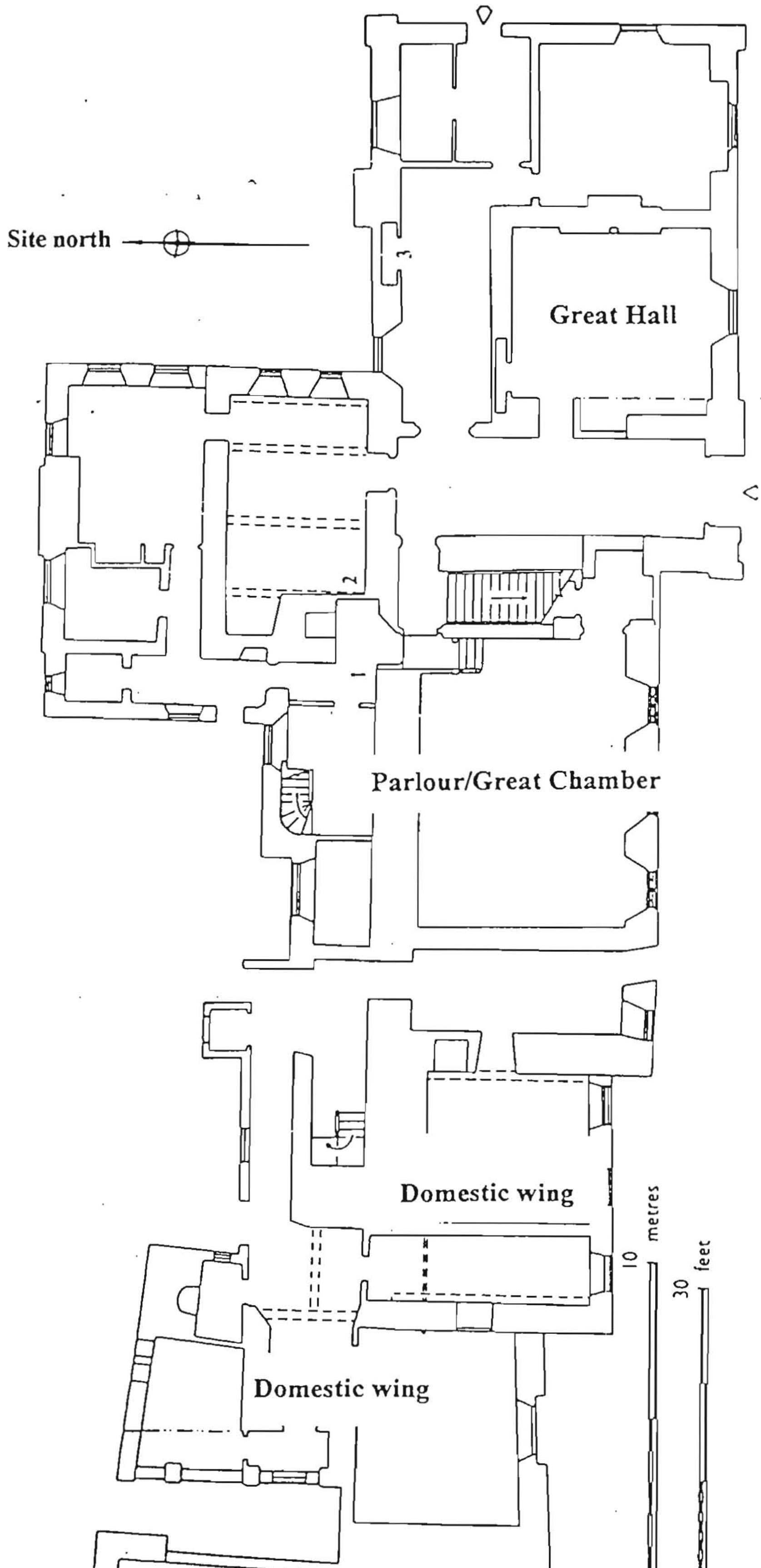


Figure 4: Illustrative example of a main truss (above) and an intermediate truss (below)

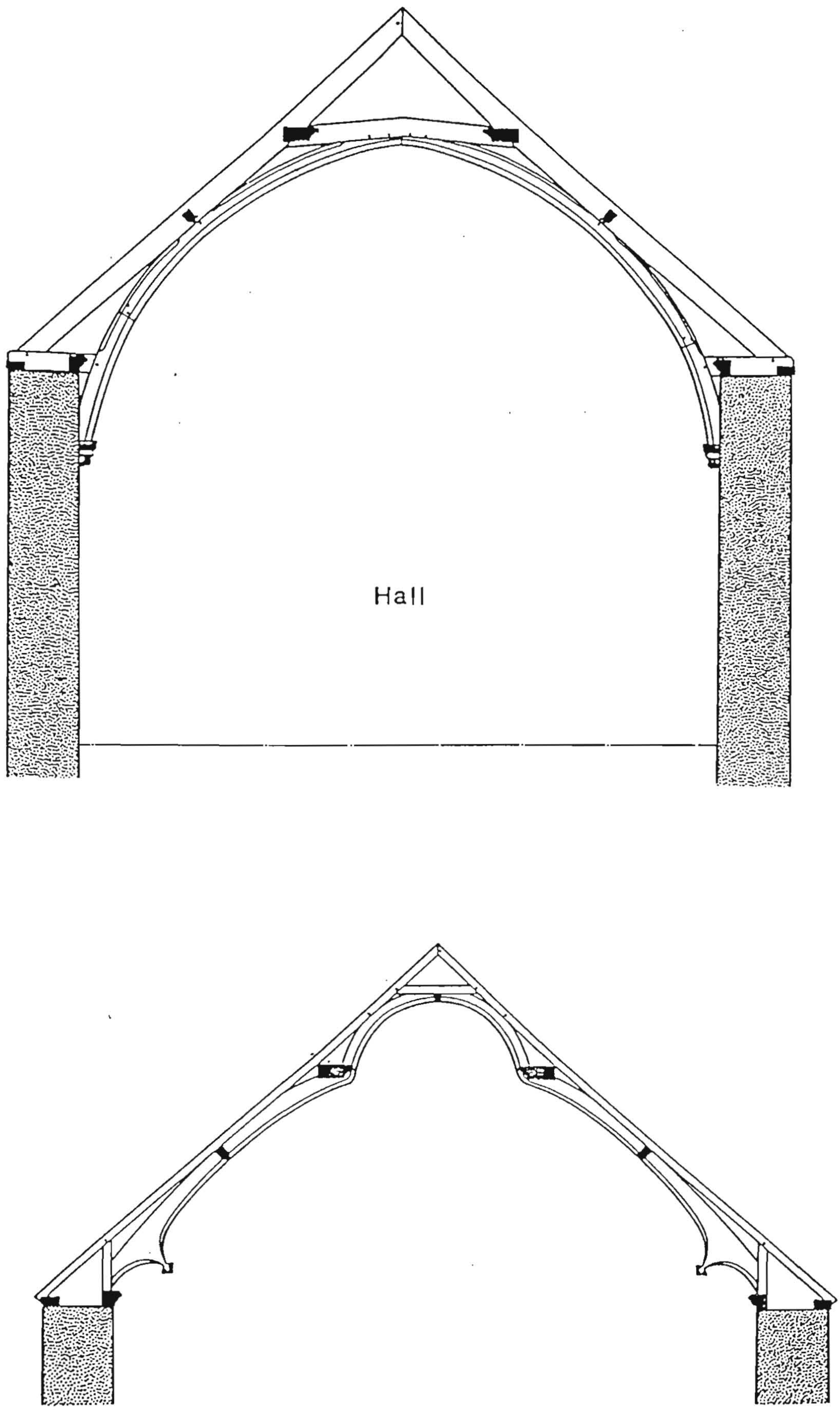


Figure 5a: Section of the Great Chamber roof looking north to show sample locations

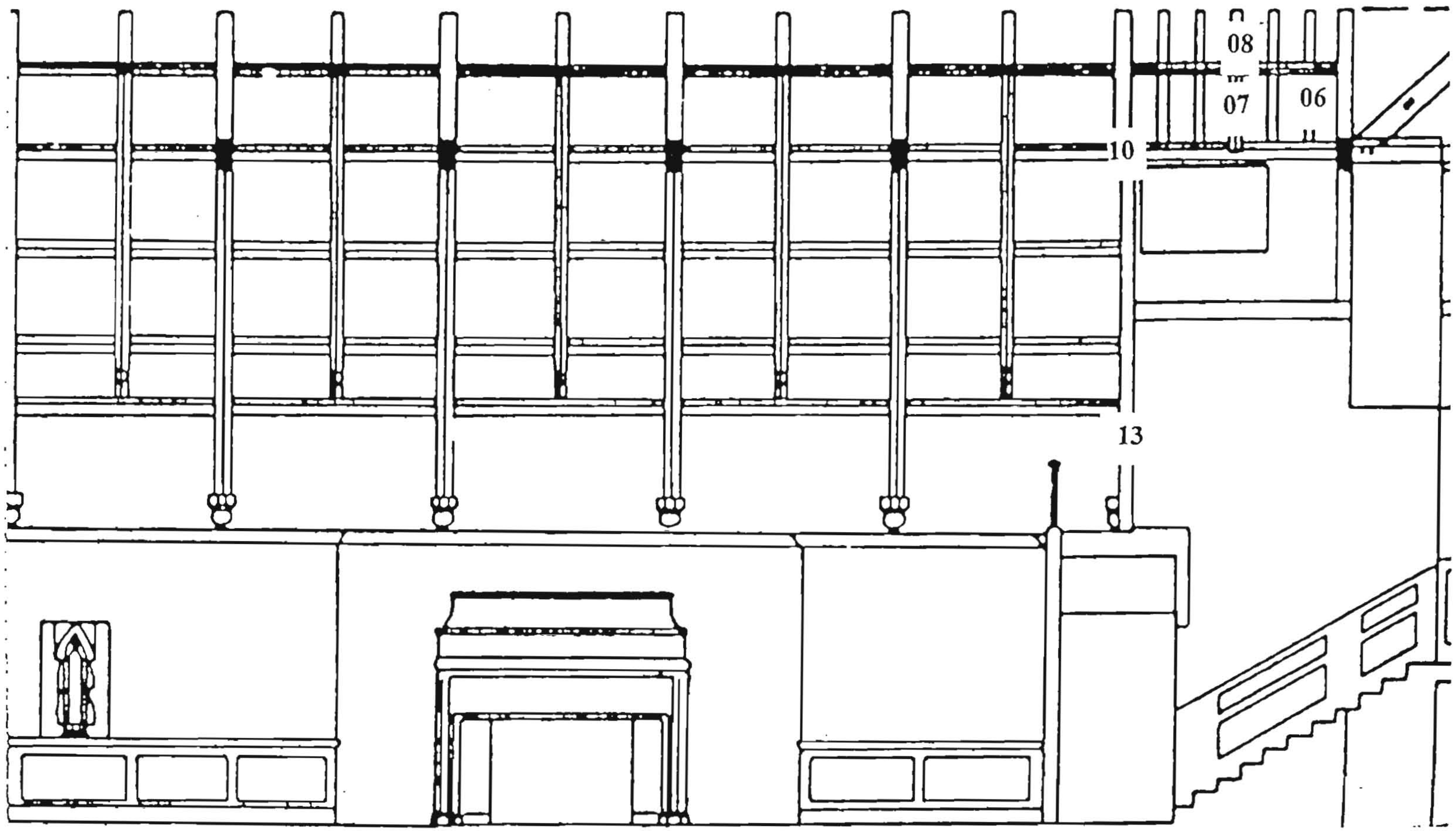


Figure 5b: Section of the Great Chamber roof looking south to show sample locations

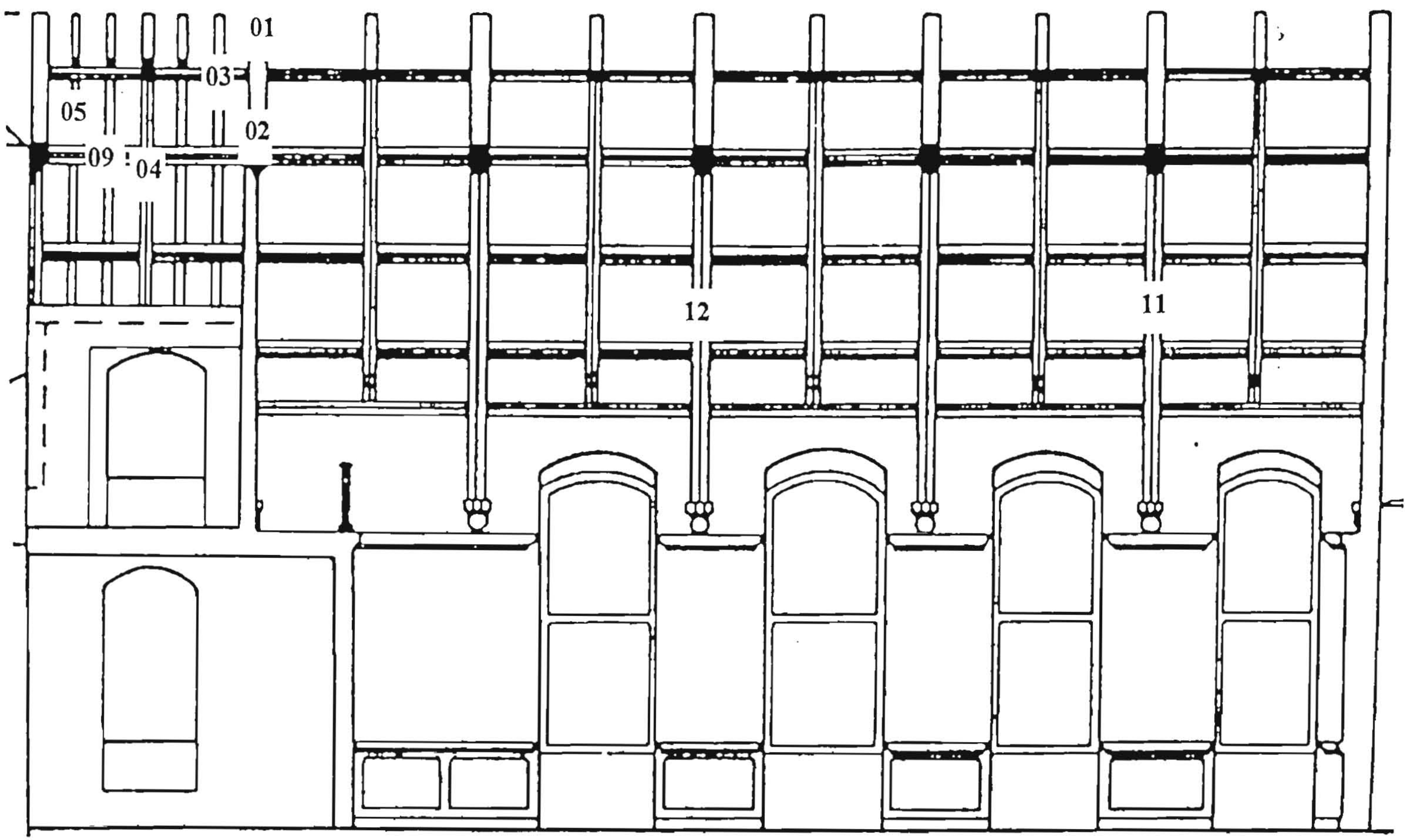


Figure 6: Plan to show location of samples from the Parlour floor

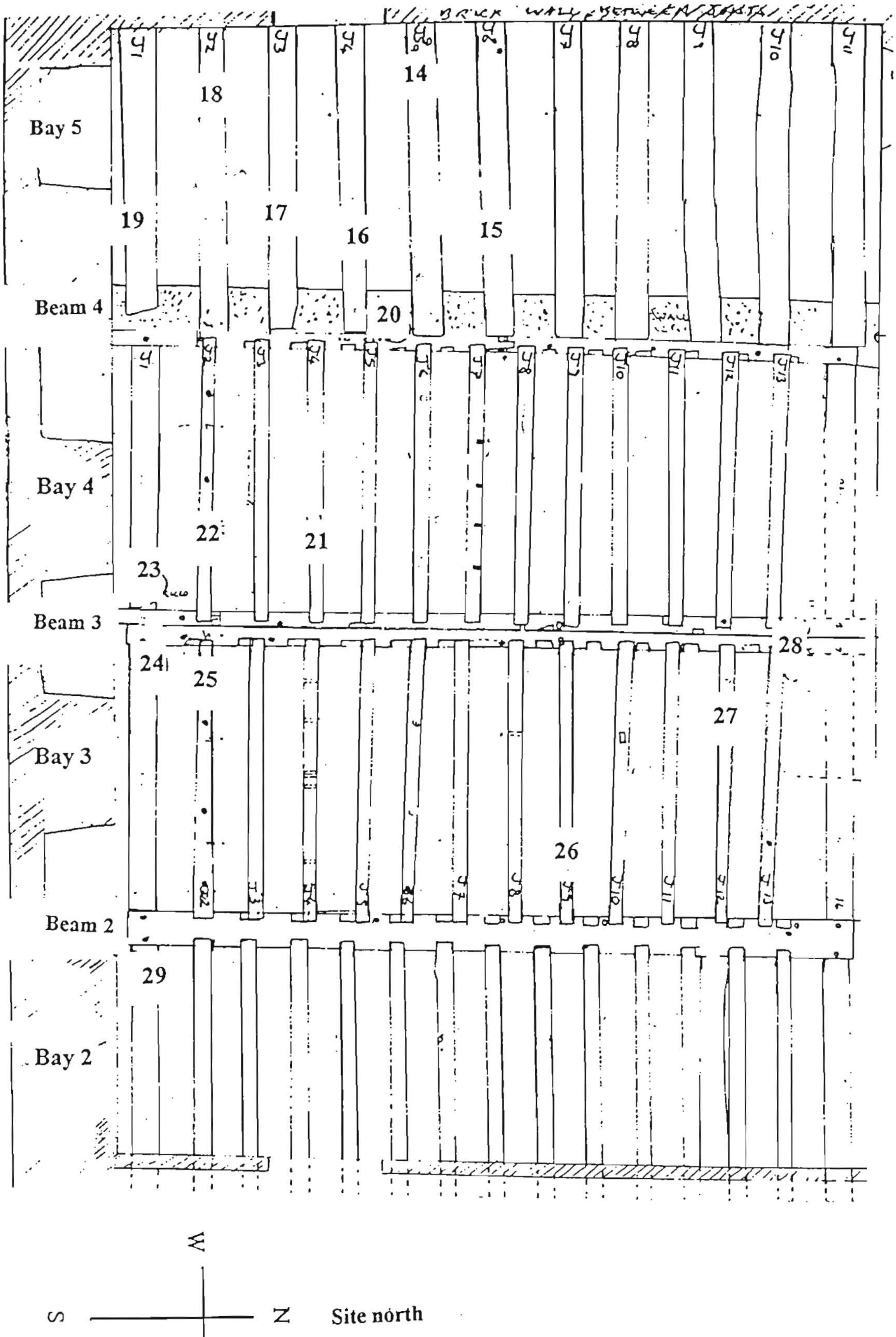
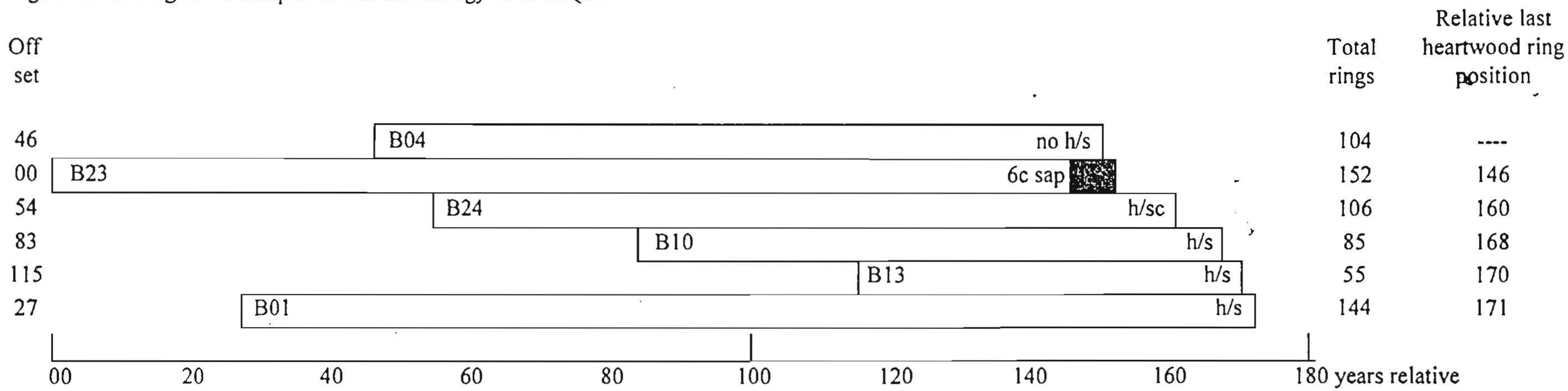
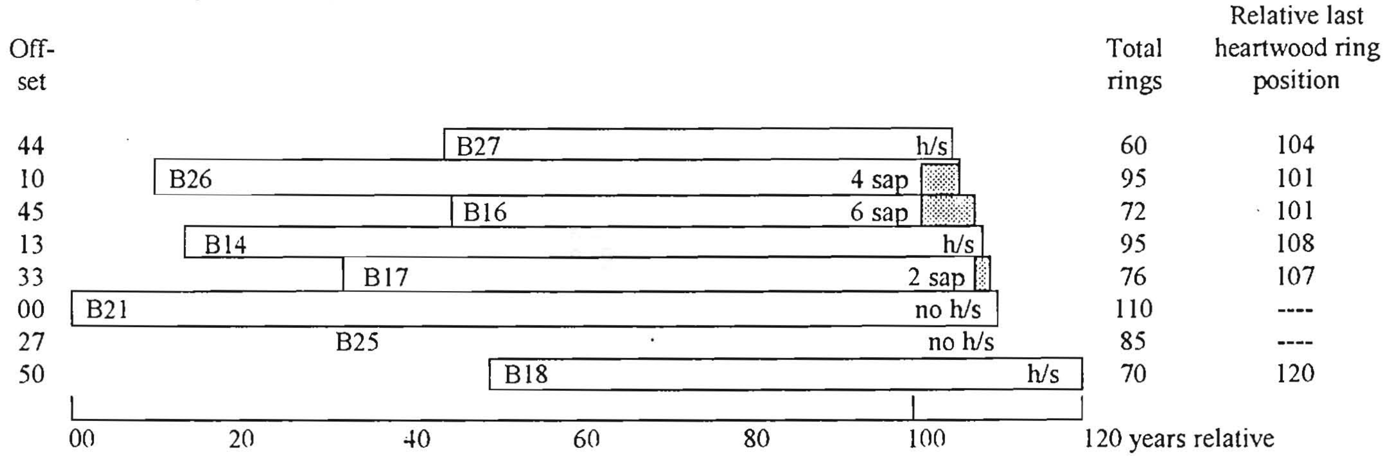


Figure 7: Bar diagram of samples in site chronology EXTBSQ01



White bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample
c = complete sapwood on timber, all or part is lost from sample in coring

Figure 8: Bar diagram of samples in site chronology EXTBSQ02



White bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring

Figure 9: Bar diagram of samples in site chronology EXTBSQ03

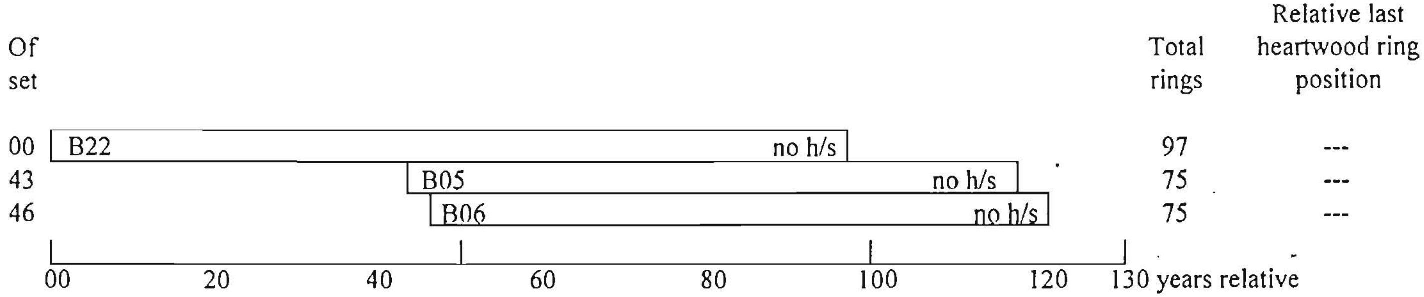
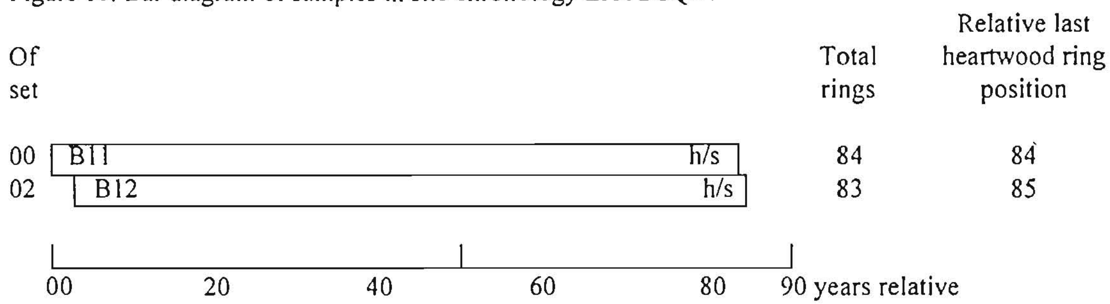


Figure 10: Bar diagram of samples in site chronology EXTBSQ04



White bars = heartwood rings

h/s = heartwood/sapwood boundary is last ring on sample

Data of measured samples – measurements in 0.01mm units

EXT-B01A 144
543 407 492 323 208 322 280 268 361 192 162 302 231 267 205 188 226 229 200 265
322 334 198 184 217 251 221 174 120 159 170 187 302 222 192 214 197 174 179 148
156 127 290 107 83 111 125 129 163 166 212 162 143 115 112 142 125 251 138 114
110 133 102 146 138 94 118 133 130 119 92 86 93 111 83 93 84 120 111 150
98 98 115 100 89 102 92 83 96 126 73 104 108 126 110 75 100 92 131 125
81 96 65 142 144 141 134 127 96 128 104 74 102 79 61 71 53 49 63 151
94 91 81 82 91 92 151 134 172 142 94 91 87 103 77 84 58 58 60 55
55 85 88 92
EXT-B01B 144
552 483 494 318 213 315 294 270 414 282 287 323 225 276 225 244 271 235 200 264
330 334 201 179 216 254 218 174 127 158 163 189 296 227 196 203 204 174 190 149
151 124 278 98 84 106 129 127 159 166 212 174 146 124 116 131 126 259 136 113
105 143 102 151 124 91 114 136 128 117 97 81 96 92 80 96 87 114 117 146
99 96 114 102 88 102 87 87 97 115 74 107 108 124 108 78 95 92 132 124
84 95 68 142 141 138 131 130 99 127 103 73 101 78 70 64 55 48 61 153
84 88 81 84 94 89 153 138 168 140 97 93 86 105 77 87 60 53 62 55
57 84 84 115
EXT-B02A 100
262 251 202 214 180 203 225 235 130 154 167 254 221 267 358 235 258 328 233 269
177 192 138 203 144 112 217 211 198 198 185 194 188 156 221 184 193 226 234 216
126 180 243 204 199 60 55 50 52 36 17 23 21 24 30 29 38 37 40 68
78 85 109 80 88 104 102 95 60 84 63 98 99 173 119 169 121 125 133 157
138 142 109 124 142 268 271 224 247 181 100 83 101 140 159 86 68 95 85 119
EXT-B02B 100
252 242 200 223 181 177 217 239 151 174 189 259 244 281 368 214 258 343 240 243
171 185 121 209 147 122 214 218 202 184 188 198 191 151 233 191 192 236 214 212
150 186 237 215 200 62 56 42 49 40 18 22 23 22 28 34 32 37 45 64
74 89 110 78 89 96 102 99 62 77 71 94 100 176 121 174 120 123 141 156
141 148 114 125 140 278 269 238 249 189 96 69 126 128 187 90 73 82 89 119
EXT-B03A 54
243 303 187 298 302 292 261 217 289 299 234 362 184 280 197 240 261 274 374 359
252 227 318 294 236 196 288 240 277 256 246 223 232 247 206 240 253 206 268 233
201 274 183 308 230 268 247 256 311 222 279 243 263 216
EXT-B03B 54
250 280 196 295 284 314 256 182 288 308 233 370 204 285 202 230 274 272 372 362
253 232 289 313 255 167 282 257 270 256 257 210 214 253 213 236 256 211 270 235
203 281 177 307 228 268 254 258 341 234 281 251 253 216
EXT-B04A 104
224 254 168 193 160 139 149 221 115 125 139 177 159 200 211 176 152 185 154 188
126 149 122 142 122 111 162 147 146 162 154 151 124 110 151 154 137 173 153 124
101 110 145 135 120 174 149 84 113 146 118 108 127 93 118 127 95 101 192 134
146 184 148 117 135 146 128 122 103 107 120 126 217 137 115 122 94 136 99 162
139 89 98 86 144 190 108 135 120 125 176 140 122 116 128 120 95 123 99 157
203 94 97 118

EXT-B04B 104
196 252 173 196 151 148 161 201 120 112 139 184 168 208 210 176 166 181 147 188
114 140 123 139 126 114 151 151 152 160 140 155 124 116 135 149 129 180 154 125
101 107 142 133 129 187 147 89 109 149 120 95 131 101 116 147 84 94 203 135
153 174 137 135 128 147 127 115 107 113 124 122 226 133 113 117 96 143 110 144
135 105 100 76 134 184 137 108 123 122 168 136 136 109 128 108 90 122 98 161
213 89 94 138
EXT-B05A 75
81 97 110 118 119 159 158 124 124 117 165 161 106 103 131 130 126 124 178 105
55 64 71 114 92 119 100 107 92 102 103 115 96 81 90 62 102 97 111 110
181 136 170 170 206 168 235 214 177 173 161 137 194 188 198 144 196 184 150 151
168 199 164 200 162 147 138 164 142 156 141 165 203 223 214
EXT-B05B 75
126 82 121 111 97 157 151 132 118 111 174 154 122 114 125 130 130 124 177 108
55 58 81 109 86 131 92 108 86 107 100 106 82 83 91 78 84 102 132 100
159 152 178 195 192 156 212 223 187 172 164 145 194 192 180 145 204 184 147 156
172 200 171 193 176 165 146 157 144 150 142 160 202 242 208
EXT-B06A 75
138 101 124 122 102 86 72 118 115 91 89 92 105 110 115 125 74 53 60 55
85 84 116 66 94 79 89 78 93 79 80 88 71 86 97 105 104 159 118 128
133 156 121 154 156 145 125 126 142 100 141 111 130 137 118 100 98 99 133 144
166 120 114 84 129 129 107 121 146 135 134 147 128 137 155
EXT-B06B 75
124 111 135 128 98 95 77 116 112 102 80 93 107 105 115 124 75 48 52 66
88 77 110 82 91 74 86 82 100 92 75 77 83 81 91 110 97 138 126 124
132 148 123 154 158 149 122 118 124 109 134 112 129 138 122 98 96 95 142 137
177 154 106 91 126 147 109 128 118 148 118 167 104 136 162
EXT-B07A 57
64 87 84 101 64 84 88 91 71 95 140 69 48 44 40 37 40 30 36 56
26 45 48 56 66 60 64 56 57 46 61 45 45 42 60 60 98 73 76 82
116 116 117 145 146 100 119 88 117 115 107 114 263 162 311 377 402
EXT-B07B 57
66 85 87 103 87 100 114 103 101 121 116 56 48 50 41 33 42 37 34 49
28 54 55 57 67 57 64 65 66 50 63 50 46 49 69 49 107 84 101 92
100 114 100 177 134 103 118 82 96 110 85 135 335 275 244 363 400
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206 150 147 135 163 137 198 223 218 197 164 176 177 177 177 183 200 186 192 165
115 120 94 122 187 147 163 155 157 129 196 117 130 126 120 110 114 108 113 113
119 132 124 166 112 129 127 129 107 78 109 143 92 109 112 116 118 146 170 149
144 118
EXT-B08B 62
193 152 138 141 154 146 203 223 219 198 171 169 178 176 177 188 205 195 207 158
92 115 101 126 169 153 155 148 160 139 198 114 130 96 128 105 115 110 107 121
121 118 133 169 130 110 131 128 102 84 106 139 96 111 108 121 101 157 167 135
126 145
EXT-B09A 71
268 277 419 217 153 83 89 99 118 129 147 187 67 73 86 78 116 71 91 95
115 86 127 149 145 168 127 127 136 136 65 55 65 142 101 169 151 103 111 159
92 110 107 125 103 95 101 141 135 155 212 161 216 133 110 85 79 130 163 170
194 154 144 157 210 185 161 182 125 132 170

EXT-B09B 71
272 275 416 166 172 83 91 101 120 144 156 214 78 55 76 72 110 78 67 102
98 82 129 150 138 163 125 110 150 133 67 42 66 139 104 154 154 92 108 149
111 99 118 116 98 90 106 134 133 154 218 172 211 129 114 85 83 122 167 171
193 157 144 145 210 200 154 177 129 128 167
EXT-B10A 85
266 217 175 104 130 184 172 210 153 146 93 127 157 133 117 122 129 109 137 77
156 183 271 194 193 220 215 173 136 190 98 132 135 180 148 201 146 206 231 206
170 199 229 171 134 120 139 296 239 199 215 172 192 154 162 139 148 135 194 175
168 119 161 152 151 142 124 132 156 136 152 153 172 117 127 128 152 135 120 181
142 108 159 154 167
EXT-B10B 85
272 220 177 113 127 182 173 210 181 134 96 131 157 130 115 126 120 114 127 70
150 179 273 188 192 209 220 187 131 189 104 120 115 174 142 191 138 220 236 204
173 199 222 167 131 127 150 324 277 194 220 164 182 153 155 137 155 144 188 186
155 131 159 167 149 144 132 138 144 139 158 173 177 106 123 116 181 135 124 175
138 114 160 152 147
EXT-B11A 84
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171 130 163 201 196 204 158 240 170 275 194 231 273 230 275 280 288 289 172 205
264 293 335 211 168 204 196 207 286 222 231 168 218 202 291 200 258 291 295 243
229 199 216 170 263 210 265 305 205 215 197 264 184 170 200 135 108 137 179 158
162 174 182 194
EXT-B11B 84
228 179 189 124 147 185 186 151 121 123 164 143 129 194 171 188 244 217 188 150
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262 301 340 205 167 212 206 204 292 228 227 179 213 204 287 201 279 279 302 232
212 220 202 170 257 235 253 297 203 218 198 250 182 168 194 132 112 139 167 166
165 177 184 189
EXT-B12A 83
182 131 135 178 170 116 117 126 129 130 113 176 146 165 218 216 162 141 151 143
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342 217 201 233 209 216 258 226 259 197 236 208 286 173 248 242 239 191 202 181
200 178 274 243 253 305 223 230 207 309 239 214 227 179 156 156 235 215 191 213
222 197 228
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186 124 140 167 171 124 114 114 120 149 118 171 140 174 228 218 165 128 158 138
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199 171 280 244 271 297 233 211 209 310 231 213 226 160 145 160 245 207 202 214
228 207 222
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137 161 155 150 146 137 224 216 170 135 162 147 160 171 170 161 161 127 167 150
145 124 122 114 123 134 125 171 157 129 159 164 172 234 141
EXT-B13B 55
161 167 224 217 171 179 159 160 147 162 159 138 121 115 122 199 198 158 197 177
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150 122 125 110 126 135 117 180 153 126 159 182 175 136 228

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242 149 282 261 286 319 170 185 282 196 212 288 125 214 233 310 190 208 172 244
207 161 229 310 298 210 271 326 201 281 281 227 150 92 118 161 155 183 159 80
76 100 137 154 127 129 92 82 128 108 100 94 102 110 110 112 141 144 166 121
122 163 147 109 97 119 179 121 126 79 101 116 135 134 124
EXT-B14B 95
294 212 171 149 239 269 306 186 271 256 193 210 186 193 194 180 155 197 260 234
220 143 266 258 282 329 190 191 281 189 199 290 131 227 225 309 180 199 170 235
212 166 223 312 300 216 274 319 198 290 290 231 152 84 124 159 146 182 140 86
70 104 136 156 128 132 93 82 137 109 97 94 101 107 121 112 133 141 166 124
128 165 146 118 100 117 173 125 132 70 103 121 133 140 127
EXT-B15A 47
413 389 444 610 443 300 361 322 301 285 280 276 269 337 390 367 376 262 197 251
264 294 225 275 244 231 267 313 256 235 226 226 274 255 322 242 323 276 250 172
214 224 344 276 270 249 234
EXT-B15B 47
400 383 439 616 444 286 365 323 302 280 280 289 276 341 400 372 366 264 200 251
266 296 233 274 260 237 259 320 254 237 232 217 274 262 319 250 316 284 246 171
206 230 347 273 281 250 199
EXT-B16A 72
114 279 249 311 199 205 159 281 239 200 195 244 222 174 148 197 194 283 272 243
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123 140 170 142 145 176 116 86 139 125 140 137 122 143 224 147 133 89 123 122
158 154 124 119 164 150 123 114 90 72 62 81
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129 261 226 316 207 204 168 272 245 184 194 247 220 173 145 202 231 288 267 246
140 101 140 177 150 167 121 154 121 218 274 253 204 248 148 119 210 164 121 115
127 144 167 140 152 179 110 90 136 123 137 138 121 137 218 143 138 94 124 118
168 155 125 119 167 151 126 111 95 69 64 93
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112 245 221 251 211 143 129 164 147 180 234 154 149 184 238 138 146 132 195 165
154 250 288 310 184 153 194 185 274 241 200 137 112 159 178 126 184 122 79 73
169 170 165 131 136 77 75 104 99 77 105 103 102 110 115 121 154 116 94 112
129 120 114 94 128 224 189 167 105 133 144 116 132 123 172
EXT-B17B 63
203 127 331 264 236 324 170 209 295 242 253 238 144 199 239 334 223 269 193 314
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144 147 162
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319 218 234 291 273
EXT-B19B 65
185 161 152 197 134 112 104 134 239 189 167 155 197 198 211 223 244 252 584 429
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65 95 62 66 72 84 83 110 85 88 81 130 123 116 137 89 77 55 91 130
135 92 180 92 124 168
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146 172 182 110 102 285 181 105 170 109 85 70 59 55 52 54 50 79 53 91
83 64 87 98 88 71 51 80 93 167 209 65 126 143 102 128 122 86 72 54
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123 106 179 101 128 162
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88 87 106 67 79 92 72 110 131 119 141 113 134 123 130 151 164 101 82 107
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124 89 93 96 207 130 184 172 217 282
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182 242 219 164 141 177 188 273 256 300 367 252 234 217 244 203 232 245 200 137
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EXT-B23A 152
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92 94 100 98 110 70 93 91 75 89 66 55 79 111 56 48 66 71 86 88
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74 83 55 60 70 90 70 78 64 59 82 95 63 51 61 61 70 67 55 70
70 70 70 61 55 66 60 58 50 55 50 75
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337 277 281 200 345 301 232 271 180 212 185 201 167 190 171 151 184 197 191 156
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103 102 90 96 102 132 90 98 98 100 68 57 72 87 86 100 90 99 51 80
68 100 105 119 92 59 58 59 51 38 33 30 49 39 58 69 70 47 55 64
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88 68 55 59 78 86 75 81 59 59 82 72 59 53 57 68 73 66 62 71
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97 102 110 128 116
EXT-B24B 106
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67 66 71 61 52 61 98 65 45 51 54 75 88 60 74 48 115 91 66 81
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53 73 95 108
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154 235 234 152 166 132 138 260 177 203 150 81 47 52 116 89 56 58 62 50
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56 68 82 119
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70 119 112 143 117 103 110 145 152 94 106 103 75 61 83 77 104 148 271 245
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127 119 121 123 135 107 93 97 98 123 118 88 64 82 106

EXT-B26B 95
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264 171 244 221 160 200 228 200 124 119 157 109 190 273 259 217 153 191 148 156
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135 109 118 123 128 114 82 80 108 108 123 91 69 77 103
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218 183
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213 193 241 204 156 175 132 127 121 143 145 141 129 95 79 74 181 118 184
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308 432 336 377 271 232 168 285 277 216 180 173 353 308 268 291 271 491 383 329
406 303 368 401 353 275 297 307 339 362 343 307 337 341 327 247 308 250 300 386
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EXT-B30B 76
428 226 349 302 327 287 294 330 202 187 276 360 292 342 221 291 371 301 182 114
315 432 328 377 266 238 183 290 249 198 172 161 365 328 263 287 274 463 433 314
398 287 355 400 348 275 298 328 340 333 353 313 343 339 310 259 309 237 295 393
275 297 300 259 267 321 273 270 261 207 260 203 242 266 221 239

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.

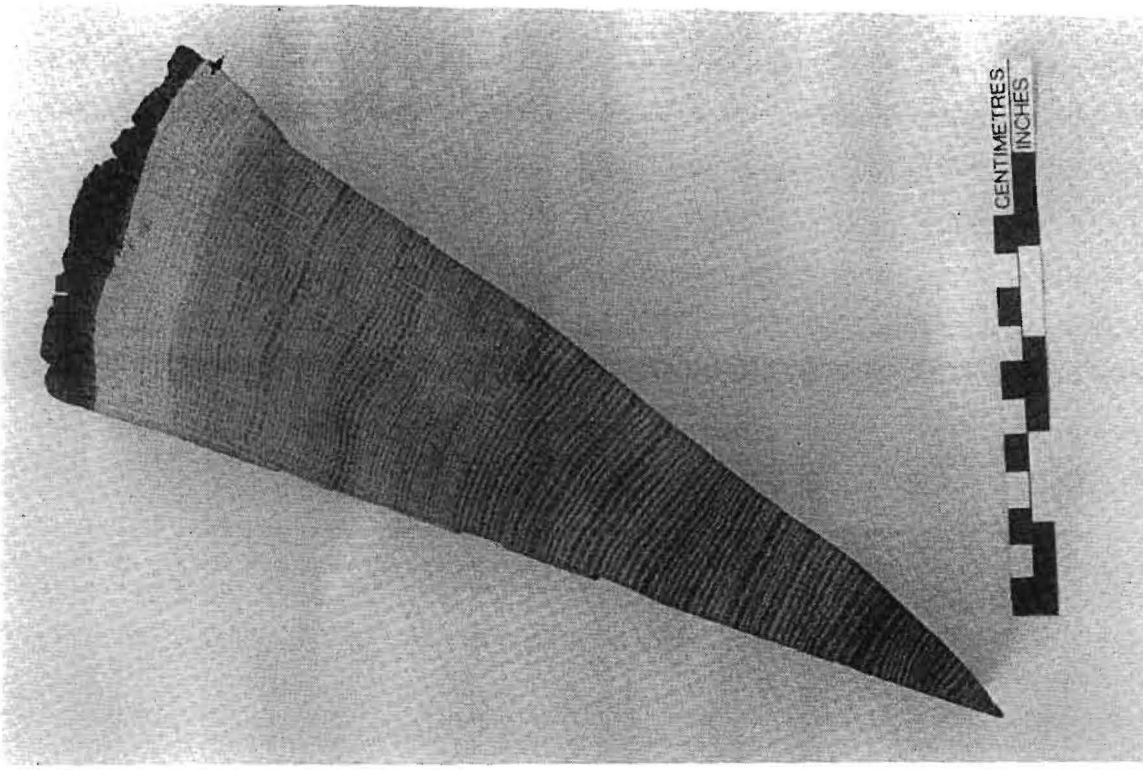

Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

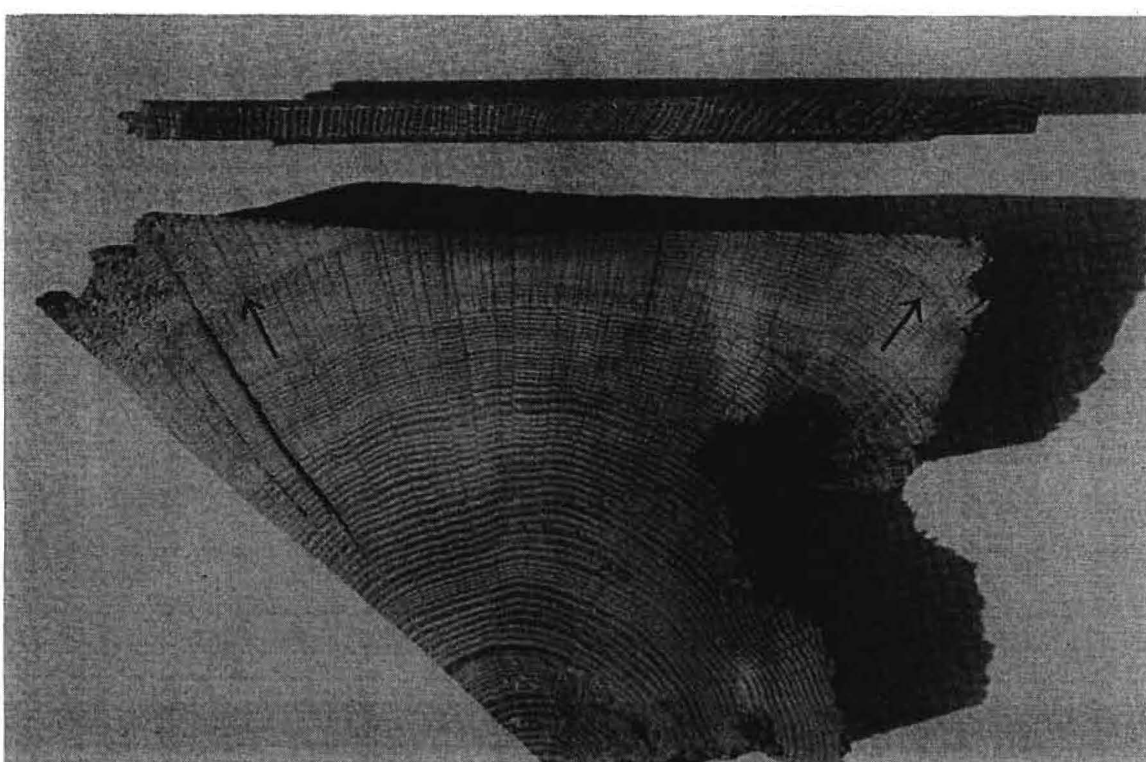

Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners; the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

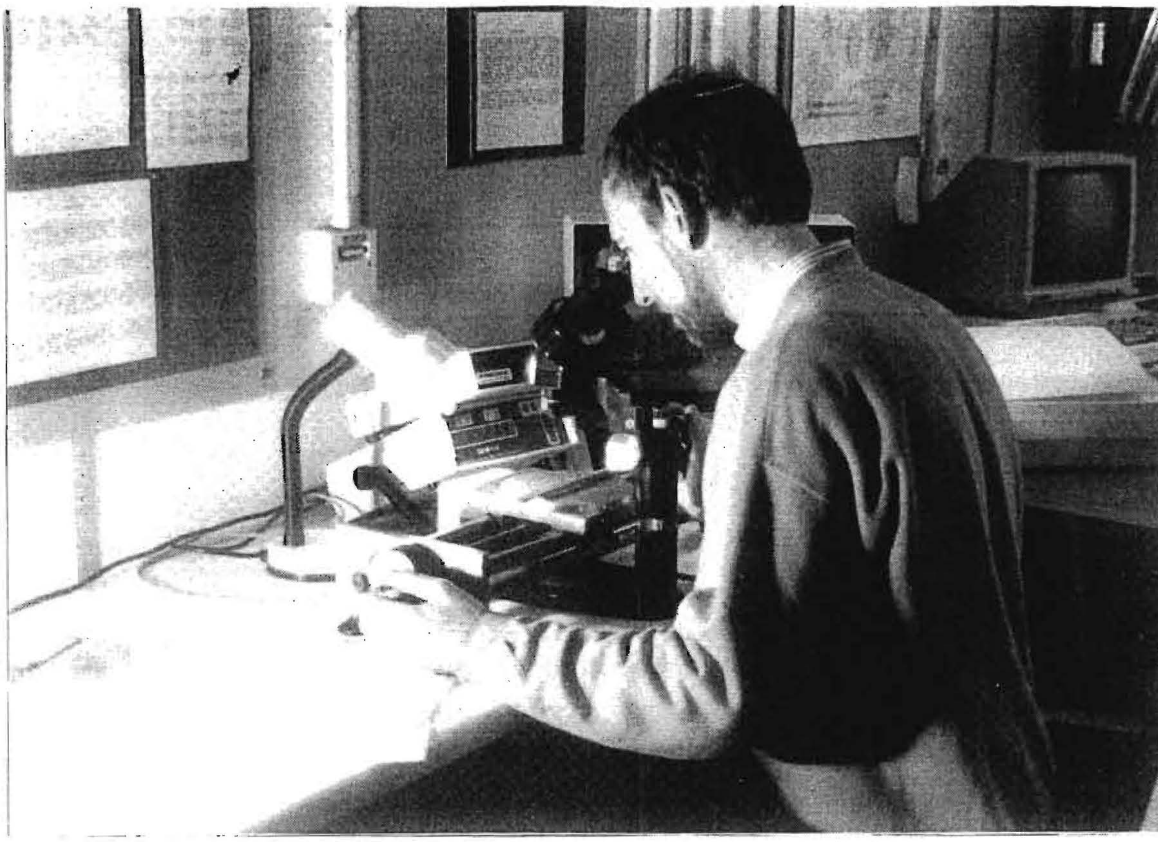

Fig 3. Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measured twice to ensure that an error has not been made. This type of apparatus is needed to process a large number of samples on a regular basis.

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.

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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

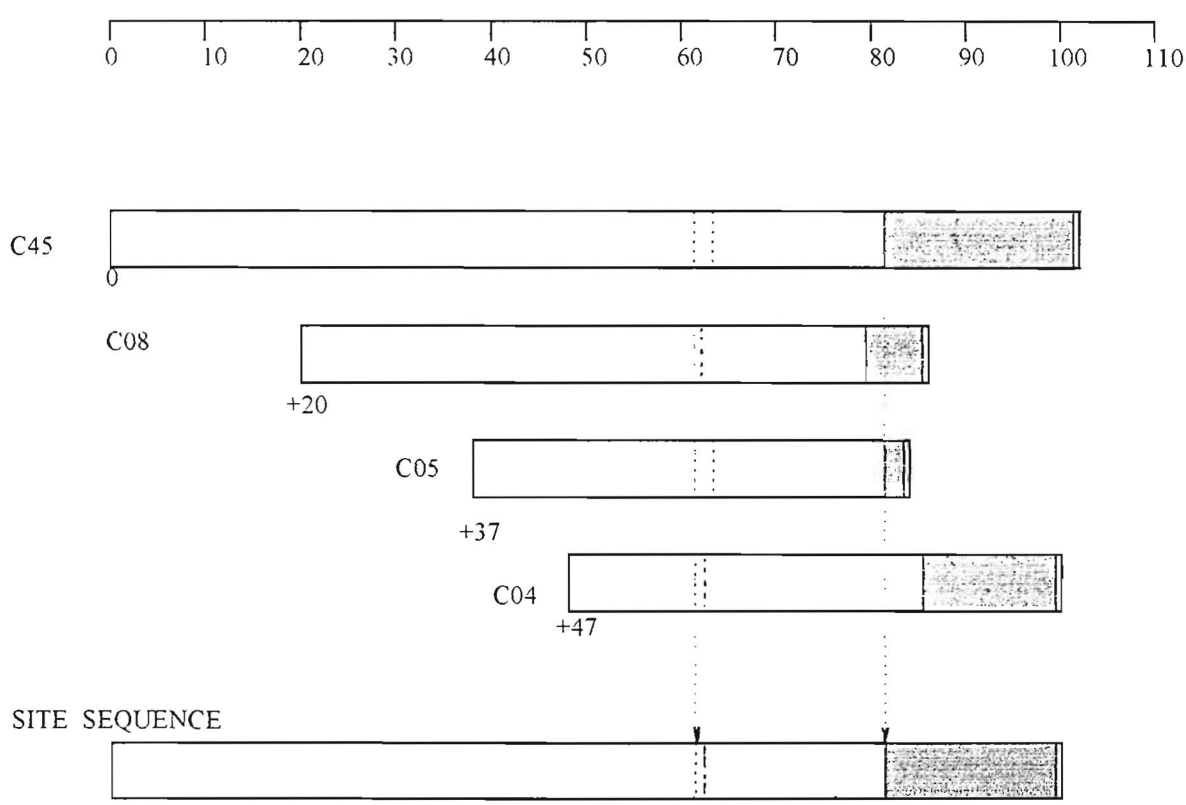

Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.
The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set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

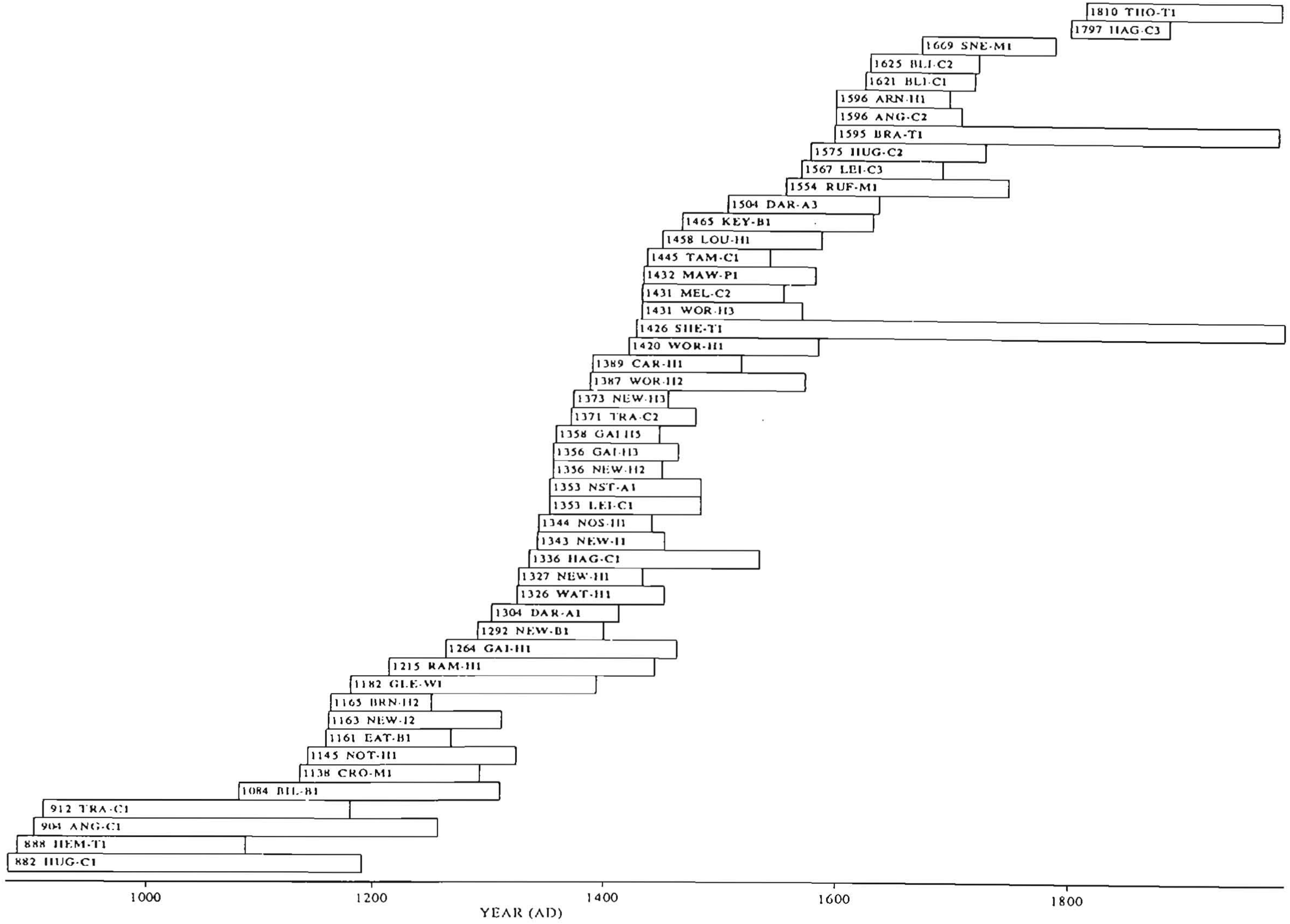

Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

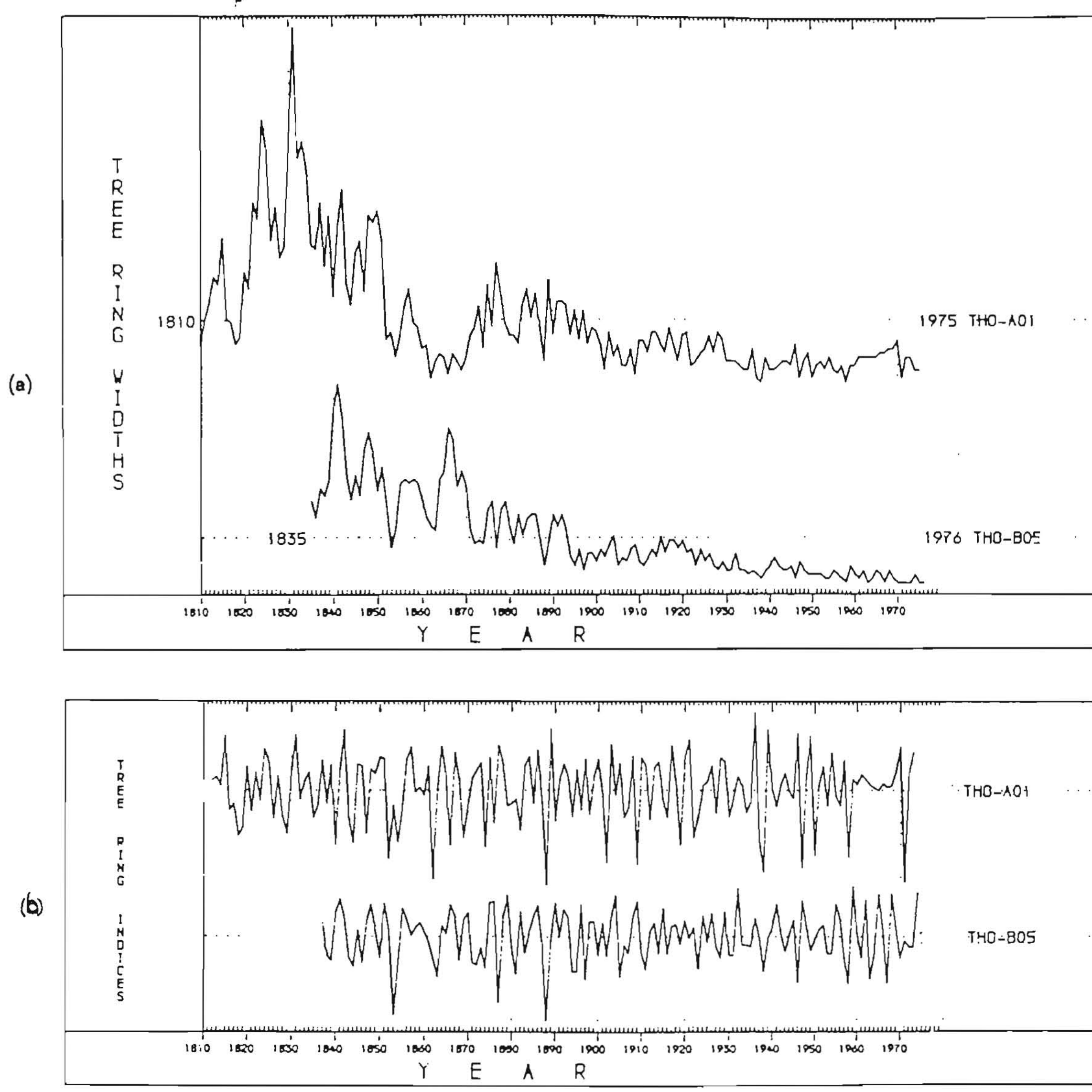

Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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