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MANOR FARM BARN, KINGSTON DEVERILL, WILTSHIRE
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Cathy Tyers, Matt Hurford, and Martin Bridge

INTERVENTION
AND ANALYSIS

ENGLISH HERITAGE

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SUMMARY

Dendrochronological analysis was undertaken on 16 samples from the barn at Manor Farm. This resulted in the production of two site sequences, KDMBSQ01 and KDMBSQ02. The former comprises eight samples with an overall length of 150 rings and the latter two samples with an overall length of 81 rings. Site sequence KDMBSQ01 is dated as spanning the years AD 1260–1409. Site sequence KDMBSQ02 is undated. A single sample, KDM-B09, with an overall length of 113 rings is dated as spanning the years AD 1371–1483. Five samples remain ungrouped and undated.

The results indicate that the timbers used in the primary construction of the barn were probably all felled in the last few years of the first decade of the fifteenth century. A single dated arcade post from the southernmost truss indicates that the building underwent repairs or modifications just under a century later, in the last few years of the fifteenth century or, the first few years of the sixteenth century.

CONTRIBUTORS

Cathy Tyers, Matt Hurford, and Martin Bridge

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The laboratories would like to thank Mr Stratton for giving permission to undertake the work. Thanks are also due to Avis Lloyd for arranging access and for supplying additional background material on the building. The drawings were provided by Nigel Fradgley of English Heritage. The dendrochronological work was funded by the English Heritage Scientific Dating Team and coordinated by Peter Marshall.

ARCHIVE LOCATION

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INTRODUCTION

In 2009 the Wiltshire Buildings Record (WBR) successfully obtained support through the English Heritage Historic Environment Enabling Programme for their project 'Wiltshire cruck buildings and other archaic roof types'. The detailed aims and objectives of the project are set out in the Project Design (Lloyd 2009). The overall aim was to establish a typological chronology of archaic roof types and hence elucidate the development of carpentry techniques in the county. This would then facilitate detailed comparison with other counties allowing Wiltshire to be placed in a regional context. Investigation of these late medieval buildings (*c* AD 1200 – *c* AD 1550) combined building survey, historical research, and dendrochronological analysis.

A series of 25 buildings identified by the WBR as having the potential to contribute to the aims and objectives of the project was assessed for dendrochronological suitability during 2009. In order to maximise the potential for dating, these detailed dendrochronological assessments and the WBR assessments of the significance of each building informed the final selection of buildings subsequently subjected to detailed study.

A single final Project Report produced by Lloyd (2012) summarises the overall results. However each building included in the project has an associated individual report produced by the WBR, whilst the primary archive of the dendrochronological analysis is the English Heritage Research Report Series.

A brief introduction to dendrochronology can be found in the Appendix. However further details can be found in the guidelines published by English Heritage (1998), which are also available on the English Heritage website (http://www.english-heritage.org.uk/publications/dendrochronology-guidelines/).

Manor Farm barn

Manor Farm is located on the south-east fringe of the village of Kingston Deverill to the south of the River Wylye and north of the B3095 (Fig 1). The Grade II* listed barn is situated in the western part of the farmyard and is on a broadly north-south axis (Fig 2). Stylistically the barn is thought to date to the early fifteenth century.

The following information is from the WBR report (2012) and the Listed Building Entry. The barn is approximately 28 metres long by 9 metres wide and comprises seven bays. Although the barn is clad in later wooden horizontal boards much of the original timber-framing survives (Figs 3, 4, and 5). The extant porch, or cart entrance, located on the east elevation is a later replacement of the original medieval entrance, probably of early eighteenth-century date and is itself flanked by nineteenth-century lean-to structures. The opposing west entrance is now blocked. The barn incorporates both base cruck trusses and post-and-aisle trusses, whilst the end bays were formerly partially hipped. The consistency of the carpentry details throughout the main barn indicates that it was the product of a single phase of construction.

Trusses 4 and 5 are base crucks (Figs 4 and 6). On the east side of the barn, the feet of the cruck blades rest on chalk padstones, whilst on the west side they are embedded in the stone plinth. The blades rise to a wall plate and slightly cambered tiebeams. Arch braces rise from springings formed from the timber of the blades. There is a ridge purlin and a single row of purlins, and originally there were two tiers of windbraces, as there were throughout the barn.

Trusses 2, 3, 6, and 7 are post-and-aisle trusses. The arcade posts are set on padstones and are slightly jowled. Curved braces rise from the arcade posts to the tiebeam. Above this the arrangement of principals, purlins, collar, and ridge purlin are broadly the same as the base cruck trusses. An unusual feature of these trusses is that they utilise cruck timbers that rise from the aisle plinth to the arcade plate. These timbers have empty mortices which formerly housed a mid-rail that is no longer extant. Trusses 1 and 8 at either end of the barn are of similar construction but the tiebeams receive the hip timbers.

SAMPLING

Dendrochronological sampling and analysis of oak (*Quercus* spp) timbers associated with the barn at Manor Farm was commissioned by English Heritage. It was hoped to provide independent dating evidence for the initial construction of the barn and hence inform the overall objectives of the 'Wiltshire cruck buildings and other archaic roof types' project. The dendrochronological study also formed a key component of the English Heritage-funded training programme for the second author, although the reporting was not completed within the duration of the training programme.

Sampling, undertaken by trainee Matt Hurford and supervised by Martin Bridge, was restricted to tiebeam level or below, due to safely issues. The sampling undertaken encompassed as wide a range of elements at this lower level as possible, whilst focussing on those timbers with the best dendrochronological potential. Timbers rejected as containing too few growth rings for reliable analysis included three of the four cruck blades, which were noticeable for their extremely fast-grown nature with only the most promising one of these being sampled. During sampling it was also noted that many of the timbers above tiebeam level were of either borderline suitability or clearly unsuitable for reliable analysis.

A total of 16 oak timbers associated with the medieval timber-framing of the barn were sampled by coring. Each sample was given the code KDM-B (for Kingston Deverill, Manor Barn) and numbered 01–16. The location of the samples was noted at the time of coring and marked on the drawings provided by Nigel Fradgley, these being reproduced here as Figures 6 to 12. It should be noted that the trusses illustrated in Figures 7–12 are based on only a single representative of each main truss type and hence do not show any variation within each truss type. Further details relating to the samples can be found in Table 1. In this table the timbers have been located and numbered following the scheme on the drawings provided.

ANALYSIS AND RESULTS

Each of the 16 samples obtained was prepared by sanding and polishing. The measurement and analysis was undertaken using a combination of software written by Tyers (2004a) and the Litton/Zainodin grouping procedure (see Appendix). Tyers (2004a) facilitates cross-matching and dating through a process of qualified statistical comparison and visual comparison. It uses a variant of the Belfast CROS programme (Baillie and Pilcher 1973).

The analysis resulted in two groups being formed, the samples of each group cross-matching with each other as shown in Tables 2 and 3 and Figures 13 and 14. The individual series in each group were combined to produce two site chronologies, KDMBSQ01 and KDMBSQ02. Both site chronologies were compared to an extensive range of reference chronologies for oak, this indicating repeated cross-matching for KDMBSQ01 when the date of its first ring is AD 1260 and the date of its last ring is AD 1409 (Table 4). No conclusive cross-matching was identified for KDMBSQ02, so this chronology remains undated.

The two site chronologies were compared with the remaining six ungrouped samples but there was no further satisfactory cross-matching. Each of these ungrouped samples was then compared individually with the reference chronologies, this indicating repeated cross-matching for KDM-B09 when it spanned AD 1371–1483 (Table 5).

The analysis can be summarised as follows:

Site chronology/sample	Number of samples	Number of rings	Date span (where dated)
KDMBSQ01	8	150	AD 1260–1409
KDMBSQ02	2	81	undated
KDM-B09	1	113	AD 1371–1483
KDM-B07, KDM-B10, KDM-B14–16	5	---	undated

INTERPRETATION

Two of the samples in site chronology KDMBSQ01 had retained a full complement of sapwood (Fig 13). Sample KDM-B11 appears to have a complete ring for AD 1409, thus suggesting that it was felled during the winter of AD 1409/10. However the highly variable growth (see below) combined with only fragmentary survival of the outer edge of sample KDM-B08 means that it is difficult to determine the season of felling. The outermost ring of KDM-B08 has spring vessels and some summer growth and hence could have been felled as early as summer AD 1408 or as late as early spring AD 1409.

A further three samples in site chronology KDMBSQ01 were taken at a point where bark edge did survive on the timbers but due to the fragile nature of the sapwood this did not survive coring intact (Fig 13). The amount of sapwood lost was in each case estimated in millimetres in order to allow an approximate felling date to be calculated. This estimate is based on the overall average ring width of the relevant sample rather than that of the outer few rings as in this instance the material shows highly variable growth patterns with no overall marked decrease in growth with age. It is therefore estimated that KDM-B03 was felled *c* AD 1408, KDM-B04 was felled *c* AD 1407, and KDM-B06 was felled *c* AD 1408.

Two of the three remaining samples in site chronology KDMBSQ01 have retained their heartwood/sapwood boundary ring (Fig 13), the average date for this being AD 1380. For consistency the sapwood estimate used in all of the dendrochronological reports on individual buildings within this project is the Nottingham Tree-ring Dating Laboratory estimate of 15–40 (95% confidence rings). This is used to calculate felling date ranges for samples with incomplete sapwood or felled-after dates for samples which are heartwood only. Thus an estimated felling date range of AD 1395–1420 is obtained for these two timbers. The remaining sample has no trace of sapwood thus, by applying the above sapwood estimate, the earliest likely felling date is AD 1371.

All of the dated samples in site chronology KDMBSQ01 are broadly coeval and appear likely to represent a single programme of felling in the latter years of the first decade of the fifteenth century.

Site sequence KDMBSQ02 could not be dated. However, the position of the heartwood/sapwood boundary ring on each sample is within five years (Fig 14) suggesting that they were likely to be part of the same programme of felling.

The individually dated sample, KDM-B09, was also taken at a point where the bark edge did survive on the timber but due to the fragile nature of the sapwood this did not survive coring intact (Fig 13). The sapwood lost comprises a segment containing eight rings plus a further *c* 5mm. This, therefore, accounts for a total of *c* 13 lost sapwood rings. However, it is possible that a small number of rings were lost at the break between the main core and the sapwood segment. Hence, an estimated felling date of *c* AD 1496–1505 is obtained.

DISCUSSION AND CONCLUSION

Tree-ring analysis of the samples from the barn at Manor Farm has demonstrated that all but one of the nine dated timbers were probably felled in the latter few years of the first decade of the fifteenth century with construction therefore likely to have occurred at around the turn of that decade. This therefore supports the early fifteenth-century date indicated on stylistic evidence. Only one timber, a tiebeam, from the base-cruck trusses was dated, but this does demonstrate that the base cruck trusses are likely to be coeval with the post-and-aisle trusses. It is unfortunate that none of the cruck blades from the central two trusses could be dated. However the sampled cruck blade serves to demonstrate the different nature of the timbers employed as cruck blades compared with the rest of the sampled timbers. KDM-B10 contained only 46 rings and yet with an average ring width of 6.98mm was one of the largest timbers found in the barn, with only the other cruck blades showing similar characteristics with respect to size and rate of growth. The trees capable of providing such cruck blades may well have been selected from a slightly different source than the rest of the timbers, one with a more open canopy such as towards the edge of woodland or parkland or hedgerow environments. However, the dendrochronological results combined with the integral nature of the overall structure strongly imply that the barn was the product of a single phase of construction.

A single timber, the east arcade post of truss 8, has been identified as being felled approximately a century later. This may simply be a single replacement timber, but it could represent more widespread alterations to the south end of the barn. Reappraisal of the structural evidence for intervention at this end of the barn may provide clarification.

The undated site sequence KDMBSQ02 comprises the two arcade posts from truss 1 at the north end of the barn. Whilst these are clearly coeval with each other it is not possible to ascertain from the dendrochronological analysis whether they are part of the initial construction of the barn or whether they also represent later alterations. Their overall characteristics are not obviously different from the primary construction material so it may simply be that they are derived from a slightly different woodland source to the dated material rather than being of a different date. Again reassessment of the structural evidence for any potential anomalies may lead to further clarification.

Site chronology KDMBSQ01 and the individually dated sample generally produce the highest *t*-values, and thus show the greatest degree of similarity, with reference chronologies from the surrounding region (Tables 4 and 5). This suggests that it is likely that the timbers were derived from relatively local woodland sources.

Five samples remain ungrouped and undated. Two of these samples, KDM-B07 and KDM-B15 have no obvious growth abnormalities which would hamper successful cross-matching and dating. However, the remaining samples, along with those in site sequence KDMBSQ02, do show highly variable growth patterns, including abrupt declines and surges in growth rate. Overall, the sampled assemblage does show a wide range in level of sensitivity (a measure of the year-to-year variation in ring width) for oak timbers ranging from 0.14 (KDM-B15) to 0.30 (KDM-B14) indicating a level of disturbance to growth within the assemblage that will have an adverse effect on both cross-matching and dating. The possible causes of growth disturbances include anthropogenic, local environmental, and general environmental effects. Causal factors include management regimes or at least some form of human intervention, such as pollarding or shredding, localised defoliation by pests, or more general environmental effects such as severe weather conditions (eg drought and late frosts). Unfortunately no definitive answer can be provided from the tree-ring analysis.

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TABLES

Table 1: Details of tree-ring samples from Manor Farm barn, Kingston Deverill, Wiltshire

Sample number	Sample location	Total rings	Sapwood rings	Average ring width (mm)	Cross-section dimensions (mm)	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
KDM-B01	Truss 1 west arcade post	67	6	1.56	200x350	----	----	----
KDM-B02	Truss 1 east arcade post	81	5	2.33	190x330	----	----	----
KDM-B03	Truss 2 east wall cruck post	109	13c (*c* 15mm sap lost)	2.03	190x260	1293	1388	1401
KDM-B04	Truss 2 west arcade post	120	8c (*c* 15mm sap lost)	1.48	330x330	1278	1389	1397
KDM-B05	Truss 3 west arcade post	122	h/s	1.95	330x330	1260	1381	1381
KDM-B06	Truss 6 east wall cruck post	64	11c (*c* 5mm sap lost)	2.25	190x260	1343	1395	1406
KDM-B07	Truss 6 west arcade post	61	h/s	2.00	310x330	----	----	----
KDM-B08	Truss 7 east arcade post	108	16C[1]	1.83	310x320	1301	1392	1408
KDM-B09	Truss 8 east arcade post	113	h/sc (*c* 8 unmeasured sap rings and *c* 5mm sap lost)	1.08	160x270	1371	1483	1483
KDM-B10	Truss 4 west cruck	46	h/s	6.98	310x370	----	----	----
KDM-B11	Bay 5 east arcade plate	126	31C[2]	1.43	220x250	1284	1378	1409
KDM-B12	Truss 5 tiebeam	57	no h/s	2.19	250x310	1305	----	1361
KDM-B13	Truss 3 tiebeam	84	h/s	1.68	250x310	1296	1379	1379
KDM-B14	Bay 3 brace from truss 3 east arcade post to arcade plate	67	h/s	1.41	210x210	----	----	----
KDM-B15	Bay 3 east arcade plate	51	h/s	2.67	210x260	----	----	----
KDM-B16	Truss 4 east arch brace from cruck to tiebeam	86	h/s	2.51	140x270	----	----	----

h/s = the heartwood/sapwood ring is the last ring on the sample
c=complete sapwood was present on the timber but a portion of the sapwood was lost during coring
C=complete sapwood is retained on the sample
[1] = felling season indeterminate
[2] = outermost measured ring appears to be fully formed indicating winter felling

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Table 2: Matrix showing the t-values obtained between the ring sequences in site chronology KDMBSQ01; - indicates t-values less than 3.00; \ indicates overlap of less than 30 years

	kdm-b04	kdm-b05	kdm-b06	kdm-b08	kdm-b11	kdm-b12	kdm-b13
kdm-b03	4.80	3.73	-	5.85	3.33	4.30	-
kdm-b04		4.17	-	5.61	6.70	5.17	4.81
kdm-b05			-	3.69	-	4.52	3.45
kdm-b06				7.60	3.16	\	-
kdm-b08					3.05	8.00	3.96
kdm-b11						3.37	-
kdm-b12							3.53

Table 3: Matrix showing the t-value obtained between the ring sequences in site chronology KDMBSQ02

	kdm-b02
kdm-b01	7.71

Table 4: Results of the cross-matching of site sequence KDMBSQ01 and relevant reference chronologies when the first-ring date is AD 1260 and the last-ring date is AD 1409

Reference chronology	t-value	Span of chronology	Reference
Devizes Castle, Devizes, Wiltshire	8.6	AD 1213–1407	Miles *et al* 2006
Old Rectory, Withington, Gloucestershire	6.6	AD 1252–1429	Howard *et al* 1998
Lodge Farm, Kingston Lacy, Dorset	6.4	AD 1248–1399	Groves 1994
Winchcombe Abbey House, Winchcombe, Gloucestershire	6.2	AD 1250–1499	Arnold *et al* 2008a
Lacock Abbey, Lacock, Wiltshire	6.2	AD 1292–1441	Esling *et al* 1990
George Inn, Norton St Philip, Somerset	6.2	AD 1258–1457	Miles and Worthington 1998
St Brannock Church, Braunton, Devon	6.2	AD 1215–1378	Tyers 2004b
Old Manor, West Lavington, Wiltshire	6.1	AD 1264–1497	Tyers and Hurford 2014

Table 5: Results of the cross-matching of sample KDM-B09 and relevant reference chronologies when the first-ring date is AD 1371 and the last-ring date is AD 1483

Reference chronology	t-value	Span of chronology	Reference
Bremhill Farm barn, Bremhill, Wiltshire	6.9	AD 1353–1484	Alcock *et al* 1991
George Inn, Norton St Philip, Somerset	6.5	AD 1290–1509	Miles and Worthington 1998
Chawton House, Chawton, Alton, Hampshire	6.5	AD 1289–1589	Miles and Worthington 2002
Abbots Lodge, Ledbury, Herefordshire	6.3	AD 1274–1519	Arnold *et al* 2008b
Old Manor, West Lavington, Wiltshire	6.2	AD 1264–1497	Tyers and Hurford 2014
Roscarrock, near Port Isaac, Cornwall	6.2	AD 1373–1500	Tyers 2004c
Old Post Office, Luccombe, Somerset	6.1	AD 1380–1436	Miles *et al* 2003
Holy Cross Church, Crediton, Devon	5.9	AD 1317–1536	Tyers 2004d

FIGURES

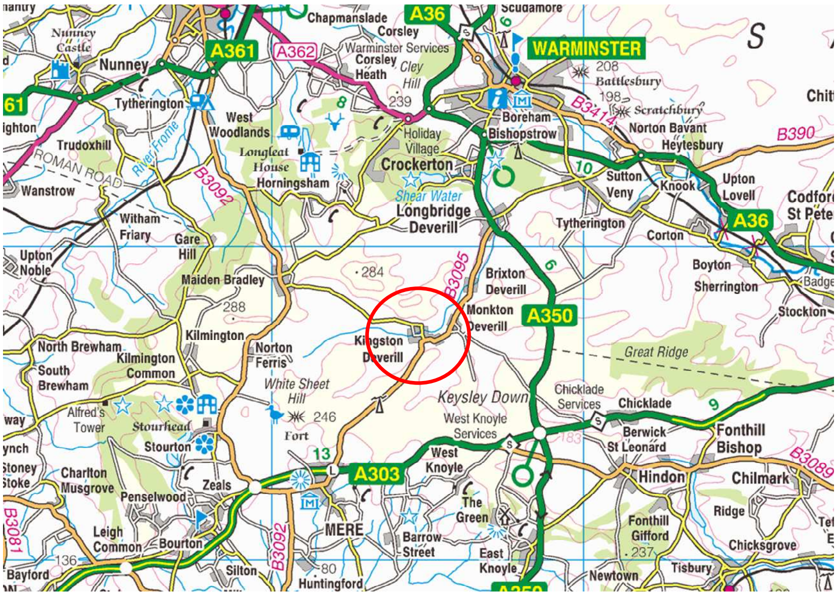

Figure 1: Map to show the location of Kingston Deverill, Wiltshire. © Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900

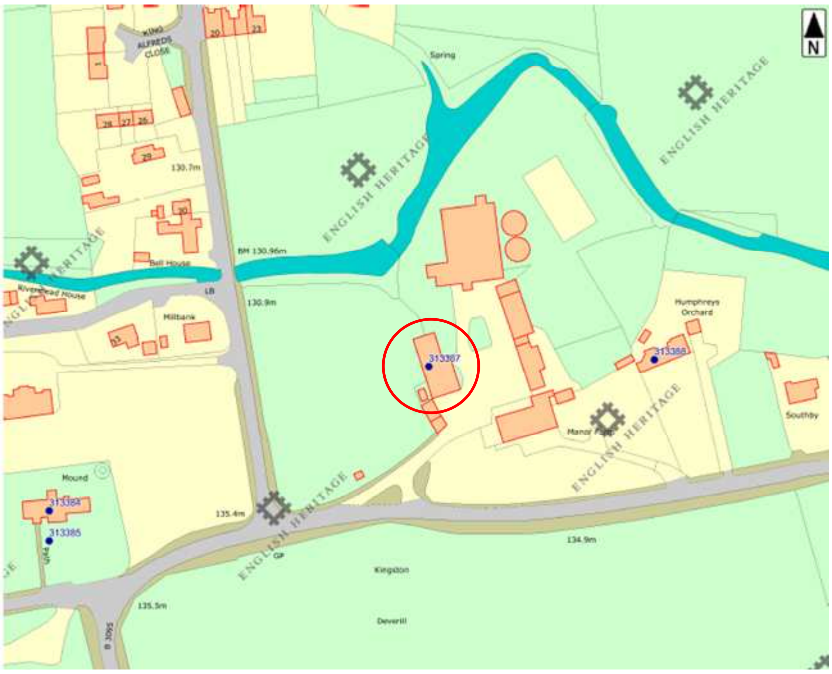

Figure 2: Map to show the location of the barn within the farmyard at Manor Farm, Kingston Deverill. © Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900

Figure 3: General view of the barn viewed looking north-west (photo Matt Hurford)

Figure 4: Truss 5 viewed looking south-west (photo Matt Hurford)

Figure 5: General view through the barn stood at Truss 2 viewed looking north (photo Matt Hurford)

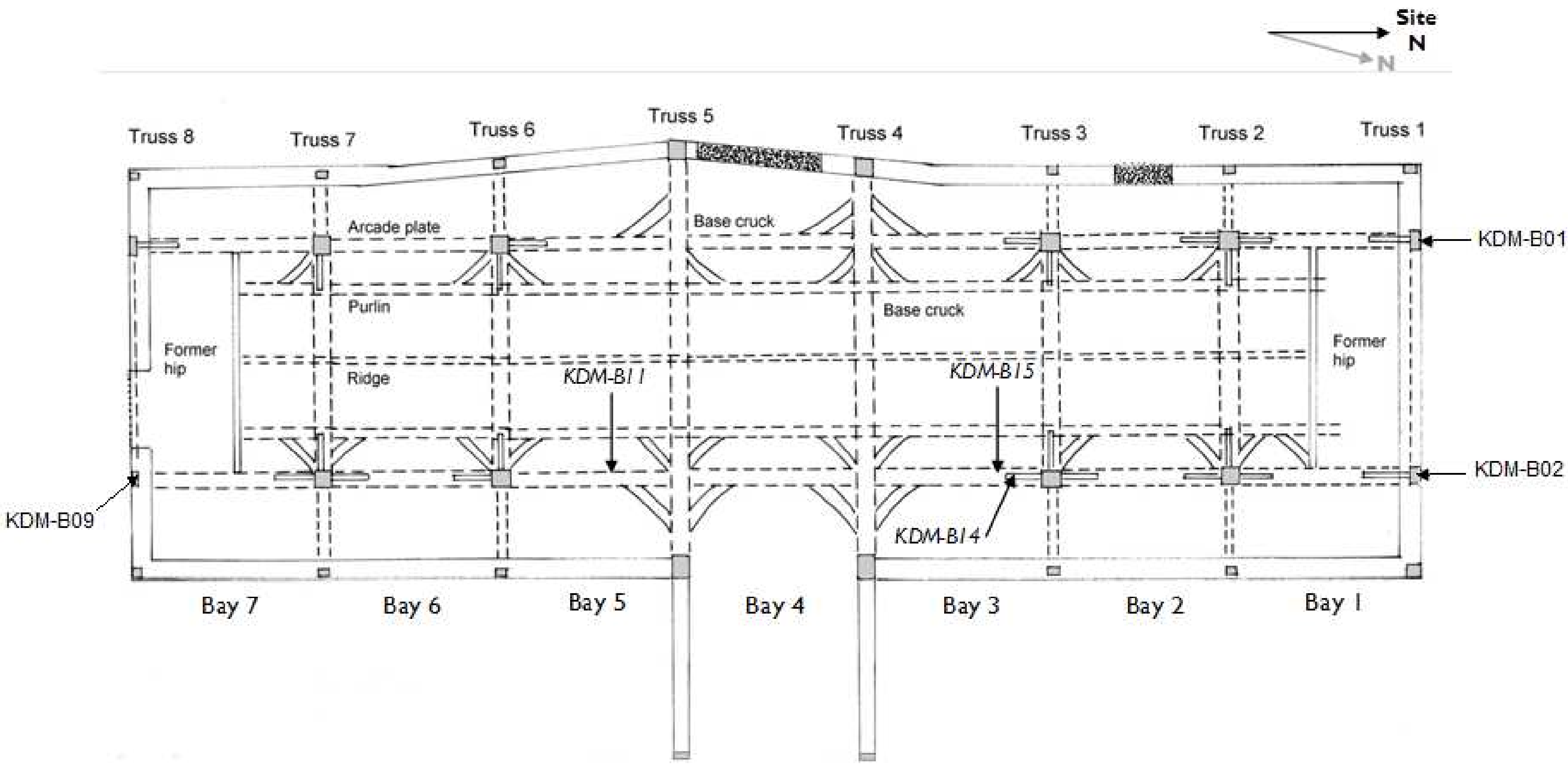

Figure 6: Plan showing the truss numbering scheme and the location of the samples (based on a drawing by P Filtness)

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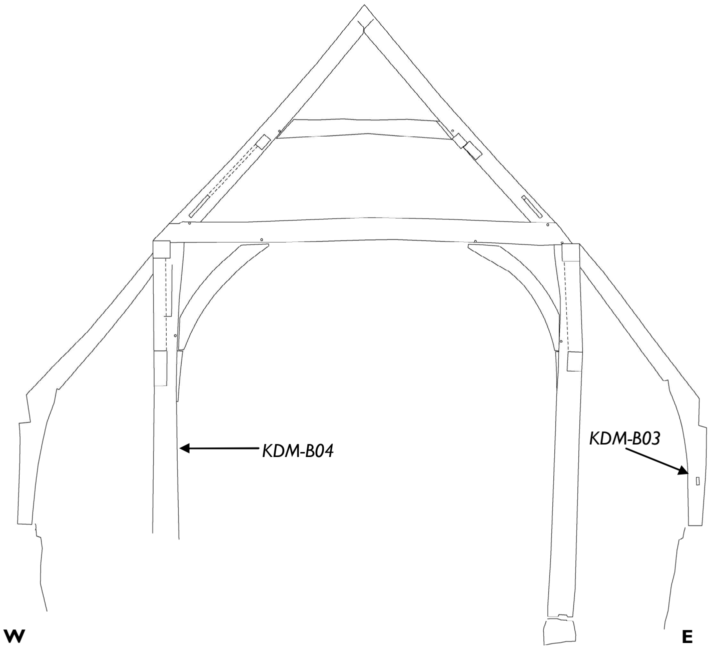


Figure 7: Truss 2 sample locations viewed looking north (based on a drawing by Nigel Fradgley of English Heritage)

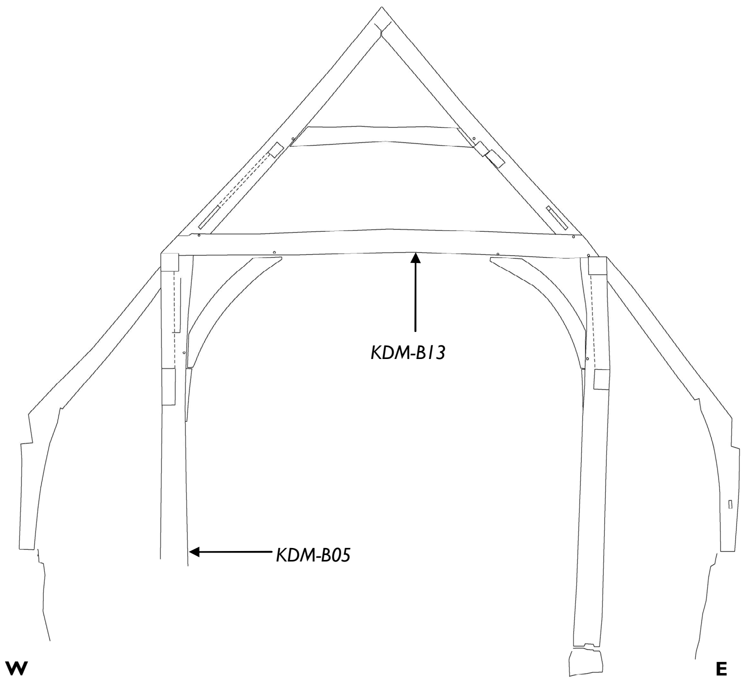


Figure 8: Truss 3 sample locations viewed looking north (based on a drawing by Nigel Fradgley of English Heritage)

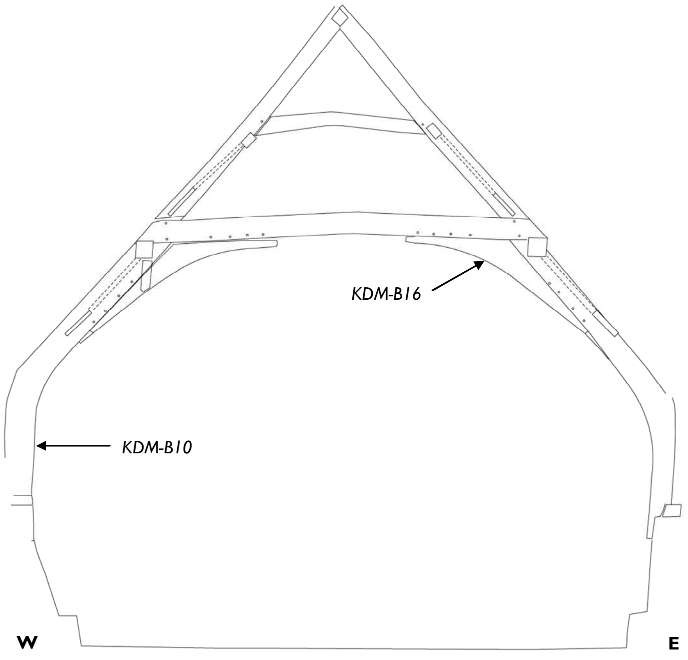


Figure 9: Truss 4 sample locations viewed looking north (based on a drawing by Nigel Fradgley of English Heritage)

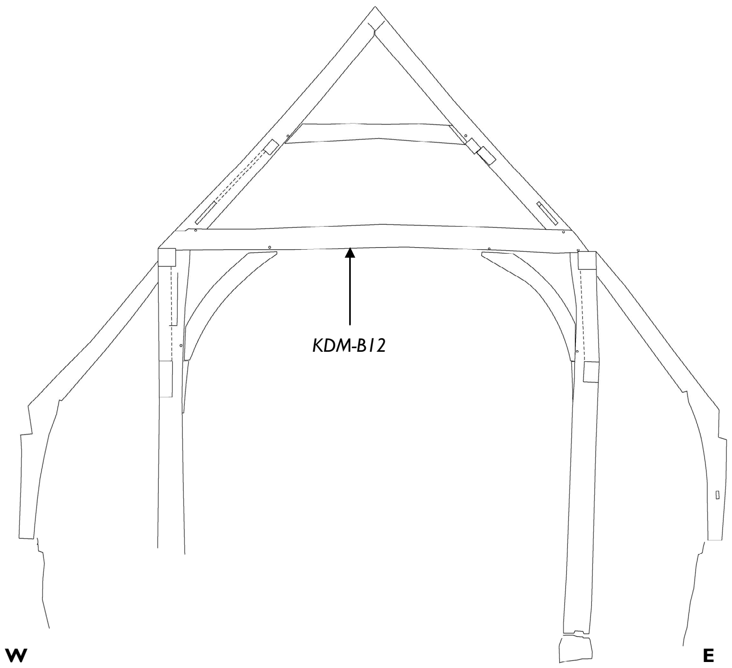


Figure 10: Truss 5 sample locations viewed looking (based on a drawing by Nigel Fradgley of English Heritage)

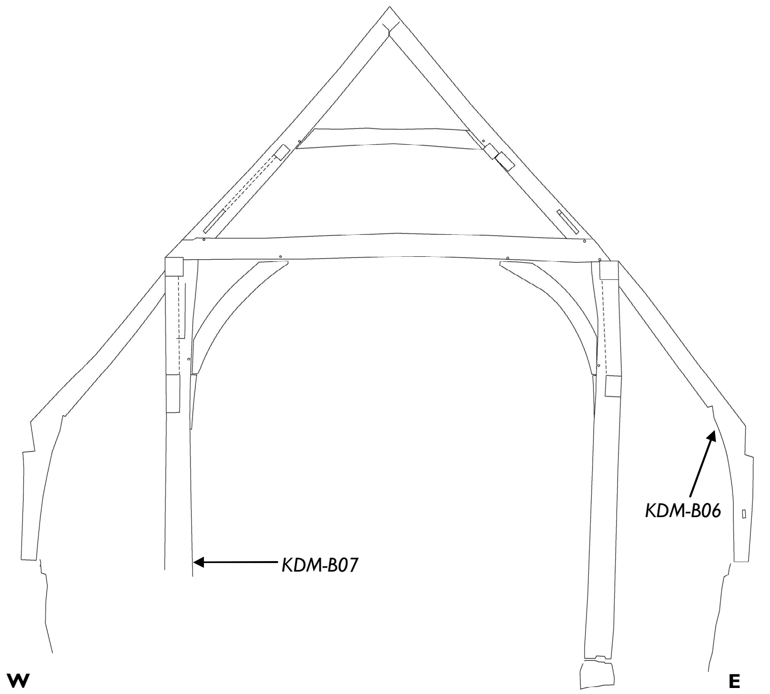


Figure 11: Truss 6 sample locations viewed looking north (based on a drawing by Nigel Fradgley of English Heritage

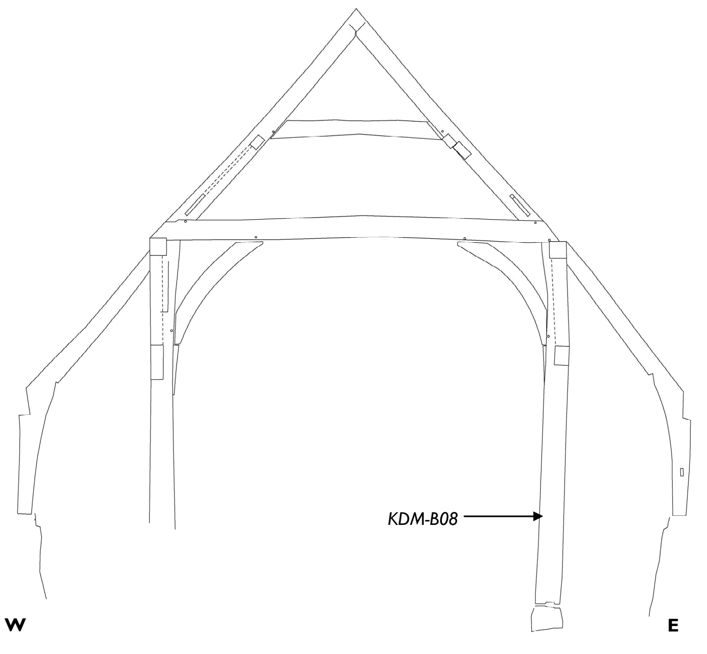
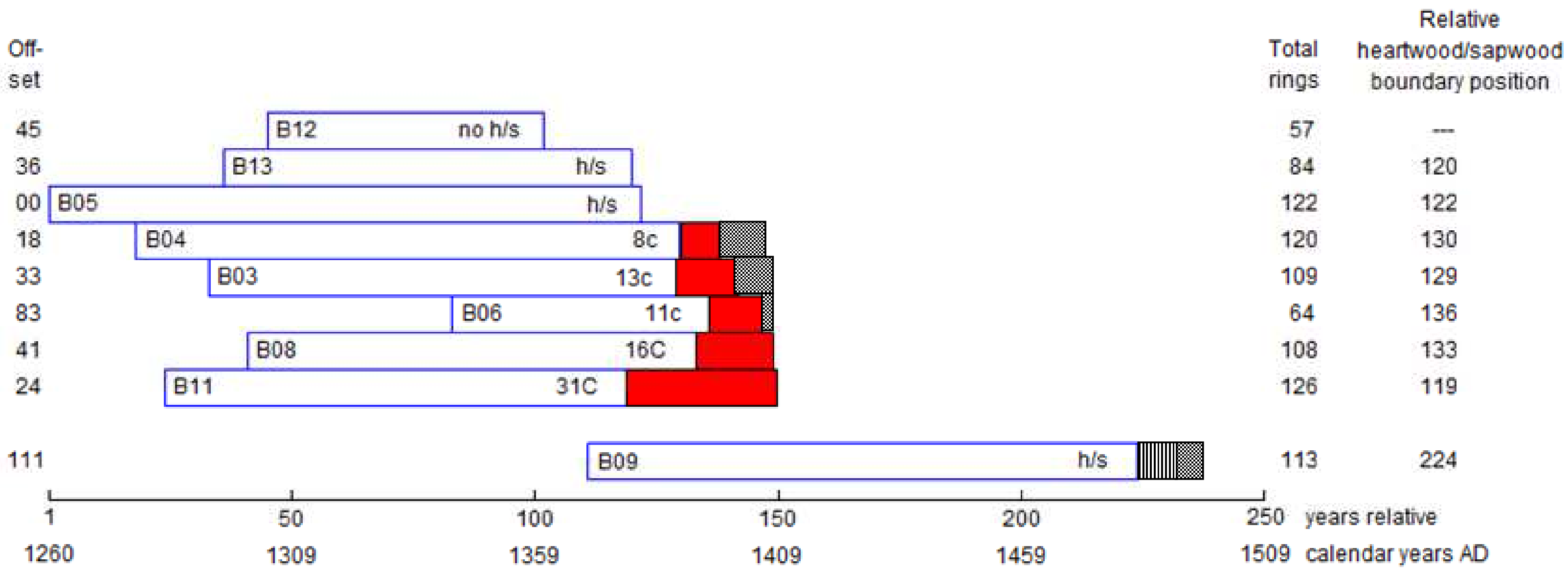


Figure 12: Truss 7 sample locations viewed looking north (based on a drawing by Nigel Fradgley of English Heritage



White bars = heartwood rings

hatched bars = estimated lost sapwood rings

Filled bars = measured sapwood rings

lined bars = extant unmeasured sapwood rings

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

c = complete sapwood exists on the timber but part of the sapwood has been lost from the sample in coring

C = complete sapwood is retained on the sample

Figure 13: Bar diagram of samples in site chronology KDMBSQ01 and sample KDM-B09

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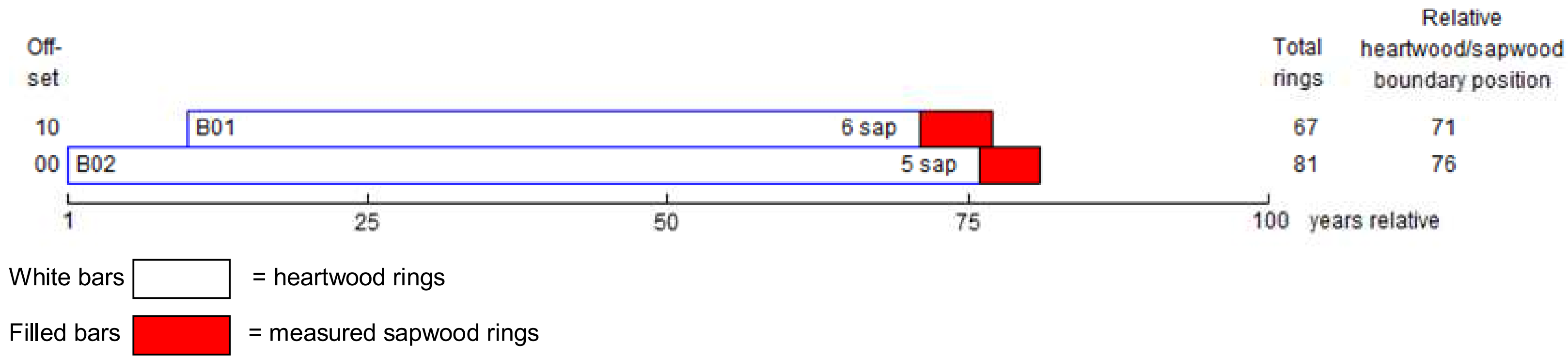

Figure 14: Bar diagram of samples in site chronology KDMBSQ02

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DATA OF MEASURED SAMPLES

Measurements in 0.01 mm units

KDM-B01A 67
133 146 203 267 342 226 378 290 88 96 130 100 207 143 77 99 95 120 194 157
101 110 88 171 128 121 93 100 145 131 161 279 282 250 162 168 229 156 144 139
139 108 101 95 110 128 199 172 174 175 153 142 116 162 204 204 167 124 140 103
134 96 167 107 164 115 148
KDM-B01B 67
139 141 208 264 342 221 381 278 90 91 131 96 181 143 76 97 100 122 190 151
91 113 84 168 129 109 92 104 141 128 174 284 281 253 167 164 232 158 152 137
146 99 110 90 105 137 200 169 179 174 155 138 120 166 198 205 157 124 137 100
140 95 166 94 162 122 141
KDM-B02A 81
75 44 40 57 66 133 105 213 140 186 139 145 209 292 305 200 326 366 183 107
120 125 210 199 119 89 107 149 204 262 179 366 306 383 357 336 206 124 167 164
210 380 408 354 272 281 496 472 336 272 250 210 297 189 253 253 275 296 390 343
345 212 224 333 433 436 315 200 156 117 167 109 168 114 208 142 213 311 351 372
386
KDM-B02B 81
64 52 39 51 71 117 101 209 140 179 130 138 203 277 296 194 324 335 173 101
120 126 200 187 126 88 98 133 211 244 172 359 309 369 363 332 208 126 159 161
205 381 396 345 279 267 507 467 345 271 257 218 301 194 250 253 274 300 390 350
335 210 225 332 434 436 336 188 151 115 167 104 167 105 200 134 220 302 333 365
375
KDM-B03A 109
504 575 491 466 366 295 222 305 423 354 129 107 174 213 276 226 207 196 134 210
253 237 370 419 381 234 148 139 130 179 205 164 149 169 242 230 324 194 152 160
262 244 272 358 169 270 203 192 197 193 219 243 207 162 140 122 252 306 349 154
162 111 112 134 138 83 88 97 147 184 248 201 190 101 126 197 97 105 65 111
119 103 138 152 163 159 199 175 209 149 173 117 145 190 171 189 281 224 114 198
165 123 100 149 158 160 121 115 171
KDM-B03B 109
504 572 490 469 364 298 224 327 407 354 131 116 166 208 282 226 187 192 137 198
251 222 372 414 397 221 142 141 147 177 206 164 153 175 241 232 327 197 157 166
268 250 277 357 191 273 200 194 196 191 218 240 211 158 141 127 253 306 363 145
157 116 111 130 140 80 94 95 151 167 257 195 205 102 109 206 90 112 73 109
102 112 142 162 161 156 211 173 201 153 167 117 147 182 171 189 279 211 113 184
163 115 102 151 154 165 121 122 169
KDM-B04A 120
226 294 224 210 176 234 239 195 157 105 145 145 167 164 199 193 266 214 321 299
172 236 262 250 237 183 132 115 141 181 154 141 114 141 117 129 82 71 104 133
84 90 59 91 120 179 99 78 105 103 125 104 54 41 48 70 82 74 97 76
86 133 95 89 101 86 144 160 90 78 86 111 123 190 151 142 138 139 166 133
135 119 131 201 146 227 197 133 105 155 203 195 230 140 142 129 87 124 76 110
119 118 174 170 170 189 232 272 257 175 233 153 127 167 162 163 121 117 153 132

KDM-B04B 120
196 308 231 206 178 234 214 206 185 107 148 144 172 180 218 188 270 200 304 287
166 239 257 249 236 184 133 113 145 177 146 144 104 143 109 145 67 76 106 131
71 90 64 88 128 161 105 80 112 110 118 108 64 32 47 73 79 78 96 81
86 134 92 92 100 88 136 157 94 81 84 118 123 185 141 152 123 142 164 125
126 116 138 206 144 225 183 151 112 146 194 201 220 141 144 123 96 109 79 122
119 119 166 171 160 182 235 273 248 183 238 160 129 160 163 176 124 101 156 133
KDM-B05A 122
176 254 292 238 308 231 235 174 233 247 205 217 247 306 213 220 253 306 252 326
394 227 96 110 128 159 175 104 74 128 202 260 348 364 252 213 285 249 204 163
173 178 312 218 164 265 277 350 333 284 307 107 43 53 47 45 66 89 91 74
41 63 78 98 63 57 73 56 99 108 61 62 113 95 113 92 147 157 173 165
177 132 186 91 121 189 163 109 144 169 232 342 249 304 278 261 326 286 216 226
186 235 311 295 286 260 216 210 301 283 301 191 165 168 205 204 264 245 208 203
243 195
KDM-B05B 122
184 256 314 248 306 224 245 170 231 245 206 224 246 307 210 219 255 309 251 328
390 228 91 113 127 162 174 107 68 132 198 263 339 367 255 214 292 247 212 168
157 199 299 211 158 252 293 361 329 282 309 103 45 50 48 49 65 90 88 70
54 54 79 103 58 52 78 69 87 126 57 63 103 101 115 100 139 141 168 174
173 139 182 92 116 189 165 118 147 166 233 342 245 302 284 252 333 289 230 215
188 230 312 301 291 248 219 208 288 285 293 206 162 171 206 204 263 248 207 203
258 177
KDM-B06A 64
373 418 454 373 337 222 265 350 345 188 295 330 259 293 418 218 162 108 121 105
162 164 108 116 122 152 241 312 207 127 149 88 206 273 239 314 281 197 203 187
205 216 253 289 181 264 194 172 174 163 131 118 131 221 204 223 274 240 226 172
243 226 181 214
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379 401 455 371 336 221 264 332 337 196 359 337 259 284 437 233 159 98 122 112
167 153 116 123 109 153 239 303 195 133 150 87 206 284 228 311 280 199 196 181
183 212 258 288 169 262 201 178 173 169 132 118 125 226 198 226 273 237 216 178
242 230 180 214
KDM-B07A 61
295 319 324 265 251 360 407 342 324 322 338 314 373 346 376 367 277 253 135 125
136 160 179 255 192 196 214 204 140 109 199 160 160 150 198 138 108 119 116 155
112 75 77 112 152 149 97 175 141 197 151 140 109 131 123 152 140 156 114 143
199
KDM-B07B 61
242 311 311 268 256 355 382 345 350 324 315 323 384 348 370 360 278 254 136 130
124 170 176 256 186 196 214 200 137 103 199 155 163 146 198 142 108 117 124 153
104 81 75 107 147 137 102 173 139 199 143 143 115 138 130 166 134 157 119 151
200
KDMB08A 108
150 225 137 69 100 243 207 215 114 177 217 141 190 141 290 261 242 72 35 34
55 80 110 84 77 77 86 133 146 72 84 131 127 207 178 214 199 256 223 224
189 196 193 353 373 222 198 161 204 212 238 107 164 146 82 109 116 66 81 96
144 180 371 349 240 199 195 294 276 336 229 201 222 141 231 243 259 266 297 233
220 176 170 204 192 255 222 187 174 163 181 133 154 130 101 190 209 223 256 239
250 211 255 234 241 161 147 69

KDMB08B 108
163 222 131 70 99 239 204 204 111 159 218 134 188 141 281 256 246 81 44 52
62 79 107 85 76 78 90 139 142 68 86 128 129 199 178 221 200 254 222 221
175 199 192 355 374 229 195 156 204 213 258 118 167 137 90 107 102 76 87 88
145 193 371 349 239 199 199 289 274 331 235 202 213 142 237 239 259 267 298 235
210 186 175 209 207 254 217 191 174 161 199 118 160 150 109 184 206 219 241 242
253 234 256 227 239 162 139 78
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119 127 76 75 123 137 125 121 143 118 119 128 79 133 166 247 258 237 187 158
198 110 175 111 145 193 150 178 205 193 207 149 179 148 139 146 95 101 68 89
92 116 127 118 100 77 84 42 50 56 54 38 87 60 45 31 31 57 36 38
37 46 38 36 41 39 42 42 37 32 53 49 80 53 42 61 70 97 72 62
83 43 75 50 98 117 102 87 67 61 51 93 135 73 127 120 143 147 83 106
133 159 121 120 155 149 102 130 185 166 231 249 211
KDM-B09B 113
121 125 78 68 120 150 117 122 149 115 113 129 74 134 165 248 263 236 190 158
197 114 173 123 133 193 145 184 208 202 197 149 186 145 148 144 96 99 75 83
89 122 120 126 97 64 89 51 42 56 61 47 80 63 40 39 38 52 33 46
34 48 37 32 33 46 53 35 42 27 53 51 83 63 38 65 65 90 79 66
78 57 60 52 91 124 97 85 61 71 50 91 139 75 124 125 146 148 81 112
119 165 122 115 162 162 102 138 183 156 234 248 209
KDM-B10A 46
785 751 989 793 711 255 265 596 1097 1189 1052 871 915 931 1003 1082 873 627 1025 850
951 1055 1044 638 871 1308 894 771 407 418 323 466 592 605 543 555 684 848 669 324
249 204 196 179 196 204
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807 1090 983 781 688 250 272 596 1117 1227 1056 870 917 935 1017 1102 873 633 1038 855
948 1008 1051 636 881 1302 883 784 403 412 326 469 598 597 535 555 682 863 678 336
247 207 205 202 201 229
KDM-B11A 126
276 342 284 232 262 264 289 307 326 262 190 195 222 220 149 136 182 187 187 127
188 104 149 143 153 156 116 117 195 136 173 164 216 170 132 126 136 184 149 191
133 168 181 168 251 185 102 113 124 214 239 147 189 183 158 189 184 160 151 130
133 122 94 65 97 123 123 139 130 105 105 114 158 155 120 132 139 202 134 142
142 80 101 82 159 225 155 106 112 107 65 103 64 97 95 87 71 70 62 86
80 87 104 86 109 66 55 55 79 52 48 47 72 90 87 105 82 92 103 136
157 130 97 111 93 76
KDM-B11B 126
282 334 285 230 250 270 289 304 326 262 190 197 216 222 152 134 184 188 191 137
184 107 146 140 147 155 114 111 193 137 175 156 212 174 135 127 131 182 149 191
125 169 181 165 256 182 105 116 123 218 239 149 187 184 155 190 182 157 156 136
125 124 96 60 102 118 123 147 126 105 107 108 156 155 123 131 144 201 128 145
142 87 94 85 154 221 157 100 131 97 68 101 69 91 101 82 77 65 65 81
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131 129 103 105 103 75
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409 271 401 333 204 255 237 188 159 198 257 383 340 225 144 107 122 196 225 143
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294 195 163 182 171 193 279 213 287 218 172 188 228 124 160 170 222
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437 267 391 361 214 259 239 172 160 194 260 382 340 220 146 114 114 200 231 164
106 129 140 267 323 133 184 216 219 225 197 304 203 183 185 210 187 258 208 368
294 187 159 179 168 183 283 215 298 228 158 196 224 125 153 179 217

KDM-B13A 84
326 176 180 227 182 197 285 214 197 160 152 164 211 208 148 140 70 75 77 164
244 268 193 203 151 197 203 279 223 175 165 289 266 188 139 161 230 227 203 149
178 178 274 274 238 278 233 199 198 192 138 140 168 147 175 229 120 143 131 143
120 122 117 104 137 154 116 186 128 101 102 122 147 143 110 80 98 63 50 74
83 96 91 87
KDM-B13B 84
319 176 178 231 175 195 285 204 175 168 152 136 193 205 145 147 66 76 75 169
240 265 197 205 148 208 223 266 216 178 168 311 257 200 138 171 225 221 219 145
186 174 267 284 232 262 237 217 203 210 135 131 149 152 175 237 125 144 128 145
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78 100 91 90
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130 163 186 196 124 191 146 187 215 183 366 364 368 124 93 79 36 52 50 72
94 131 131 205 167 112 89 159 222 145 78 82 55 46 57 60 91 148 116 180
139 166 116 74 46 85 86
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304 272 126 90 154 96 75 118 116 126 164 210 149 131 156 174 112 175 229 131
125 166 194 191 110 176 141 185 216 194 360 358 373 115 96 69 38 56 60 66
92 134 132 198 167 105 101 164 213 136 75 83 52 46 59 55 97 148 120 175
138 166 113 79 50 81 86
KDM-B15A 51
371 314 323 340 345 388 351 463 371 338 296 272 302 300 313 270 239 291 187 235
289 239 194 214 284 265 232 184 227 241 242 230 271 249 240 256 218 220 211 243
254 275 353 278 264 195 215 199 167 220 159
KDM-B15B 51
378 303 321 338 339 387 361 468 366 329 300 287 301 297 305 269 232 284 169 243
298 258 198 215 279 271 236 194 210 238 246 220 278 242 246 263 206 217 198 273
236 268 343 275 271 187 213 199 176 231 163
KDM-B16A 86
405 514 497 551 452 397 345 172 77 68 65 62 68 158 141 148 166 206 217 262
326 404 465 463 440 211 146 63 109 120 184 188 148 325 294 246 219 212 214 260
174 276 196 228 226 168 252 335 351 301 288 262 231 252 226 112 117 191 185 186
331 375 349 284 181 308 243 231 186 178 233 191 261 272 339 271 276 248 242 250
340 284 344 335 317 243
KDM-B16B 86
390 507 504 539 443 397 349 167 86 72 64 63 70 151 137 153 173 204 209 267
328 407 454 446 447 210 148 69 108 127 172 191 149 312 314 243 221 206 215 267
170 262 190 227 224 162 248 320 355 309 274 253 233 251 221 113 115 186 180 206
325 371 355 258 194 306 237 235 183 181 220 188 267 270 347 285 271 252 249 245
334 273 346 325 324 227

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 Nottingham Tree-ring Dating Laboratory's Monograph, *An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Building* (Laxton and Litton 1988) and *Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates* (English Heritage 1998). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The width of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure A1 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 for oaks, 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 oak 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 A1, 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 or soon after. 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 Nottingham Tree-Ring Dating Laboratory

1. **Inspecting the Building and Sampling the Timbers.** Together with a building historian the timbers in a building are inspected 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 A2 has about 120 rings; about 20 of which are sapwood rings – the lighter rings on the outside. Similarly the core has just over 100 rings with a few sapwood 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 8–10 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.

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 A2; it is about 150mm long and 10mm diameter. Great care has to be taken to ensure that as few as possible of the outer rings are lost in coring. This can be difficult as these outer rings are often very soft (see below on sapwood). Each sample is given a code which identifies uniquely which timber it comes from, which building it is from and where the building is located. For example, CRO-A06 is the sixth core taken from the first building (A) sampled by the Laboratory in Cropwell Bishop. Where it came from in that building will be shown in the sampling records and drawings. No structural damage is done to any timbers by coring, nor does it weaken them.

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

All sampling by the Laboratory is undertaken according to current Health and Safety Standards. The Laboratory's dendrochronologists are insured.

Figure A1: 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

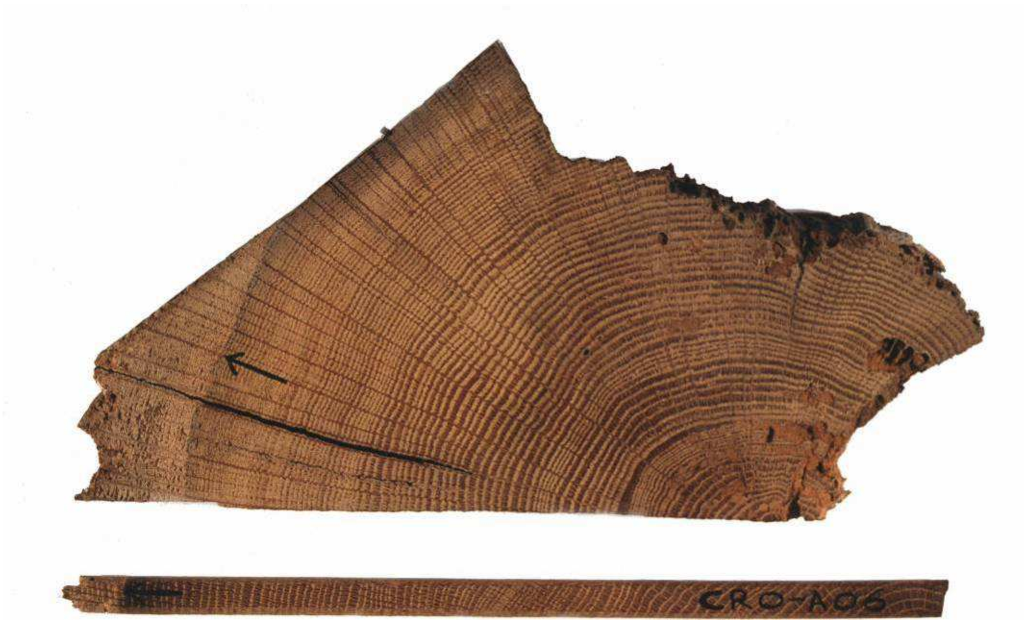

Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

Figure A3: 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

Figure A4: 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

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 A2. 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 A3).

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 A4). 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 at least 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton and Litton 1988; Laxton *et al* 1988; Howard *et al* 1984–1995).

This is illustrated in Figure A5 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 the sequence of ring widths of C08 matches the sequence of ring widths of C45 best when it is at a position starting 20 rings after the first ring of C45, 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 found between these two among all the positions of one sequence relative to the other.

It is standard practice in our Laboratory first to cross-match as many as possible of the ring-width 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 Figure A5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences of the 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. Thus in Fig A5 if the widths shown are 0.8mm for C45, 0.2mm for C08, 0.7mm for C05, and 0.3mm for C04, then the corresponding width of the site sequence is the average of these, 0.55mm. 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.

The 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'. It is a modification of the straightforward method and was successfully developed and tested in the Laboratory and has been published (Litton and Zainodin 1991; Laxton *et al* 1988).

4. **Estimating the Felling Date.** As mentioned above, if the bark is present on a sample, then the date of its last ring is the date of the felling of its tree (or the last full year before felling, if it was felled in the first three months of the following calendar year, 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, sapwood can be seen in the corner of the rafter and at the outer end of the core in Figure A2, both indicated by arrows. 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 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 so that the date of the last ring on the sample is only a few years before the date of the original last ring on the tree, and so to the date of felling.

Various estimates have been made and used for the average number of sapwood rings in mature oak trees (English Heritage 1998). A fairly conservative range is between 15 and 50 and that this holds for 95% of mature oaks. This means, of course, that in a small number of cases there could be fewer than 15 and more than 50 sapwood rings. For example, the core CRO-A06 has only 9 sapwood rings and some have obviously been lost over time – either they were removed originally by the carpenter and/or they rotted away in the building and/or they were lost in the coring. It is not known exactly how many sapwood rings are missing, but using the above range the Laboratory would estimate between a minimum of 6 (=15-9) and a maximum of 41 (=50-9). If the last ring of CRO-A06 has been dated to 1500, say, then the estimated felling-date range for the tree from which it came originally would be between 1506 and 1541. The Laboratory uses this estimate for sapwood in areas of England where it has no prior information. It also uses it when dealing with samples with very many rings, about 120 to the last heartwood ring. But in other areas of England where the Laboratory has accumulated a number of samples with complete sapwood, that is, no sapwood lost since felling, other estimates in place of the conservative range of 15 to 50 are used. In the East Midlands (Laxton *et al* 2001) and the east to the south down to Kent (Pearson 1995) where it has sampled extensively in the past, the Laboratory uses the shorter estimate of 15 to 35 sapwood rings in 95% of mature oaks growing in these parts. Since the sample CRO-A06 comes from a house in Cropwell Bishop in the East Midlands, a better estimate of sapwood rings lost since felling is between a minimum of 6 (=15-9) and 26 (=35-9) and the felling would be estimated to have taken place between 1506 and 1526, a shorter period than before. Oak boards quite often come from the Baltic region and in these cases the 95% confidence limits for sapwood are 9 to 36 (Howard *et al* 1992, 56).

Even 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 A2 was taken still had complete sapwood but that some of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 20mm, a reasonable estimate can be made of the number of sapwood rings lost, 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 35 years later we would have estimated without this observation. In the example, the felling is now estimated to have taken place between AD 1512 and 1515, which is much more precise than without this extra information.

Even if all the sapwood rings are missing on a sample, but none of the heartwood rings are, then an estimate of the felling-date range is possible by adding on the full compliment of, say, 15 to 35 years to the date of the last heartwood ring (called the heartwood/sapwood boundary or transition ring and denoted H/S). Fortunately it is often easy for a trained dendrochronologist to identify this boundary on a timber. If a timber does not have its heartwood/sapwood boundary, then only a *post quem* date for felling is possible.

5. Estimating the Date of Construction. There is a considerable body of evidence collected by dendrochronologists over the years that oak timbers used in buildings were not seasoned in medieval or early modern times (English Heritage 1998; Miles 1997, 50–5). Hence, provided that all the samples in a building have estimated felling-date ranges broadly in agreement with each other, so that they appear to have been felled as a group, then this should give an accurate estimate of the period when the structure was built, or soon after (Laxton *et al* 2001, fig 8; 34–5, where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storage before use, or if there is evidence the oak came from abroad (eg Baltic boards), then some allowance has to be made 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 Figure A6 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 Figure A6. 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 (1988), 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* 1988). 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 (1988) and is illustrated in the graphs in Figure A7. Here ring-widths are plotted vertically, one for each year of growth. In the upper sequence of (a), the generally large early growth after 1810 is very apparent as is the smaller later growth from about 1900 onwards when the tree is maturing. A similar phenomenon can be observed in the lower sequence of (a) 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 corresponding to good and poor growing seasons, respectively. The two corresponding sequence of Baillie-Pilcher indices are plotted in (b) where the differences in the immature and mature growths have been removed and only the rapidly changing peaks and troughs remain, that are associated with the common climatic signal. This makes cross-matching easier.

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

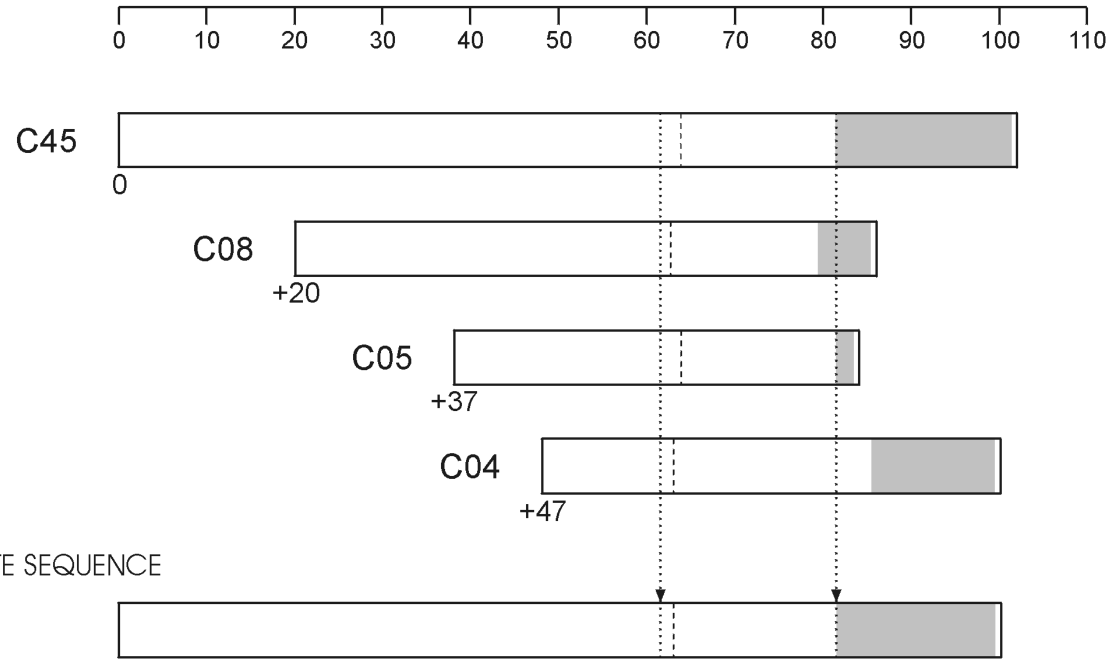

Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

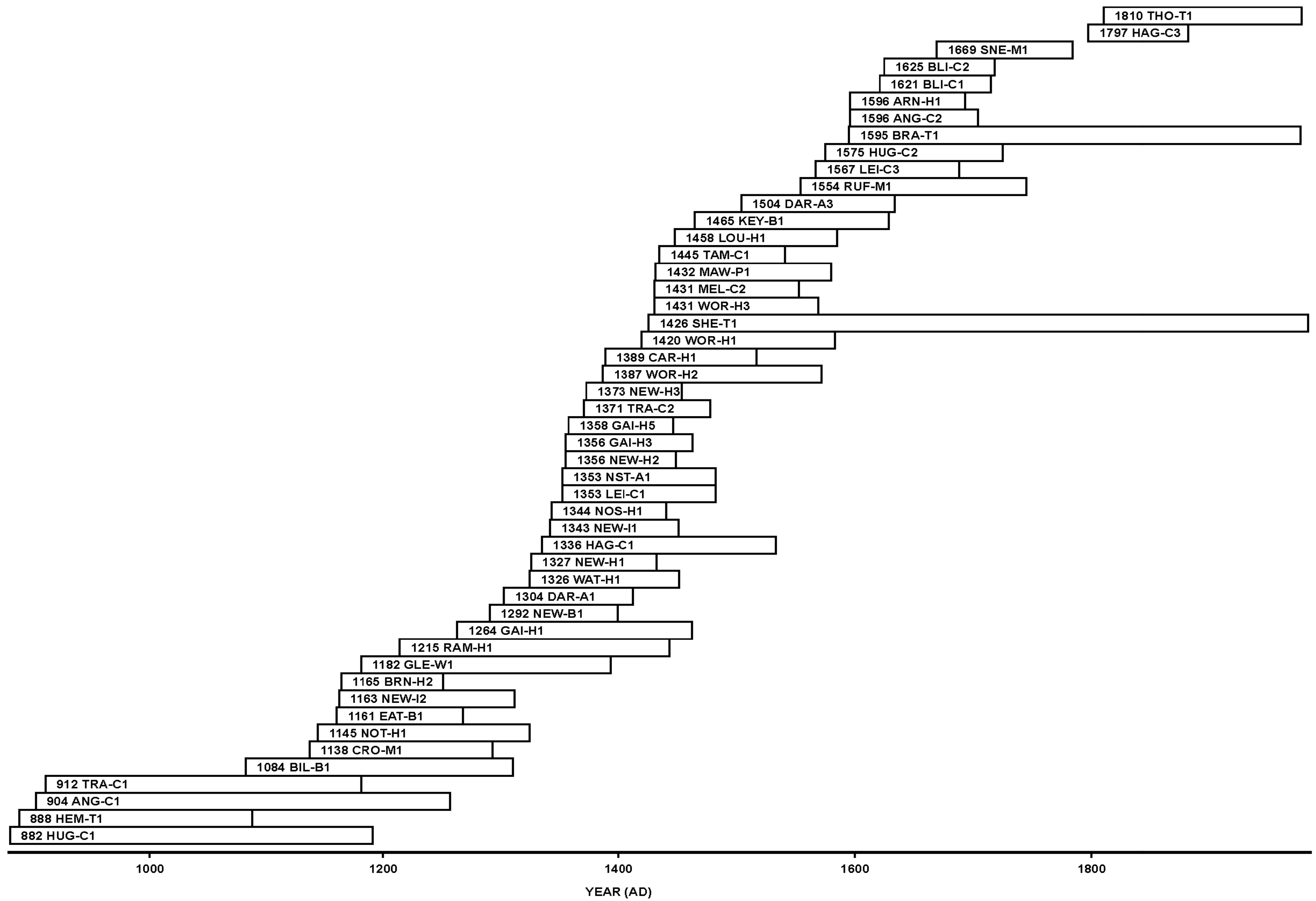

Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)

(b)

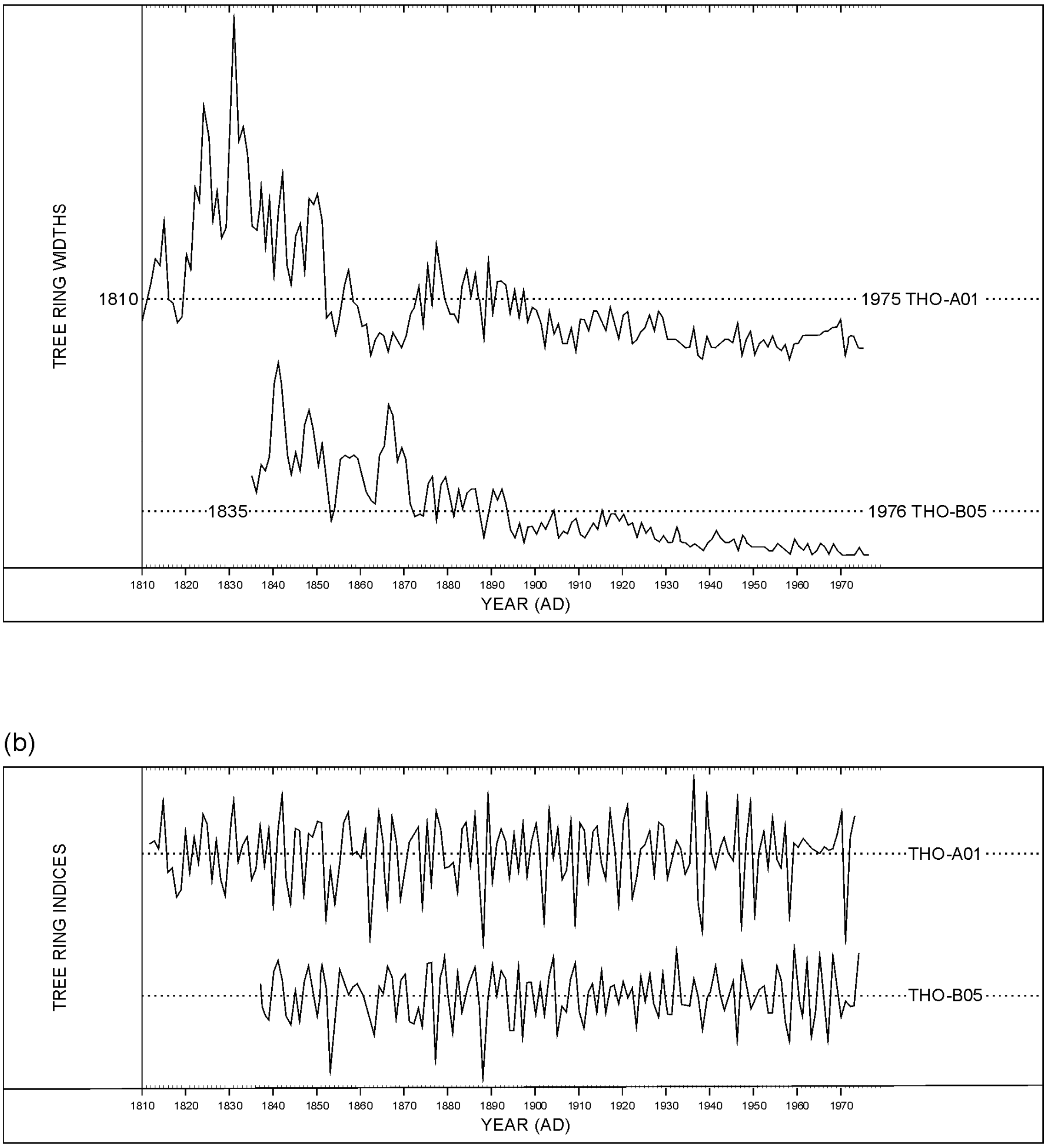

Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

Figure A7 (b): The Baillie-Pilcher indices of the above widths

The growth trends have been removed completely

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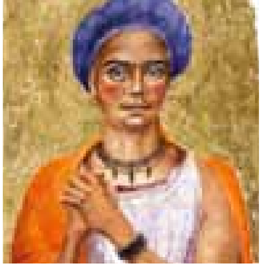


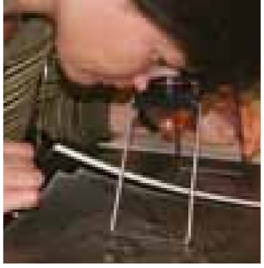


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