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THE OLD RECTORY, YATTON KEYNELL, WILTSHIRE
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Matt Hurford, Martin Bridge and Cathy Tyers

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SUMMARY
Dendrochronological analysis was undertaken on 16 of the 17 samples taken from The Old Rectory, Yatton Keynell, Wiltshire. This resulted in the production of four site sequences, YKORSQ01–04, comprising four, two, three, and three samples respectively. YKORSQ01 and YKORSQ03 were both dated: YKORSQ01 as spanning the years AD 1404–92 and YKORSQ03 as spanning the years AD 1190–1293.
The results indicate that the dated timbers used in the construction of the hall roof are likely to represent a single programme of felling in the period AD 1300–25, whilst those used in the construction of the attic roof, also likely to represent a single programme of felling, were felled in the period AD 1505–30.

CONTRIBUTORS
Matt Hurford, Dr Martin Bridge, and Cathy Tyers

ACKNOWLEDGEMENTS
The laboratories would like to thank Mr Worlock for giving permission to undertake the work. Thanks are also due to Avis Lloyd for arranging access and for providing additional background material on the building and to Clive Carter of the Wiltshire Buildings Record for providing the drawings. Robert Howard, Nottingham Tree-ring Dating Laboratory, kindly produced the final versions of Figures 12–16. The Wiltshire Buildings Record project work was supported by the English Heritage Historic Environment Enabling Programme. The dendrochronological work was funded by English Heritage and co-ordinated by Peter Marshall from the Scientific Dating Team.

ARCHIVE LOCATION
Wiltshire Archaeological Service
The Wiltshire and Swindon History Centre
Cocklebury Road
Chippenham SN15 3QN

DATE OF INVESTIGATION
2009–10

CONTACT DETAILS
Matt Hurford and Cathy Tyers
Dendrochronology Laboratory
Graduate School of Archaeology
Sheffield University
West Court, 2 Mappin Street
Sheffield S1 4DT
Tel: 0114 276 3146
Email: m.hurford@sheffield.ac.uk, c.m.tyers@sheffield.ac.uk

Dr Martin Bridge
UCL Institute of Archaeology
31–34 Gordon Square
London WC1H 0PY
Email: martin.bridge@ucl.ac.uk

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INTRODUCTION

In 2009 the Wiltshire Buildings Record 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 is to establish a typological chronology of archaic roof types and hence elucidate the development of carpentry techniques in the county. This will then facilitate detailed comparison with other counties allowing Wiltshire to be placed in the regional context. Investigation of these late-medieval buildings (*c* AD 1200 – *c* AD 1550) will combine building survey, historical research, and dendrochronological analysis.

A series of buildings identified by the Wiltshire Buildings Record 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, these detailed dendrochronological assessments and the WBR's assessments of the significance of the buildings within the project, informed the selection of the buildings subsequently subjected to detailed study.

A single final report produced by the Wiltshire Buildings Record (forthcoming a) will summarise the overall results from the project. However, each building included in the project will have an associated individual report produced by the WBR (forthcoming b), whilst the primary archive of the dendrochronological analysis is the English Heritage Research Department Report Series.

A brief introduction to dendrochronology can be found in the Appendix. 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/).

The Old Rectory

The Old Rectory, a grade II listed property, lies in the centre of the village of Yatton Keynell, to the east of the Church of St Margaret of Antioch (ST 86717639; Figs 1 and 2). It is aligned on a north-west to south-east axis, but for ease of reference within this report the building has been described so that the front elevation facing The Street is described as the west elevation.

The focus of this investigation is on the surviving elements of the medieval open hall and the medieval extension to the south of the open hall (Fig 3). Details of the medieval remains are given below based on information provided in the Wiltshire Buildings Record report (forthcoming b).

The open hall, which is of base-cruck construction, is believed to date to the early fourteenth century on stylistic evidence. A single bay remains, incorporating two trusses, trusses A and B, although it is thought that this structure probably extended further north and originally comprised two bays. Truss A (Fig 4) has straight principals and quadrilateral arch braces with plain chamfers rising from a cambered tie beam, with the plate being clasped between the principals and lower arch braces. The collar is also cranked and there are two rows of tenoned purlins. The apex appears to be plain-butted, but is partially obscured. Whilst all other timbers are tenoned and pegged, the lateral timber above the collar is nailed and hence likely to be a later addition. Although only partially exposed, Truss B appears to be of largely similar form to Truss A.

The attic roof, immediately to the south of the open hall, comprises three partially visible cruck trusses, trusses C–E, which are on a slightly different alignment to trusses A and B. These are thought to represent a medieval extension to the open hall. The timbers of all three trusses are of similar scantling but there are some differences in detail. Truss D shows evidence for wind braces both to the north and south of this truss and also appears to have had an upper and lower collar. Truss E (Fig 5), probably originally an open truss, has a chamfered cranked collar with ogee-moulded arch braces.

SAMPLING

Sampling and analysis by tree-ring dating of the timbers associated with the remains of the roofs of the medieval open hall and attic were commissioned by English Heritage. It was hoped to provide independent dating evidence for the construction of the original medieval open hall and its subsequent medieval extension and hence inform the overall objectives of the *Wiltshire Cruck Buildings and other archaic roof types* project. The dendrochronological study also formed part of the English Heritage-funded training programme for the first author.

A total of ten timbers associated with the open hall and seven timbers associated with the attic roof were sampled by coring. Each sample was given the code YKO-R (for Yatton Keynell, Old Rectory) and numbered 01–17. The sampling encompassed as wide a range of elements as possible, whilst focussing on those timbers with the best dendrochronological potential. The timbers excluded from sampling in the open-hall roof appeared to be derived from fast-grown trees and were hence considered highly unlikely to provide samples with an adequate number of rings for reliable dendrochronological analysis. The limited access to trusses C, D, and E resulted in the sampling being restricted to the principals, the only exception being the collar of Truss E.

The location of samples was noted at the time of coring and marked on the drawings subsequently provided by the Wiltshire Buildings Record, these being reproduced here as Figures 6–11. 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, with the trusses being labelled A–E from the north to the south.

ANALYSIS AND RESULTS

Each of the 17 oak (*Quercus* spp.) cores obtained was prepared by sanding and polishing. It was seen at this point that one sample, YKO-R16, had too few rings for reliable dating purposes and so it was rejected from this programme of analysis. The annual growth rings of the remaining 16 samples were measured, the data of these measurements being given at the end of this report.

The ring sequences derived from these 16 samples were initially compared with each other by the Litton/Zainodin grouping procedure (see Appendix), allowing four groups of timbers to be formed. The samples of each group cross-match with each other as shown in Figures 12–15 and Tables 2–5. This analytical process was aided by the use of software written by Tyers (2004).

The individual series in each group were then combined at the indicated offsets to form site chronologies YKORSQ01–SQ04 (Figs 12–15). Intra-group cross-matching (Tables 2–5) indicated the possibility that some timbers may have been derived from the same-tree as suggested by *t*-values in excess of 10.0. However, to maintain consistency between all of the dendrochronological reports on individual buildings within this project, these potential same-tree series were not combined prior to incorporation into the site chronology, thus following the Nottingham Tree-Ring Dating Laboratory standard practice. All four site chronologies were compared to an extensive range of reference data for oak, this indicating repeated cross-matching for YKORSQ01 when the date of the first ring is AD 1404 and the date of its last ring is AD 1492 (Table 6) and for YKORSQ03 when the date of the first ring is AD 1190 and the date of its last ring is AD 1293 (Table 7). There was no conclusive cross-matching for either of the other two site chronologies, which therefore remain undated.

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% confindence) rings. This is used to calculate felling date ranges for samples with incomplete sapwood or felled-after dates for samples which are heartwood only.

The four site chronologies were compared with the remaining four ungrouped samples, but there was no further satisfactory cross-matching. Each of the four ungrouped samples was then compared with the reference chronologies, but again there was no satisfactory cross-matching and these therefore remain undated.

This analysis can be summarised as follows:

Site chronology	Number of samples	Number of rings	Date span (where dated)
YKORSQ01	4	89	AD 1404–1492
YKORSQ02	2	95	undated
YKORSQ03	3	104	AD 1190–1293
YKORSQ04	3	61	undated
	4	--	ungrouped and undated
	1	--	not measured

INTERPRETATION

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.

The extant remains of the roof of the open hall of The Old Rectory are represented by three dated samples in site sequence YKORSQ03 (Fig 14). None of these samples has complete sapwood and it is thus not possible to calculate a precise felling date for the timbers represented. However, two samples did retain their heartwood/sapwood boundary ring, which varies in date by only two years, suggesting that these timbers are likely to represent a single felling programme. The average date for the heartwood/sapwood boundary ring is AD 1285, thus an estimated felling date in the range AD 1300–25 is obtained.

The remaining dated sample in site chronology YKORSQ03 has no trace of sapwood and thus it is not possible to calculate its likely felling date range. The date of its last measured ring is AD 1293. This produces an earliest likely felling date of AD 1309, indicating that it could have been felled during the same felling programme as the other two timbers in site sequence YKORSQ03. The level of cross-matching between the samples does not preclude them being a coherent group (Table 4).

The attic roof is represented by four dated samples in site sequence YKORSQ01 (Fig 12). None of these samples has complete sapwood and it is thus not possible to calculate a precise felling date for the timbers represented. Two of the samples, however, did retain their heartwood/sapwood boundary ring. This varies in date by only five years, again suggesting that these timbers are likely to represent a single felling phase. The average date for the heartwood/sapwood boundary is AD 1490. Hence estimated felling date in the range of AD 1505–30 is obtained.

The remaining two dated samples in site chronology YKORSQ01, YKO-R04 and YKO-R05, have no trace of sapwood and thus it is not possible to calculate their likely felling date ranges. The date of their last measured rings indicates that they have earliest likely felling dates of AD 1498 and AD 1508 respectively. Thus they may also have been part of the same early sixteenth century felling programme identified above. This interpretation seems very likely when taking note of the high *t*-values obtained between pairs within this group (Table 2), which indicates the possibility that the pairs of samples represent the same tree or trees growing in close proximity.

The undated samples in site sequence YKORSQ02 are clearly likely to be coeval, with a heartwood/sapwood boundary date variation of only two years (Fig 13), as are those in YKORSQ04, the two heartwood/sapwood boundary dates again varying by only two years (Fig 14).

DISCUSSION AND CONCLUSION

Tree-ring analysis has indicated a felling date for three timbers associated with the open-hall roof in the early fourteenth century, thus supporting the date suggested previously based on stylistic evidence. Whilst this tree-ring evidence is based on only three timbers, these represent both extant trusses and also appear integral to the roof structure with no evidence of insertion or reuse.

The dated timbers from the attic roof are all four principals from trusses D and E which, in the absence of any evidence of insertion or reuse, suggests a construction date for this part of the extension to the south of the open hall in the early sixteenth century. Unfortunately the samples from truss C could not be dated, so the dating of this truss relies on its integral nature with the rest of the attic roof.

The high *t*-values have already been noted between the dated principals in the attic roof (see above; Table 4), the timbers from each truss representing halved trees. The level of cross-matching is also suggestive of the two truss C principals, forming YKORSQ02, potentially being derived from the same tree. In addition, the three samples in YKORSQ04, representing two plates and a tiebeam in the open-hall roof, appear likely to be derived from either the same tree or trees located in close proximity to each other, which further demonstrates the likelihood that the open-hall roof structure is of a single phase of construction. With respect to the potential same-tree pair from truss E, it is interesting to note the date of the heartwood/sapwood boundary of the east principal is earlier in date than the outermost measured heartwood ring of the west principal of truss E. This potentially serves to demonstrate the variation in heartwood formation throughout the outermost rings, which is usual in oak trees.

The inability to date YKORSQ02, which represents the truss C principals in the attic, does not necessarily suggest that they are of a different date to trusses D and E, but may simply mean that they are derived from a tree that has responded to different, potentially highly localised growth conditions. The latter half of this sequence is clearly dominated by a series of bands of narrow rings followed by a period of recovery, indicating that this tree suffered a number of growth-retardation events, which will have masked the more general climatic signal required for successful dating purposes. Site chronology YKORSQ04 also remains undated. Again, this may simply be due to the timbers represented being derived from a tree or trees that have responded to different growth conditions. In this instance the sequence is very short and includes a sudden growth retardation event towards the middle. Both of these factors will significantly reduce the chances of successful dating.

It is apparent from Tables 6 and 7 that the timbers from both the open hall and attic are most likely to be from relatively local woodlands. Site chronology YKORSQ03 produces the highest *t*-values, and thus shows the greatest degree of similarity, with reference chronologies from Wiltshire and the surrounding region. Site chronology YKORSQ01 produces high *t*-values with a more diverse set of reference chronologies. Nevertheless, the strongest overall cross-matching is with reference chronologies from Wiltshire and the surrounding region.

Two of the four ungrouped and undated samples, YKO-R02 and YKO-R17, show clear disturbances to their growth patterns, which again would reduce the chances of successful cross-matching and dating. The chances of dating individual ring sequences are always lower than that of a well-replicated site sequence in which the common climatic signal is enhanced at the expense of the background 'noise' resulting from the local growth conditions of individual trees.

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TABLES

Table 1: Details of tree-ring samples from The Old Rectory, Yatton Keynell, Wiltshire

Sample number	Sample location	Total rings	Sapwood rings	Average Ring Width	Cross-section dimensions	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Attic Roof								
YKO-R01	Truss E west principal	59	--	2.55	200+x280	1431	----	1489
YKO-R02	Truss E collar	50	h/s	1.83	180+x250	----	----	----
YKO-R03	Truss E east principal	53	h/s	2.56	140+x280	1435	1487	1487
YKO-R04	Truss D east principal	79	--	3.32	170x280	1404	----	1482
YKO-R05	Truss D west principal	77	h/s	2.49	170x300	1416	1492	1492
YKO-R06	Truss C west principal	95	19	2.09	170x280	----	----	----
YKO-R07	Truss C east principal	81	16c	2.19	150x300	----	----	----
Hall Roof								
YKO-R08	Truss B tiebeam	93	h/s	1.15	150x290	1194	1286	1286
YKO-R09	Truss B east arch brace to collar	80	5c	1.18	100x220	----	----	----
YKO-R10	Truss B east plate	53	--	3.50	220x220	----	----	----
YKO-R11	Truss A east plate	59	h/sc	2.94	190x210	----	----	----
YKO-R12	Truss A tiebeam	55	h/s	2.52	220x290	----	----	----
YKO-R13	Truss A west principal	104	--	1.40	140x180	1190	----	1293
YKO-R14	Truss A east arch brace to collar	65	h/s	1.27	100x190	1220	1284	1284
YKO-R15	Truss A west plate	68	h/s	1.25	180x210	----	----	----
YKO-R16	Truss A collar	nm	--	--	170x180	----	----	----
YKO-R17	Truss B east principal	76	--	1.88	160x180	----	----	----

nm = not measured
h/s = the heartwood/sapwood ring is the last ring on the sample
c = complete sapwood was present on the timber but part was lost from the sample during coring
+ = the timber was embedded within the wall thus the complete dimension could not be measured

Table 2: Cross-matching between the samples in site sequence YKORSQ01; - indicates that the t-value is less than 3.0

	yko-r03	yko-r04	yko-r05
yko-r01	9.72	4.37	3.31
yko-r03		3.44	-
yko-r04			10.28

Table 3: Cross-matching between the samples in site sequence YKORSQ02

	yko-r07
yko-r06	12.01

Table 4: Cross-matching between the samples in site sequence YKORSQ03

	yko-r13	yko-r14
yko-r08	4.45	4.98
yko-r13		5.35

Table 5: Cross-matching between the samples in site sequence YKORSQ04

	yko-r11	yko-r12
yko-r10	14.75	9.73
yko-r11		9.02

Table 6: Results of the cross-matching of site sequence YKORSQ01 and relevant reference chronologies when the first-ring date is AD 1404 and the last-ring date is AD 1492

Reference chronology	*t*-value	Span of chronology	Reference
Fulham Palace, Hammersmith, London	7.3	AD 1356–1494	(Bridge and Miles 2004)
Acton Court, Gloucestershire	7.0	AD 1328–1575	(Haddon-Reece *et al* 1990)
Dauntsey House, Dauntsey, Wiltshire	6.8	AD 1393–1580	(Hurford *et al* forthcoming a)
St Johns Hospital, Lichfield, Staffordshire	6.6	AD 1356–1494	(Worthington and Miles 2002)
West Molesey, Elmbridge, Surrey	6.6	AD 1382–1502	(Arnold and Howard 2006)
Daubeneys, Colerne, Wiltshire	6.4	AD 1347–1497	(Hurford *et al* forthcoming b)
Sherbourne Abbey Church, Dorset	6.4	AD 1339–1474	(Bridge 1993)
Frocester barn, Gloucestershire	6.2	AD 1380–1513	(Fletcher *et al* 1985)

Table 7: Results of the cross-matching of site sequence YKORSQ03 and relevant reference chronologies when the first-ring date is AD 1190 and the last-ring date is AD 1293

Reference chronology	*t*-value	Span of chronology	Reference
Exeter Cathedral, Exeter, Devon	8.7	AD 1132–1315	(Howard *et al* 2001)
Polesworth Abbey Gatehouse, Warwickshire	8.4	AD 1095–1342	(Arnold and Howard 2007)
Fiddleford Manor, Sturminster Newton, Dorset	8.2	AD 1167–1315	(Bridge 2003)
Tithe Barn, Englishcombe, near Bath	8.1	AD 1157–1304	(Groves and Hillam 1994)
Bremhill Court, Bremhill, Wiltshire	8.0	AD 1111–1323	(Hurford *et al* 2010)
Dauntsey House, Dauntsey, Wiltshire	7.6	AD 1122–1355	(Hurford *et al* forthcoming a)
Great Coxwell Barn, Oxfordshire	7.4	AD 1043–1267	(Siebenlist-Kerner *et al* 1978)
Wick Farm Cottage, Heddington Wick, Wiltshire	7.1	AD 1158–1335	(Hurford *et al* forthcoming c)

FIGURES

Figure 1: Map to show the location of Yatton Keynell, Wiltshire (based on the Ordnance Survey map with permission of the Controller of Her Majesty's Stationery Office, © Crown Copyright

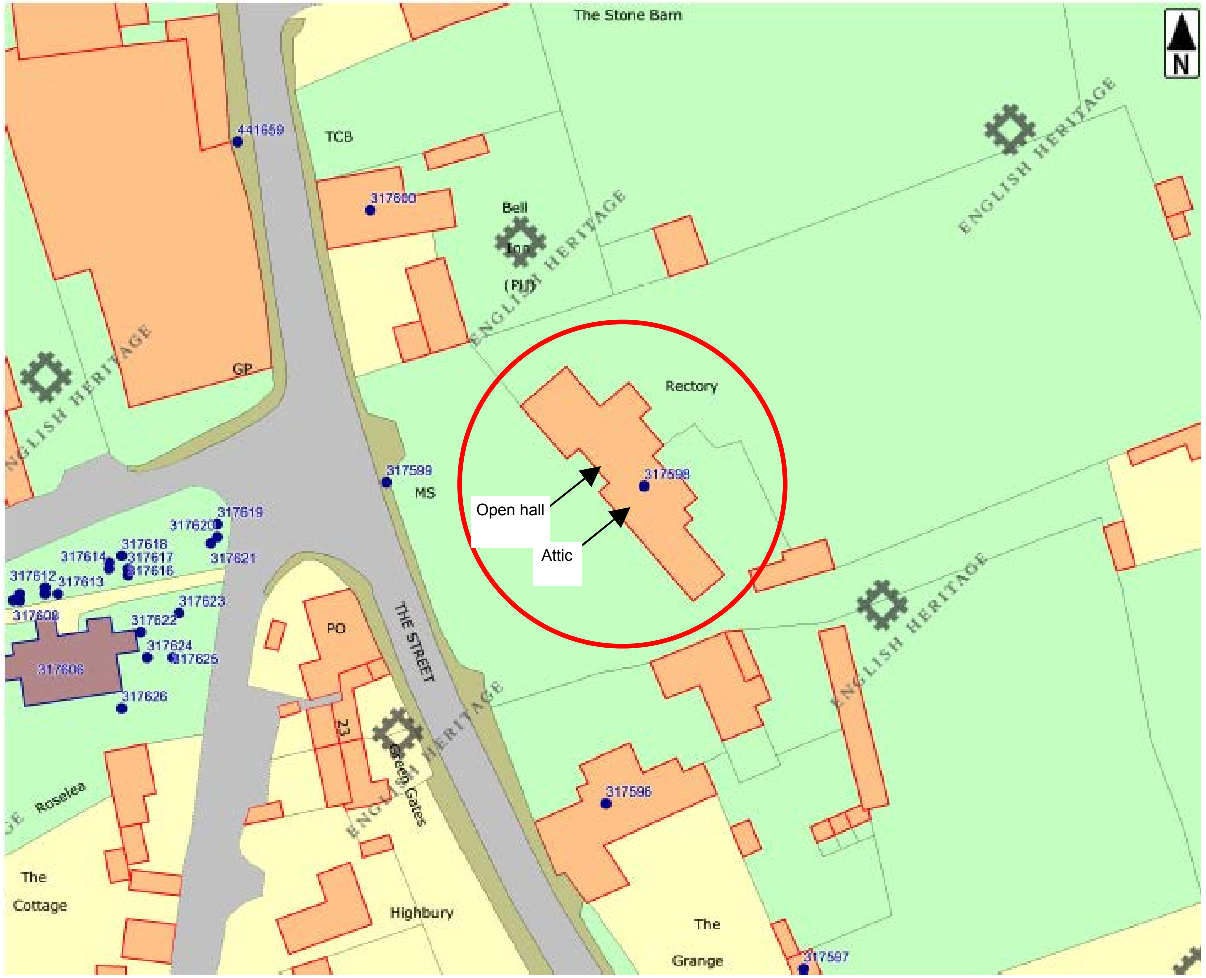


Figure 2: Map to show the location of The Old Rectory within the village of Yatton Keynell (based on the Ordnance Survey map with permission of the Controller of Her Majesty's Stationery Office, © Crown Copyright

Figure 3: General view of west (south-west) elevation of The Old Rectory showing locations of the open hall and attic roof

Figure 4: South face of open hall truss A

Figure 5: North face of attic truss E

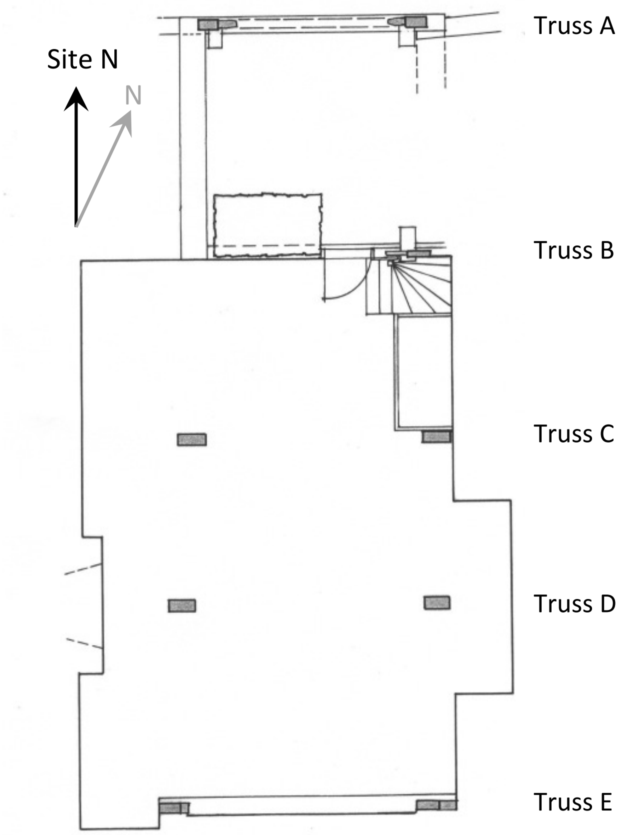


Figure 6: Basic plan of the roof showing the truss locations in the open hall and attic

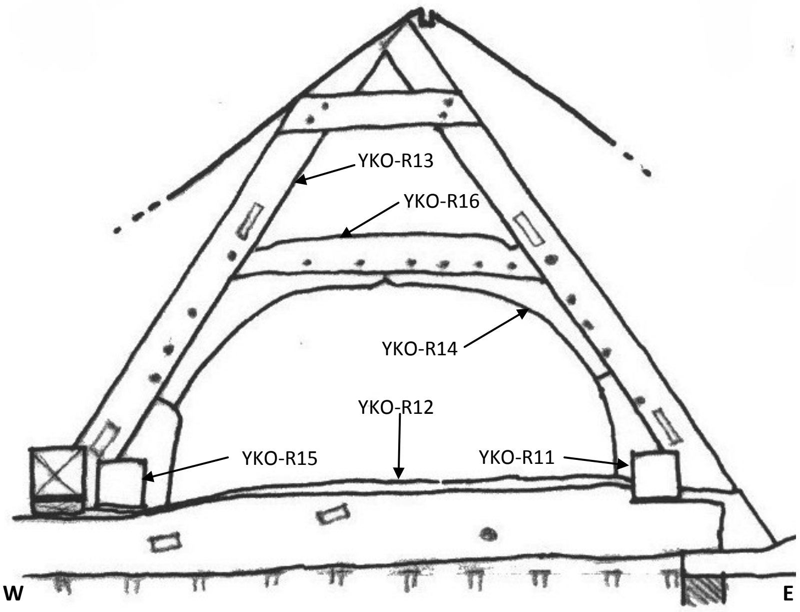


Figure 7: South face of truss A showing the sample locations

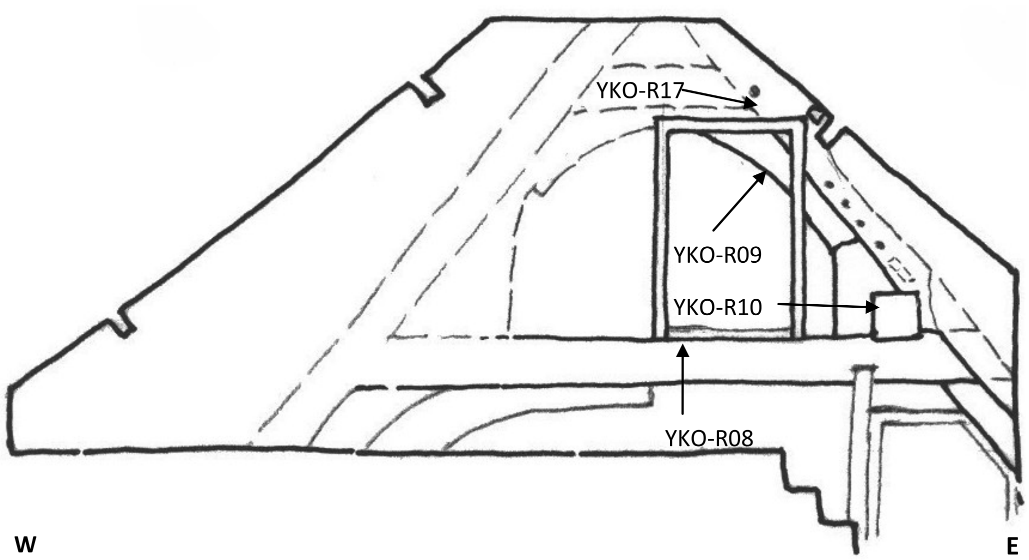


Figure 8: South face of truss B showing the sample locations

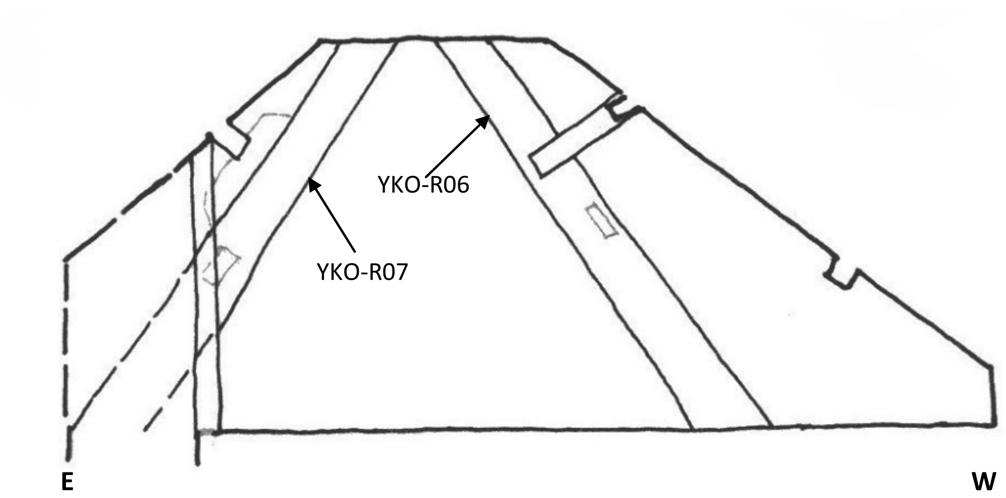


Figure 9: North face of truss C showing the sample locations

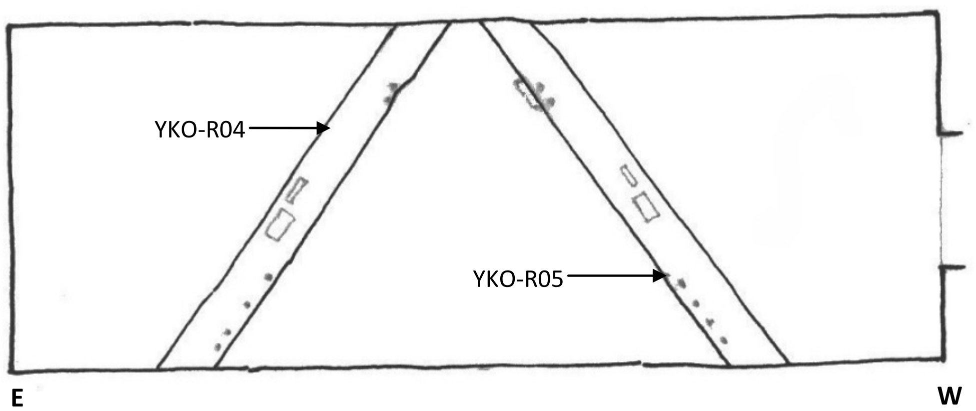


Figure 10: North face of truss D showing the sample locations

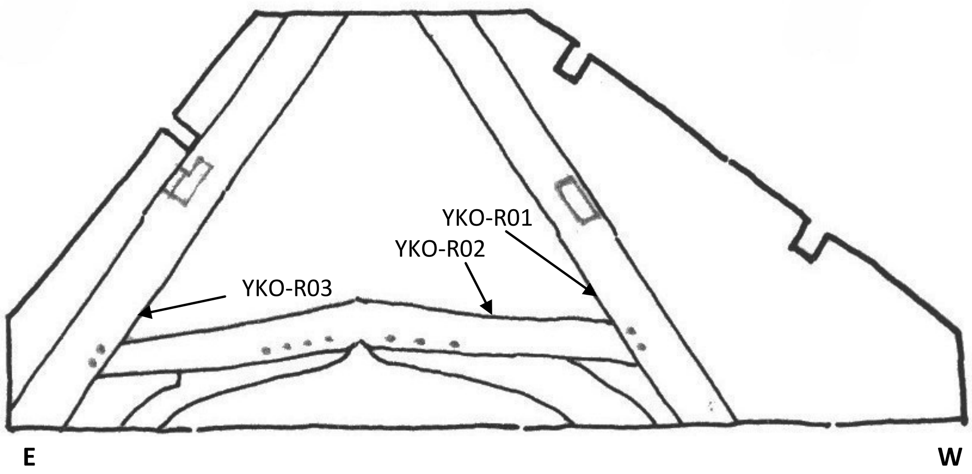
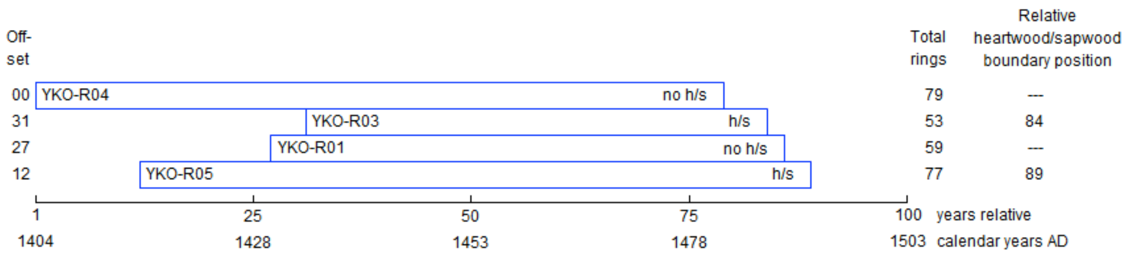
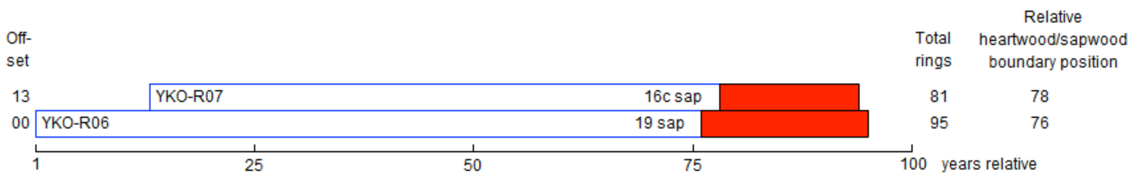


Figure 11: North face of truss E showing the sample locations



White bars = heartwood rings
h/s = the last ring of the sample is at the heartwood/sapwood boundary

Figure 12: Bar diagram of the samples in site chronology YKORSQ01



White bars = heartwood rings
Filled bars = sapwood rings
c = complete sapwood exists on the timber but part of the sapwood on the sample has been lost during coring

Figure 13: Bar diagram of the samples in site chronology YKORSQ02

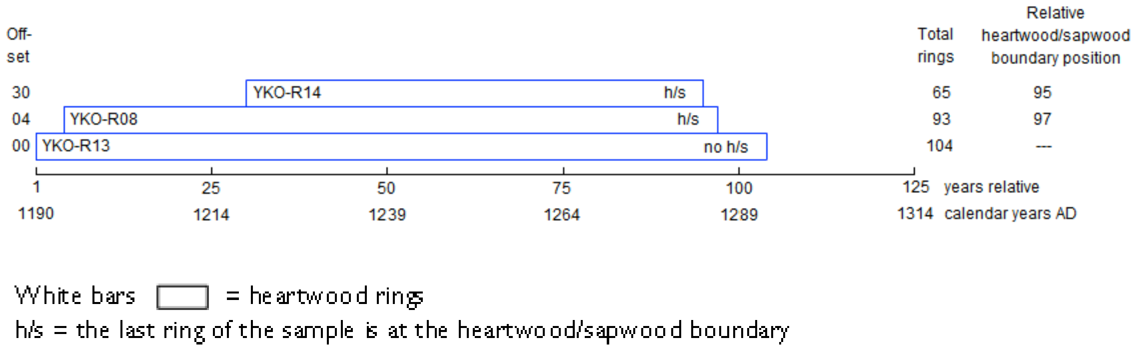


Figure 14: Bar diagram of the samples in site chronology YKORSQ03

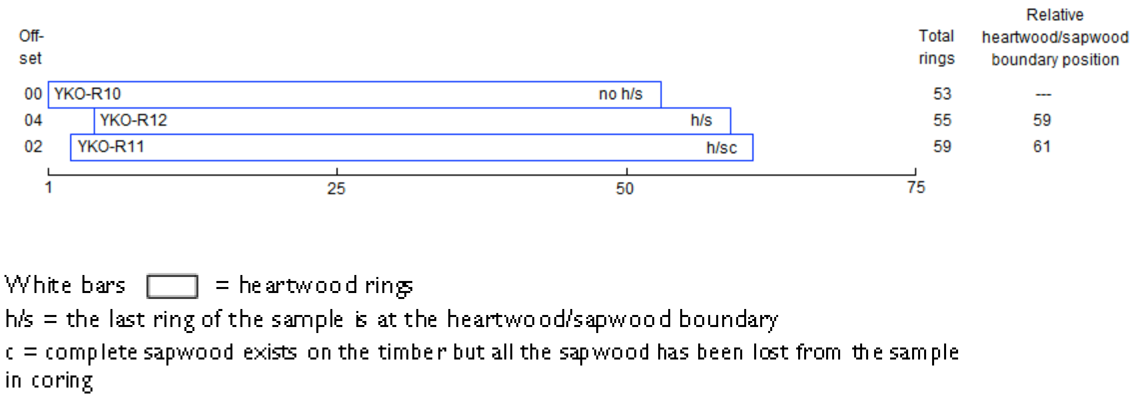


Figure 15: Bar diagram of the samples in site chronology YKORSQ04

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

YKO-R01A 59
324 335 154 210 219 322 368 314 293 309 408 262 292 301 256 260 285 248 257 212
232 229 250 307 279 315 337 284 262 272 229 231 203 127 153 270 337 360 307 343
365 243 250 223 241 242 144 153 230 244 228 206 239 194 169 161 198 170 171
YKO-R01B 59
320 335 152 209 217 329 366 309 301 302 403 262 289 302 253 266 284 249 258 208
236 221 265 306 274 319 331 290 276 280 249 229 211 128 161 285 347 357 304 350
357 246 252 217 246 247 136 160 216 245 206 206 221 198 179 166 191 168 170
YKO-R02A 50
135 224 382 258 221 103 102 51 55 85 118 162 129 235 230 246 235 299 257 86
94 104 95 102 103 163 149 196 171 279 238 270 371 78 80 108 83 107 128 188
189 266 269 181 283 219 202 237 278 327
YKO-R02B 50
141 221 377 263 213 106 103 45 59 86 122 154 121 217 246 258 229 252 273 94
84 109 83 97 93 158 156 197 175 271 236 263 372 80 77 111 80 110 129 188
186 273 267 183 289 218 209 240 275 328
YKO-R03A 53
424 510 473 513 437 406 453 345 417 424 316 311 356 400 461 274 341 270 212 326
195 210 229 208 155 150 128 123 100 83 98 226 302 267 227 237 224 173 145 139
176 160 98 121 190 225 167 207 214 207 184 156 204
YKO-R03B 53
418 510 469 551 440 415 469 335 419 423 327 309 352 406 422 283 345 266 215 316
200 194 204 191 168 153 133 117 101 78 104 220 315 279 226 237 219 179 145 141
176 154 104 117 197 223 166 202 209 208 182 167 212
YKO-R04A 79
236 258 499 381 473 493 386 506 573 402 376 377 361 437 444 276 358 407 335 328
351 272 367 412 460 477 414 395 503 230 122 124 131 147 109 108 185 227 150 185
203 216 216 201 343 413 421 429 334 269 380 407 360 386 396 367 365 307 271 384
232 307 350 376 334 360 364 312 305 322 364 412 381 270 294 306 379 334 251
YKO-R04B 79
244 258 494 394 481 511 420 495 577 413 366 381 366 443 442 280 356 410 331 327
353 270 371 430 467 468 420 393 507 225 118 133 134 151 109 103 188 228 148 191
205 211 213 206 340 406 426 423 328 270 376 406 356 388 403 365 426 312 269 381
236 298 339 372 330 347 362 301 301 329 368 410 400 258 293 306 379 333 246
YKO-R05A 77
331 431 434 265 274 294 210 296 330 232 274 333 303 296 235 246 326 127 84 78
68 91 124 118 186 230 152 197 212 211 160 168 221 323 341 347 342 299 362 319
342 391 390 373 401 321 300 396 284 392 355 374 304 323 245 272 293 296 331 284
245 198 204 231 287 256 262 235 159 71 62 67 51 70 92 107 89
YKO-R05B 77
330 435 434 261 275 300 209 293 330 237 256 308 313 292 237 251 320 126 89 74
65 102 120 115 189 238 149 192 200 216 155 172 211 328 334 351 336 295 374 318
338 389 395 366 391 328 302 393 285 389 348 368 303 324 251 275 299 287 330 292
248 203 207 230 293 259 259 238 171 63 65 68 53 66 90 110 93
YKO-R06A 95
235 174 499 169 393 246 263 299 184 300 272 365 270 298 378 397 351 203 116 140
235 253 241 209 217 292 345 356 423 456 196 298 298 233 450 324 325 364 100 53
43 45 35 56 83 75 127 151 159 225 226 314 212 384 201 215 227 362 132 61

81 113 74 128 135 211 308 231 315 128 57 55 84 57 62 128 182 92 50 49
62 87 92 112 76 186 192 236 196 204 173 266 251 274 368
YKO-R06B 95
252 166 496 162 395 241 270 288 182 296 273 364 259 298 384 384 347 223 104 135
234 242 233 198 229 295 345 365 419 447 205 288 311 228 457 326 324 359 97 56
50 47 36 48 81 69 130 153 152 224 228 305 213 382 208 215 218 366 138 56
85 108 79 126 133 207 314 227 327 125 64 51 87 55 63 124 188 93 52 50
57 94 80 122 67 191 192 239 194 212 175 267 248 276 372
YKO-R07A 81
367 443 338 442 242 257 421 679 343 408 338 393 491 405 369 528 513 221 349 337
274 502 314 359 423 140 53 43 79 76 82 174 131 285 172 224 256 196 226 146
228 214 185 198 275 124 58 56 59 65 122 108 166 260 190 194 87 46 51 72
60 53 99 107 82 72 103 146 197 172 167 119 128 178 183 147 213 184 237 143
214
YKO-R07B 81
369 439 332 440 226 253 417 679 338 408 335 398 492 420 354 489 488 218 343 347
273 499 326 374 418 139 48 52 77 65 98 161 138 286 171 226 255 195 221 145
229 212 185 195 277 117 64 59 51 69 114 103 163 253 195 199 75 46 58 67
56 59 96 111 83 70 101 147 194 172 165 126 127 182 175 151 217 181 236 143
212
YKO-R08A 93
426 448 312 201 145 136 167 151 124 114 94 110 197 61 128 122 151 137 90 134
143 152 173 125 97 125 161 146 89 87 124 171 209 126 175 174 102 114 99 98
101 115 61 101 115 92 92 79 90 100 116 100 110 75 75 124 111 105 79 88
81 90 65 83 56 70 77 80 87 78 50 68 72 60 58 44 43 63 65 91
108 70 72 92 83 88 113 86 115 74 93 96 118
YKO-R08B 93
427 440 309 195 136 135 177 148 126 119 86 110 193 74 132 130 159 132 86 135
140 157 171 123 92 130 165 136 87 98 123 171 207 126 172 174 111 106 103 102
98 116 61 111 111 92 88 85 79 114 110 111 120 77 80 121 110 99 89 94
86 100 75 78 55 74 87 68 80 76 52 74 68 64 53 46 44 63 62 92
107 69 71 88 89 92 116 87 113 77 90 100 115
YKO-R09A 80
148 120 82 138 153 128 134 128 112 158 149 112 147 127 82 83 128 120 175 149
92 92 111 137 103 109 110 140 116 129 102 118 135 168 175 140 147 166 103 128
116 93 104 93 113 119 104 98 103 136 107 123 129 133 96 141 164 117 105 97
94 102 96 114 129 100 91 85 92 105 96 93 97 110 116 107 132 87 120 100
YKO-R09B 80
151 117 84 138 155 118 134 133 110 155 147 113 150 123 81 83 130 119 180 138
99 92 104 127 105 102 113 144 111 140 93 112 129 166 169 147 141 170 99 135
115 85 104 100 109 121 116 98 108 126 109 124 130 133 98 141 155 120 104 97
94 101 94 112 133 93 97 87 87 107 96 84 92 115 133 103 134 118 90 93
YKO-R10A 53
393 444 331 289 243 311 334 434 347 481 400 361 225 303 378 469 555 537 495 417
411 369 327 94 441 431 540 452 576 497 349 346 378 440 468 408 397 397 187 257
316 426 290 199 211 247 283 252 213 210 167 132 129
YKO-R10B 53
393 456 335 224 226 313 333 433 346 474 398 350 226 307 372 474 551 542 529 420
413 373 326 112 446 433 515 447 584 494 347 345 383 441 466 418 405 397 199 256
326 419 288 191 205 247 272 258 222 194 170 134 133
YKO-R11A 59
369 242 290 313 355 388 333 380 361 355 222 244 353 443 493 456 445 370 311 286
238 59 326 355 405 345 415 362 271 290 342 338 306 287 265 287 211 204 263 341

288 241 263 255 252 282 249 260 174 142 196 221 230 221 236 284 233 201 204
YKO-R11B 59
366 231 291 298 355 397 326 384 370 358 226 241 352 446 498 459 446 366 304 290
236 65 328 360 403 355 424 357 276 283 341 336 306 283 275 306 213 215 254 342
286 235 263 252 254 279 247 255 184 159 179 224 227 229 228 287 236 193 207
YKO-R12A 55
482 516 665 502 499 663 569 483 313 390 401 389 366 295 289 260 253 218 147 73
197 252 267 274 233 287 218 217 283 283 269 254 324 278 177 202 200 218 167 147
146 140 144 157 131 97 85 82 67 67 57 59 66 61 55
YKO-R12B 55
425 519 665 499 500 650 567 477 309 383 399 386 368 295 292 262 252 217 144 74
198 252 271 279 237 291 218 213 280 284 263 255 322 279 178 202 192 218 160 147
142 135 146 154 130 95 92 78 69 72 48 66 62 64 49
YKO-R13A 104
162 66 97 137 149 165 178 113 100 117 120 142 103 95 61 81 73 82 127 121
157 126 88 80 102 120 101 112 92 118 166 194 119 118 169 190 212 163 219 201
128 70 70 68 63 124 75 124 111 117 86 98 83 173 105 93 104 108 85 97
101 123 139 223 151 247 275 255 256 196 240 230 255 215 233 225 190 179 170 144
112 195 178 171 158 136 126 184 135 117 115 134 93 149 110 124 149 120 116 138
166 132 192 171
YKO-R13B 104
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152 134 85 78 100 119 107 108 94 115 144 189 117 112 165 181 206 158 224 201
130 76 65 70 63 120 77 123 117 120 89 92 96 164 104 93 107 108 84 97
99 127 137 220 150 284 273 253 257 197 237 236 254 215 231 237 191 172 164 144
113 214 172 168 153 133 130 180 134 120 116 125 109 131 115 123 141 130 121 148
166 114 195 168
YKO-R14A 65
233 176 82 110 271 178 228 157 228 253 132 163 150 210 134 185 128 284 187 217
200 110 98 152 110 93 132 120 67 120 117 105 105 96 79 132 93 97 75 83
96 80 63 69 58 122 89 109 167 91 127 173 113 159 97 121 82 127 88 76
81 63 50 63 47
YKO-R14B 65
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200 107 96 133 106 81 139 126 65 111 119 106 99 99 86 123 96 98 82 82
100 73 68 70 62 100 108 89 175 88 136 172 112 160 98 109 97 120 92 74
81 62 58 54 47
YKO-R15A 68
102 101 90 86 60 75 118 110 80 137 133 83 49 47 99 124 118 93 84 117
177 212 214 193 156 184 185 149 121 123 139 147 127 138 131 259 206 127 110 77
145 109 120 103 111 136 144 125 101 180 131 143 141 119 134 137 105 127 150 173
127 104 103 111 125 95 78 43
YKO-R15B 68
102 106 86 92 60 73 126 102 89 134 129 85 50 54 96 118 114 87 90 118
171 216 209 203 152 188 185 150 123 124 136 150 118 143 127 256 203 121 106 84
152 107 122 102 112 136 140 118 113 186 125 140 132 117 136 133 104 130 151 176
124 106 102 111 128 99 81 45
YKO-R17A 76
279 385 356 262 455 419 462 489 555 430 517 522 388 377 412 485 238 265 260 200
247 296 257 127 170 203 262 115 178 180 160 161 214 202 185 159 139 207 159 114
60 106 66 75 113 145 101 127 93 147 171 111 126 133 128 63 54 47 45 34
58 49 31 41 76 74 56 104 89 69 43 27 53 59 57 62
YKO-R17B 76

270 392 363 240 473 392 453 483 554 423 509 516 388 361 402 476 249 265 262 207
241 294 259 125 161 211 255 114 179 199 133 165 215 183 198 155 133 197 167 120
69 89 78 84 110 140 95 140 88 149 170 110 124 136 129 64 55 42 43 40
57 46 30 48 69 76 60 98 91 68 43 34 46 66 59 63

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 Building* (Laxton and Litton 1988) and *Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates* (English Heritage 1988). 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

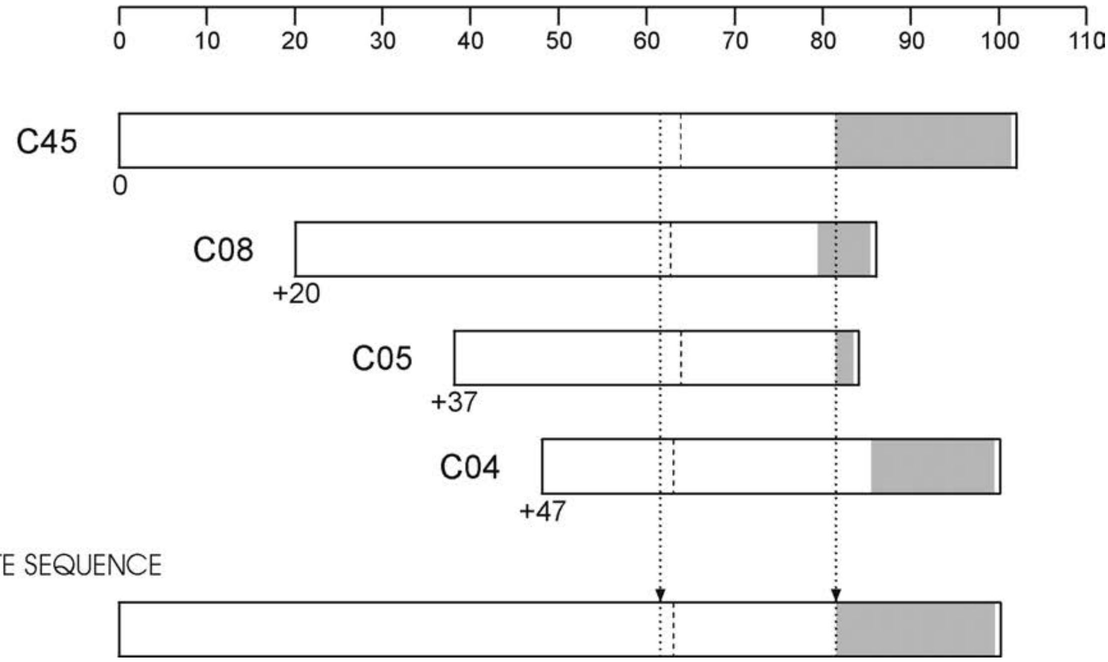


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

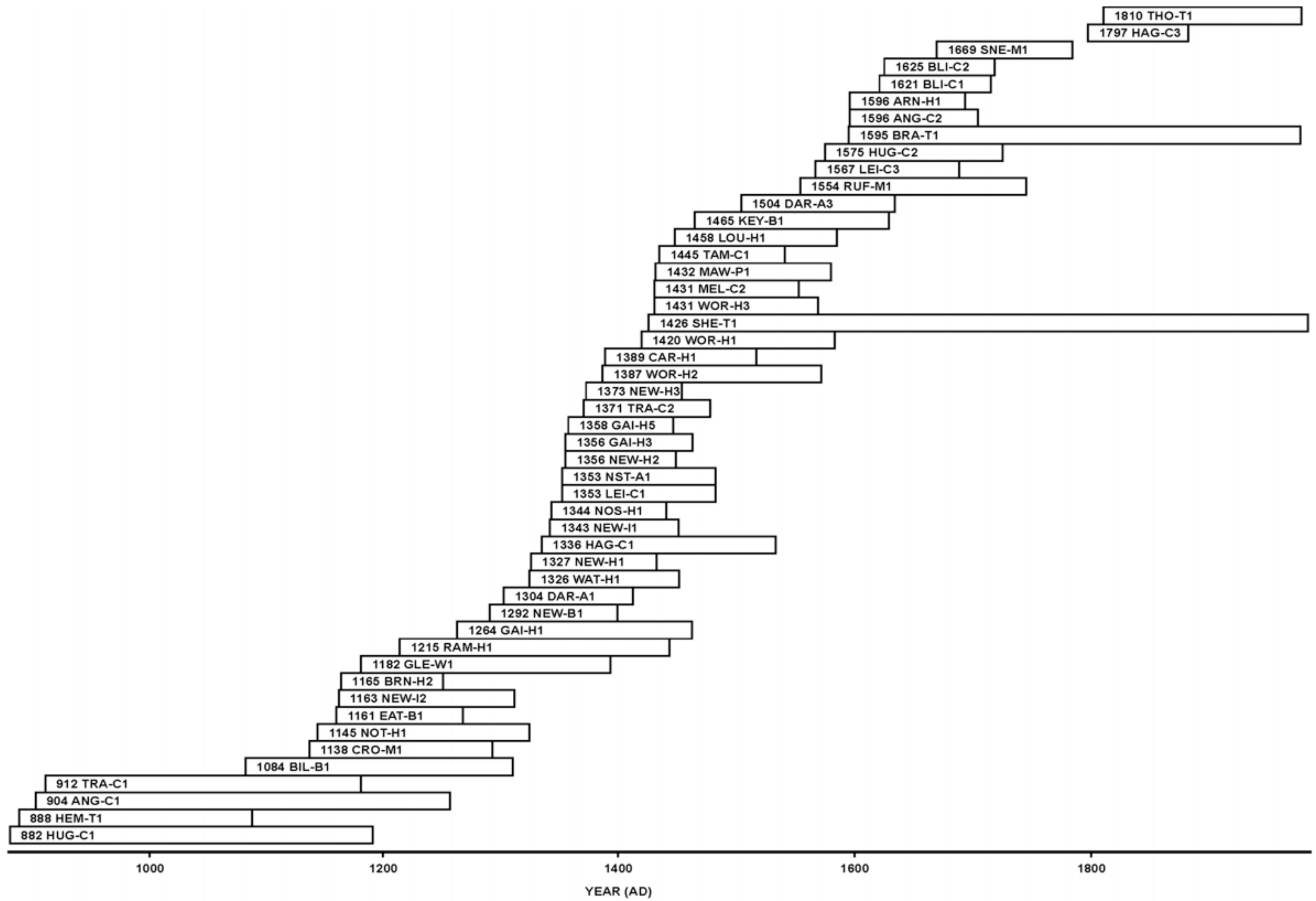
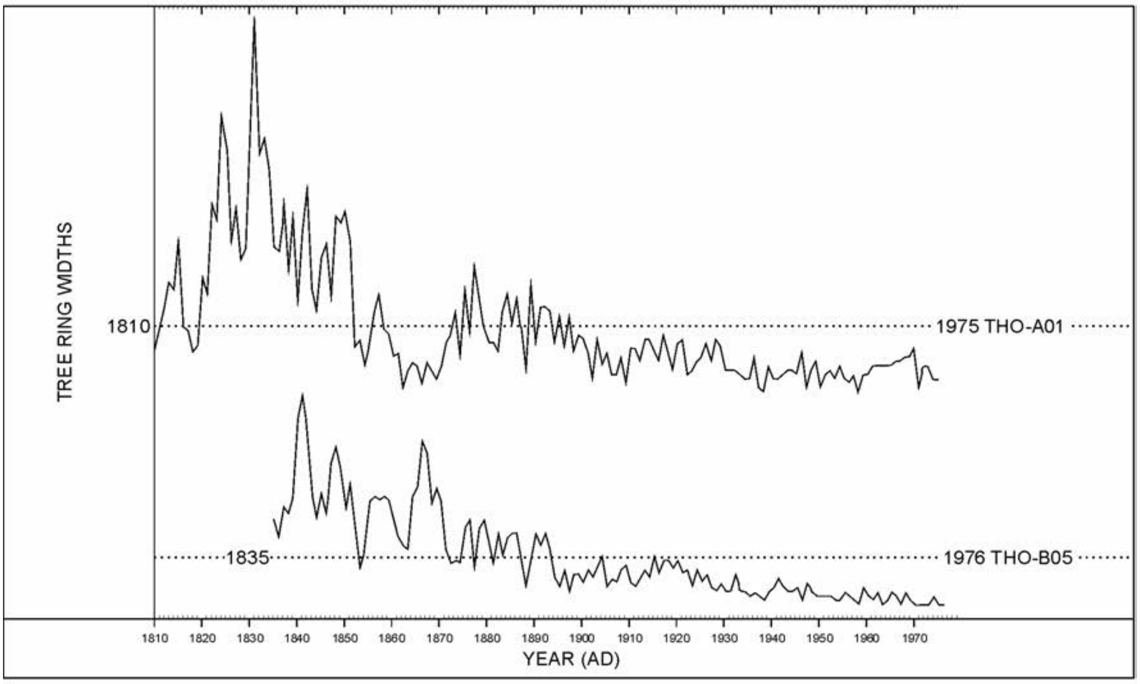


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

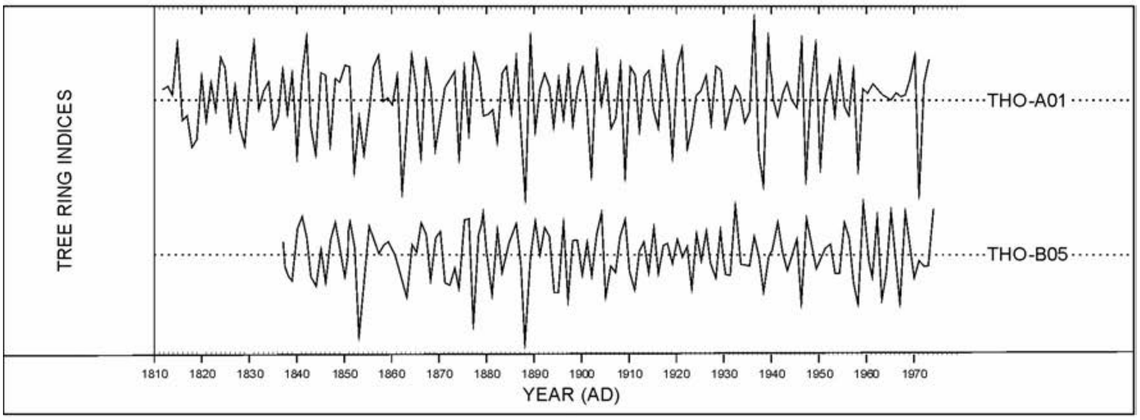


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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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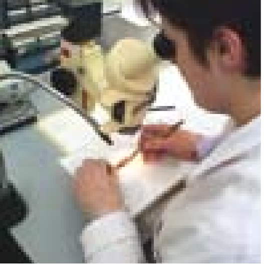
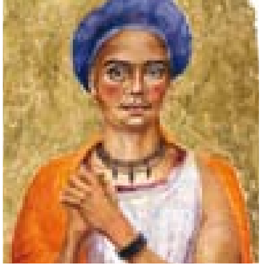



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