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CHURCH OF ALL SAINTS, BERRINGTON, NEAR SHREWSBURY, SHROPSHIRE
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

INTERVENTION
AND ANALYSIS

ENGLISH HERITAGE

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SUMMARY
Dendrochronological analysis was undertaken on 26 core samples obtained from the chancel and nave roofs of All Saints' Church, Berrington. This analysis produced a single dated site chronology comprising 22 samples. This site chronology has an overall length of 82 rings. These dated as spanning the years AD 1368–1449.

Interpretation of the sapwood on the dated samples would suggest the likelihood that the timbers used for each roof may have been cut as part of two slightly different episodes of felling. The timbers of the chancel roof appear to be the earlier of the two, these having an estimated felling date of AD 1446–71. The timbers of the nave roof appear to be slightly later, these having an estimated felling date AD 1457–82. It will thus be seen that there is some overlap in the estimated felling dates of the two sets of timbers, and it is likely that work on the nave roof followed on almost immediately, or with only a short hiatus, after the completion of the chancel roof.

CONTRIBUTORS
Alison Arnold and Robert Howard

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INTRODUCTION

The Church of All Saints at Berrington, less than three miles southeast of Shrewsbury in Shropshire (Figs 1a/b), is built of roughly squared and coursed red sandstone and dressed red and grey sandstone, all with ashlar stonework. On the basis of what appears to be an original lancet window in the north wall, the nave is believed to be of thirteenth-century date, while the chancel is thought to date to the fourteenth century. To the west end there is a Perpendicular period, fifteenth-century tower, of two stages, this having diagonal buttresses with six offsets (Fig 2). The tower is surmounted by a battlemented parapet to a low pyramidal roof, and has a large west window with Perpendicular tracery. There is a short aisle to the south side of the nave, possibly of fifteenth-century date, along with a porch. The church has undergone some late nineteenth-century restoration, the roof of the south aisle and the porch appearing to be entirely of this date. The church contains an unusual carved circular font, believed to be Norman (Fig 3), and is a Grade I listed building.

The chancel roof comprises twelve close-set, arch-braced, principal-rafter-with-collar frames; the arch braces each composed of an upper and lower section. The nave roof comprises twenty similar, if not identical frames (Fig 4a). The division of the two roofs is formed not only by a change in the level of the north and south wall plates, but also by the position of a much more substantial traceried, tiebeam with kingpost, screen truss to the nave, this truss immediately abutting an arch-braced frame of the chancel (Fig 4b). All frames carry a moulded ridge beam and single purlins to each pitch of the roof.

SAMPLING

Sampling and analysis by dendrochronology of the chancel and nave roofs of All Saints' Church were requested by John Tiernan (English Heritage) to inform grant-aided repairs to the two roofs. Although it is believed that both are of fifteenth-century date, it was hoped that tree-ring analysis would confirm this with greater reliability and establish with greater precision, if possible, whether both roofs were of the same date or were substantially different.

Although at the time of the initial assessment of the timbers as to their suitability for tree-ring analysis it was seen that many of the timbers appeared to have relatively low numbers of rings, it was also seen that, within each roof, there appeared to be a sufficient number of timbers, with sufficient numbers of rings, to make sampling worthwhile, particularly given the number of timbers potentially available. Thus from these timbers a total of 26 samples was obtained by coring. Each sample was given the code BER-A (for Berrington, site 'A') and numbered 01–26 (Table 1). Twelve samples, BER-A01–A12, were obtained from the timbers of the chancel roof, with a further 14 samples, BER-A13–A26, being obtained from the nave roof. The locations of these samples were recorded at the time of sampling, the positions of these being shown in Figure 5a-e, with details of the samples being given in Table 1. In this table, as in the drawings and plans, the frames of each roof have been numbered separately from east to west, with individual timbers then being further identified on a north–south basis as appropriate.

ANALYSIS AND RESULTS

Each of the 26 samples obtained from the two roofs was prepared by sanding and polishing and their annual growth ring widths were measured, the data of these measurements being given at the end of this report. The data of the 26 samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), allowing a single group comprising 22 cross-matching samples to be formed, the samples cross-matching as shown in Figure 6. The 22 samples were combined at their indicated offset positions to form site chronology BERASQ01, this, having an overall length of 82 rings.

Site chronology BERASQ01 was then compared to an extensive corpus of reference material for oak, this indicating a consistent and repeated match with a series of these when the date of its first ring is AD 1368 and the date of its last measured ring is AD 1449 (Table 2).

Site chronology BERASQ01 was also compared to the four remaining measured but ungrouped samples, but there was no further satisfactory cross-matching. These four ungrouped samples were then compared individually to the full corpus of reference data, but again there was no satisfactory cross-matching and must, therefore, remain undated.

INTERPRETATION AND CONCLUSION

Analysis by dendrochronology of the roof timbers of All Saints' Church has produced a single dated site chronology comprising 22 of the 26 samples obtained, its 82 rings dated as spanning the years AD 1368–1449.

As may be seen from Table 1 and Figure 6, none of the samples retain complete sapwood (the last ring produced by the tree before it was cut down), the timbers possibly having been heavily defrassed at some time in the past, and it is thus not possible to determine a precise felling date for any of the timbers represented. All the samples do, however, retain a few sapwood rings or the heartwood/sapwood boundary at the very least, this latter meaning that the timbers have lost only their sapwood rings, and it is thus possible to estimate a likely felling date for the timbers.

Interpretation of the heartwood/sapwood boundaries on the dated samples would suggest the likelihood that the timbers used for the chancel and nave roofs may have been cut as part of two slightly different episodes of felling, with the timbers of the chancel roof appearing to be the earlier. The date of the heartwood/sapwood boundary on the samples from the chancel ranges from AD 1425, on sample BER-A03, to AD 1435 on sample BER-A06, the average date of the boundary on the eight dated samples from this roof being AD 1431. Using a 95% confidence range of 15–40 sapwood rings would give the timbers represented an estimated felling date of AD 1446–71. The date of the heartwood/sapwood boundary on the samples from the nave, on the other hand, ranges from AD 1435, on sample BER-A13, to AD 1449 on sample BER-A14, the average date of the boundary on the 14 dated samples from this roof being later, at AD 1442. Using the same sapwood range, 15–40 rings, would give these timbers an estimated felling date of AD 1457–82. It will thus be seen that there is some overlap in the estimated felling dates of the two sets of timbers, and it is likely that work on the nave roof followed on almost immediately, or with only a short hiatus, after the completion of the chancel roof, and that both roofs date from about the middle- to third-quarter of the fifteenth century.

The inference that the timbers of each roof were felled at slightly different times is further supported by the internal cross-matching of the samples. Although there is satisfactory inter-roof sample cross-matching (hence the formation of a single site chronology), there tend to be a greater number of higher *t*-values between timbers within the same roof. This could be taken as evidence that the trees used within a roof were growing reasonably close to each other, but that the timbers for the two roofs were sourced from different woodlands or woodland areas. Indeed, the cross-matching between some samples, BER-A15 and BER-A16, with a cross-match of t=10.8, or BER-A10 and BER-A14 with a match of t=11.5, or BER-A15 and BER-A21, with a match of t=16.4, is sufficiently high to suggest that some pairs of timbers have been derived from one tree. Had all the timber for both roofs been felled at exactly the same time, it is perhaps more likely that it would all have come from a single woodland or woodland area and the inter-roof cross-matching of samples would produce higher *t*-values.

Although compared with reference data for all parts of England, and indeed matching well with chronologies from many areas, there is a clear tendency for the dated material from Berrington to cross-match best, or have the highest levels of similarity, with chronologies made up of data from other sites in western England and the West Midlands. This suggests the oak timbers used at All Saints' Church are from relatively local regional woodland source

Four of the 26 samples obtained remain ungrouped and undated. None of these four samples shows any problems with its annual growth rings, such as distortion or compression, which would make cross-matching and dating difficult. Although, with only 41 rings, one of the undated samples is the shortest of any from this site, the other three all have sufficient rings for satisfactory analysis. It is, however, a common feature of tree-ring analysis for one or more samples not to combine with the main group or to date individually. It will, though, be seen from Table 1, that two of the undated samples are those taken from the traceried tiebeam truss forming the division between the nave and the chancel. It is not clear if this has any major significance for the dating of this truss in particular.

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TABLES

Table 1: Details of tree-ring samples from the Church of All Saints, Berrington, Shropshire

Sample number	Sample location	Total rings	Sapwood rings*	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	Chancel					
BER-A01	North upper archbrace, frame 6	67	4	1368	1430	1434
BER-A02	North upper archbrace, frame 7	59	h/s	1370	1428	1428
BER-A03	South upper archbrace, frame 7	48	h/s	1378	1425	1425
BER-A04	South lower archbrace, frame 11	63	2	------	------	------
BER-A05	South strut, frame 12	54	2	1378	1429	1431
BER-A06	Collar, frame 5	56	h/s	1380	1435	1435
BER-A07	North strut, frame 6	54	h/s	1380	1433	1433
BER-A08	Collar, frame 10	48	h/s	1386	1433	1433
BER-A09	Collar, frame 12	41	h/s	------	------	------
BER-A10	South upper archbrace, frame 12	46	h/s	1388	1433	1433
	Nave					
BER-A11	Tiebeam, screen truss	58	h/s	------	------	------
BER-A12	King post, screen truss	54	h/s	------	------	------
BER-A13	South lower archbrace, frame 3	63	h/s	1373	1435	1435
BER-A14	North upper archbrace, frame 7	62	h/s	1388	1449	1449
BER-A15	North lower archbrace, frame 7	63	h/s	1376	1438	1438
BER-A16	South lower archbrace, frame 7	60	h/s	1386	1445	1445
BER-A17	South lower archbrace, frame 8	54	h/s	1386	1439	1439
BER-A18	South rafter, frame 8	66	h/s	1377	1442	1442
BER-A19	South lower archbrace, frame 10	61	h/s	1386	1446	1446
BER-A20	North lower archbrace, frame 14	63	5	1386	1443	1448

Table 1: continued

Sample number	Sample location	Total rings	Sapwood rings*	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	Nave continued					
BER-A21	Collar, frame 14	52	h/s	1391	1442	1442
BER-A22	North lower archbrace, frame 15	73	h/s	1370	1442	1442
BER-A23	North lower archbrace, frame 19	58	h/s	1390	1447	1447
BER-A24	South lower archbrace, frame 20	54	h/s	1387	1440	1440
BER-A25	North lower archbrace, frame 21	72	h/s	1371	1442	1442
BER-A26	North lower archbrace, frame 22	62	h/s	1383	1444	1444

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

Table 2: Results of the cross-matching of site sequence BERASQ01 and relevant reference chronologies when the first-ring date is AD 1368 and the last-ring date is AD 1449

Reference chronology	Span of chronology	*t*-value	Reference
Brookgate Farm, Plealy, Shropshire	AD 1362–1611	9.6	(Miles *et al* 1993)
16–18 Hightown/Booth Hall Hereford	AD 1302–1489	9.4	(Boswijk and Tyers 1997)
The Commandery, Worcester	AD 1284–1473	9.2	(Arnold and Howard 2006)
Herefordshire Wigmore Abbey, Herefordshire	AD 1055–1729	8.9	(Tyers 2002)
The Tram Inn Eardisley Herefordshire	AD 1353–1513	8.8	(Tyers 2005)
Mercer's Hall, Westgate Street, Gloucester	AD 1289–1541	8.0	(Howard *et al* 1996)
The Celyn, Lower Maescoed, Longtown, Herefordshire	AD 1347–1466	8.0	(Arnold and Howard 2006 unpubl)
Primrose Hill, Kings Norton, Birmingham	AD 1354–1593	7.7	(Arnold and Howard 2008)

FIGURES

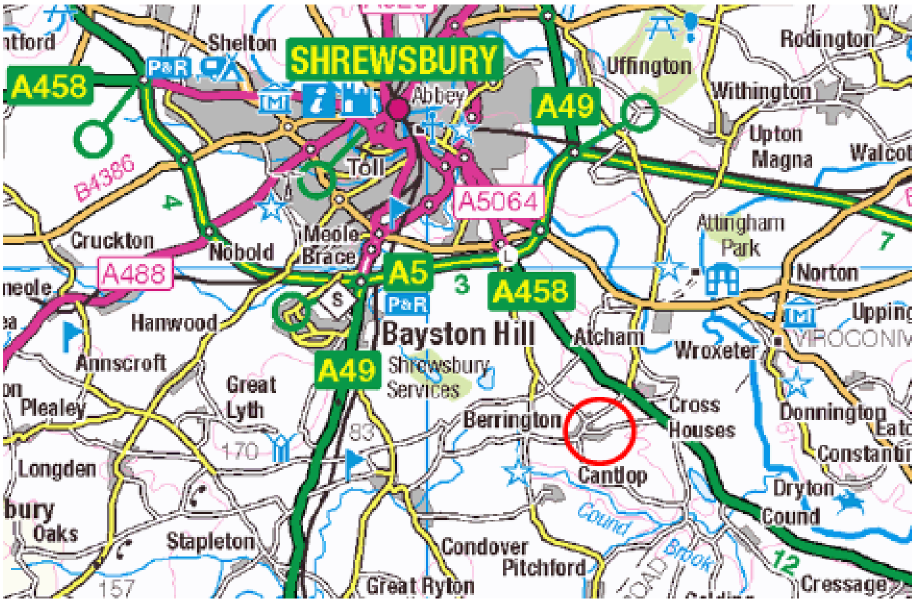


Figure 1a/b: Map to show the location of Berrington (top) and All Saint's Church (bottom) © Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900

Figure 2: View of All Saints' Church from the northwest showing the buttressed and battlemented tower (photograph Robert Howard)

Figure 3: The font (photograph Robert Howard)

Figure 4a/b: View of the nave roof (top), looking west to east, and the screen truss at the junction of the nave and chancel roofs (bottom) (photographs Robert Howard)

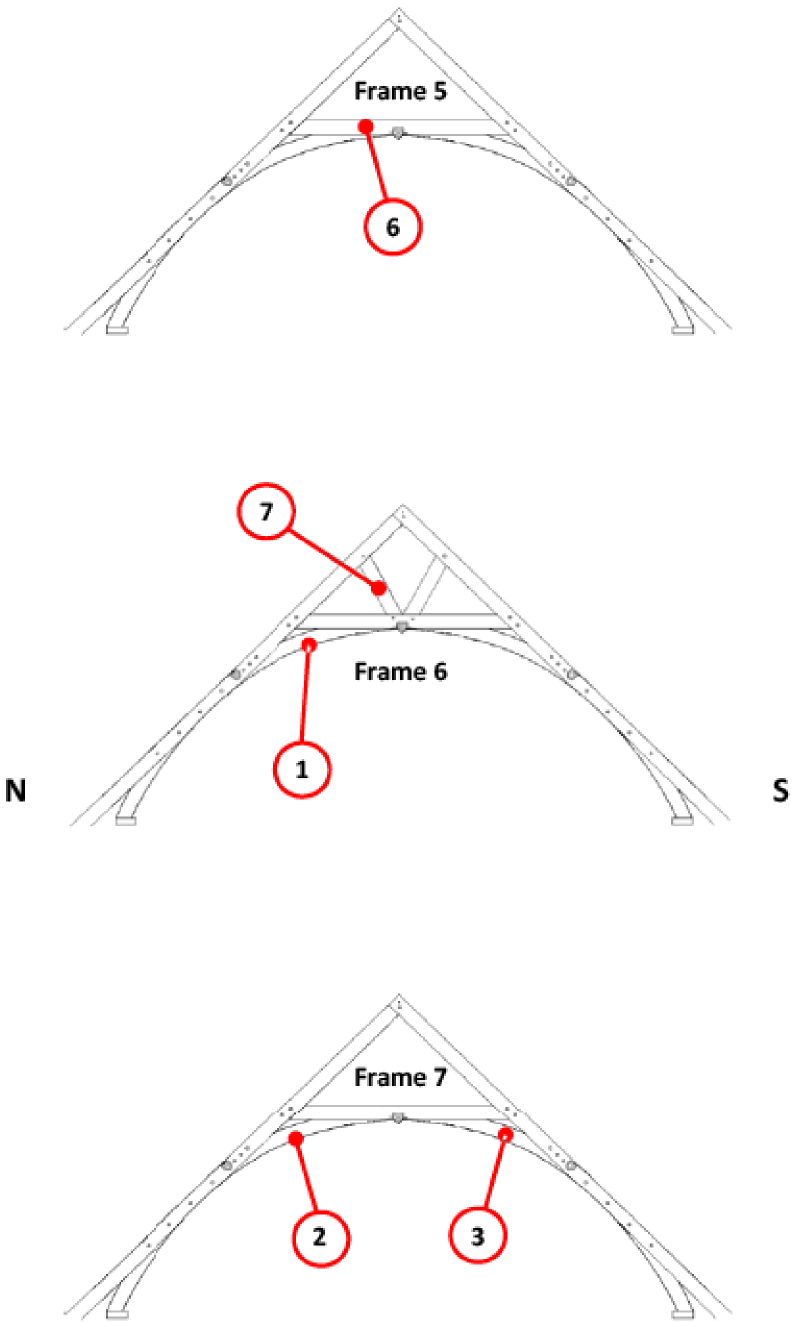


Figure 5a: The chancel roof trusses to show sampled timbers (after Baart Harries Newall, Architects, Shrewsbury)

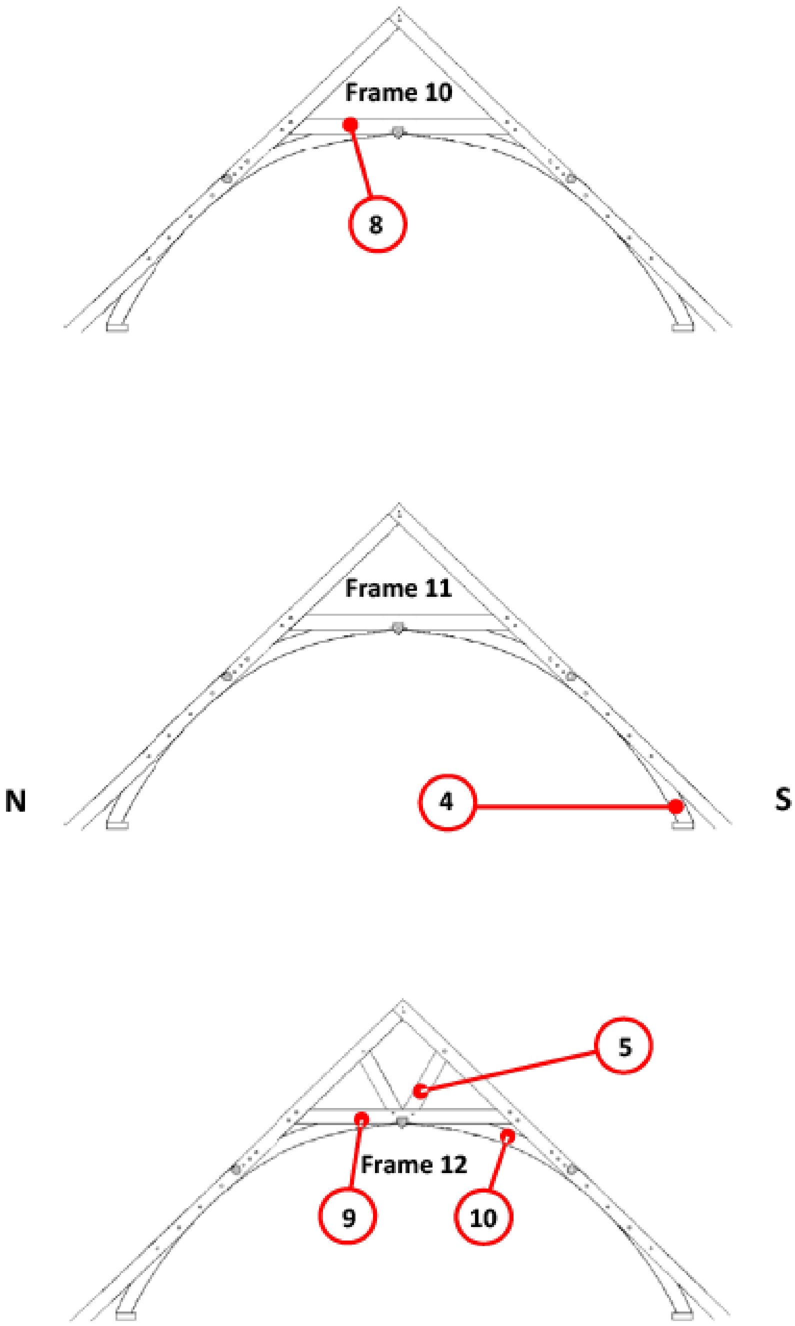


Figure 5b: The chancel roof trusses to show sampled timbers (after Baart Harries Newall, Architects, Shrewsbury)

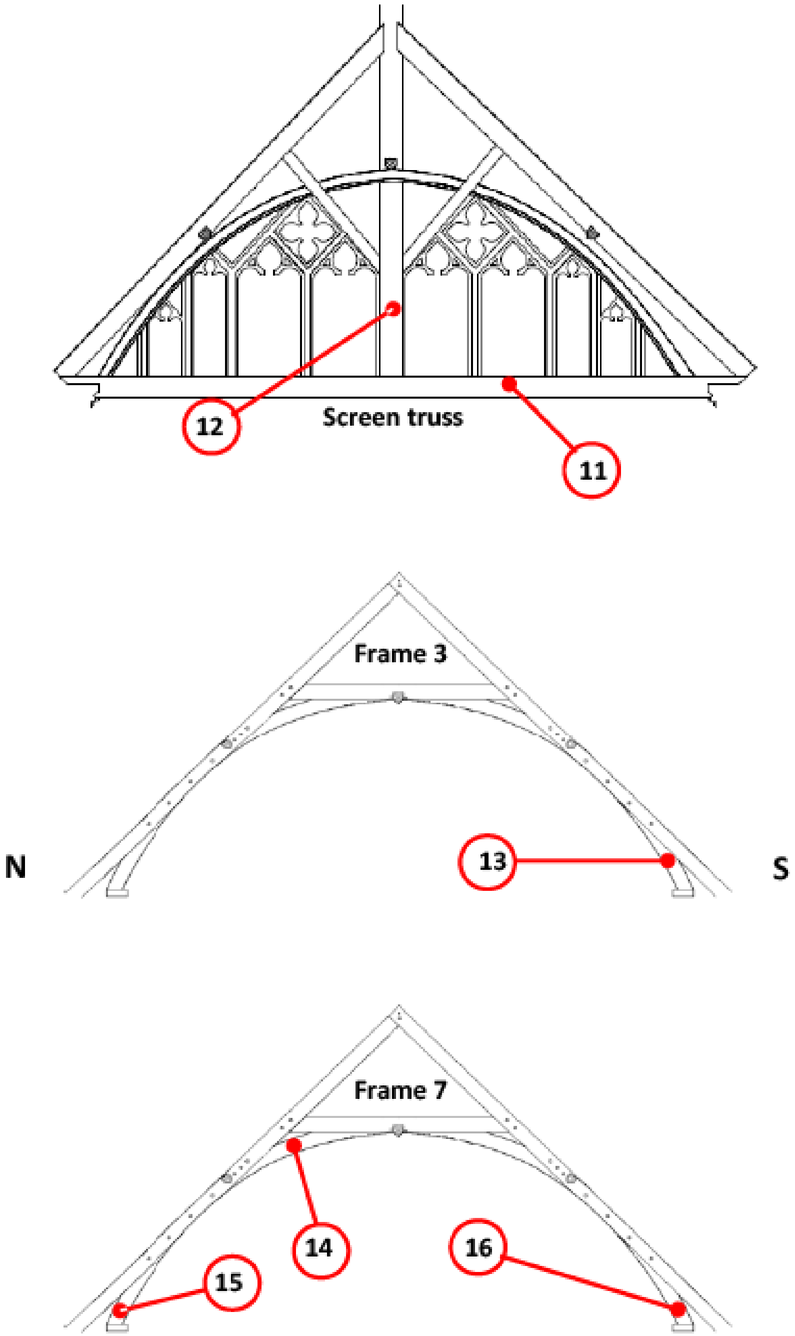


Figure 5c: The nave roof trusses to show sampled timbers (after Baart Harries Newall, Architects, Shrewsbury)

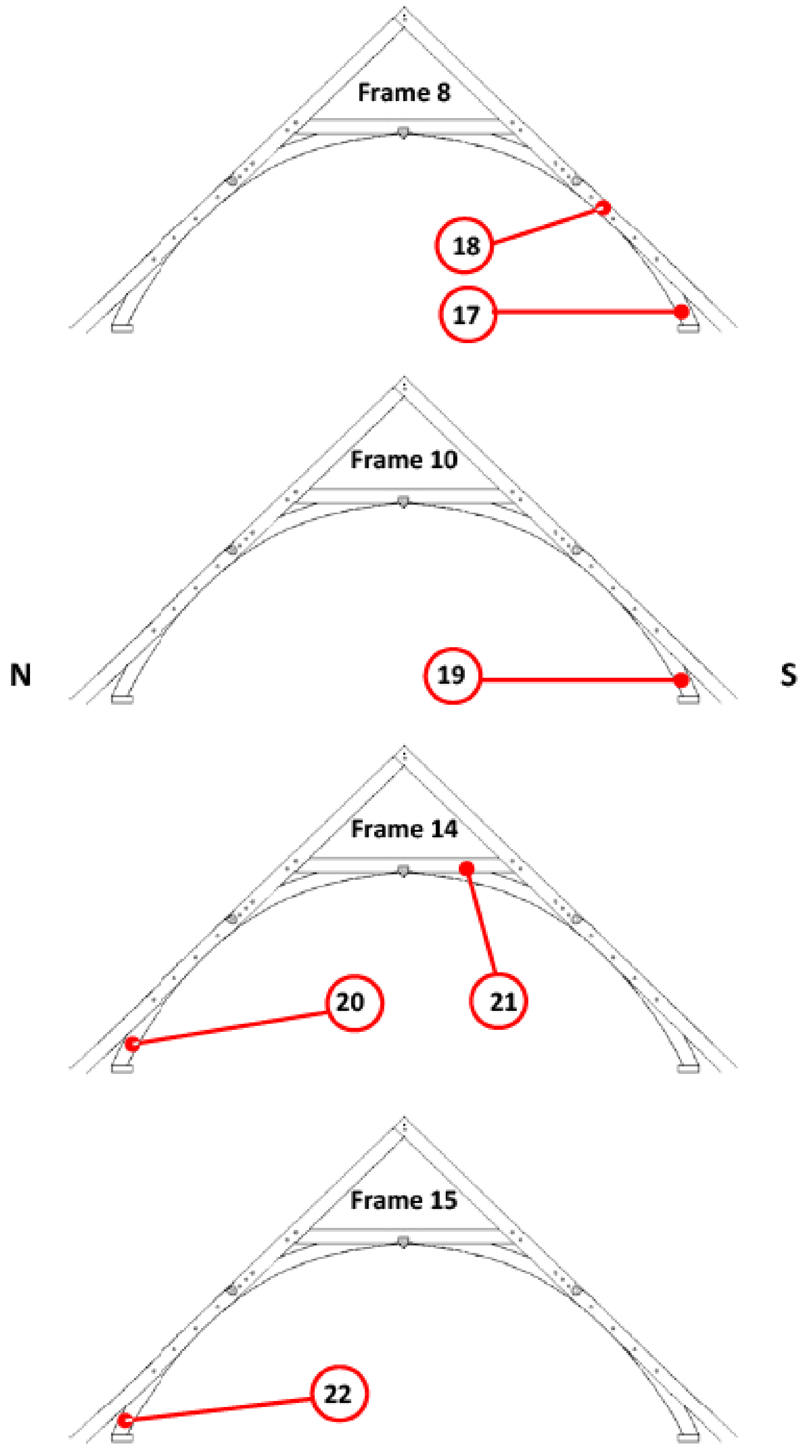


Figure 5d: The nave roof trusses to show sampled timbers (after Baart Harries Newall, Architects, Shrewsbury)

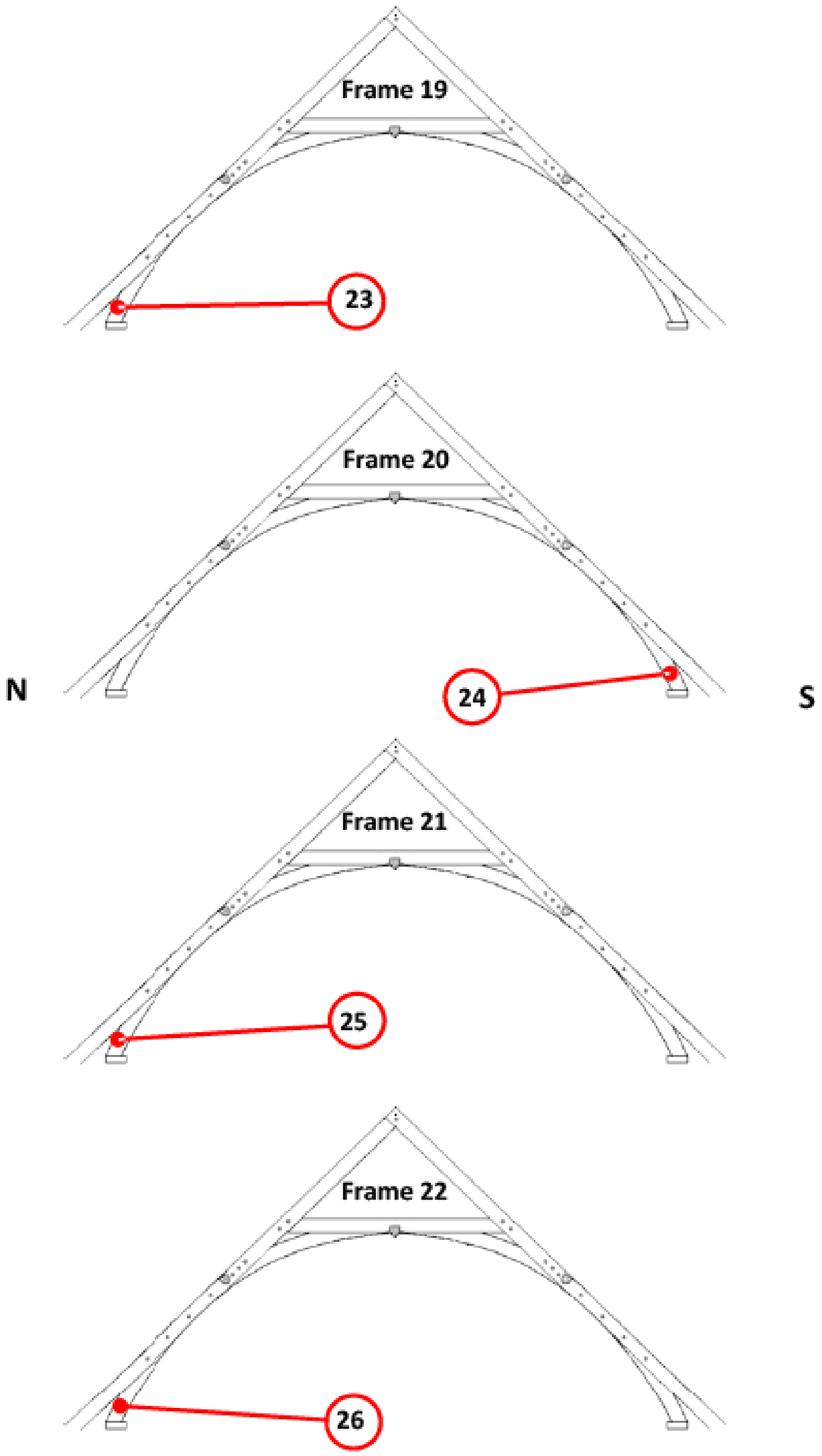
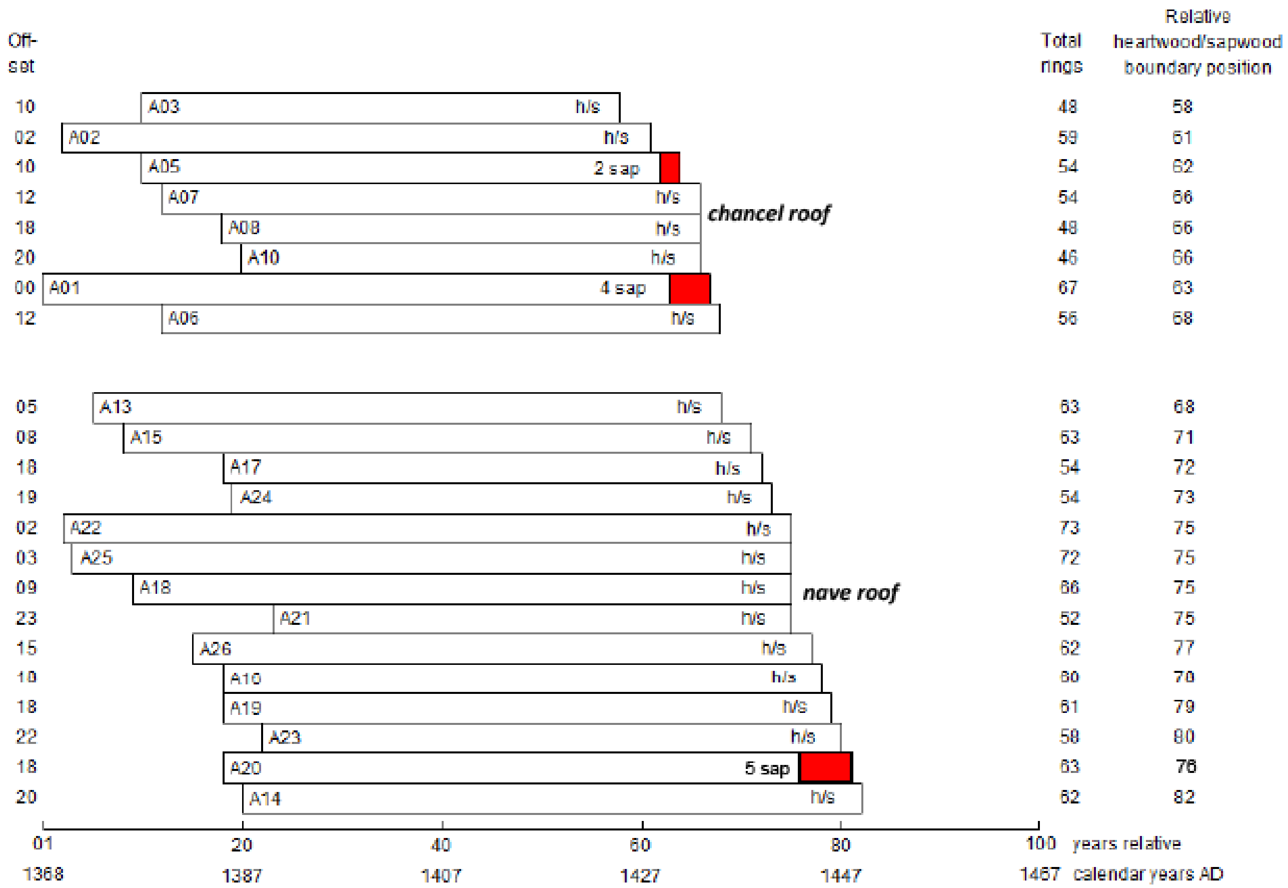


Figure 5e: The nave roof trusses to show sampled timbers (after Baart Harries Newall, Architects, Shrewsbury)



white bars = heartwood rings, filled bars = sapwood rings; h/s = heartwood/sapwood boundary

Figure 6: Bar diagrams of the samples in site chronology BERAQ01

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

BER-A01A 67
333 459 335 332 358 219 216 153 184 181 205 318 165 110 155 134 110 128 194 220
204 191 146 171 130 116 81 139 268 340 385 343 293 192 268 293 337 281 268 182
201 228 284 162 171 118 171 248 160 109 137 113 229 211 134 279 236 177 114 146
214 203 202 181 159 121 162
BER-A01B 67
337 476 335 308 365 216 209 153 180 167 264 258 143 96 166 143 102 129 188 207
169 183 160 178 121 129 77 125 239 350 380 317 258 191 288 273 340 261 278 192
214 231 276 170 170 126 173 256 162 98 137 115 228 195 156 281 229 178 106 147
209 201 207 184 147 119 163
BER-A02A 59
376 357 420 326 385 259 391 248 289 408 417 278 335 282 178 165 241 280 385 405
373 396 285 313 190 139 275 229 275 267 295 304 243 339 220 171 159 137 126 138
120 76 51 65 55 60 51 51 70 73 92 125 106 120 104 81 40 62 106
BER-A02B 59
380 336 396 338 384 273 389 244 289 419 400 303 318 279 169 173 227 276 355 452
373 406 273 303 192 143 276 225 279 267 288 300 245 343 217 167 157 118 133 117
134 73 54 65 56 65 53 54 64 71 92 114 110 117 101 83 53 60 108
BER-A03A 48
475 571 575 437 485 388 395 344 444 422 457 445 385 356 275 360 240 209 323 310
335 369 366 382 290 342 223 223 187 162 201 164 168 114 104 129 115 139 135 95
73 78 153 128 92 79 75 96
BER-A03B 48
501 564 580 432 491 400 369 387 461 420 462 453 378 360 271 364 240 210 334 318
328 364 371 380 299 335 223 226 184 165 201 165 168 116 107 126 121 133 134 84
78 69 165 123 92 72 79 96
BER-A04A 63
175 226 269 205 176 207 159 92 127 167 201 255 293 196 233 267 221 207 175 256
328 293 184 178 189 261 175 171 166 216 138 191 192 193 143 220 167 134 218 239
134 128 193 150 134 118 118 156 140 182 162 176 187 162 131 112 110 223 182 146
175 220 193
BER-A04B 63
181 224 261 211 174 201 150 89 123 161 217 240 298 199 230 251 213 203 182 276
328 300 177 175 204 250 184 172 164 214 135 194 190 201 139 221 167 126 231 228
132 128 197 146 123 123 134 159 146 158 181 173 192 155 145 100 104 221 199 145
176 190 195
BER-A05A 54
459 466 505 325 541 567 425 431 557 521 607 524 420 355 312 357 185 190 476 453
454 551 462 437 425 449 296 369 371 331 268 184 146 83 87 124 109 171 162 137
125 116 224 242 182 290 235 153 86 100 150 193 196 228
BER-A05B 54
453 476 503 368 551 557 430 444 568 518 613 518 415 357 321 342 203 191 476 442
454 562 475 444 434 451 333 379 382 320 253 190 129 95 90 114 100 174 162 146
123 116 219 253 193 243 262 130 86 113 154 190 198 219
BER-A06A 56
422 282 328 277 181 160 238 277 387 400 149 164 136 118 94 141 273 337 381 337
691 603 553 682 512 446 341 318 343 578 484 312 340 339 314 325 246 162 229 173
312 365 304 404 292 354 235 334 418 415 464 414 434 385 374 289

BER-A06B 56
420 329 321 271 170 163 229 274 375 412 159 168 131 119 97 135 259 346 370 328
693 615 550 703 523 443 346 320 354 558 439 303 351 316 290 313 243 156 223 182
300 379 310 360 306 353 228 312 395 432 461 409 438 384 369 283
BER-A07A 54
490 305 523 553 405 421 545 511 599 519 420 342 362 412 185 265 455 350 459 450
460 410 321 421 378 318 349 389 414 305 327 203 183 202 153 210 194 160 200 150
230 240 276 318 262 187 171 164 276 320 335 339 472 353
BER-A07B 54
487 308 511 549 400 414 552 511 603 508 411 337 360 418 221 264 451 380 460 453
463 404 321 407 385 336 352 389 385 329 322 202
187 206 160 196 203 154 187 150
235 237 267 329 259 201 168 168 261 323 351 353
487 348
BER-A08A 48
184 212 198 187 139 168 125 119 87 142 273 329 373 571 606 450 509 589 368 393
386 350 392 432 435 253 239 271 258 309 282 212 299 198 289 354 313 469 362 385
218 314 479 393 381 319 332 303
BER-A08B 48
180 217 179 189 120 171 119 109 79 134 259 340 379 568 604 450 499 578 349 398
384 352 389 431 438 268 231 271 241 302 279 215 298 200 284 332 303 474 359 379
220 315 464 393 390 312 343 301
BER-A09A 41
333 318 380 382 282 291 301 317 235 243 325 328 407 347 311 242 244 292 167 175
132 195 231 225 139 231 251 365 301 225 312 295 330 164 318 258 237 265 300 275
217
BER-A09B 41
336 331 373 399 296 281 293 325 228 250 335 341 404 349 299 250 261 265 163 175
143 177 228 223 131 237 246 365 304 221 307 296 318 169 321 248 238 256 298 261
211
BER-A10A 46
392 399 152 160 139 124 100 139 264 341 446 473 526 346 371 560 521 419 549 435
517 446 443 257 309 331 368 407 346 215 282 232 456 431 290 398 318 332 226 256
339 401 478 369 420 331
BER-A10B 46
395 402 154 165 132 179 99 133 255 344 443 472 542 379 346 562 551 417 541 430
487 443 444 275 341 350 312 407 326 215
298 245 425 425 285 404 310 345 221 271
310 409 470 369 422 335
BER-A11A 58
305 433 454 420 466 407 517 487 551 610 559 610 617 489 454 414 476 457 440 387
390 304 360 335 290 203 173 161 251 285 323 280 317 436 302 465 393 281 393 287
272 372 352 278 246 256 356 327 382 521 503 505 498 393 300 326 354 311
BER-A11B 58
307 386 425 464 410 405 485 484 544 604 557 608 609 485 453 423 465 457 443 389
396 292 357 331 282 200 176 170 256 279 309 292 312 416 290 462 371 284 380 285
290 350 350 282 251 260 350 325 356 510 501 507 492 403 298 326 353 314
BER-A12A 54
409 418 436 417 401 503 537 536 644 116 114 96 167 255 297 282 317 434 292 389
382 414 353 381 367 281 166 293 189 252 296 190 207 262 232 292 168 140 167 228
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BER-A12B 54
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402 401 337 375 343 271 170 293 194 239 298 193 209 257 234 280 175 151 164 242
282 217 258 267 200 190 218 294 291 276 188 169 223 200
BER-A13A 63
505 486 365 503 385 453 473 462 342 393 328 288 289 343 345 398 465 431 525 293
251 248 199 254 245 209 206 217 202 155 225 162 154 176 151 203 196 178 106 104
112 85 135 129 128 120 101 154 146 143 156 131 108 89 93 133 100 99 81 176
103 132 135
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494 483 367 499 396 459 475 460 342 388 300 294 303 344 344 364 440 450 537 287
249 207 196 267 234 213 214 223 195 167 213 173 146 168 153 186 206 184 120 98
110 79 143 120 132 123 96 162 152 143 156 130 100 88 90 139 109 100 83 175
100 129 140
BER-A14A 62
462 453 376 405 357 506 343 407 446 393 389 327 353 289 256 375 490 389 345 398
429 335 328 182 201 209 128 126 107 107 85 76 161 184 154 235 189 248 137 133
225 202 206 182 289 216 196 240 252 137 103 75 83 97 81 75 96 114 131 126
174 142
BER-A14B 62
467 450 384 411 376 475 353 403 451 387 421 318 373 273 294 378 500 424 354 392
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228 204 193 181 276 212 200 237 257 137 87 81 84 96 76 81 106 106 135 124
173 140
BER-A15A 63
249 180 419 423 268 87 191 334 406 361 528 391 339 375 272 308 227 229 253 300
287 201 235 200 218 214 139 246 273 292 278 213 285 383 242 178 235 229 207 214
201 181 226 164 245 281 182 268 179 229 163 221 222 155 167 146 217 98 129 150
98 77 116
BER-A15B 63
248 172 426 438 248 78 237 347 426 354 522 392 340 374 275 291 234 223 233 268
276 195 232 193 225 217 135 259 292 301 259 228 264 376 229 190 242 228 204 226
195 189 224 168 239 284 184 267 193 218 162 223 221 153 171 142 221 87 136 153
100 76 116
BER-A16A 60
505 416 376 440 336 418 336 299 205 235 307 222 269 225 242 259 141 270 348 373
414 360 420 553 365 284 371 285 262 242 264 220 259 179 349 373 240 368 239 301
184 259 278 201 229 206 328 205 220 250 220 169 175 186 187 184 130 120 126 110
BER-A16B 60
507 415 372 453 323 426 345 295 205 243 301 231 253 227 253 253 144 271 346 364
421 360 425 546 376 287 360 292 271 230 265 226 251 176 351 358 253 371 240 306
181 268 277 197 227 209 333 206 225 240 217 166 181 190 188 185 131 121 128 115
BER-A17A 54
471 369 260 305 424 557 562 571 407 475 463 275 296 254 271 289 216 316 367 304
229 175 215 306 215 192 243 184 181 170 182 157 223 131 224 217 173 212 159 200
130 156 167 110 164 157 207 125 153 164 132 76 100 118
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468 367 264 302 392 548 559 564 410 482 463 270 290 236 259 267 205 306 370 315
241 179 209 296 223 183 243 185 187 168 171 160 220 153 204 220 176 209 164 199
134 145 174 115 171 140 212 123 149 162 107 83 100 117
BER-A18A 66
260 294 253 215 169 436 425 330 405 713 687 581 542 462 627 520 407 300 209 338
339 298 273 342 212 156 229 262 131 156 149 134 151 129 107 70 59 59 75 46
61 63 89 118 123 121 150 110 79 53 80 105 98 90 70 97 65 75 65 70
50 48 39 37 47 118

BER-A18B 66
255 300 248 217 172 418 434 323 412 696 673 589 529 416 628 526 378 286 188 330
334 292 268 335 222 157 230 264 135 156 148 132 154 123 107 73 58 58 79 43
64 68 92 114 134 117 150 112 75 53 71 101 101 89 72 100 62 80 71 63
56 49 40 40 49 117
BER-A19A 61
646 567 658 699 921 837 528 359 421 343 368 417 359 331 487 381 384 478 331 275
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93 95 168 209 189 157 217 112 183 188 172 152 153 107 119 128 89 98 67 91
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BER-A19B 61
648 560 663 689 921 846 518 354 405 301 362 437 344 335 510 364 379 476 332 278
200 212 264 210 209 110 153 145 121 189 112 108 149 189 288 178 175 279 182 130
92 93 175 206 181 158 213 131 159 209 175 153 164 103 115 117 100 91 75 91
105
BER-A20A 63
582 509 584 484 596 667 405 298 326 231 250 393 286 331 375 335 281 337 295 282
242 231 237 198 229 153 176 182 137 196 123 131 148 159 221 156 156 226 173 140
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567 524 597 491 577 668 415 297 325 239 254 382 287 333 386 325 269 334 279 270
256 235 250 201 224 164 189 188 144 194 118 128 157 145 228 160 150 232 173 135
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216 287 287 250 258 561 544 514 416 636 572 612 546 532 353 456 446 377 363 348
279 296 229 151 193 105 156 181 162 253 250 223 231 182 148 113 154 218 210 162
148 191 179 177 156 128 106 71 114 173 166 209
BER-A21B 52
217 284 260 275 269 560 550 514 419 633 572 593 531 515 366 451 434 377 345 346
259 304 222 166 213 98 165 171 156 261 262 228 248 164 148 112 153 217 207 159
159 176 165 168 152 125 104 75 119 175 151 206
BER-A22A 73
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181 100 96 100 59 84 70 115 90 93 119 111 120 133 163 163 94 103 137 99
109 100 155 86 118 126 111 113 103 87 94 138 126
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557 433 615 530 520 458 550 439 485 588 476 263 325 235 264 384 529 451 327 398
275 357 270 240 150 135 235 212 212 215 220 187 162 184 112 120 140 189 196 200
190 99 103 97 53 84 74 103 96 92 112 112 109 134 159 156 94 96 137 105
109 90 168 88 126 121 109 112 101 92 90 137 125
BER-A23A 58
341 468 257 323 205 185 328 357 266 260 339 328 340 353 193 228 271 284 357 325
350 177 196 229 142 181 156 212 269 178 260 175 175 259 201 265 146 153 198 169
135 128 201 109 139 195 151 157 143 106 150 167 107 106 99 142 98 148
BER-A23B 58
343 449 259 323 207 185 322 346 265 269 362 335 355 353 207 225 275 280 365 346
357 179 198 218 140 179 162 221 271 170 283 183 171 242 203 245 153 159 207 170
143 146 189 128 138 192 168 167 135 117 141 149 112 96 107 131 115 150
BER-A24A 54
472 444 401 403 408 285 339 264 278 416 378 332 288 409 323 274 397 408 495 418

342 248 244 173 112 87 120 98 114 90 96 100 85 151 171 154 125 157 89 68
79 121 111 129 117 144 92 120 126 90 73 53 71 73
BER-A24B 54
480 432 399 396 421 290 327 269 233 412 381 327 303 439 354 291 403 396 470 431
354 250 214 195 109 84 127 101 118 76 107 89 87 153 171 157 124 160 100 59
82 118 122 124 117 129 90 126 134 91 73 57 73 78
BER-A25A 72
544 630 519 405 359 445 444 459 547 464 294 375 290 283 499 586 398 326 328 279
437 362 295 198 185 332 268 232 260 292 250 227 217 126 137 154 169 183 197 221
133 123 139 62 93 73 126 108 79 125 115 122 122 151 146 96 96 112 87 85
81 118 70 106 104 84 100 93 71 73 128 194
BER-A25B 72
539 623 527 391 378 467 413 448 541 455 294 387 275 270 527 583 409 331 317 282
448 368 295 195 182 329 263 233 271 290 256 223 215 133 135 153 168 187 190 218
134 129 140 63 84 80 134 86 94 131 125 121 126 143 150 88 101 113 87 87
87 124 67 101 93 89 92 96 62 81 126 193
BER-A26A 62
522 428 608 649 489 389 666 500 599 347 407 160 210 393 295 339 314 365 343 308
392 257 270 273 260 368 318 340 170 148 167 92 118 150 187 142 109 232 165 151
211 201 203 151 125 148 133 134 140 171 126 129 160 130 144 137 98 128 136 104
93 109
BER-A26B 62
527 437 618 678 489 380 662 496 599 359 403 171 208 396 298 340 312 375 341 298
385 265 258 286 261 375 315 342 178 160 154 92 127 146 203 135 100 260 165 156
232 198 209 151 114 153 139 131 141 184 115 133 158 133 146 130 96 121 156 82
99 111

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 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.** As m 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

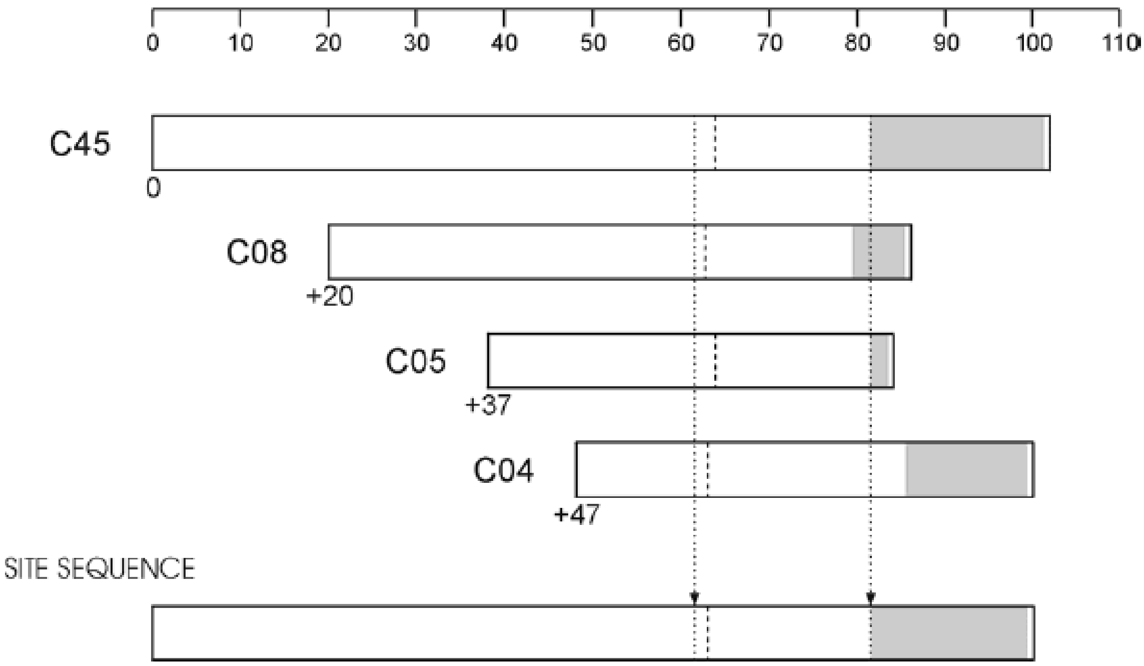


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

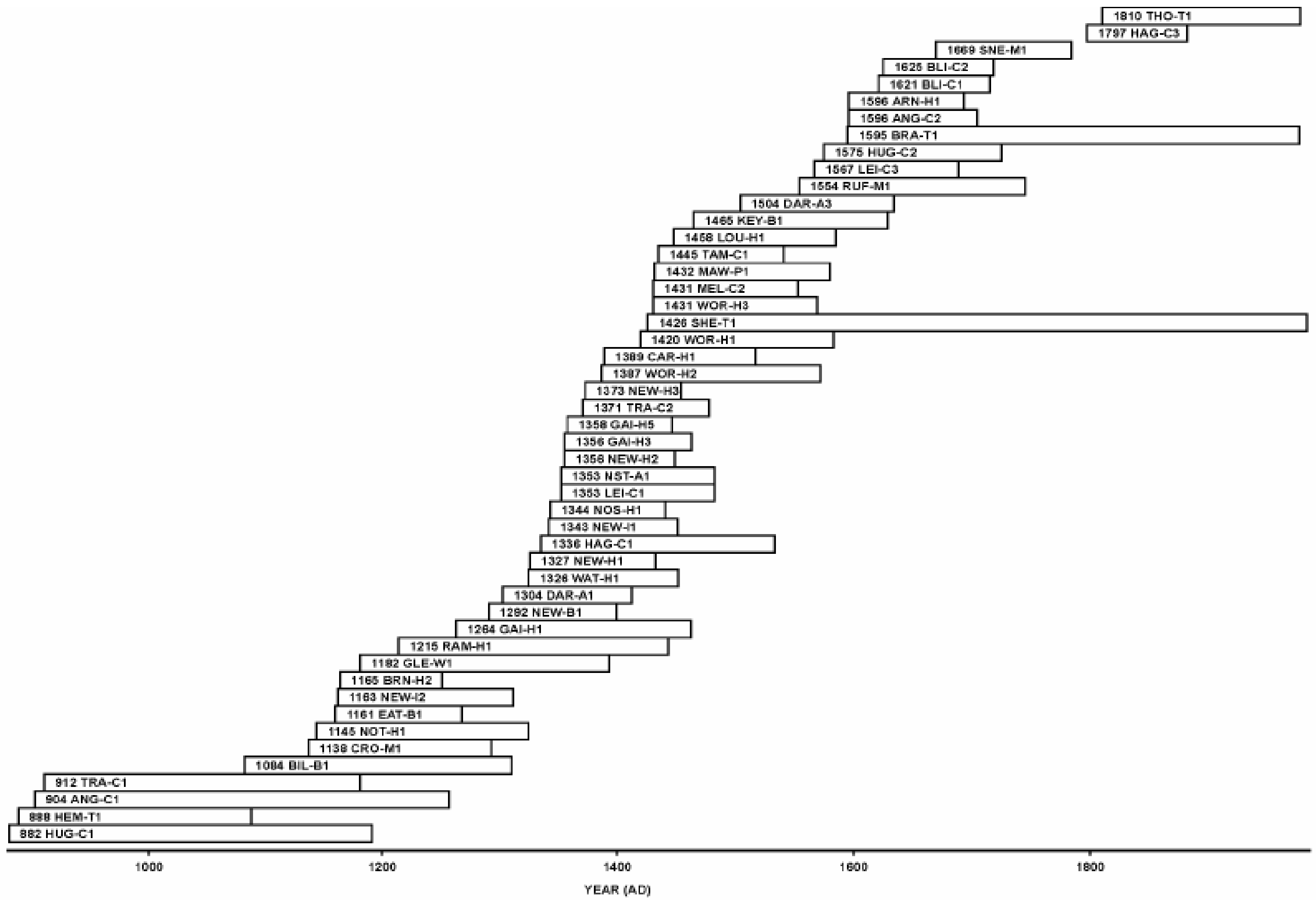
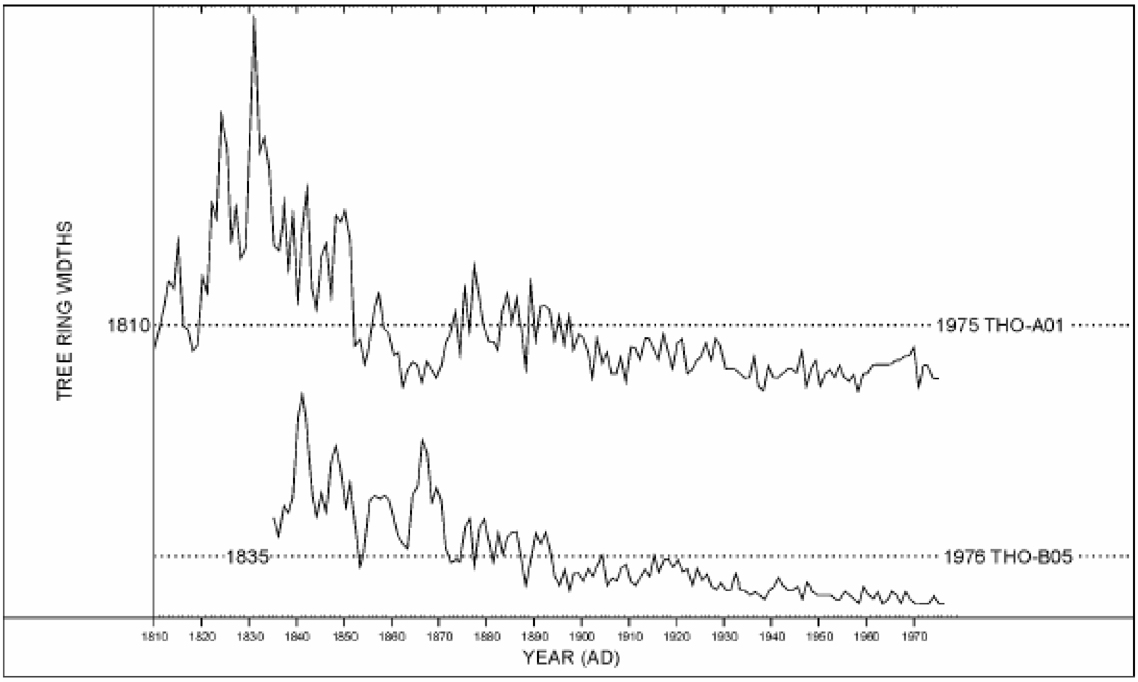


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

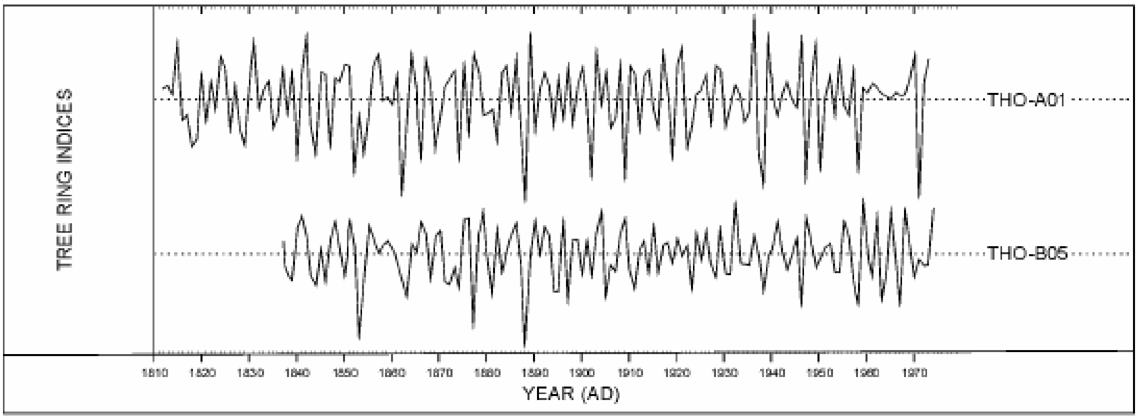


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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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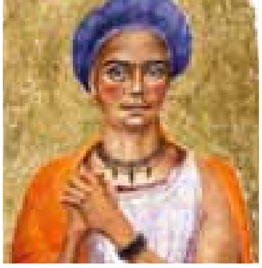


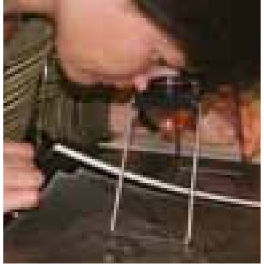


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- Remote Sensing (including Mapping, Photogrammetry and Geophysics)

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We make the results of our work available through the Research Report Series, and through journal publications and monographs. Our newsletter *Research News*, which appears twice a year, aims to keep our partners within and outside English Heritage up-to-date with our projects and activities.

A full list of Research Reports, with abstracts and information on how to obtain copies, may be found on www.english-heritage.org.uk/researchreports

For further information visit www.english-heritage.org.uk

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