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OLD HALL FARMHOUSE, BRIGHTHOLMLEE, BRADFIELD, SHEFFIELD, SOUTH YORKSHIRE
TREE-RING DATING OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

INTERVENTION
AND ANALYSIS

ENGLISH HERITAGE

Research Report Series 44-2014

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SUMMARY

Analysis undertaken on samples from the roof of the hall at Old Hall Farmhouse resulted in the construction of two site sequences, only one of which could be securely dated.

Site sequence BRTHSQ01 contains four samples and spans the period AD 1365–1484. Interpretation of the sapwood suggests felling of all four timbers in AD 1484, with construction of the roof following shortly after.

CONTRIBUTORS

Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS

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CONTENTS

INTRODUCTION

The Grade II listed Old Hall Farmhouse is situated in a very small hamlet on the north side of Sheffield (Figs 1 and 2). The house, aligned roughly east-west, is thought to be of three phases, the primary medieval hall, an addition to the west (west range), and an offset parlour block to the north-east (Fig 3).

The hall

At the core of this house is the medieval hall, thought to be the oldest surviving part of the building. It consists of two rooms at ground- and first-floor level, although there may have once been further bays to one or both ends. At ground-floor level the two rooms are separated by a plank-and-muntin screen, and both have exposed ceiling timbers. The roof over this part of the building consists of two cruck trusses, one of which (truss 2) is smoke blackened, suggesting the existence of an open hearth. The collar of truss 2 survives and each truss has a yoke.

West range

This addition of the west range consists of two stories and appears to be a house in its own right. Its basic plan is of two rooms with the western room having a firehood and the eastern room having cellars beneath it. The roof over this part of building has a single king-post truss with collar. This addition is thought to date to the late-seventeenth century.

Parlour block

Also thought to date to the late-seventeenth century (although perhaps slightly later than the west range) is the parlour block. This building is again of two stories but with the addition of attics. Present access is via an early nineteenth-century stair. The rooms were heated at both ground- and first-floor level and the building as a whole appears to be of superior quality.

SAMPLING

Sampling of the roof of the hall range was requested by Nicola Wray, English Heritage Designation Advisor, to inform a potential listing upgrade from its present Grade II status.

A total of 11 timbers from the roof over the hall range was sampled by coring. Each sample was given the code BRT-H and numbered 01–11. The location of all samples was noted at the time of sampling and has been marked on Figures 4 and 5. Further details relating to the samples can be found in Table 1.

ANALYSIS AND RESULTS

Three of the samples had too few rings for secure dating and so were rejected prior to measurement. The remaining eight samples were prepared by sanding and polishing and their growth-ring widths measured; the data of these measurements are given at the end of the report. These eight samples were then compared with each other by the Litton/Zainodin grouping programme (see Appendix), resulting in six samples matching to form two groups.

Firstly, four samples matched each other and were combined at the relevant offset positions to form BRTHSQ01, a site sequence of 120 rings (Fig 6). This site sequence was compared against a series of relevant reference chronologies for oak where it was found to span the period AD 1365–1484. The evidence for this dating is given in Table 2.

Two further samples matched each other and were again combined at the relevant offset position to form BRTHSQ02, a site sequence of 67 rings (Fig 7). Attempts to date this site sequence and the ungrouped samples were unsuccessful and all remain undated.

INTERPRETATION

Four samples, all taken from cruck blades, have been successfully dated. Two of these (samples BRT-H01 and BRT-H03) have complete sapwood and the last-measured ring date of AD 1484, the felling date of the two timbers represented. The other two samples (BRT-H02 and BRT-H04) have broadly contemporary heartwood/sapwood boundary ring dates, the average of which is AD 1469, allowing an estimated felling date to be calculated for the two timbers represented of AD 1484–1509, consistent with these timbers also having been felled in AD 1484.

DISCUSSION

The dendrochronological analysis has demonstrated that the timber used for the four cruck blades was felled in AD 1484. It is unfortunate that none of the other elements of this roof could be securely dated, however, the cruck blades are thought likely to represent the primary phase of construction of the roof, whereas it is possible that elements such as purlins could be more readily replaced.

It is perhaps disappointing that only the four samples in site sequence BRTHSQ01 have been dated. However, as both samples in the undated BRTHSQ02 have complete sapwood and the same end position it is possible to say that the two timbers represented, both purlins, were felled at the same time, although when this might be is not known.

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TABLES

Table 1: Details of tree-ring samples from Old Hall Farmhouse, Brightholmlee, South Yorkshire

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last measured heartwood ring date (AD)	Last measured ring date (AD
BRT-H01	North blade, truss 1	120	22C	1365	1462	1484
BRT-H02	South blade, truss 1	78	10	1406	1473	1483
BRT-H03	North blade, truss 2	83	27C	1402	1457	1484
BRT-H04	South blade, truss 2	98	12	1380	1465	1477
BRT-H05	Collar, truss 2	NM	--	----	----	----
BRT-H06	North purlin, east end to truss 1	NM	--	----	----	----
BRT-H07	South purlin, east gable to truss 1	70	h/s	----	----	----
BRT-H08	North purlin, truss 1–2	67	14C	----	----	----
BRT-H09	South purlin, truss 1–2	44	11C	----	----	----
BRT-H10	North purlin, truss 2 to west gable	57	17C	----	----	----
BRT-H11	South purlin, truss 2 to west gable	NM	--	----	----	----

NM = not measured

C = complete sapwood retained on sample, last measured ring is the felling date

Table 2: Results of the cross-matching of site sequence BRTHSQ01 and reference chronologies when the first ring date is AD 1365 and the last-measured ring date is AD 1484

Reference chronology	*t*-value	Span of chronology	Reference
Barnburgh Hall dovecote, Doncaster, South Yorkshire	6.6	AD 1417–1477	Tyers 2000
Hardwick Old Hall, Doe Lea, Chesterfield, Derbyshire	6.5	AD 1375–1590	Howard *et al* 2002
Black Ladies, near Brewood, Staffordshire	6.3	AD 1372–1671	Tyers 1999
Boconnoc House, Cornwall	6.1	AD 1410–1476	Arnold and Howard 2007
Hall Broom Farm, Dungworth, Derbyshire	6.1	AD 1382–1495	Howard *et al* 1993
Oak House, West Bromwich, West Midlands	5.4	AD 1405–1590	Arnold and Howard 2009a
Abbots Lodge, Ledbury, Herefordshire	5.4	AD 1274–1519	Arnold and Howard 2009b

FIGURES

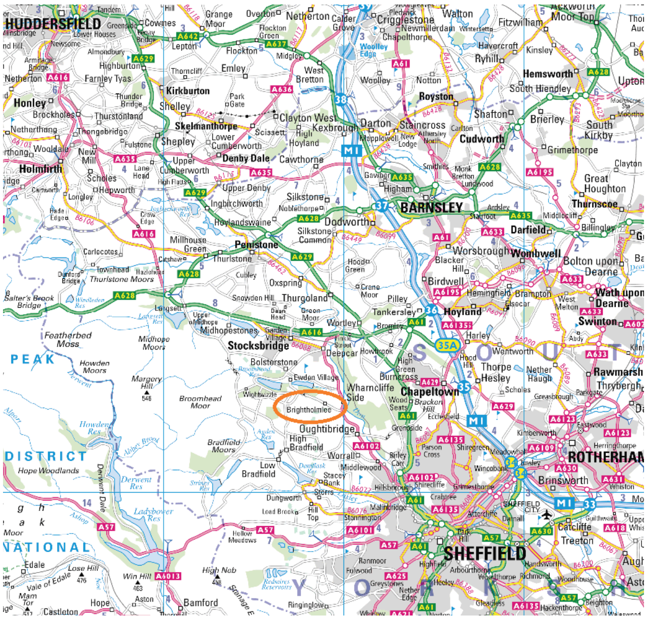

Figure 1: Map to show the location of Brightholmlee, Yorkshire, circled. ©Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900

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Figure 2: Map to show the location of Old Hall Farmhouse, arrowed. ©Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900

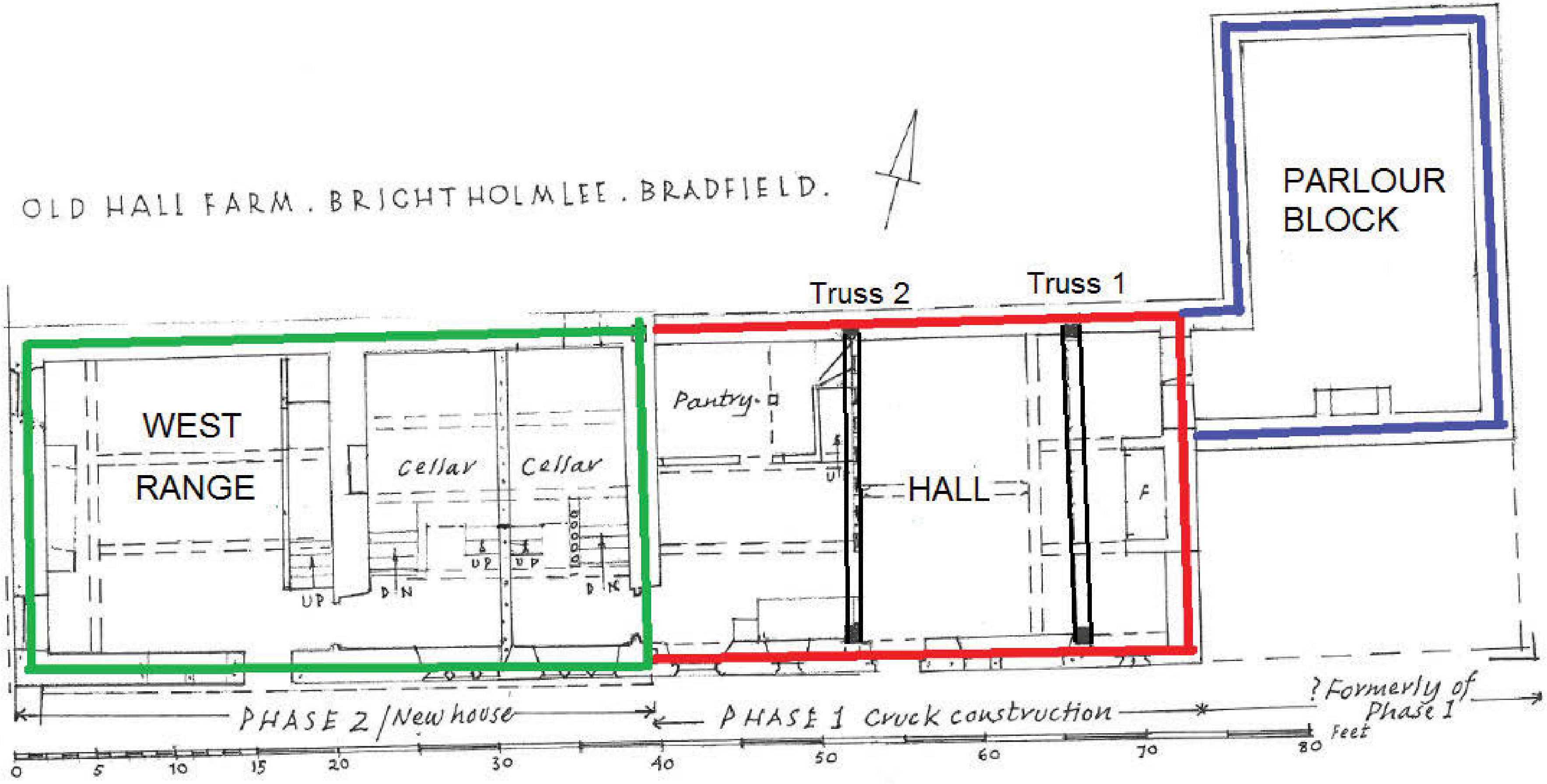

Figure 3: Ground-floor plan, showing the three phases of Old Hall Farmhouse and the location of cruck trusses in the hall range (Hunter Archaeological Society)

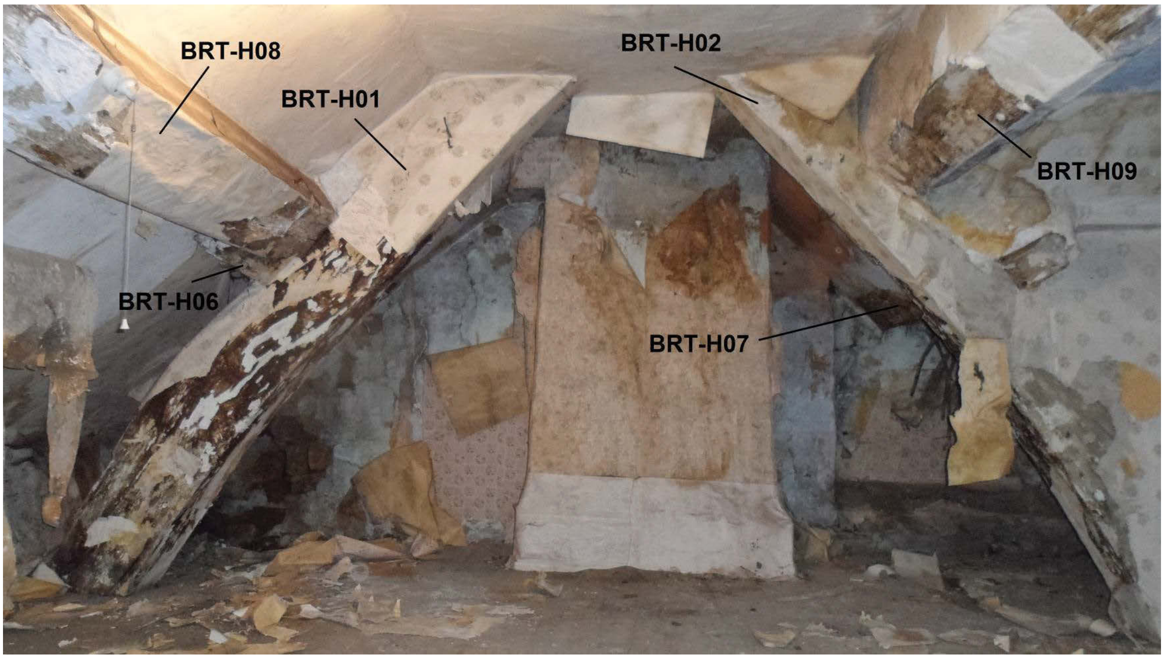

Figure 4: Photograph of truss 1, showing the location of samples BRT-H01, BRT-H02, and BRT-H06–09 (Alison Arnold)

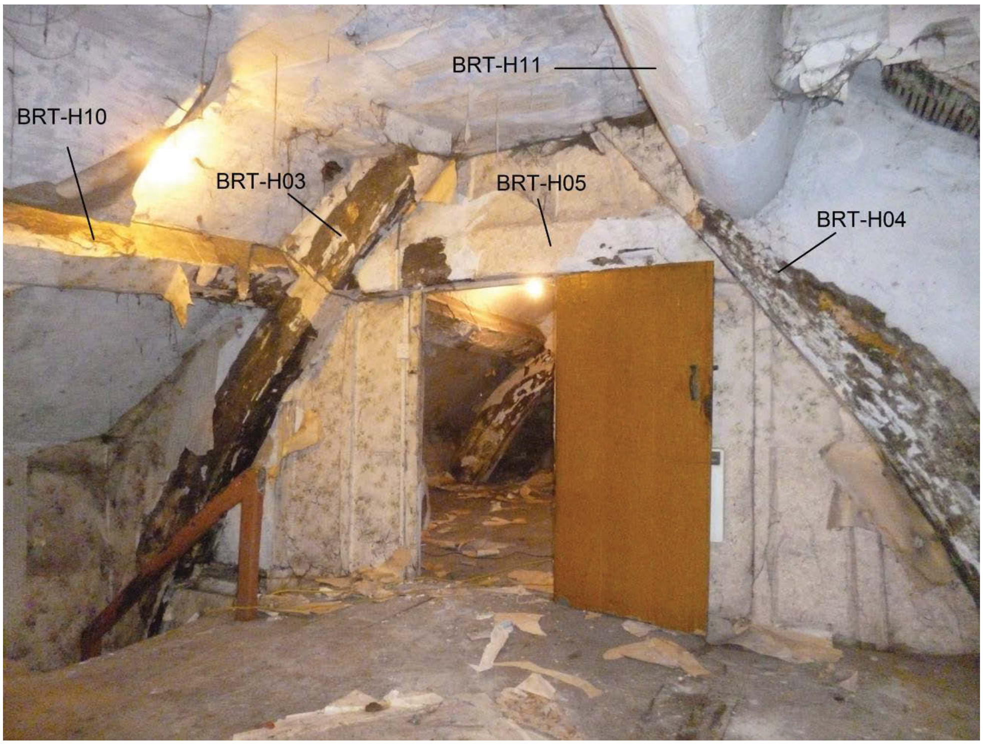

Figure 5: Photograph of truss 2, showing the location of samples BRT-H03–05 and BRT-H10–11 (Alison Arnold)

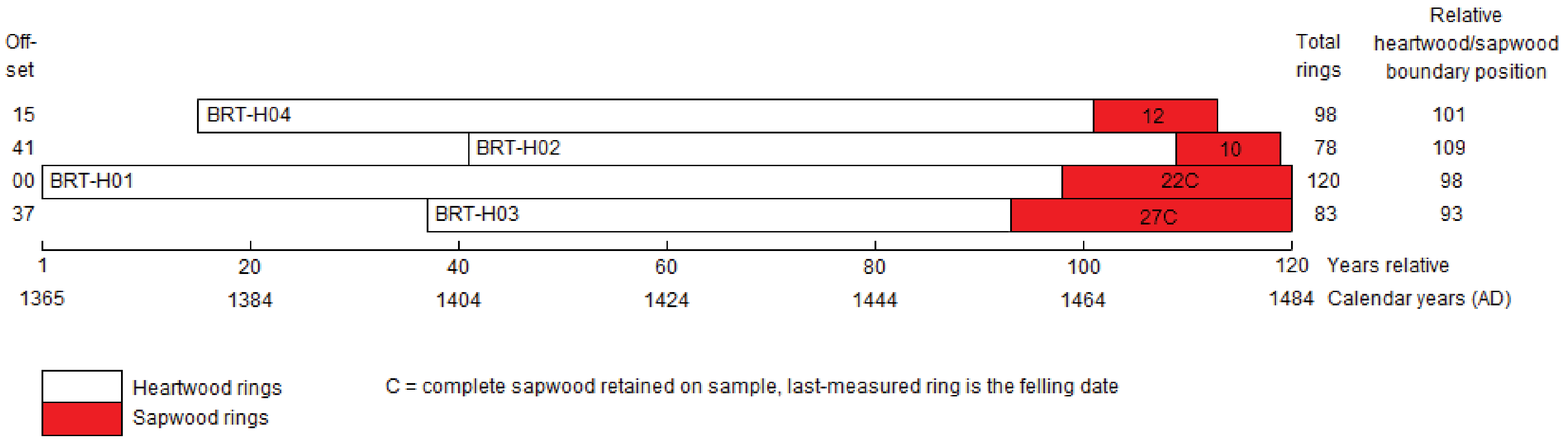

Figure 6: Bar diagram of samples in site sequence BRTHSQ01

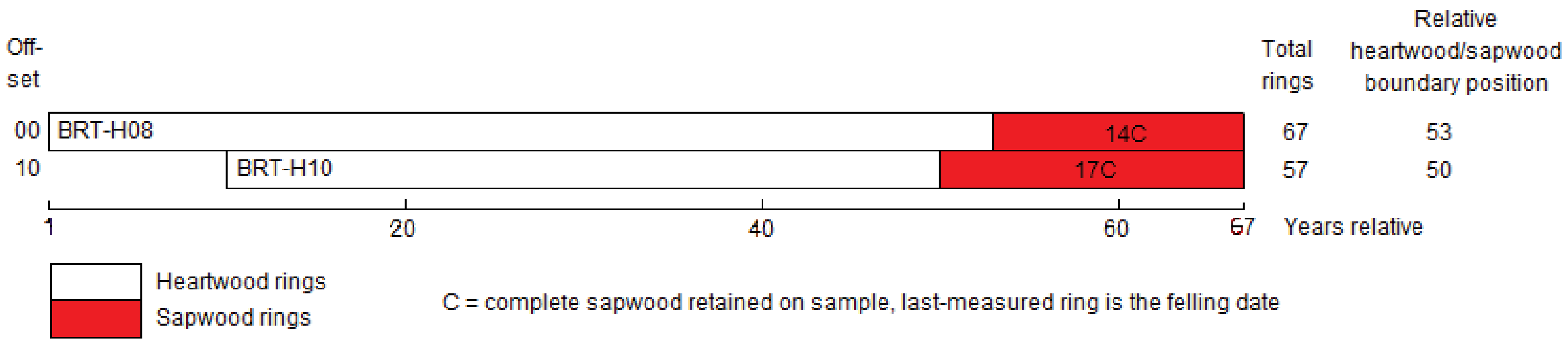

Figure 7: Bar diagram of samples in site sequence BRTHSQ02

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

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BRT-H01A 120
 112  99 108 188 198 175 166 140  65  89  74 120  99 131 307 363 439 474 480 192
 154 165 243 213 158 187 156 194 125 211 160 298 116 134 186 149  88 213 201 229
 166 218 144 162 155 160 148 195 187 159 145 106 119  94 122 210 156 207 205 198
 179 137  85 104 174 198 175 215 132 119 106 116 101  95  96 117 110  95 111 118
 112  91  85 106  96 154 124 111 105 103 101  96  90  81  69  78  76  69  60  56
  75  80  69 110  82  88  80  70  74  77 106 111 114 107  83 112 102  89  98  94
BRT-H01B 120
  95  92 107 168 192 171 164 128  69  79  71 128  96 140 291 361 435 476 478 181
 157 164 248 210 156 191 158 192 127 207 162 300 114 137 184 146  85 217 194 231
 165 214 154 160 153 161 147 198 187 154 150 103 117  92 117 216 158 209 206 193
 180 135  80 112 175 190 176 213 127 112 116 113 102  93  95 114 117  96 110 122
 112  95  83 106  99 144 131 103 107 113  95 104  93  76  70  71  88  69  64  52
  78  78  69 110  83  85  84  64  78  81 100 111 112 111  83 122  98  88 100  92
BRT-H02A 78
 597 383 562 448 437 449 546 478 576 525 496 421 439 341 688 520 429 526 465 484
 418 390 336 397 310 300 460 243 284 246 258 249 202 203 138 121 119 162 168 152
 135 161 231 227 312 360 387 335 455 249 198 206 285 158 207 179 200 149 120 107
 156 265 318 297 302 435 263 317 158 349 412 429 326 311 349 325 111  90
BRT-H02B 78
 584 386 566 438 428 430 552 479 566 523 491 420 442 339 680 502 433 541 463 488
 411 380 336 395 305 303 461 242 280 256 249 246 199 202 135 123 115 165 168 154
 137 156 239 225 312 368 384 331 398 252 200 216 297 171 194 190 190 144 126 106
 153 252 338 299 260 416 270 305 153 351 419 437 307 300 357 318 107  89
BRT-H03A 83
 277 327 331 283 198 137 111 177 135 135 171 192 219 199 181 215 200 132 213 184
 148 202 194 163 144 106  99 133 141 153 171 122 132 108  86 109 105  79  98  96
  90  95 108 139 113 144 131 145 184 163 145 133 134 116 132 147 128 112 122 147
 132 125 131 141 152 174 109 134 126 144 149 120 130 125 131 149 177 167 175 207
 170 234 203
BRT-H03B 83
 261 325 336 298 193 117 112 166 146 132 171 188 208 198 186 203 199 151 229 192
 152 189 189 156 137  95 103 134 144 148 144 140 137 103  84 108 100  80  97  99
  90  96 107 139  97 138 128 134 174 172 146 129 134 117 129 146 125 121 119 144
 126 132 119 149 161 170 111 130 128 145 147 126 126 124 133 170 155 164 178 206
 170 227 215
BRT-H04A 98
 283 266 269 412 443 379 392 390 404 332 367 296 370 409 408 241 431 274 286 365
 337 228 445 403 499 317 424 337 358 332 313 241 292 349 375 316 329 321 190 202
 452 266 300 312 301 270 209 202 244 419 299 323 343 227 253 215 209 216 223 194
 219 206 183 216 264 239 196 196 261 253 244 245 232 206 224 207 241 225 184 146
 160 204 207 195 153 158 316 231 204 160 182 215 207 150 176 240 242 227
BRT-H04B 98
 283 300 274 393 424 366 371 372 387 316 359 299 352 407 390 242 434 272 289 365
 324 228 446 413 506 312 418 332 357 328 319 236 301 348 369 331 324 316 194 200
 456 263 301 307 302 270 224 205 244 416 299 322 350 217 257 218 209 216 227 198
 215 206 185 230 259 237 188 200 252 259 238 252 226 202 236 204 239 226 184 133
 164 190 206 200 147 167 289 260 207 169 179 204 215 147 173 239 245 220
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BRT-H07A 70
 115 161  71 203 224 144 101 105 127 232 257 251 263 243 298 338 284 355 293 353
 302 318 437 263 436 385 364 367 265 300 297 351 422 379 477 419 390 280 232 235
 284 370 325 216 339 281 284 281 355 217 288 316 379 289 334 211 223 181 174 137
 187 232 208 193 190 212 211 132 230 183
BRT-H07B 70
 132 172  61 205 224 145 101  98 119 182 263 294 260 309 358 300 294 371 289 324
 313 314 429 268 438 379 362 365 269 302 296 344 421 371 475 426 382 280 237 238
 292 393 324 206 347 278 289 273 360 219 291 309 379 287 342 206 221 182 171 141
 191 220 208 204 182 196 236 127 236 204
BRT-H08A 67
 198 142 234 350 450 386 353 438 383 223 294 293 426 427 349 282 387 337 284 233
 227 233 407 502 371 376 385 338 257 332 271 303 284 347 348 279 372 314 360 378
 309 269 244 271 237 246 233 200 251 273 186 195 225 267 240 214 263 319 316 292
 293 342 301 304 277 370 358
BRT-H08B 67
 215 149 225 348 448 430 364 438 384 236 287 296 430 425 334 290 387 328 294 228
 225 235 400 499 378 370 382 334 268 336 281 326 309 353 346 287 366 316 356 376
 306 248 267 260 251 245 237 210 245 265 192 193 238 263 245 209 257 326 320 285
 284 357 297 298 284 372 339
BRT-H09A 44
 283 307 587 524 426 285 289 436 448 394 562 444 422 595 433 470 516 374 258 184
 198 216 343 301 314 304 476 469 385 352 339 248 278 232 432 424 339 311 435 343
 327 338 395 388
BRT-H09B 44
 273 317 580 541 427 281 277 427 450 400 560 435 417 602 414 472 512 374 251 188
 203 219 348 297 316 311 463 453 359 344 342 247 281 230 427 425 348 304 437 339
 333 322 422 377
BRT-H10A 57
 195 252 695 435 275 235 268 178 180 166 160 208 359 387 314 374 361 336 216 315
 274 344 383 427 430 315 314 238 309 310 298 218 224 233 214 239 209 198 249 318
 242 250 331 276 242 231 278 331 324 336 311 254 256 256 254 290 298
BRT-H10B 57
 231 263 691 449 270 233 260 198 174 166 157 197 348 388 306 370 368 326 213 314
 277 344 392 425 439 311 329 226 307 304 300 212 229 238 215 231 208 201 239 319
 228 258 327 277 244 232 278 334 323 342 298 263 243 239 265 269 315
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APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

Tree-ring dating, or dendrochronology as it is known, is discussed in some detail in the Laboratory's Monograph, *An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Building* (Laxton and Litton 1988) and *Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates* (English Heritage 1998). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The width of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure A1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths for oaks, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of oak timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring.

If the bark is still on the sample, as in Figure A1, then the date of the last ring will be the date of felling of the oak from which it was cut. There is much evidence that in medieval times oaks cut down for building purposes were used almost immediately, usually within the year or so (Rackham 1976). Hence if bark is present on several main timbers in a building, none of which appear reused or are later insertions, and if they all have the same date for their last ring, then we can be quite confident that this is the date of construction or soon after. If there is no bark on the sample, then we have to make an estimate of the felling date; how this is done is explained below.

The Practice of Tree-Ring Dating at the Nottingham Tree-Ring Dating Laboratory

1. **Inspecting the Building and Sampling the Timbers.** Together with a building historian the timbers in a building are inspected to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can sample in situ timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer rings than this, 50 for example, sequences of widths become difficult to match to a unique

position within a master sequence of ring widths and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure A2 has about 120 rings; about 20 of which are sapwood rings – the lighter rings on the outside. Similarly the core has just over 100 rings with a few sapwood rings.

To ensure that we are getting the date of the building as a whole, or the whole of a phase of construction if there is more than one, about 8–10 samples per phase are usually taken. Sometimes we take many more, especially if the construction is complicated. One reason for taking so many samples is that, in general, some will fail to give a date. There may be many reasons why a particular sequence of ring widths from a sample of timber fails to give a date even though others from the same building do. For example, a particular tree may have grown in an odd ecological niche, so odd indeed that the widths of its rings were determined by factors other than the local climate! In such circumstances it will be impossible to date a timber from this tree using the master sequence whose widths, we can assume, were predominantly determined by the local climate at the time.

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

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

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

Figure A1: A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976

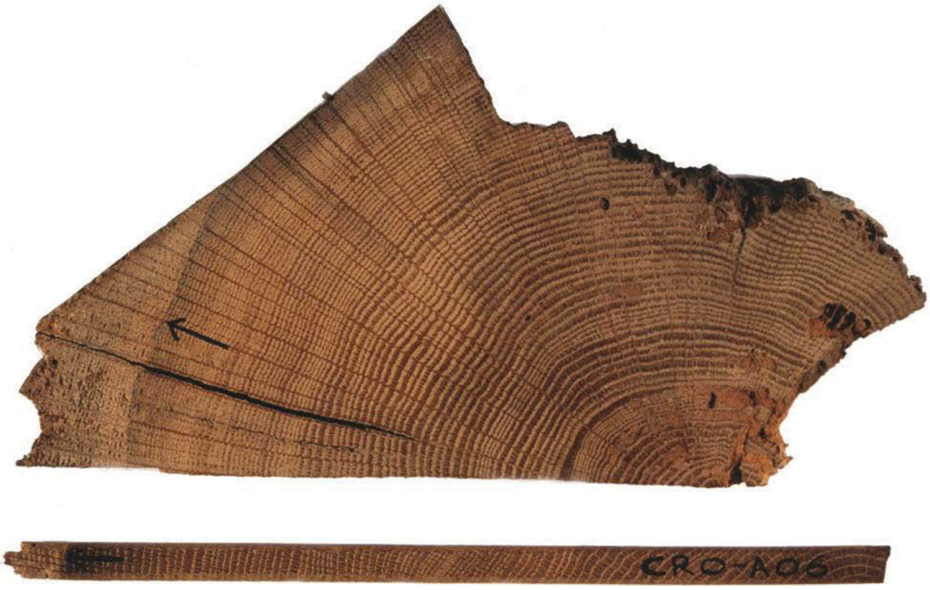


Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

Figure A3: Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measured twice to ensure that an error has not been made. This type of apparatus is needed to process a large number of samples on a regular basis

Figure A4: Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical

2. Measuring Ring Widths. Each core is sanded down with a belt sander using medium-grit paper and then finished by hand with flourgrade-grit paper. The rings are then clearly visible and differentiated from each other with a result very much like that shown in Figure A2. The core is then mounted on a movable table below a microscope and the ring-widths measured individually from the innermost ring to the outermost. The widths are automatically recorded in a computer file as they are measured (see Fig A3).

3. Cross-Matching and Dating the Samples. Because of the factors besides the local climate which may determine the annual widths of a tree's rings, no two sequences of ring widths from different oaks growing at the same time are exactly alike (Fig A4). Indeed, the sequences may not be exactly alike even when the trees are growing near to each other. Consequently, in the Laboratory we do not attempt to match two sequences of ring widths by eye, or graphically, or by any other subjective method. Instead, it is done objectively (ie statistically) on a computer by a process called cross-matching. The output from the computer tells us the extent of correlation between two sample sequences of widths or, if we are dating, between a sample sequence of widths and the master, at each relative position of one to the other (offsets). The extent of the correlation at an offset is determined by the *t*-value (defined in almost any introductory book on statistics). That offset with the maximum *t*-value among the *t*-values at all the offsets will be the best candidate for dating one sequence relative to the other. If one of these is a master chronology, then this will date the other. Experiments carried out in the past with sequences from oaks of known date suggest that a *t*-value of at least 4.5, and preferably at least 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton and Litton 1988; Laxton *et al* 1988; Howard *et al* 1984–1995).

This is illustrated in Figure A5 with timbers from one of the roofs of Lincoln Cathedral. Here four sequences of ring widths, LIN-C04, 05, 08, and 45, have been cross-matched with each other. The ring widths themselves have been omitted in the bar diagram, as is usual, but the offsets at which they best cross-match each other are shown; eg the sequence of ring widths of C08 matches the sequence of ring widths of C45 best when it is at a position starting 20 rings after the first ring of C45, and similarly for the others. The actual t-values between the four at these offsets of best correlations are in the matrix. Thus at the offset of +20 rings, the *t*-value between C45 and C08 is 5.6 and is the maximum found between these two among all the positions of one sequence relative to the other.

It is standard practice in our Laboratory first to cross-match as many as possible of the ring-width sequences of the samples in a building and then to form an average from them. This average is called a site sequence of the building being dated and is illustrated in Figure A5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences of the four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. Thus in Fig A5 if the widths shown are 0.8mm for C45, 0.2mm for C08, 0.7mm for C05, and 0.3mm for C04, then the corresponding width of the site sequence is the average of these, 0.55mm. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

The straightforward method of cross-matching several sample sequences with each other one at a time is called the 'maximal *t*-value' method. The actual method of cross-matching a group of sequences of ring-widths used in the Laboratory involves grouping and averaging the ring-width sequences and is called the 'Litton-Zainodin Grouping Procedure'. It is a modification of the straightforward method and was successfully developed and tested in the Laboratory and has been published (Litton and Zainodin 1991; Laxton *et al* 1988).

4. **Estimating the Felling Date.** As mentioned above, if the bark is present on a sample, then the date of its last ring is the date of the felling of its tree (or the last full year before felling, if it was felled in the first three months of the following calendar year, before any new growth had started, but this is not too important a consideration in most cases). The actual bark may not be present on a timber in a building, though the dendrochronologist who is sampling can often see from its surface that only the bark is missing. In these cases the date of the last ring is still the date of felling.

Quite often some, though not all, of the original outer rings are missing on a timber. The outer rings on an oak, called sapwood rings, are usually lighter than the inner rings, the heartwood, and so are relatively easy to identify. For example, sapwood can be seen in the corner of the rafter and at the outer end of the core in Figure A2, both indicated by arrows. More importantly for dendrochronology, the sapwood is relatively soft and so liable to insect attack and wear and tear. The builder, therefore, may remove some of the sapwood for precisely these reasons. Nevertheless, if at least some of the sapwood rings are left on a sample, we will know that not too many rings have been lost since felling so that the date of the last ring on the sample is only a few years before the date of the original last ring on the tree, and so to the date of felling.

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

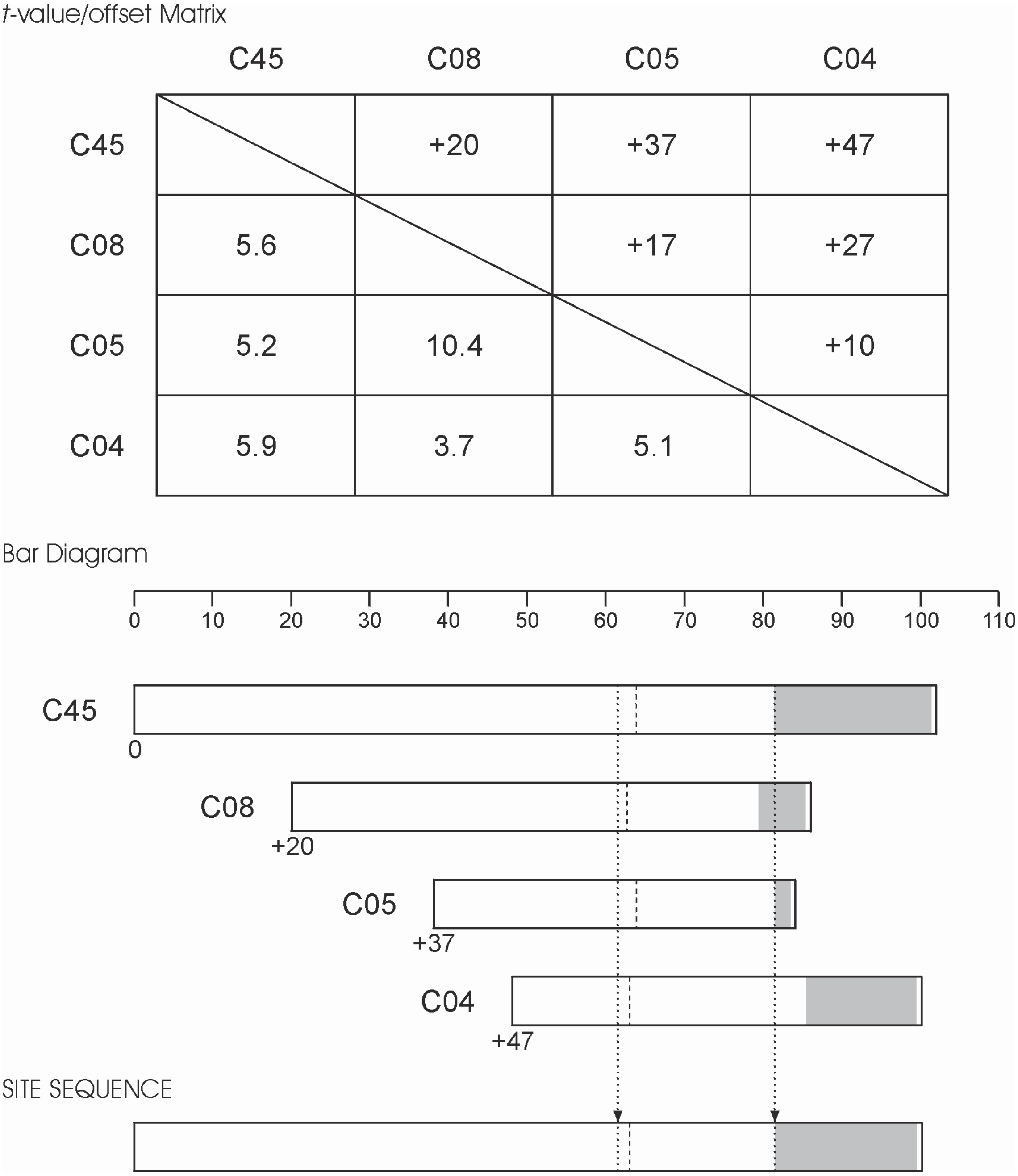
Even more precise estimates of the felling date and range can often be obtained using knowledge of a particular case and information gathered at the time of sampling. For example, at the time of sampling the dendrochronologist may have noted that the timber from which the core of Figure A2 was taken still had complete sapwood but that some of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 20mm, a reasonable estimate can be made of the number of sapwood rings lost, say 12 to 15 rings in this case. By adding on 12 to 15 years to the date of the last ring on the sample a good tight estimate for the range of the felling date can be obtained, which is often better than the 15 to 35 years later we would have estimated without this observation. In the example, the felling is now estimated to have taken place between AD 1512 and 1515, which is much more precise than without this extra information.

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

5. Estimating the Date of Construction. There is a considerable body of evidence collected by dendrochronologists over the years that oak timbers used in buildings were not seasoned in medieval or early modern times (English Heritage 1998; Miles 1997, 50–5). Hence, provided that all the samples in a building have estimated felling-date ranges broadly in agreement with each other, so that they appear to have been felled as a group, then this should give an accurate estimate of the period when the structure was built, or soon after (Laxton *et al* 2001, fig 8; 34–5, where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storage before use, or if there is evidence the oak came from abroad (eg Baltic boards), then some allowance has to be made for this.

6. **Master Chronological Sequences.** Ultimately, to date a sequence of ring widths, or a site sequence, we need a master sequence of dated ring widths with which to cross-match it, a Master Chronology. To construct such a sequence we have to start with a sequence of widths whose dates are known and this means beginning with a sequence from an oak tree whose date of felling is known. In Figure A6 such a sequence is SHE-T, which came from a tree in Sherwood Forest which was blown down in a recent gale. After this other sequences which cross-match with it are added and gradually the sequence is 'pushed back in time' as far as the age of samples will allow. This process is illustrated in Figure A6. We have a master chronological sequence of widths for Nottinghamshire and East Midlands oak for each year from AD 882 to 1981. It is described in great detail in Laxton and Litton (1988), but the components it contains are shown here in the form of a bar diagram. As can be seen, it is well replicated in that for each year in this period there are several sample sequences having widths for that year. The master is the average of these. This master can now be used to date oak from this area and from the surrounding areas where the climate is very similar to that in the East Midlands. The Laboratory has also constructed a master for Kent (Laxton and Litton 1989). The method the Laboratory uses to construct a master sequence, such as the East Midlands and Kent, is completely objective and uses the Litton-Zainodin grouping procedure (Laxton *et al* 1988). Other laboratories and individuals have constructed masters for other areas and have made them available. As well as these masters, local (dated) site chronologies can be used to date other buildings from nearby. The Laboratory has hundreds of these site sequences from many parts of England and Wales covering many short periods.

7. **Ring-Width Indices.** Tree-ring dating can be done by cross-matching the ring widths themselves, as described above. However, it is advantageous to modify the widths first. Because different trees grow at different rates and because a young oak grows in a different way from an older oak, irrespective of the climate, the widths are first standardized before any matching between them is attempted. These standard widths are known as ring-width indices and were first used in dendrochronology by Baillie and Pilcher (1973). The exact form they take is explained in this paper and in the appendix of Laxton and Litton (1988) and is illustrated in the graphs in Figure A7. Here ring-widths are plotted vertically, one for each year of growth. In the upper sequence of (a), the generally large early growth after 1810 is very apparent as is the smaller later growth from about 1900 onwards when the tree is maturing. A similar phenomenon can be observed in the lower sequence of (a) starting in 1835. In both the widths are also changing rapidly from year to year. The peaks are the wide rings and the troughs are the narrow rings corresponding to good and poor growing seasons, respectively. The two corresponding sequence of Baillie-Pilcher indices are plotted in (b) where the differences in the immature and mature growths have been removed and only the rapidly changing peaks and troughs remain, that are associated with the common climatic signal. This makes cross-matching easier.



t-value/offset Matrix

	C45	C08	C05	C04
C45		+20	+37	+47
C08	5.6		+17	+27
C05	5.2	10.4		+10
C04	5.9	3.7	5.1	

Bar Diagram

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

The bar diagram represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set at relative positions (offsets) to each other at which they have maximum correlation as measured by the *t*-values. The *t*-value/offset matrix contains the maximum *t*-values below the diagonal and the offsets above it. Thus, the maximum *t*-value between C08 and C45 occurs at the offset of +20 rings and the *t*-value is then 5.6. The site sequence is composed of the average of the corresponding widths, as illustrated with one width.

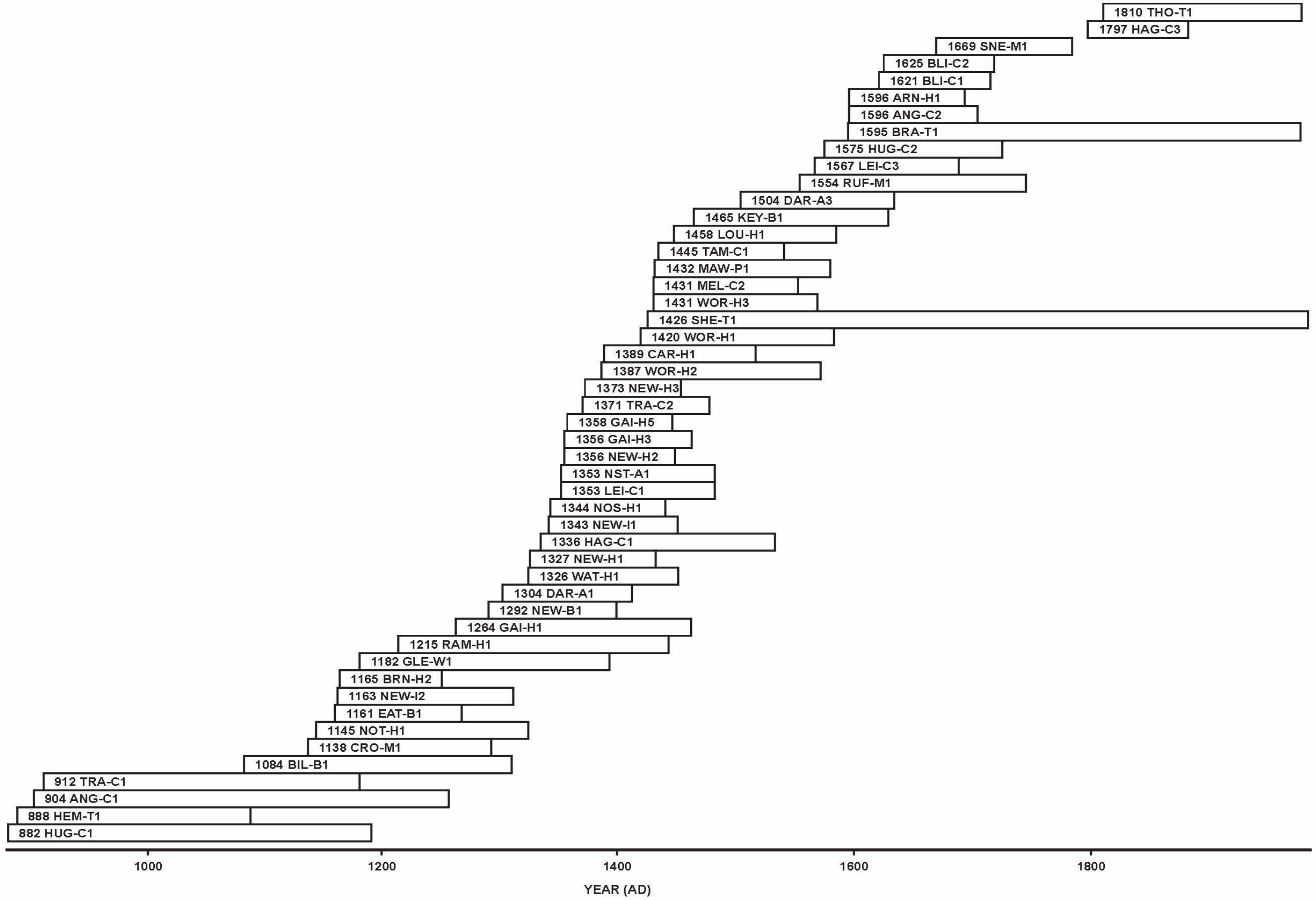


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

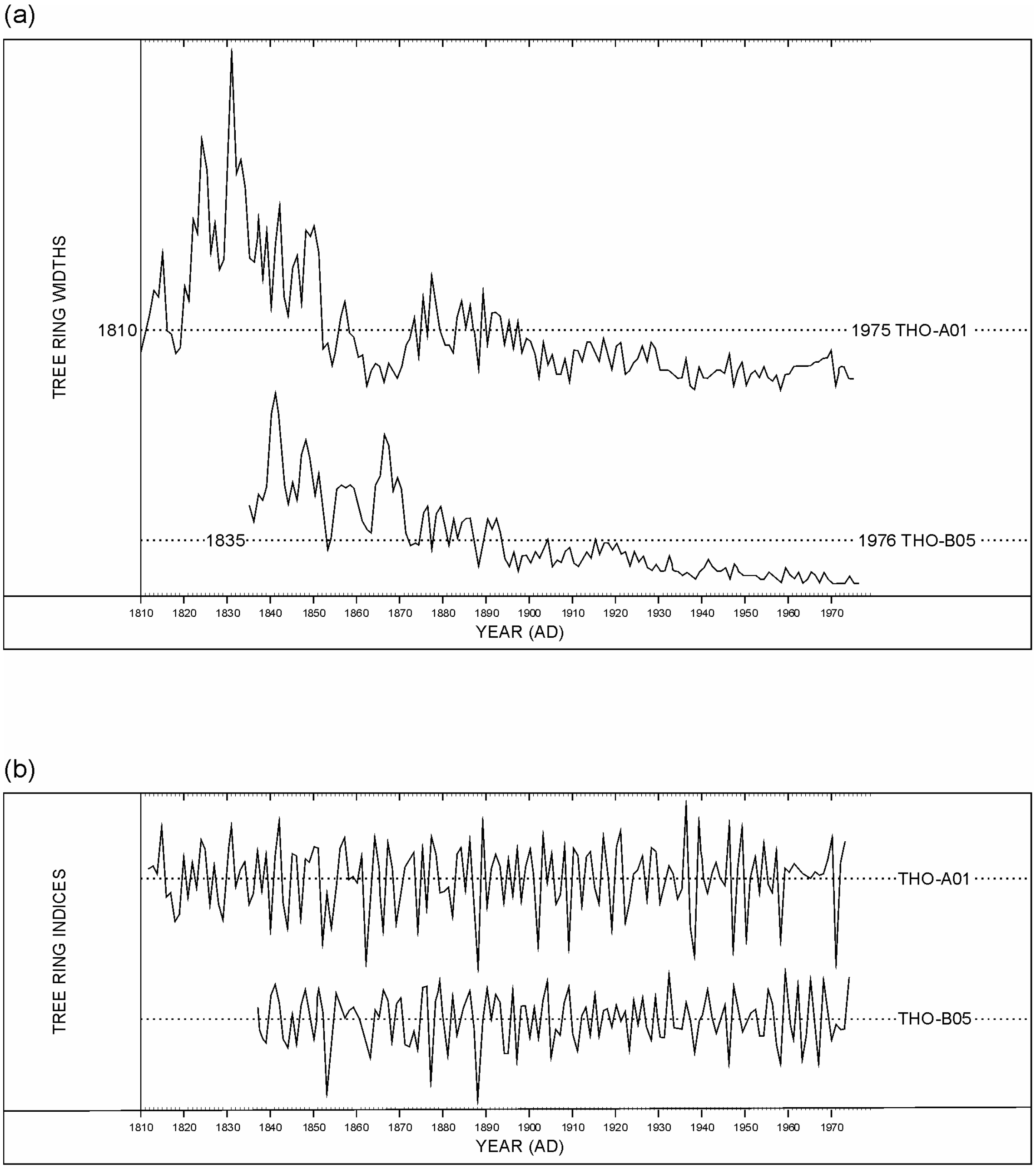


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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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