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HALL FARM BARN, MAIN STREET, HORKSTOW, NORTH LINCOLNSHIRE
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 seven samples from a series of reused timbers in this barn. There was no cross-matching between any of the samples, and none of the samples could be dated individually.

CONTRIBUTORS

Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS

The Nottingham Tree-ring Dating Laboratory would like to take this opportunity to thank the owner of Hall Farm barn, Mr Bruce Rowles, for his help and cooperation with this programme of tree-ring analysis, and for his interest in the process during sampling. We would also like to thank Keith Miller (English Heritage) for his considerable help in arranging sampling at this site and in interpreting the possible phases of timberwork found here, as well as Simon Savage (Pre-Construct Archaeology Ltd Lincoln) for his help in respect of phasing. Peter Gaze Pace Chartered Architects kindly allowed the use of plans and drawings in this report, as had Ed Dennison Archaeological Services Ltd. Finally we would like to thank Peter Marshall (English Heritage Scientific Dating Team) and Cathy Tyers (Sheffield University Dendrochronology Laboratory) for commissioning the analysis and their advice and assistance throughout the production of this report.

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CONTENTS

INTRODUCTION

The grade II listed barn at Hall Farm under consideration in this report, stands to the west side of Main Street, Horkstow (SE 9857 1920), approximately five kilometres south-west of Barton-upon-Humber (Figs 1 and 2). According to Dennison (2009) and Gaze Pace (2011), from which the following information is summarised, it is believed to be the oldest and most important structure amongst a collection of other agricultural buildings here. These other buildings include a stable, sheds, and granary, set about a former farmyard, part of a larger farm complex (Fig 3). The farm complex stands immediately to the north of Hall Farm Cottage, and some way north of Horkstow Hall itself.

It is believed that the extant barn dates to the late-sixteenth or early-seventeenth century and, as originally built, would have been a substantial timber-framed building. It was originally six bays long, one bay probably equipped with gabled porches forming a cross-passage for wagon access, and had aisles along its north and south sides. However, although the present structure is possibly of sixteenth- or seventeenth-century date it incorporates several large timbers which, on the basis of their redundant mortices and joint housings, are believed to be re-used from a similarly substantial, but earlier, timber-framed building. It is, though, thought that all these re-used timbers are originally from a single building.

Since its original construction the barn has undergone a number of alterations, most notably the loss of its southern aisle and its shortening by one bay from the east. Despite these changes the interior of the barn still retains a substantial frame comprising four trusses dividing the building into five bays, and its aisle to the north side (Fig 4). The trusses are numbered 'I' to 'IIII' from west to east, using incised marks usually located at the joint of the post and brace to the tiebeam.

Each truss comprises what would originally have been north and south aisle posts with a tiebeam. Slightly curved braces rise from the aisle posts to the tiebeams, there then being raking queen struts from the tiebeams to the principal rafters. These trusses support a single row of purlins to each pitch of the roof. The north aisle posts now support an aisle plate, and there are short ties between the north aisle posts and the north wall plate (Fig 5).

SAMPLING

Sampling and analysis by dendrochronology of the timbers at Hall Farm barn, Horkstow, were requested by Keith Miller, Inspector of Ancient Monuments and Historic Buildings at English Heritage's York office, the primary purpose of this being to inform a potential listing upgrade. It was hoped that tree-ring analysis would establish a date for both the re-used timbers as well as a date for the construction of the extant barn. An additional benefit of sampling for tree-ring dating was the contribution the data might make to the corpus of reference material available for this region. Although the reference data for this area is now increasing, it is still under-represented.

With these aims in mind, an initial assessment of the timbers prior to sampling was undertaken. This assessment showed that a large number of timbers, almost all of them associated with the primary construction phase of the barn, were either of elm (*Ulmus* spp), or were derived from fast-grown oak (*Quercus* spp). As such, the oak timbers were perceived to have too few rings (ie less than 54) to provide suitable samples. Whilst elm can on occasion be reliably dated, it generally requires the presence of contemporary dateable oak timbers and in this instance the elm timbers also appeared to have too few rings anyway. The only timbers which appeared potentially suitable for tree-ring analysis were a small number of oak timbers which showed clear evidence, by way of redundant mortices, tenons, and peg holes, of having been reused in the construction of the present barn.

From this small assemblage of suitable oak timbers, a total of seven samples was obtained by coring. Each sample was given the code HKS-A (for Horkstow, site 'A') and numbered 01–07. The location of these samples was noted at the time of coring and marked on the drawings that were kindly made available by Simon Savage of Pre-Construct Archaeology Ltd (Lincoln). These illustrations are reproduced here as Figures 6a-e. Further details relating to the samples can be found in Table 1.

ANALYSIS AND RESULTS

Each of the seven samples obtained was prepared by sanding and polishing, and although two of them had less than the statistically reliable minimum of 54 rings, the widths of the annual growth rings of all seven samples were measured, the data of these measurements being given at the end of this report. The data of these seven samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), but unfortunately there was no cross-matching between any of them, and thus no site chronologies could be formed. Each of the seven samples was then compared individually with an extensive corpus of reference material, not only that held by the Nottingham Tree-ring Dating Laboratory, but also that held by other laboratories in England. There was, however, no reliable cross-matching, and all the samples must, therefore, remain undated.

DISCUSSION AND CONCLUSION

Sadly, despite obtaining some samples with high, or at least sufficient, numbers of rings for analysis, and despite being compared to an extensive collection of reference material, none of the samples can be dated. In at least two cases, this may be as a result of the samples having slightly low numbers of rings, and it is possible that the sampled timbers are of a particular time period and location that is not yet sufficiently well represented in the reference material, although this seems relatively unlikely. The lack of cross-matching between the reused samples could be taken to suggest that they are from different source woodlands and hence potentially might actually represent more than one building. Although this lack of success is naturally disappointing, the data is now archived and it is possible that when further regional data is obtained in the future, the Hall Farm barn samples will be dated. The lack of intra-site cross-matching does however suggest that the chances of successful dating in the future are relatively low.

BIBLIOGRAPHY

Ed Dennison Archaeological Services Ltd, 2009 *Barn, north-east of Hall Farm Cottage, Main Street, Horkstow, North Lincolnshire; Architectural and Wildlife Survey*, Rep no. 2009/362.R01

Peter Gaze Pace, Architects, 2011 *Horkstow Hall Aisled Threshing Barn, Stables and Implement*, Heritage Statement with Design and Access Statement and Statement of Significance

TABLES

Table 1: Details of tree-ring samples from Hall Farm barn, Main Street, Horkstow, North Lincolnshire

Sample number	Sample location	Total rings	Sapwood rings*	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
HKS-A01	Tiebeam, truss 2	86	7	------	------	------
HKS-A02	Tiebeam, truss 1	97	13	------	------	------
HKS-A03	North aisle post, truss 3	54	3	------	------	------
HKS-A04	North aisle post, truss 4	66	h/s	------	------	------
HKS-A05	South wall plate (east section)	55	h/s	------	------	------
HKS-A06	South wall plate (middle section)	50	no h/s	------	------	------
HKS-A07	South wall plate (west section)	48	h/s	------	------	------

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

FIGURES

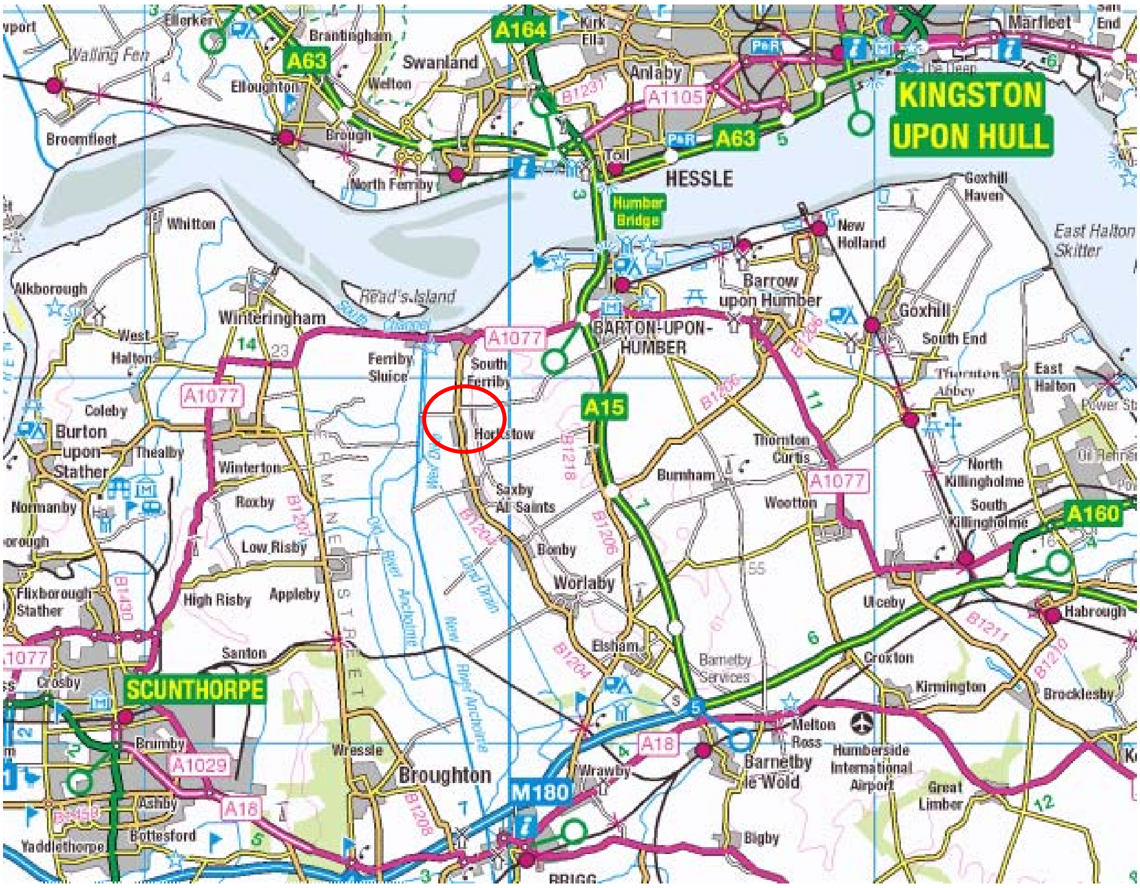


Figure 1: Map to show the location of Horkstow. © Crown Copyright. All rights reserved. English Heritage 100019088. 2012

Figure 2: Map to show the location of Hall Farm, Horkstow. ©Crown Copyright. All rights reserved. English Heritage 100019088. 2012

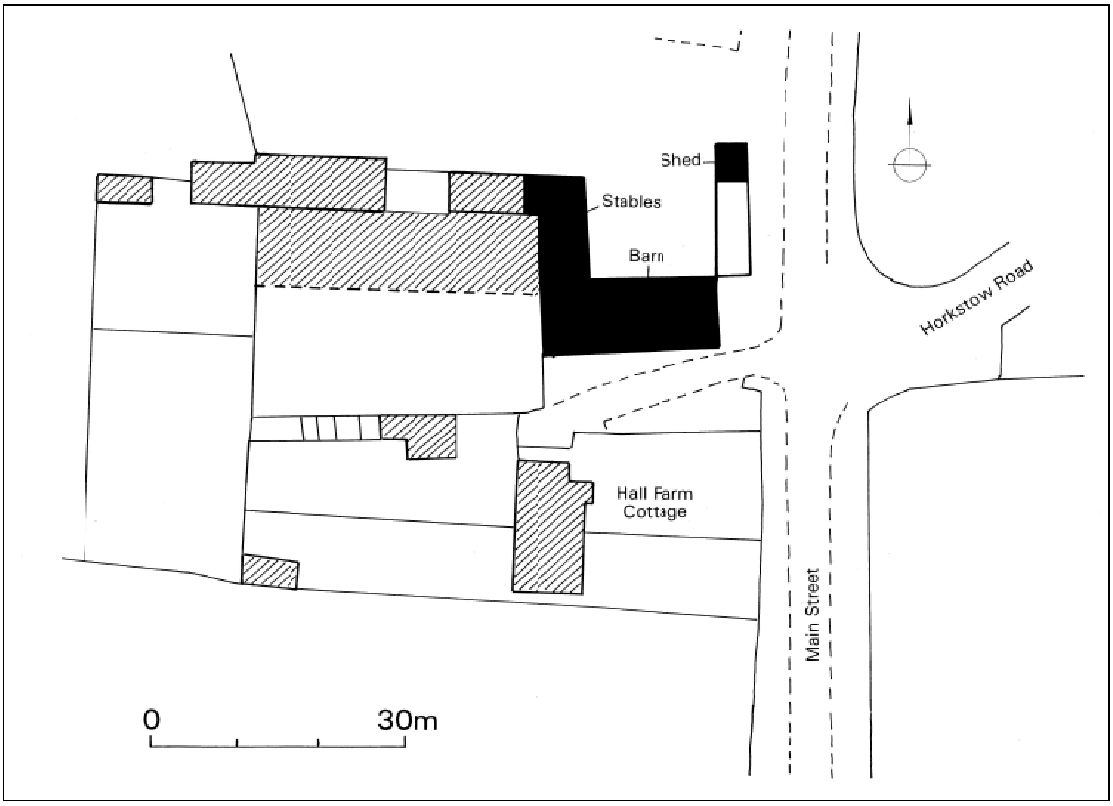


Figure 3: Plan to show the layout and position of the buildings at Hall Farm, Horkstow (after Ed Dennison Archaeological Services Ltd)

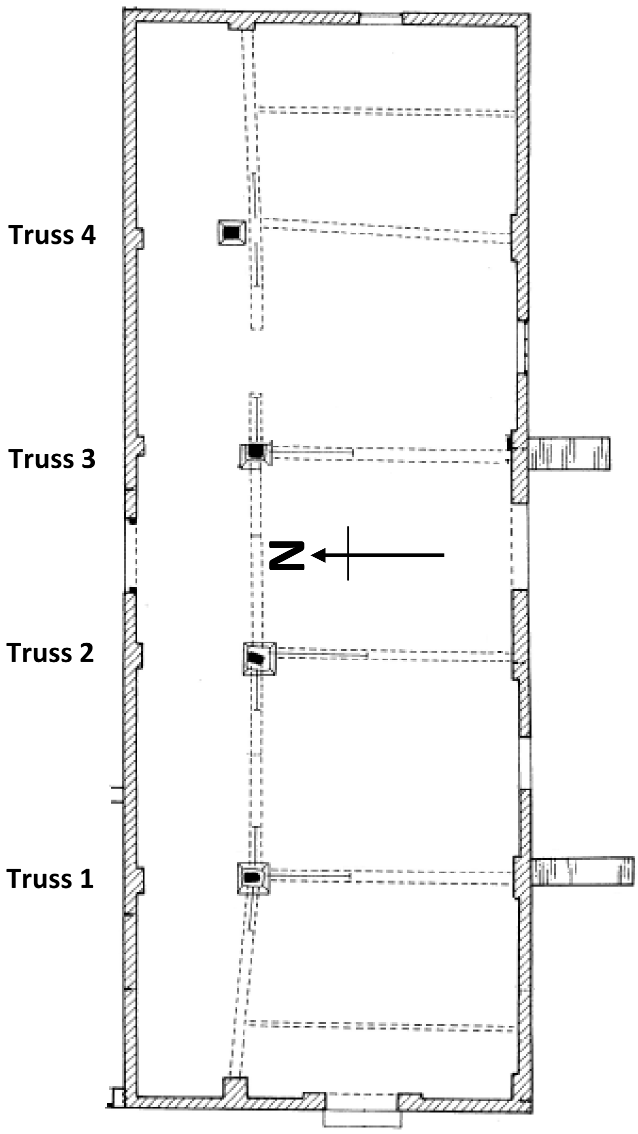


Figure 4: Basic plan of Hall Farm barn (after Peter Gaze Pace Chartered Architects)

Figure 5: View of the trusses looking east

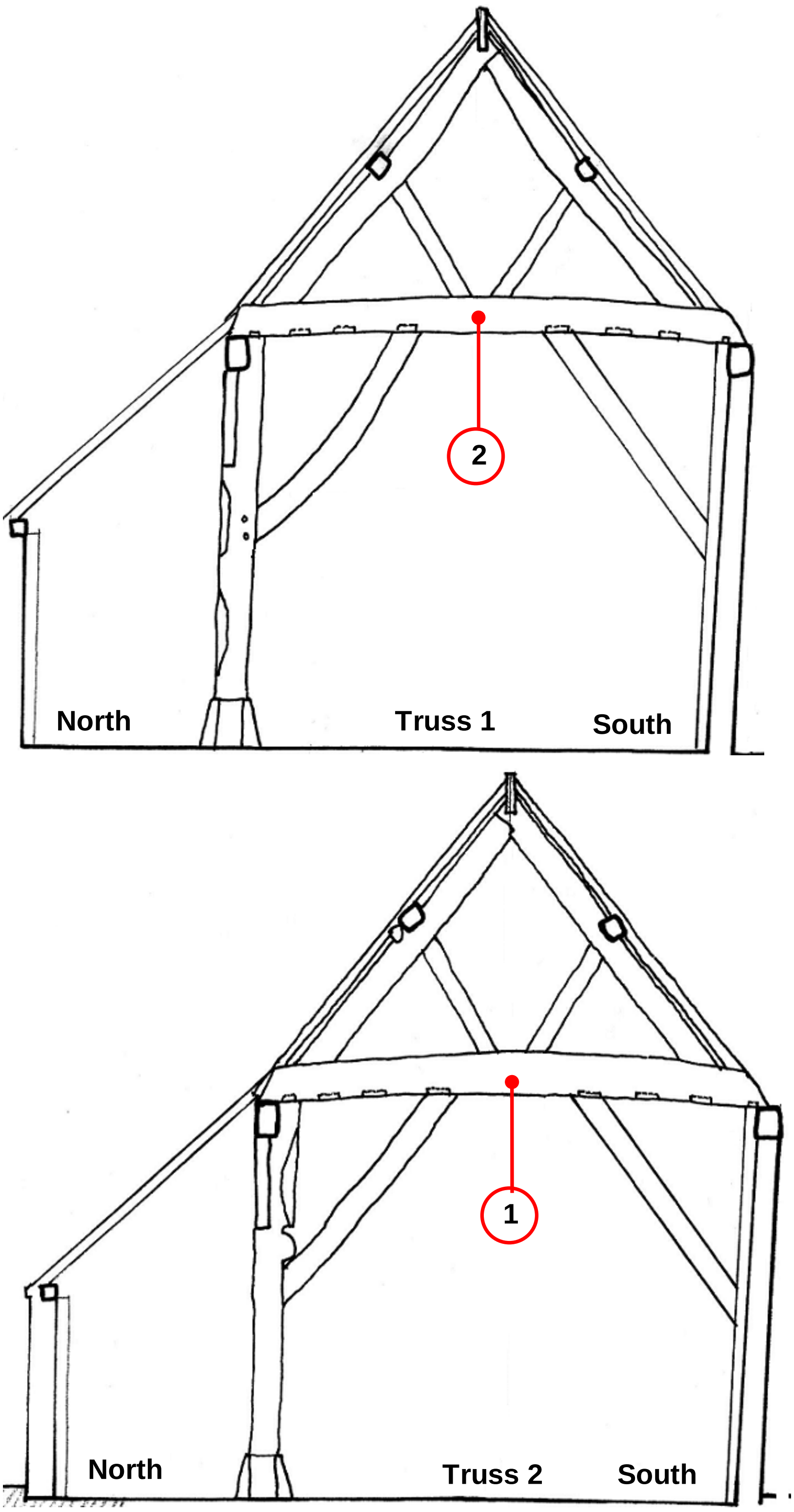


Figure 6a/b: Cross-sections through the barn to show sampled timbers (after Peter Gaze Pace Chartered Architects)

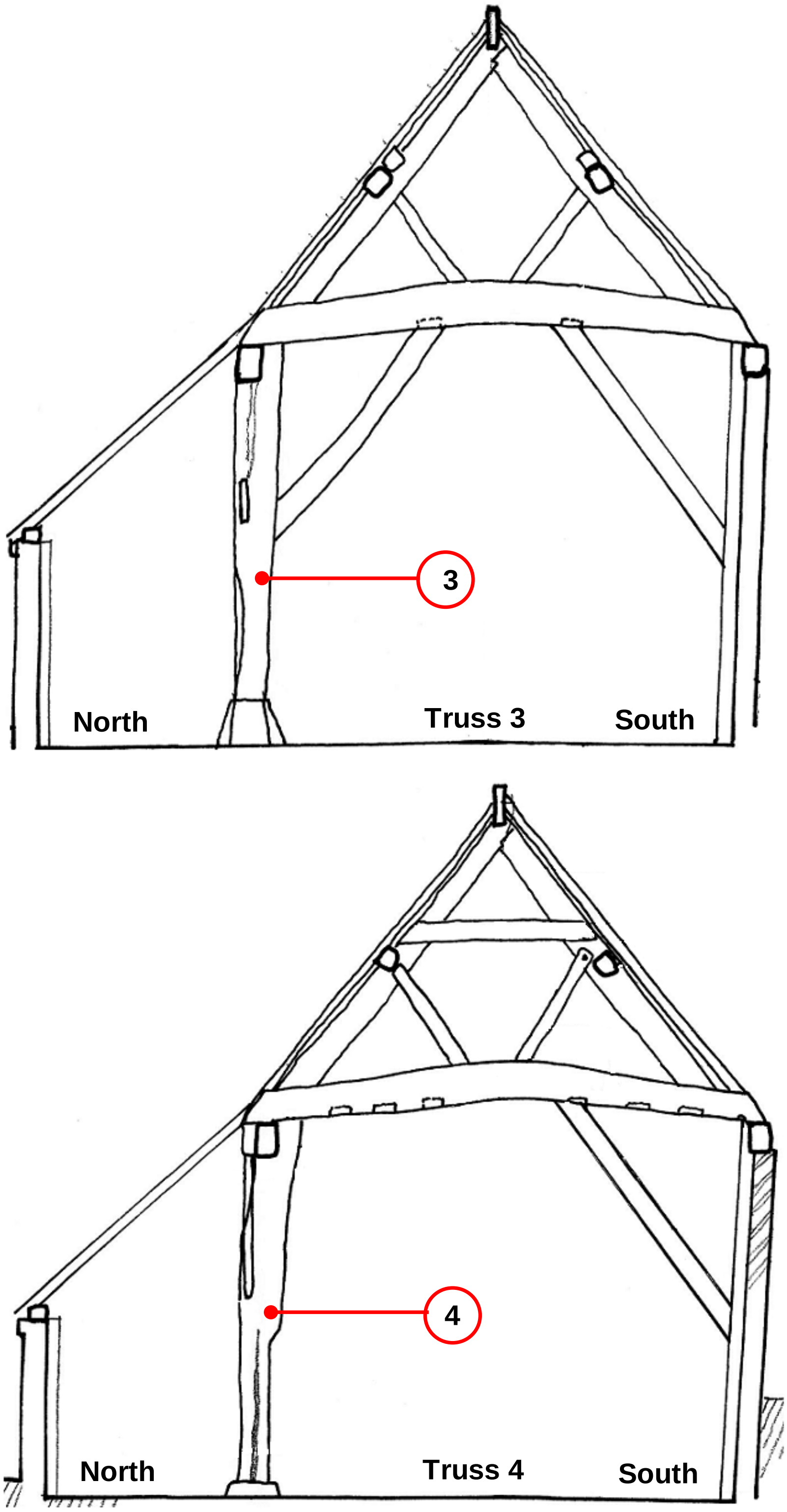


Figure 6c/d: Cross-sections through the barn to show sampled timbers (after Peter Gaze Pace Chartered Architects)

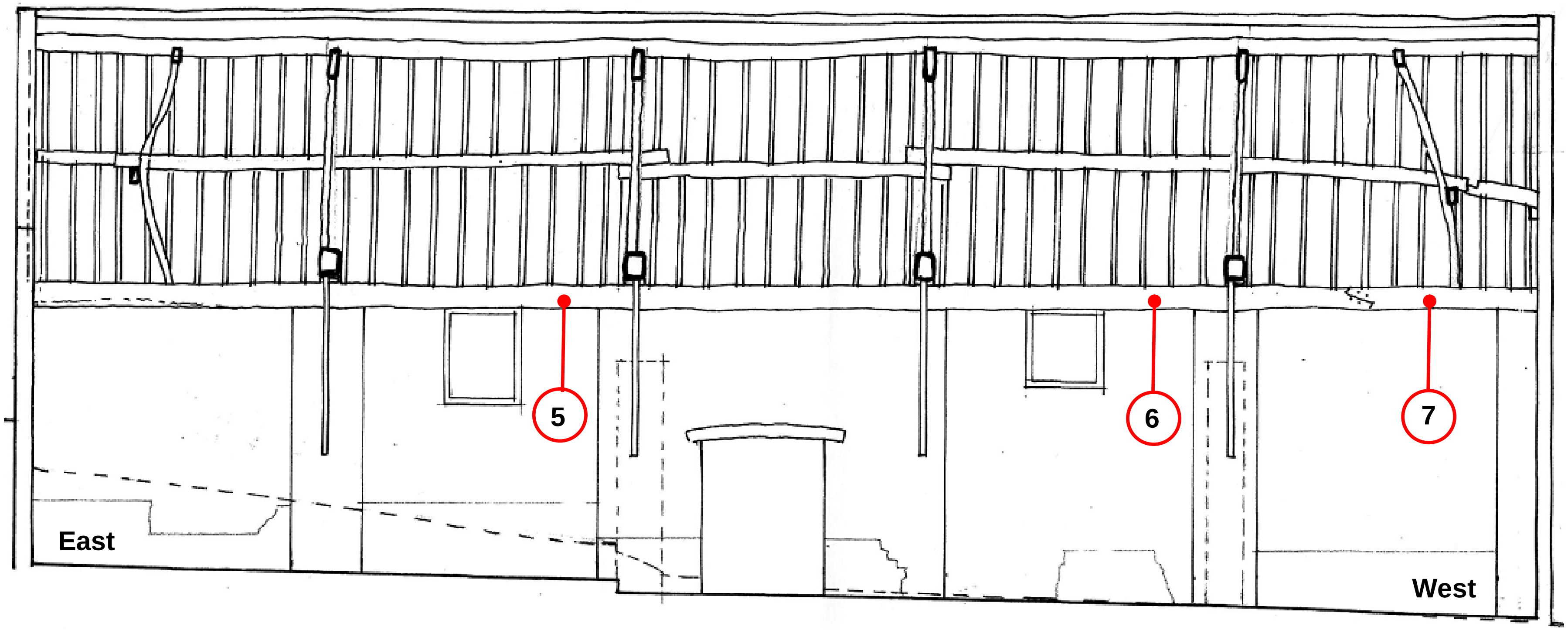


Figure 6e: Long-section through the barn (south wall, internal) to show sampled timbers (after Peter Gaze Pace Chartered Architects)

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

HKS-A01A 86
460 539 551 571 571 622 550 446 399 500 510 470 371 458 484 391 326 331 388 406
229 257 209 224 337 315 205 216 231 291 191 170 180 118 133 217 214 196 202 133
127 112 75 123 178 215 187 139 149 252 294 281 252 226 229 194 249 214 186 224
234 191 115 135 138 164 118 92 87 122 166 153 177 196 183 165 173 181 212 265
181 193 307 154 170 134
HKS-A01B 86
480 585 526 593 523 589 563 457 397 486 521 525 375 461 479 414 318 344 378 395
223 273 224 217 325 333 199 213 209 298 196 169 197 118 129 216 216 195 222 133
131 111 94 116 195 218 186 131 177 240 287 276 251 224 252 173 262 183 177 235
200 196 113 130 139 193 118 102 87 116 159 150 175 213 180 156 178 193 218 264
179 194 287 135 201 147
HKS-A02A 97
177 207 229 196 241 250 239 273 381 478 402 310 298 321 399 329 370 239 256 277
170 175 280 309 248 155 106 171 234 252 223 242 203 329 324 210 172 154 162 211
173 205 140 152 135 186 181 198 172 112 102 98 77 82 112 86 156 96 98 88
154 153 154 188 140 116 97 115 151 167 92 137 149 154 117 159 102 101 188 191
203 194 185 262 165 110 214 192 246 238 125 182 173 156 258 198 163
HKS-A02B 97
182 196 239 194 215 252 249 281 372 470 405 312 294 325 393 326 372 254 249 254
171 174 293 299 254 163 111 164 223 260 221 243 199 332 307 215 165 158 163 214
183 199 146 141 138 191 183 193 180 109 95 96 83 88 102 91 152 103 91 93
150 155 148 187 151 117 90 123 141 169 99 138 144 154 110 160 99 104 184 214
186 196 177 271 179 94 217 177 240 246 117 181 182 150 233 151 248
HKS-A03A 54
545 547 469 538 402 459 426 436 178 149 127 189 454 418 591 516 357 465 444 270
243 184 227 412 345 193 113 184 229 302 80 53 59 84 80 90 95 136 158 133
31 43 49 85 32 30 25 59 61 66 78 49 59 69
HKS-A03B 54
551 566 455 511 418 409 403 448 173 151 116 208 443 448 572 569 331 520 436 260
226 193 226 438 334 170 109 189 245 304 75 62 59 66 81 98 98 135 173 143
32 39 49 76 35 34 29 59 60 62 76 52 61 70
HKS-A04A 66
316 321 242 305 291 340 276 330 378 229 262 346 300 277 181 238 147 134 125 264
190 251 260 279 203 183 99 137 161 211 223 147 252 154 145 121 140 136 195 292
274 144 163 125 196 169 194 272 157 133 135 120 202 218 192 165 196 233 179 247
138 129 184 238 155 199
HKS-A04B 66
302 323 232 321 293 354 247 342 394 273 269 379 330 267 177 216 164 132 127 256
197 248 255 287 189 185 115 119 176 199 223 154 245 152 150 121 137 129 201 295
267 145 166 121 196 168 188 277 158 136 121 138 197 224 187 165 196 232 170 251
143 128 195 216 173 179
HKS-A05A 55
433 436 342 304 143 203 148 188 230 258 387 306 307 392 370 476 412 377 367 501
438 472 514 437 377 380 406 385 373 352 327 277 281 276 364 229 169 300 260 362
328 264 346 176 139 225 204 251 216 219 237 366 281 128 177
HKS-A05B 55
423 435 342 310 149 188 139 180 224 250 399 336 296 380 379 476 396 391 348 520

452 498 506 431 377 370 399 380 370 344 317 263 268 277 380 232 173 277 269 357
328 273 335 181 132 228 201 228 202 223 248 376 286 128 178
HKS-A06A 50
393 392 387 444 307 449 450 370 380 384 363 354 345 300 282 343 242 297 313 410
223 121 172 132 205 125 131 159 187 223 257 170 241 244 198 266 229 265 260 172
224 223 229 139 176 156 166 207 157 132
HKS-A06B 50
424 395 401 413 326 451 451 368 334 368 360 381 352 290 272 336 236 287 294 418
208 130 188 130 214 114 131 163 189 228 276 171 241 238 214 284 227 255 262 192
214 235 224 145 169 158 168 211 156 128
HKS-A07A 48
357 310 202 424 343 174 170 233 221 213 289 201 255 315 151 118 140 181 211 256
118 125 87 78 78 253 216 179 223 373 351 338 326 407 303 196 188 231 230 249
100 123 166 132 160 133 124 113
HKS-A07B 48
389 289 205 428 353 173 179 222 210 216 291 206 247 319 114 119 152 176 243 259
134 113 94 84 77 236 226 181 222 370 355 333 318 412 293 194 190 225 226 237
110 130 171 140 170 133 121 111

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 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

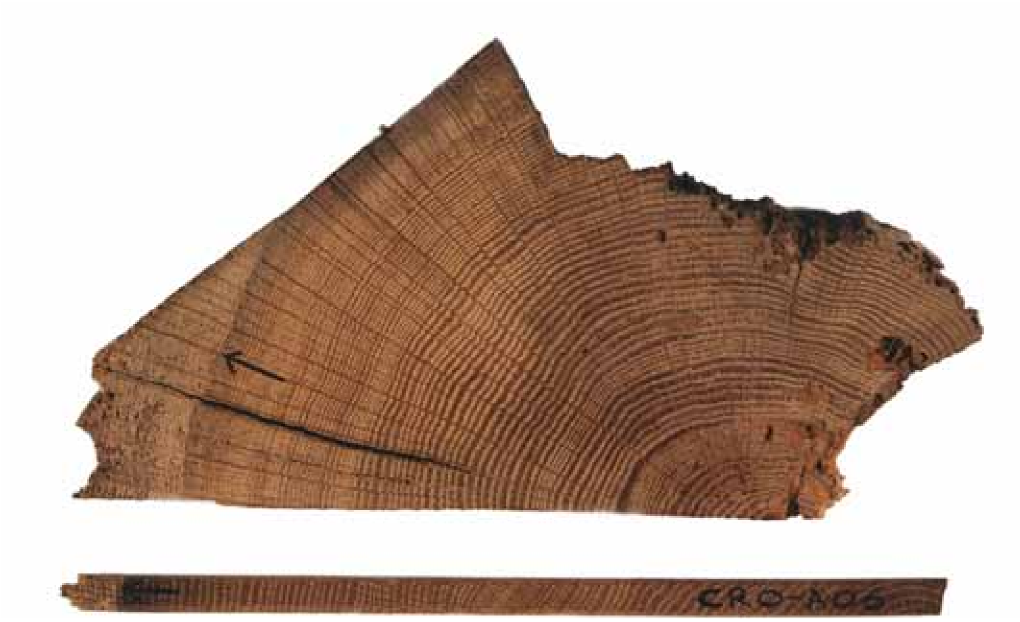


Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

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

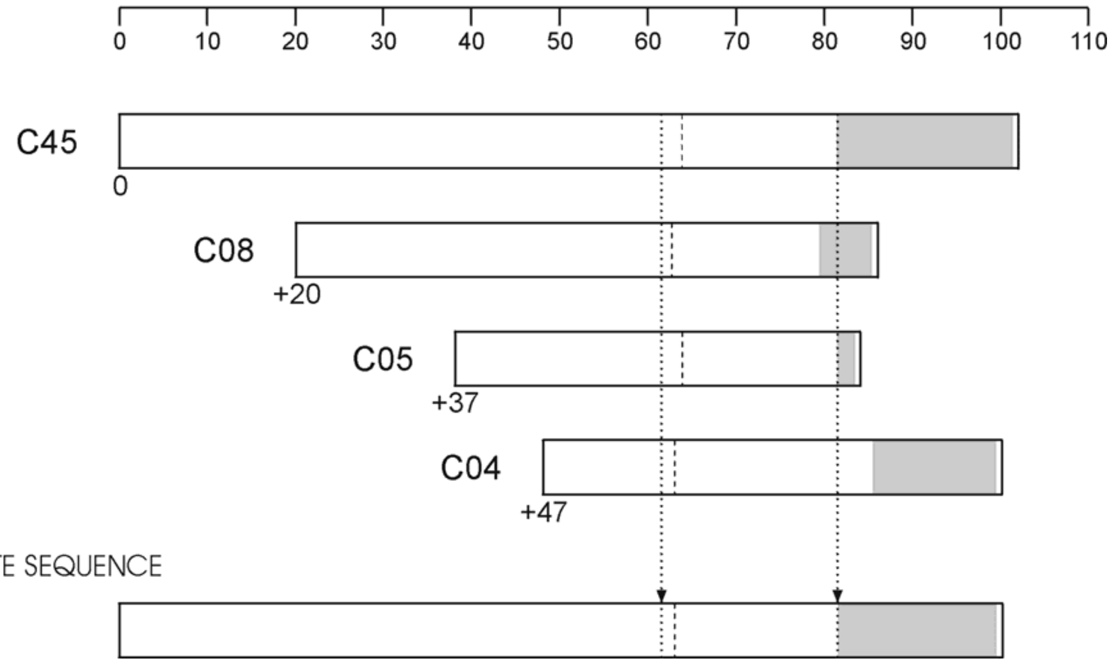


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

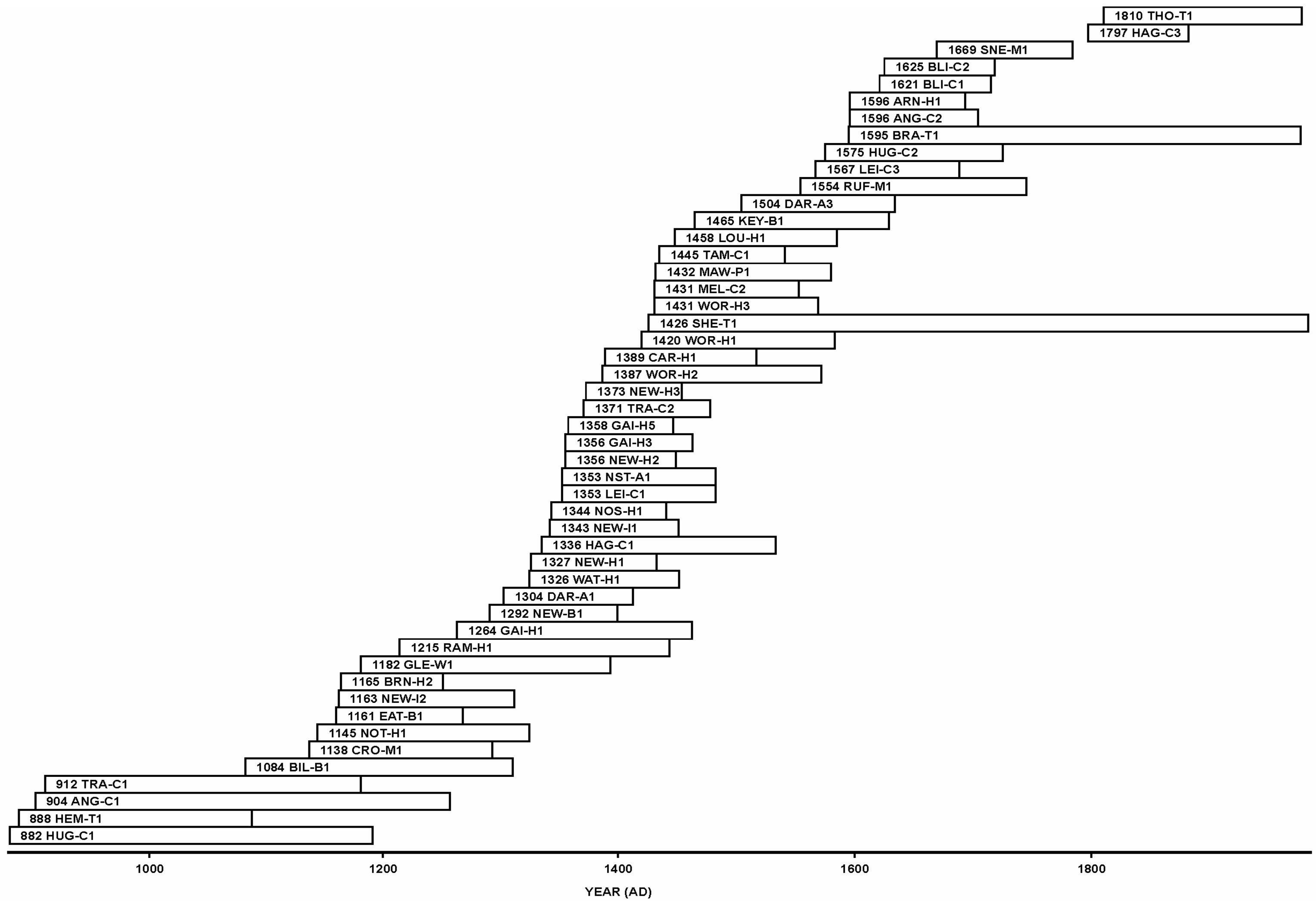
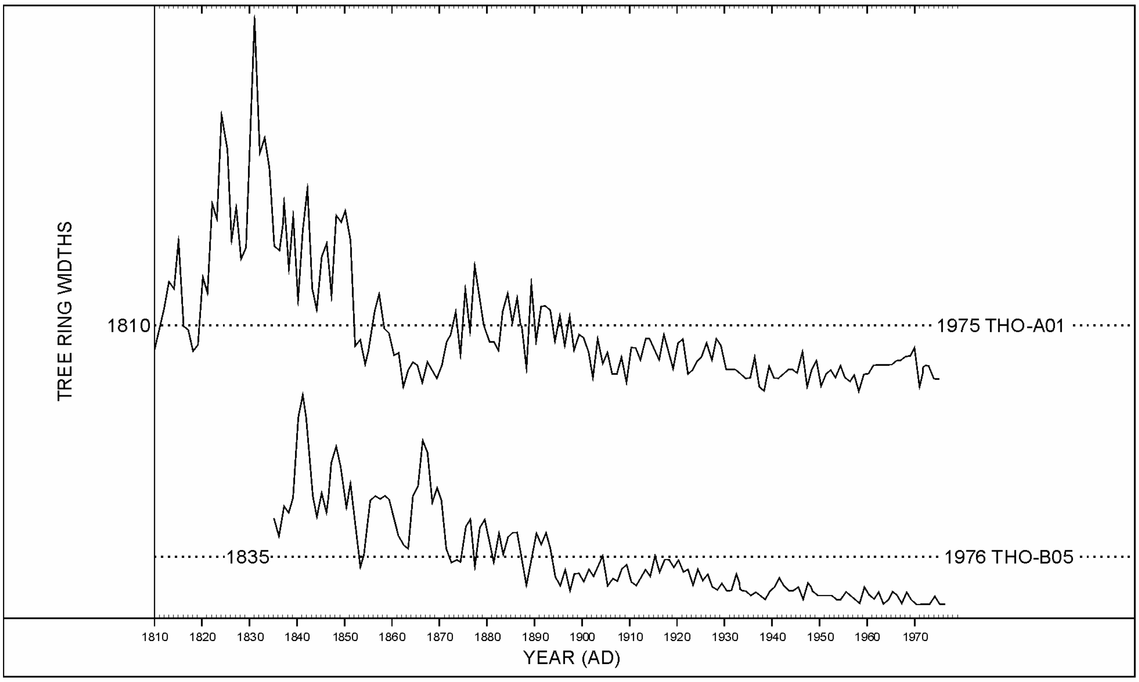


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

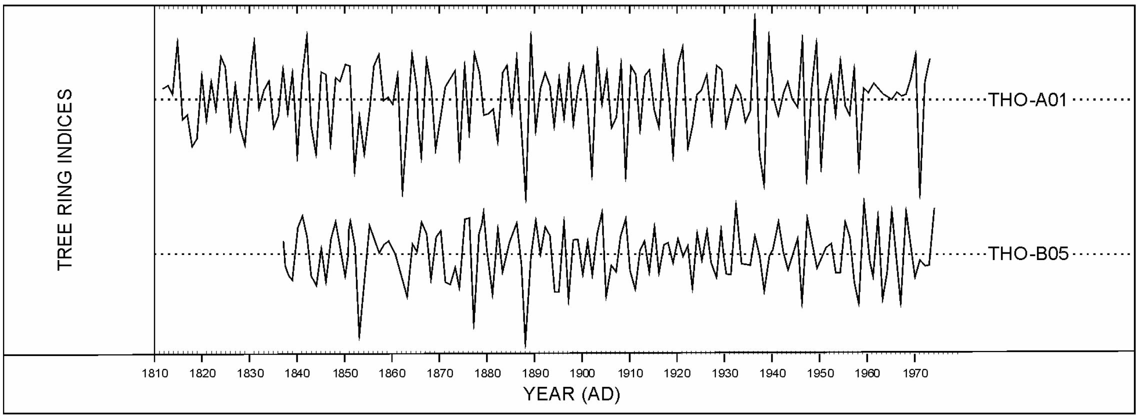


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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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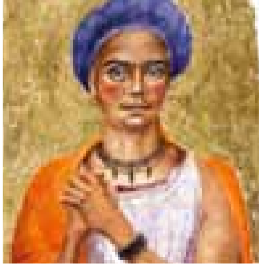


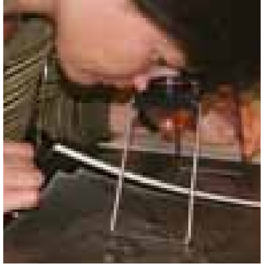


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