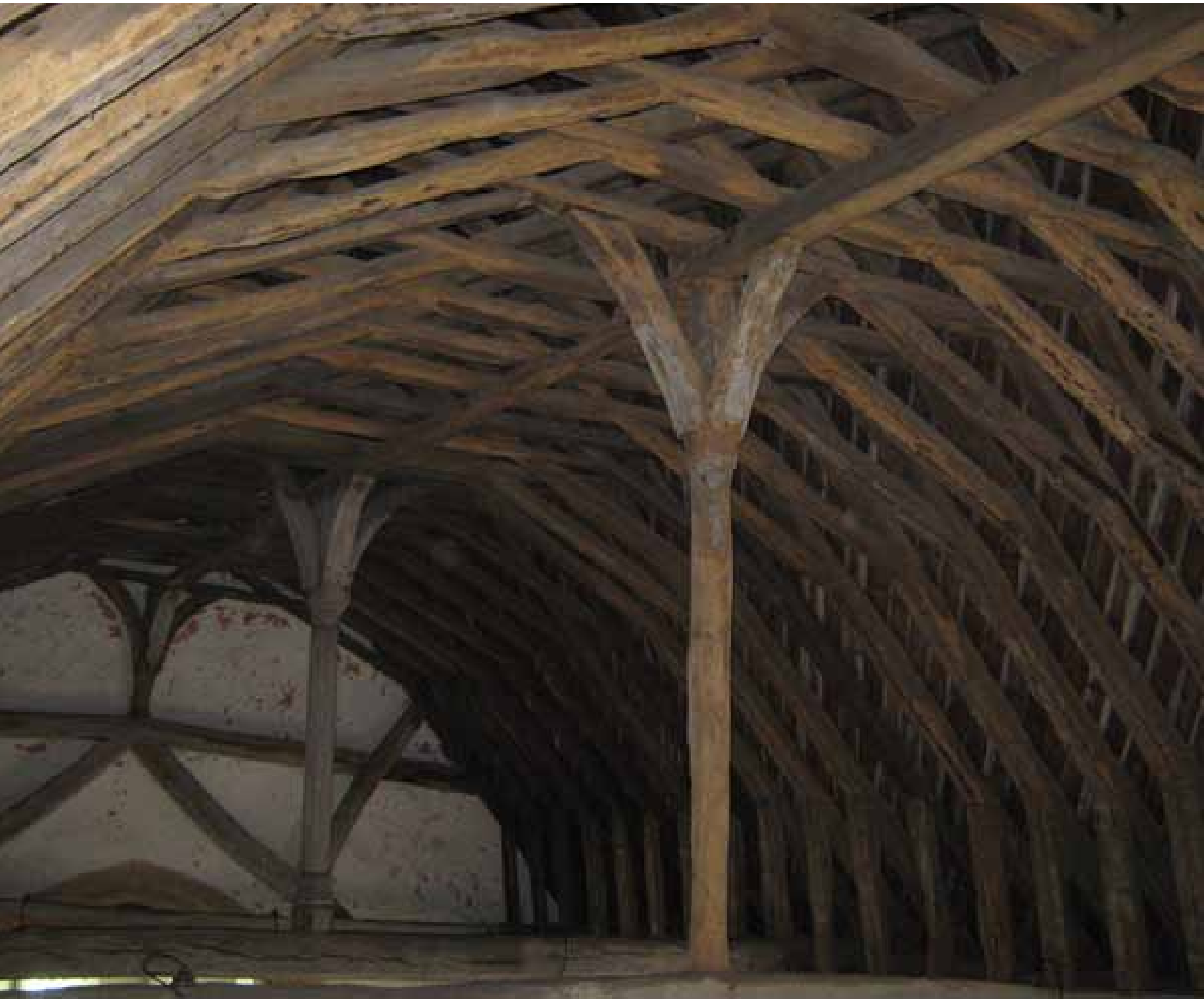
RESEARCH REPORT SERIES no. 106-2011

CHURCH OF ST PETER, SWINGFIELD, KENT
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard



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Research Report Series 106-2011

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TREE-RING ANALYSIS OF TIMBERS

Alison Arnold and Robert Howard

NGR: TR 2329 4342

ISSN 2046-9799 (Print)
ISSN 2046-9802 (Online)

SUMMARY
Tree-ring analysis was undertaken on samples taken from timbers of the nave and chancel roofs, resulting in the construction of two site sequences. Unfortunately, attempts to date these two site sequences and the remaining ungrouped samples were unsuccessful and all samples remain undated. The timbers of the porch roof were rejected prior to sampling as unsuitable.

CONTRIBUTORS
Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS
The Laboratory would like to thank Stuart Codling, of Paye Stonework & Restoration, for facilitating access and all contractors for their assistance whilst we were on site. The architect, Karen Butti of Thomas Ford & Partners, was extremely helpful in identifying phasing and provided the drawings used to locate the samples. We would also like to thank Cathy Tyers from the University of Sheffield Dendrochronology Laboratory and Peter Marshall from the English Heritages Scientific Dating Team for their comments and advice throughout the writing of this report.

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INTRODUCTION

The present parish church of St Peter (TR 2329 4342; Figs 1–3) is believed to date predominantly to the thirteenth and fifteenth centuries, although it is thought it may possibly have late eleventh or twelfth-century origins. In plan, the church consists of nave, with nineteenth-century north aisle, chancel, south porch, and late-fifteenth century west tower (Fig 4). The church was restored in AD 1870. It was closed to regular worship in AD 2001 but remains consecrated.

Nave

The roof to this part of the church consists of five crown-post trusses and intermediate common frames. The central trusses (Fig 5) are slightly different in form to the two end trusses but all have slender, octagonal crown posts with braces running from crown post to the collar and collar purlin, sole plates, ashlar pieces, and scissor braces, trenched passed the collars and each other. Truss 5, at the east end, is thought to be a later alteration. Here the crown post sits on a low secondary collar. This truss has curving braces between the tiebeam and collar and further braces running from these first ones to the principal rafters (Fig 6). Two out of the five crown posts (trusses 2 and 4) look to be in somewhat better condition than the other three and it has been suggested that these might be early repairs, although when this might have occurred is unknown.

Chancel

The roof over the chancel is of collared, common rafter type and has straight braces which run from the rafter to collar (Fig 7). Each frame also has soulaces and ashlar pieces. There are five tiebeams. On brickwork evidence it had been suggested that the chancel roof was the result of more than one phase of construction but nothing within the timberwork could be seen to support this hypothesis.

Porch

The porch roof consists of two trusses, both with chamfered, rectangular crown posts, crown plate, ties, and braces. It is thought to be fourteenth or fifteenth century in date.

SAMPLING

Tree-ring sampling was requested by English Heritage's South-East Regional office, in support of the repair programme being undertaken as part of the work to turn the former church into a community and visitor centre.

The surface growth pattern seen on the majority of the timbers during the assessment in both the nave and chancel roofs was generally wide which greatly reduced those timbers which were deemed worthwhile sampling; none of the timbers of trusses 1–4 in the nave were, for instance, thought to be suitable. Following discussions with respect to the viability of the analysis, it was decided to proceed with sampling in these two areas. However it was evident from a surface examination of the timbers in the roof of the porch that they were derived from fast-grown trees and unlikely to provide samples with sufficient growth rings.

A total of 21 timbers was sampled with each sample being given the code SWN-B and numbered 01–21. Fifteen of these timbers were from the nave roof, 12 from timbers thought to represent the primary construction (SWN-B01–12) and three from timbers of the east end, believed to be a later alteration (SWN-B13–15). The remaining six samples are from timbers of the chancel roof (SWN-B16–21). Sampling was suspended in the chancel after only two of the six samples contained sufficient numbers of rings for analysis.. The location of samples was noted at the time of sampling and has been marked on Figures 8 and 9. Further details of samples can be found in Table 1.

ANALYSIS AND RESULTS

It was seen that nine of the samples (four from the primary timbers of the nave, one from the altered east end, and four from the chancel) had too few rings to make secure dating a possibility and these samples were discarded prior to measurement. A further six samples had less than the usual 54 growth-rings preferred for measurement but the decision was taken that, as short samples from St John's Commandery in Swingfield (Howard *et al* 1997) had been successfully dated providing a local reference chronology, that these would be measured and analysed. Therefore, 12 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 samples were compared with each other by the Litton/Zainodin grouping procedure (see Appendix), resulting in two groups, of two samples each.

Firstly, samples SWN-B01 and SWN-B02 matched each other at a value of t=8.0 and were combined at the relevant offset positions to form SWNBSQ01, a site sequence of 91 rings (Fig 10). This site sequence was compared against a series of relevant reference chronologies for oak but no secure match could be found and it remains undated.

Secondly, samples SWN-B13 and SWN-B14 matched each other at a value of t=9.1 and again these were combined to form SWNBSQ02, a site sequence of 55 rings (Fig 11). Attempts to date this site sequence by comparing it against the reference chronologies were again unsuccessful and this site sequence is also undated.

Attempts were then made to date the remaining eight ungrouped samples by comparing them individually against the reference chronologies but these were unsuccessful and all remain undated.

DISCUSSION

It was hoped that tree-ring dating would be able to provide secure dating for the construction of the nave and chancel roofs and also allow a greater understanding of the history of the former by dating timbers of the supposed later alteration at the east end and confirm whether or not two of the crown-posts were indeed early repairs. Unfortunately, due to the generally fast-grown nature of the timber used in these roofs, sampling was severely restricted and in the case of the possible early repairs, none of the timbers were considered suitable.

The lack of dating at this site is most likely due to the fast-grown nature of the timber resulting in short-ring width sequences in the samples taken. The longest sample is SWN-B02 with 91 rings, but the majority of the measured samples have less than 60 rings (75%). With short-ring width sequences successful analysis relies on good intra-site matching allowing the construction of longer well replicated site sequences with which to cross-match against the reference chronologies. Unfortunately, in this case in addition to short-ring width sequences the intra-site matching is poor making it unsurprising that it has not been possible to date any samples at this site.

Although undated, it is possible to make some comments about the two site sequences constructed. By looking at the relative heartwood/sapwood boundary positions of the samples in both site sequences, it is possible to say that in each case, it is likely that the two samples represented were felled at the same time. This is not surprising given that the two samples in SWNBSQ01 were both from primary timbers of the nave roof whilst the two represented in SWNBSQ02 were both from the east end alteration.

BIBLIOGRAPHY

Howard, R E, Laxton, R R, and Litton, C D, 1997 *Tree-ring analysis of timbers from St John's Commandery, Swingfield, Kent*, Anc Mon Lab Rep, **74/1997**

TABLES

Table 1: Details of tree-ring samples from the Church of St Peter, Swingfield, Kent

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Nave						
SWN-B01	North rafter, frame 5, bay 1	78	h/s	----	----	----
SWN-B02	South ashlar, frame 5, bay 1	91	h/s	----	----	----
SWN-B03	South rafter, frame 6, bay 1	71	h/s	----	----	----
SWN-B04	South ashlar, frame 2, bay 2	NM	--	----	----	----
SWN-B05	North ashlar, frame 3, bay 2	47	--	----	----	----
SWN-B06	North rafter, frame 4, bay 2	51	h/s	----	----	----
SWN-B07	South ashlar, frame 4, bay 2	NM	--	----	----	----
SWN-B08	South rafter, frame 5, bay 2	48	h/s	----	----	----
SWN-B09	South rafter, frame 4, bay 3	49	--	----	----	----
SWN-B10	North ashlar, frame 1, bay 4	NM	--	----	----	----
SWN-B11	North rafter, frame 2, bay 4	NM	--	----	----	----
SWN-B12	North rafter, frame 6, bay 3	49	h/s	----	----	----
Nave – east end						
SWN-B13	North brace, tie to collar, truss 5	54	h/s	----	----	----
SWN-B14	South brace, tie to collar, truss 5	55	h/s	----	----	----
SWN-B15	North brace, brace to collar, truss 5	NM	--	----	----	----
Chancel						
SWN-B16	South rafter, frame 3	NM	--	----	----	----
SWN-B17	North rafter, frame 7	46	--	----	----	----
SWN-B18	South rafter, frame 7	59	h/s	----	----	----
SWN-B19	South rafter, frame 8	NM	--	----	----	----
SWN-B20	North rafter, frame 8	NM	--	----	----	----
SWN-B21	South rafter, frame 9	NM	--	----	----	----

*NM = not measured. **h/s = the heartwood/sapwood boundary is the last measured ring on the sample.

FIGURES

Figure 1: Map to show the general location of Swingfield, Kent, circled (based on the Ordnance Survey Map, with the Permission of The Controller of Her Majesty's Stationery Office, © Crown Copyright)

Figure 2: Map to show the general location of the Church of St Peter, Swingfield, Kent, circled (based on the Ordnance Survey Map with the permission of The Controller of Her Majesty's Stationery Office, © Crown Copyright)

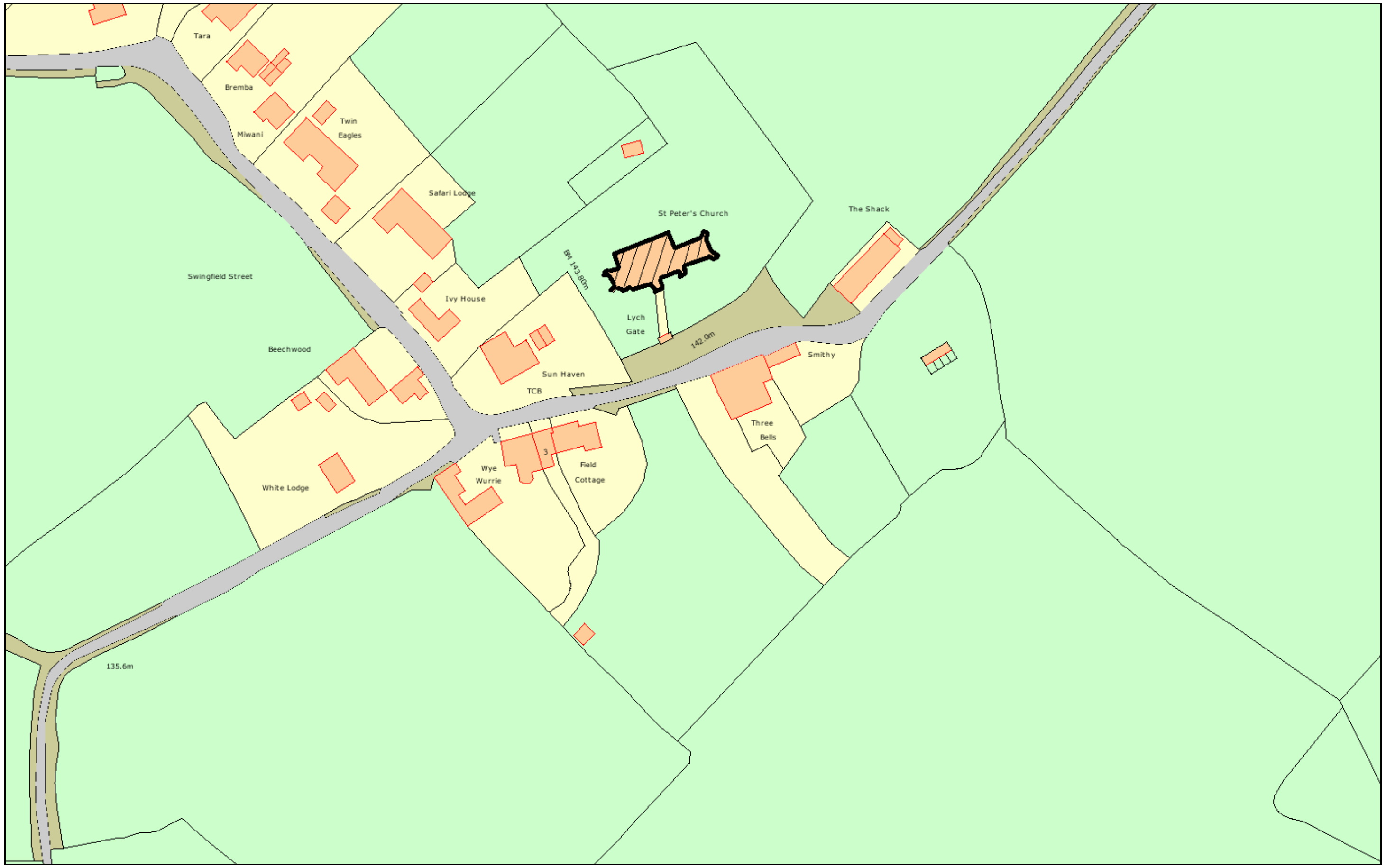


Figure 3: Map to show the location of the Church of St Peter, Swingfield, Kent, hashed (based on the Ordnance Survey Map, with the Permission of The Controller of Her Majesty's Stationery Office, © Crown Copyright)

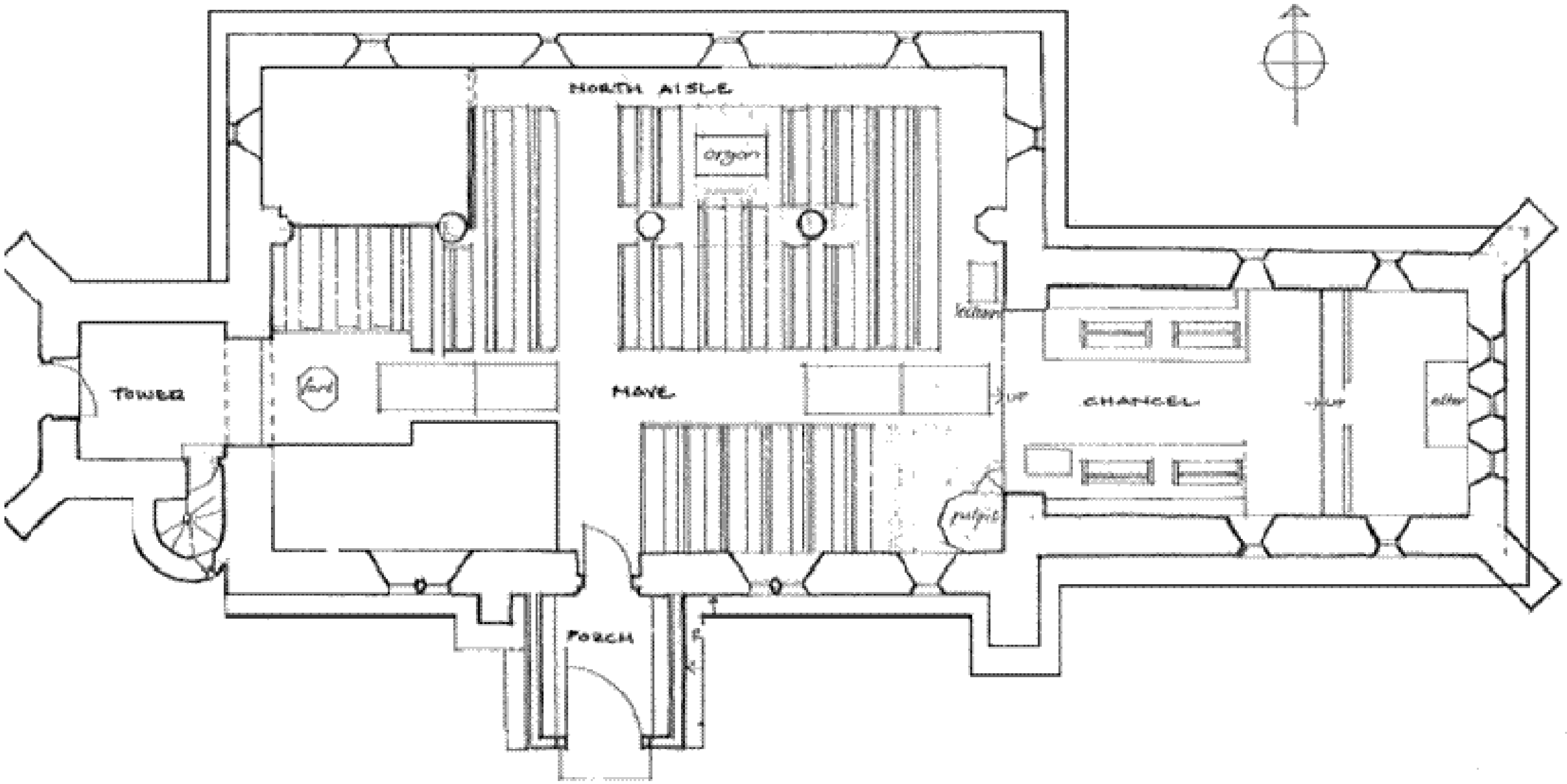


Figure 4: Plan of the Church of St Peter (Thomas Ford & Partners)

Figure 5: Nave roof, truss 3 in foreground

Figure 6: The Nave; altered east end

Figure 7: Chancel roof, looking east

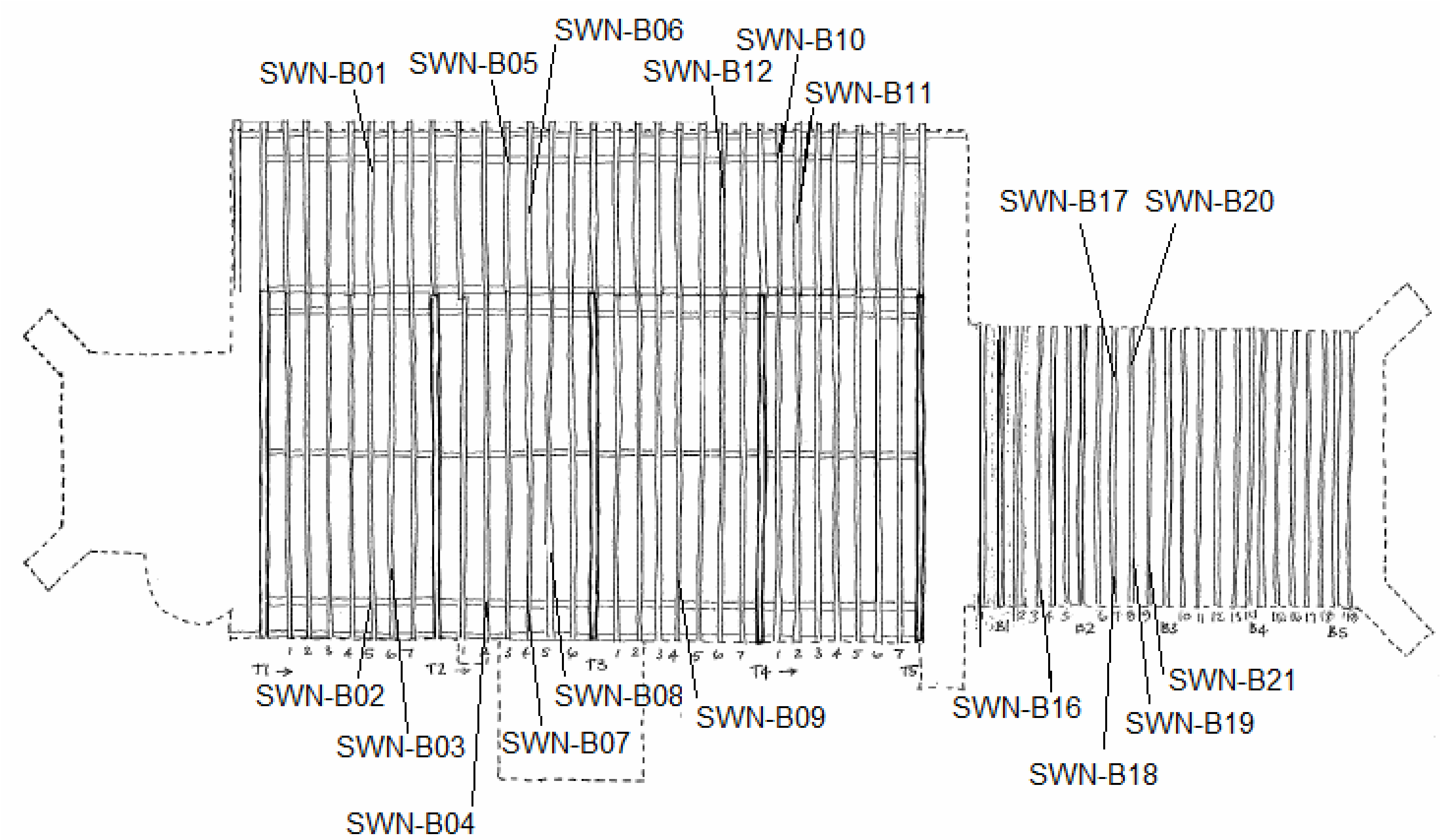


Figure 8: Plan of roof frames, showing the location of samples SWN-B01–12 and SWN-B16–21 (Thomas Ford & Partners)

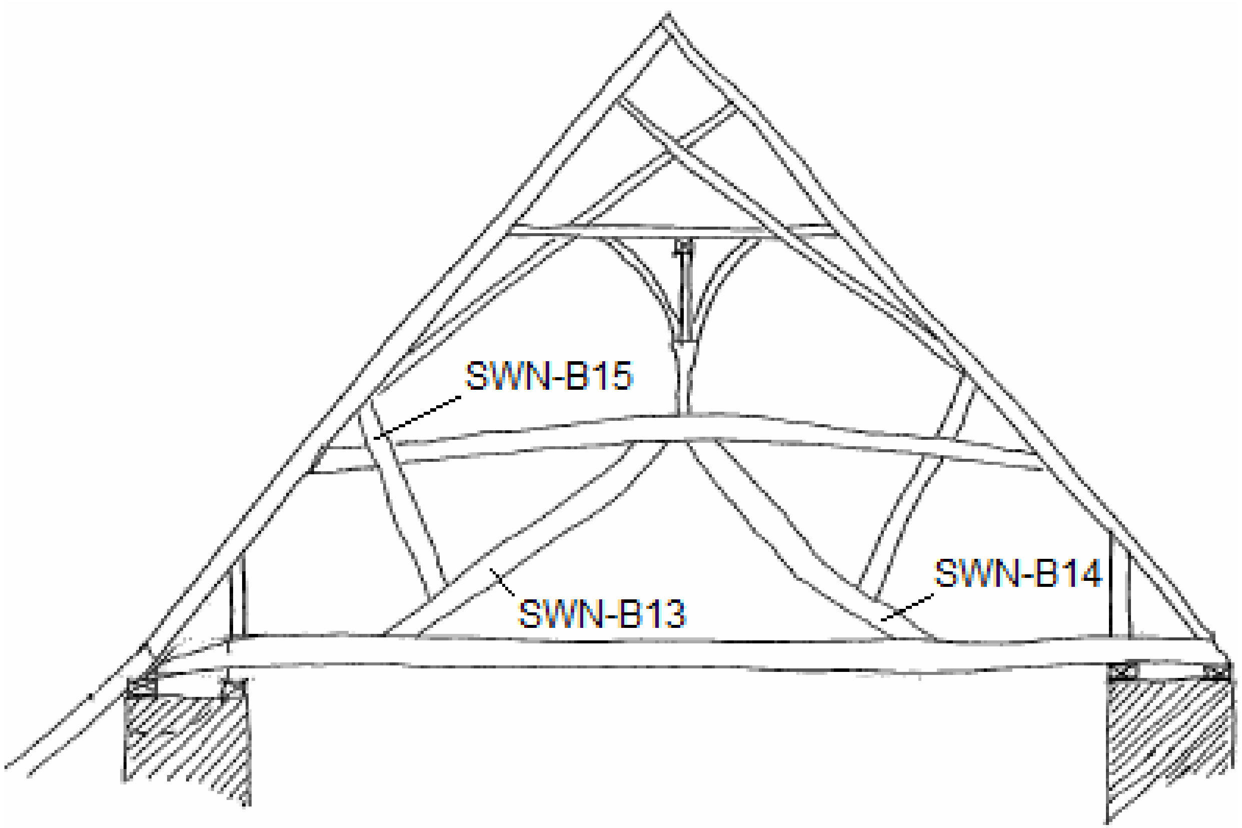


Figure 9: Truss 5, showing the location of samples SWN-B13–15 (Thomas Ford & Partners)

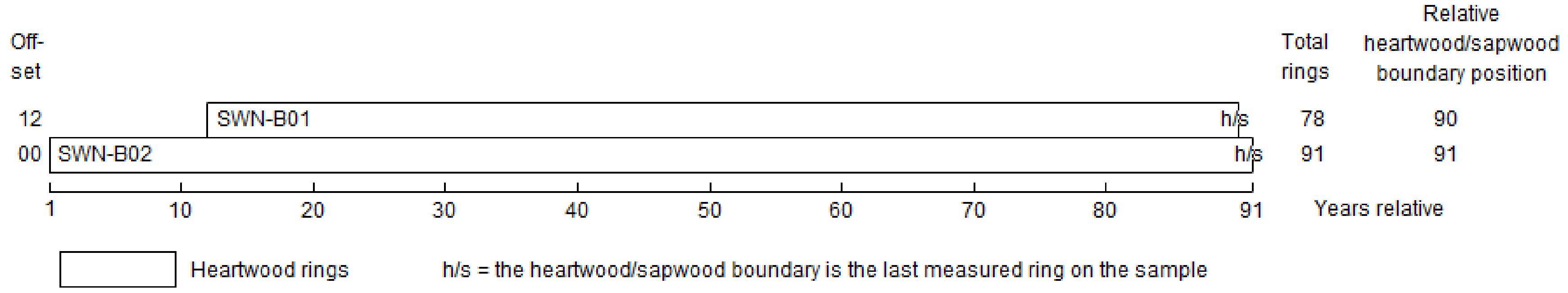


Figure 10: Bar diagram of samples in undated site sequence SWNBSQ01

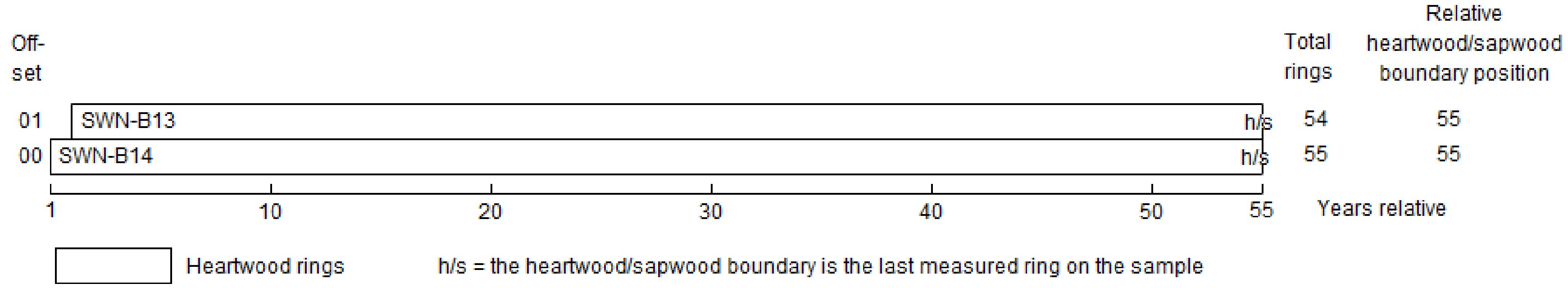


Figure 11: Bar diagram of samples in undated site sequence SWNBSQ02

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

SWN-B01A 78
180 281 290 348 284 234 262 185 161 202 194 248 245 288 225 251 148 173 128 97
132 132 122 128 222 255 286 232 232 227 168 185 178 111 139 136 152 131 117 128
119 134 91 86 103 87 62 81 100 102 93 79 61 75 71 90 73 88 49 75
87 86 86 62 134 225 218 132 107 101 99 142 112 123 119 83 81 79
SWN-B01B 78
169 290 283 347 288 235 253 173 163 208 207 250 246 280 228 242 139 171 125 106
125 120 125 130 237 265 277 230 237 226 167 189 171 113 127 140 160 137 123 123
120 131 93 84 103 90 63 83 102 89 90 93 60 63 78 88 76 75 54 65
96 93 78 63 133 233 228 129 105 91 108 141 111 123 122 75 81 79
SWN-B02A 91
145 203 299 253 162 239 195 153 130 169 152 141 144 157 142 169 132 157 165 142
139 176 144 190 169 147 147 173 118 137 88 75 93 106 102 77 135 206 317 238
199 222 146 137 120 72 84 89 98 110 95 78 106 97 91 83 74 75 57 58
67 84 83 78 55 65 58 56 60 63 43 47 67 53 49 57 169 258 231 144
102 93 98 97 109 112 74 85 95 97 56
SWN-B02B 91
145 202 299 256 162 228 195 158 144 164 156 132 138 168 143 172 135 156 177 134
153 183 159 190 169 153 156 172 119 132 96 67 99 107 101 80 127 220 301 243
202 218 151 135 107 85 75 98 94 112 97 81 102 98 94 78 78 72 61 65
62 85 84 73 64 57 60 54 57 64 47 50 61 55 49 62 166 260 235 143
106 90 101 92 115 110 72 82 100 87 67
SWN-B03A 71
219 237 198 165 129 170 266 249 216 251 186 123 153 195 208 130 113 113 119 74
98 115 137 104 159 119 117 136 254 146 108 118 95 115 131 201 204 219 132 164
160 186 206 201 146 123 99 147 156 189 159 101 101 93 78 101 75 78 66 95
102 91 105 82 50 65 84 74 70 64 57
SWN-B03B 71
214 231 209 191 123 163 228 241 213 252 186 119 165 187 205 128 106 118 119 80
93 108 139 106 159 123 112 142 269 155 99 122 98 109 128 199 209 218 134 162
166 191 199 209 147 118 108 142 152 193 155 104 109 82 87 90 84 75 67 96
106 84 114 77 53 67 75 84 59 61 77
SWN-B05A 47
187 145 112 160 173 137 211 215 191 210 263 219 150 178 95 81 119 90 94 76
156 167 251 201 233 230 236 187 197 164 178 215 154 199 301 328 194 223 343 424
342 359 249 294 307 289 205
SWN-B05B 47
165 154 109 167 169 131 216 213 176 201 263 214 155 183 92 87 111 96 88 78
164 176 245 204 229 230 229 177 204 155 172 210 155 187 283 330 192 238 345 419
344 355 259 284 296 292 214
SWN-B06A 51
305 331 278 285 436 458 183 239 322 369 260 237 254 280 360 215 257 209 160 137
232 234 180 146 67 75 120 116 134 135 237 209 208 247 203 220 82 138 168 244
271 284 190 122 231 230 186 236 248 284 290
SWN-B06B 51
365 336 271 290 434 466 186 234 316 364 272 237 258 280 354 214 253 216 153 136
240 226 182 145 69 60 132 124 152 165 233 212 215 249 206 214 73 171 199 239
269 283 180 124 230 236 188 229 248 284 265

SWN-B08A 48
206 230 227 244 255 430 254 356 317 207 211 268 298 162 133 131 115 133 174 96
105 100 123 219 304 325 189 217 231 332 231 170 280 303 234 160 93 75 61 165
165 111 137 140 197 153 144 258
SWN-B08B 48
223 238 213 242 250 427 258 359 315 194 206 274 276 159 138 138 115 121 181 101
96 104 131 215 303 323 193 211 232 337 228 174 277 308 231 154 90 78 54 167
161 105 133 133 202 146 152 285
SWN-B09A 49
234 376 417 424 338 251 279 231 106 213 189 132 161 187 155 222 252 144 194 97
111 141 151 201 187 289 268 360 218 154 144 192 193 254 288 147 150 254 294 199
155 221 286 290 304 315 302 292 305
SWN-B09B 49
238 379 407 369 360 251 262 246 97 210 186 131 149 160 162 226 258 149 191 87
115 160 158 191 192 282 275 355 216 152 150 189 187 259 257 144 158 260 294 220
158 219 287 297 299 311 306 301 295
SWN-B12A 49
185 228 301 344 188 346 216 194 298 284 402 338 278 208 101 183 178 288 294 177
170 317 85 81 178 276 278 336 284 379 375 273 395 362 270 263 295 147 222 344
309 237 262 226 293 271 307 119 259
SWN-B12B 49
234 264 255 336 225 323 199 189 281 264 407 353 264 195 109 164 164 309 286 167
172 304 86 79 180 274 284 344 282 380 361 272 391 359 282 273 286 144 238 335
302 233 260 214 298 274 306 130 242
SWN-B13A 54
398 241 373 688 748 295 290 276 195 424 417 347 248 152 211 229 254 321 231 205
411 413 334 124 128 172 280 384 341 242 84 126 184 139 75 206 132 107 165 183
173 163 205 264 225 221 194 217 247 241 135 107 164 173
SWN-B13B 54
352 255 358 681 741 286 293 263 192 412 420 353 235 140 210 227 259 307 205 169
413 408 330 124 111 199 305 401 356 235 80 132 172 152 106 192 116 110 173 205
171 177 205 252 231 221 197 232 249 252 124 127 141 190
SWN-B14A 55
194 366 183 285 689 715 282 311 348 256 419 428 450 271 126 302 247 243 349 184
105 141 143 156 156 108 178 271 332 254 221 122 232 333 230 219 328 156 142 211
183 184 226 287 337 267 276 333 268 379 301 205 260 222 294
SWN-B14B 55
222 375 162 304 752 713 323 314 341 246 407 428 452 273 124 275 201 238 347 181
105 143 138 157 161 114 176 267 334 253 218 124 232 334 232 220 334 150 139 218
187 187 220 284 328 260 265 330 281 370 300 210 261 231 277
SWN-B17A 46
309 511 244 192 284 190 200 127 130 234 496 351 362 325 387 459 308 191 236 280
113 108 125 173 155 204 252 237 201 208 275 289 326 494 398 395 430 334 264 271
237 210 237 207 148 192
SWN-B17B 46
356 420 232 220 276 194 190 119 120 201 531 367 378 327 370 437 308 194 226 284
105 112 133 171 149 209 251 234 203 219 281 295 322 502 401 392 430 337 269 269
239 208 243 203 151 200
SWN-B18A 59
541 441 373 263 133 145 91 199 76 63 62 71 76 61 97 493 581 430 540 565
495 157 73 41 57 50 107 106 122 193 156 229 194 191 178 183 231 262 173 466
352 353 355 370 217 369 153 381 230 234 134 225 80 159 111 86 72 69 54

SWN-B18B 59
521 451 394 301 135 155 90 203 70 58 67 67 78 62 113 481 570 430 528 572
470 159 69 41 56 48 113 99 128 193 152 231 198 191 172 174 233 266 179 452
358 343 361 368 222 362 166 376 227 231 139 221 84 153 109 85 73 70 52

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

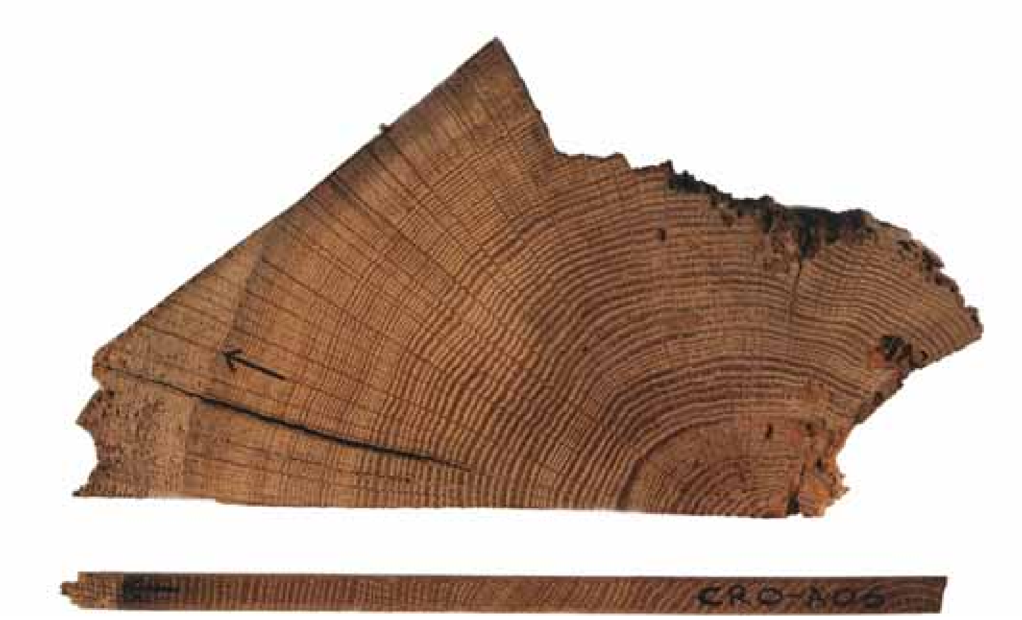


Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

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

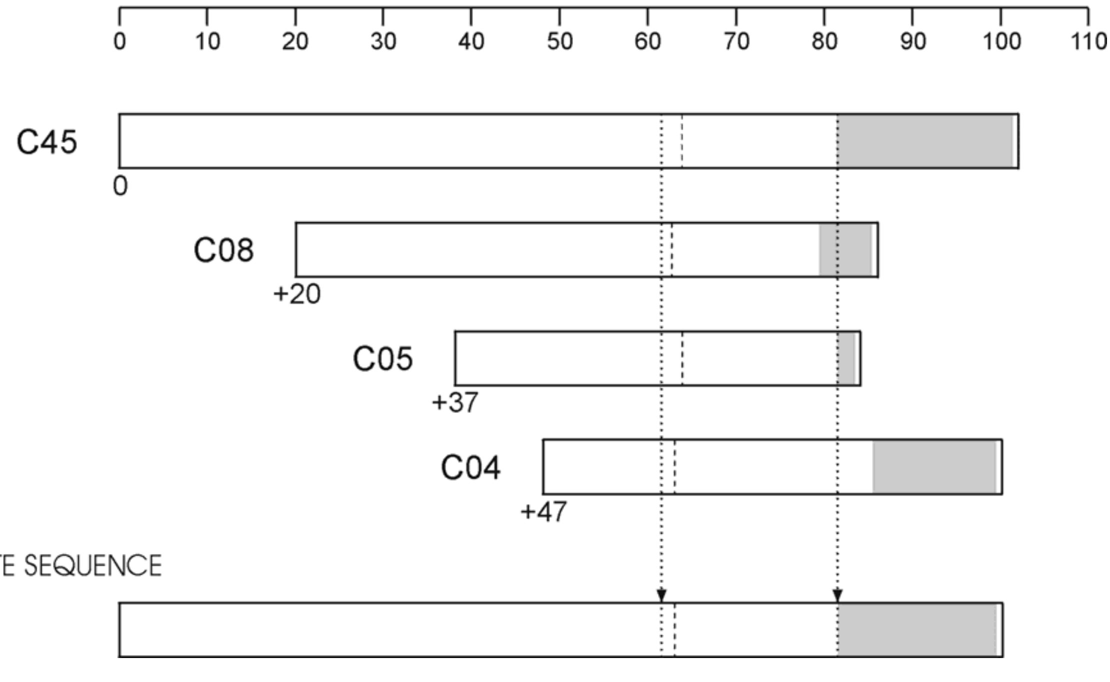


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

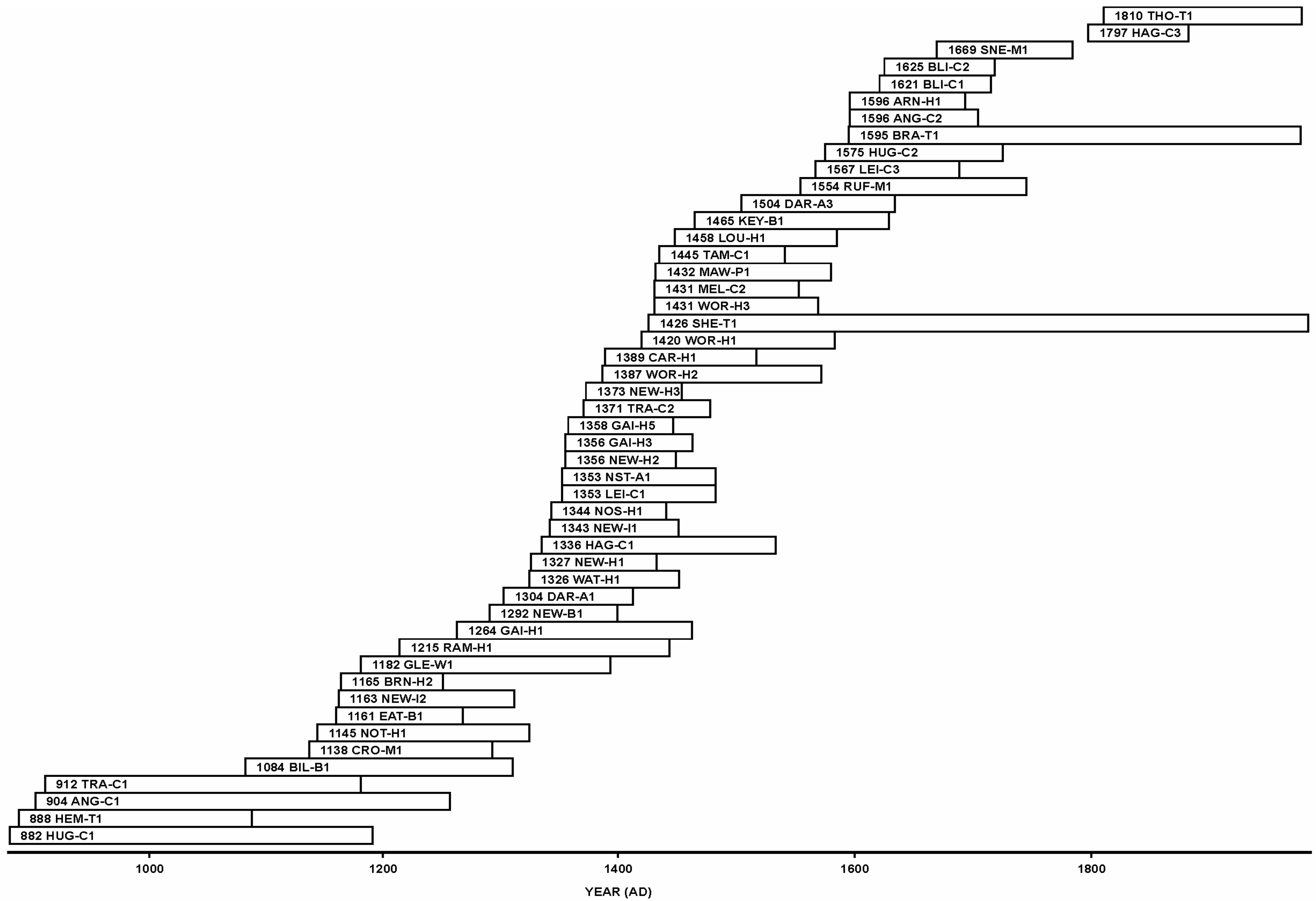
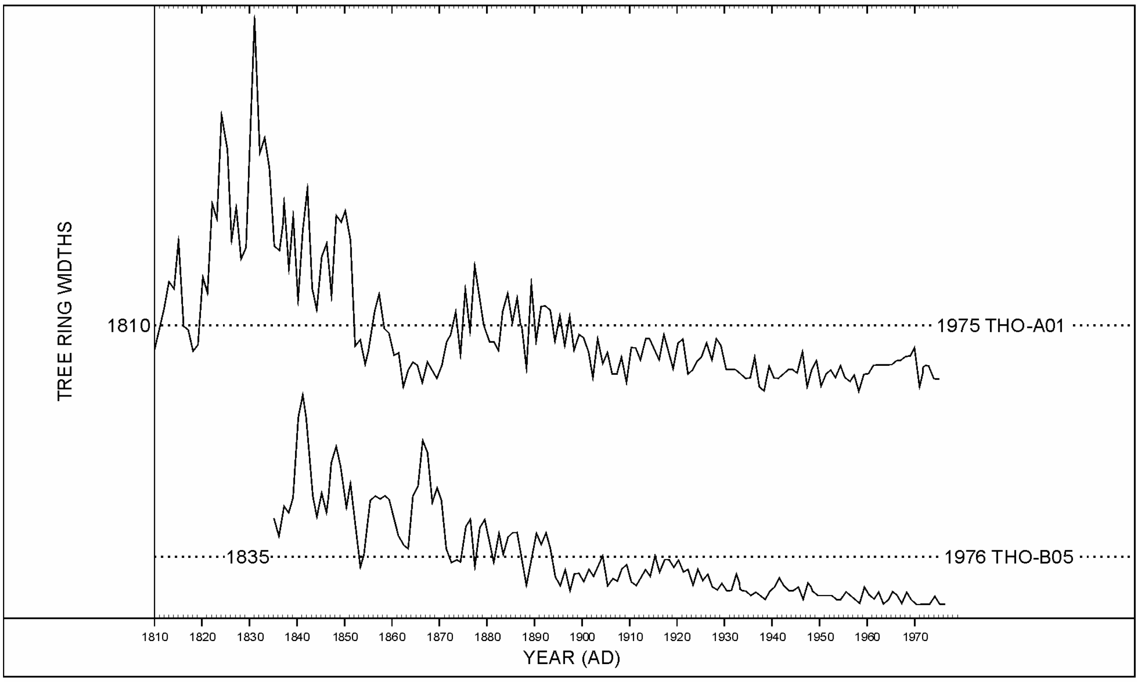


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

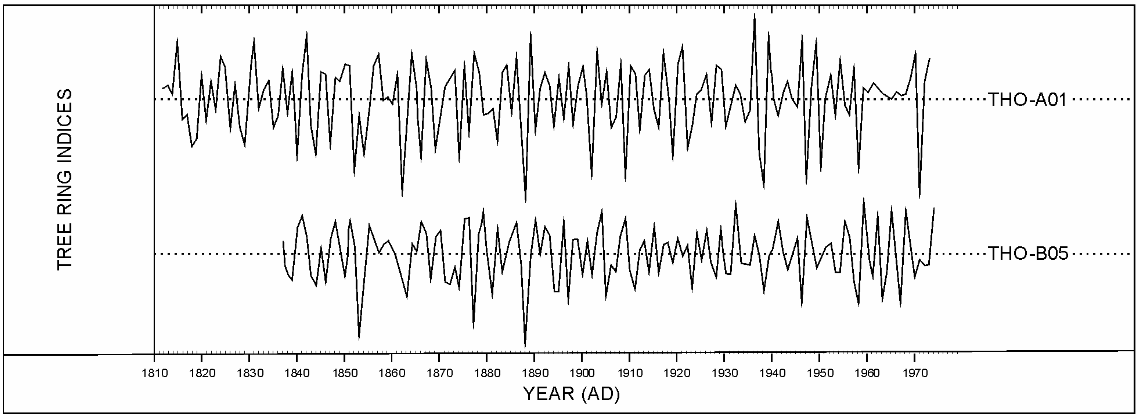


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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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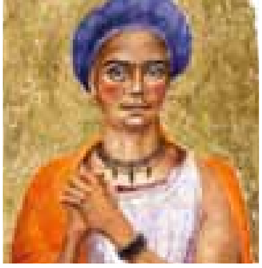


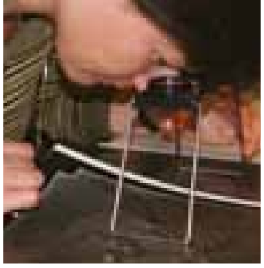


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ENGLISH HERITAGE

ISSN 2046-9799 (Print)
ISSN 2046-9802 (Online)