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Summary

Previous analysis undertaken on samples from principal rafters, struts, and central posts of this roof structure resulted in it being dated to AD 1660. In AD 2005 a further ten samples were taken from a number of wall plates from this roof.

The second phase of analysis produced the dated site sequence WORCSQ08 which contains all ten samples and spans the period AD 1552 - 1660. Two of these samples have complete sapwood and the last ring date of AD 1660, the felling date of the timbers represented. Interpretation of the heartwood/sapwood boundary on the other samples, where this exists, is also consistent with an AD 1660 felling.

The earlier analysis had shown this roof was constructed from timbers felled in AD 1660 rather than belonging to the renovations of the Chapter House of AD 1386 - 92 as was previously thought. This latter phase of analysis has shown the wall plates, rather than representing a separate phase, also belong to this AD 1660 felling.

Keywords

Dendrochronology
Standing Building

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Introduction

Worcester Cathedral, standing in a prominent position on the east bank of the River Severn (SO 850 545; Fig 1) has a long history. The bishopric was founded in the seventh century and the first Cathedral was dedicated to St Peter. Oswald, who was made bishop in AD 961, built a new cathedral, dedicated to St Mary. The presbytery of St Peter's was rebuilt following a Danish raid in AD 1041. Both early cathedrals appear to have been demolished around the time St Wulfstan started the present cathedral in AD 1084.

Surviving work of St Wulfstan's period includes the crypt, western transepts, cloisters, and Chapter House. In AD 1175 the crossing tower fell down and was rebuilt (Guy 1994). It was rebuilt again in the AD 1370s. In AD 1224 the construction of a new east end was started under bishop William of Blois. Much of the existing decorated architecture at the east end belongs to this phase, with additional work in the Perpendicular style dating from the late-fourteenth or early-fifteenth century. There was also a considerable amount of rebuilding activity in the nineteenth century.

The Chapter House is polygonal and Perpendicular on the outside but circular and Norman within, and is dated to *c* AD 1120, although its timber roof is not the original one. This was thought to date to documented restorations carried out between AD 1386–92. The present roof concentrates most of its weight onto the central pier, from which radiate ten principals. There are three straight purlins between each principal and each principal is stiffened by tied straight braces at its centre and by strutted curved braces at its wallposts. In AD 2004, samples were taken from principal rafters, struts, and central posts of this roof resulting in these being dated to AD 1660 (Arnold *et al* 2004a).

Other work carried out at Worcester Cathedral by this Laboratory has resulted in timbers of the nave roof being dated to the early-seventeenth century, with these being thought to represent repair work undertaken at that time (Howard *et al* 1995). A much larger programme of sampling of timbers from the choir, the north-east and south-east transepts, and the crossing between them showed that major repairs took place here in the early-eighteenth century, reusing some earlier timbers (Howard *et al* 2000). A further programme of tree-ring analysis undertaken on the timbers of the roof of St John Chapel, and on the roof connecting the Chapel to the Chapter House (Howard *et al* 2001a) showed these roofs again contained much reused timber, and that the last major repair phase was in the AD 1740s. Finally, work in AD 2003 on timbers of the Lady Chapel and Choir roofs identified the latest periods of work again being in the eighteenth century (Arnold *et al* 2003).

The Laboratory would like to take this opportunity to thank all those who assisted with the sampling of the timbers. In particular thanks are due to the Chapter of Worcester Cathedral and to the Vergers' Office, whose staff assisted with access to the roof. The Laboratory would also like to thank Mr

Christopher Guy, the Cathedral Archaeologist, for his advice and assistance, in particular with the descriptive introduction to the site given above.

Sampling and analysis by tree-ring dating was commissioned and funded by English Heritage. It was hoped that dendrochronological investigation would provide a precise date for the wall plates of the roof and hence both inform the on-going repair programme and contribute to the research into the roofs of the Cathedral.

Sampling

Five core samples were taken from wall plates still *in situ* within this roof. The cores were taken using a 15mm diameter corer attached to an electric drill. Each sample was given the code WOR-C (for Worcester Cathedral) and numbered 215–9. In addition, a further five sliced samples were taken, using a chainsaw, from wall plates which had been removed from the building. These have been numbered WOR-C220–4. The position of samples WOR-C215–9 was noted at the time of sampling and has been marked on Figure 2. Unfortunately, at the time the sliced samples were taken the timbers had already been removed from the roof and it is not known exactly where these timbers were from within the roof. Further details relating to the samples can be found in Table 1.

Analysis and Results

All ten 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 then compared with each other by the Litton/Zainodin grouping procedure (see appendix).

At a value of t=4.5, all ten samples had matched forming two groups. Firstly, six samples matched each other and were combined at the relevant offset positions to form WORCSQ06, a site sequence of 98 rings (Fig 3). This site sequence was then compared with a large number of relevant reference chronologies for oak indicating a consistent match when the date of its first ring is AD 1552 and of its last measured ring is AD 1649. The evidence for this dating is given by the t-values in Table 2.

Four samples matched each other and were combined at the relevant offset positions to form WORCSQ07, a site sequence of 86 rings (Fig 4). This site sequence was then compared with the reference chronologies where it was found to match consistently at a first-ring date of AD 1575 and a last-ring date of AD 1660. The evidence for this dating is given by the t-values in Table 3.

These two site sequences match each other at the expected offset position at a value of t=4.2. Therefore, a third site sequence of 109 rings, WORCSQ08, was then constructed containing all ten samples (Fig 5). This site sequence was again compared with the reference material, where it was found to match at a first-ring date of AD 1552 and a last-ring date of AD 1660. The evidence for this dating is given by the *t*-values in Table 4.

Interpretation and Discussion

Analysis of ten samples taken from wall plates in the roof of the Chapter House resulted in the construction and dating of a single site sequence.

Site sequence WORCSQ08, of 109 rings, contains all ten samples and spans the period AD 1552–1660. Two of the samples contained within this site sequence have complete sapwood and a last ring date of AD 1660, the felling date of the timbers represented. Seven other samples have the heartwood/sapwood boundary ring, which is broadly contemporary and suggestive of a single felling. The average heartwood/sapwood boundary ring date is AD 1639 which, allowing for sample WOR-C221 having a last measured ring date of AD 1657 with incomplete sapwood, calculates to an estimated felling date for the timbers represented to within the range AD 1658–79, consistent with an AD 1660 felling. This felling date range is calculated using the estimate that 95% of mature oak trees in this area have between 15 and 40 sapwood rings. The final sample, WOR-C216, does not have the heartwood/sapwood boundary ring and so an estimated felling date cannot be calculated for it. However, by adding the minimum number of expected sapwood rings (15) to its last measured ring date of AD 1623 this would provide a *terminus post quem* date of AD 1638, not inconsistent with a felling along with the other timbers in AD 1660.

Prior to the analysis carried out in AD 2004 (Arnold *et al* 2004a), the present roof of the Chapter House was thought to be a replacement of the original, dating to documented renovations in AD 1386–92. That phase of tree-ring dating showed that the principal rafters, struts, and posts of the roof were actually from timbers felled over 250 years later. This latest phase of analysis has shown that rather than belonging to a separate felling, the wall plates are also from timber felled in AD 1660.

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Table 1: Details of tree-ring samples from the roof of the Chapter House, Worcester Cathedral, Worcestershire

Sample number	Sample location	Total rings	Sapwood rings*	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
WOR-C215	Wall plate	60	05	1580	1634	1639
WOR-C216	Wall plate	60	--	1564	----	1623
WOR-C217	Wall plate	86	30C	1575	1630	1660
WOR-C218	Wall plate	75	28C	1586	1632	1660
WOR-C219	Wall plate	67	02	1580	1644	1646
WOR-C220	Wall plate	82	08	1568	1641	1649
WOR-C221	Wall plate	81	22	1577	1635	1657
WOR-C222	Wall plate	84	h/s	1552	1635	1635
WOR-C223	Wall plate	90	04	1557	1642	1646
WOR-C224	Wall plate	89	10	1561	1639	1649

*h/s = the heartwood/sapwood boundary is the last ring on the sample
C = Complete sapwood on timber, last measured ring is the felling date

Table 2: Results of the cross-matching of site sequence WORCSQ06 and relevant reference chronologies when the first-ring date is AD 1552 and the last-ring date is AD 1649

Reference chronology	*t*-value	Span of chronology	Reference
East Midlands	5.8	AD 882–1981	Laxton and Litton 1988
England	6.0	AD 404–1981	Baillie and Pilcher 1982 unpubl
Sherwood Trees, Notts	5.0	AD 1426–1981	Laxton and Litton 1988
Worcester Cathedral, Lady Chapel and Choir	5.0	AD 1484–1772	Arnold *et al* 2003
Gunns Mills, Glos	4.9	AD 1438–1681	Howard *et al* 2001b
Kibworth Harcourt Mill. Leics	4.8	AD 1582–1773	Arnold *et al* 2004b
Worcester Cathedral, Chapter House (roof)	4.6	AD 1558–1660	Arnold *et al* 2004a

Table 3: Results of the cross-matching of site sequence WORCSQ07 and relevant reference chronologies when the first-ring date is AD 1575 and the last-ring date is AD 1660

Reference chronology	*t*-value	Span of chronology	Reference
England	5.2	AD 404–1981	Baillie and Pilcher 1982 unpubl
Worcester Cathedral, Chapter House (roof)	7.3	AD 1558–1660	Arnold *et al* 2004a
Gunns Mills, Glos	6.6	AD 1438–1681	Howard *et al* 2001b
Staircase House, Stockport, Greater Manchester	5.4	AD 1069–1248	Howard et al 2003
Sinai House, Burton on Trent, Staffs (central range)	5.4	AD 1555–1665	Howard *et al* 1999
Worcester Cathedral, Lady Chapel and Choir	5.0	AD 1484–1772	Arnold *et al* 2003

Table 4: Results of the cross-matching of site sequence WORCSQ08 and relevant reference chronologies when the first-ring date is AD 1552 and the last-ring date is AD 1660

Reference chronology	*t*-value	Span of chronology	Reference
East Midlands	6.0	AD 882–1981	Laxton and Litton 1988
England	7.1	AD 404–1981	Baillie and Pilcher 1982 unpubl
Worcester Cathedral, Chapter House (roof)	7.0	AD 1558–1660	Arnold *et al* 2004a
Gunns Mills, Glos	6.3	AD 1438–1681	Howard *et al* 2001b
Worcester Cathedral, Lady Chapel and Choir	5.9	AD 1484–1772	Arnold *et al* 2003
Staircase House, Stockport, Greater Manchester	5.9	AD 1069–1248	Howard *et al* 2003
Sherwood Trees, Notts	5.6	AD 1426–1981	Laxton and Litton 1988

Figure 1: Map to show the location of Worcester Cathedral.

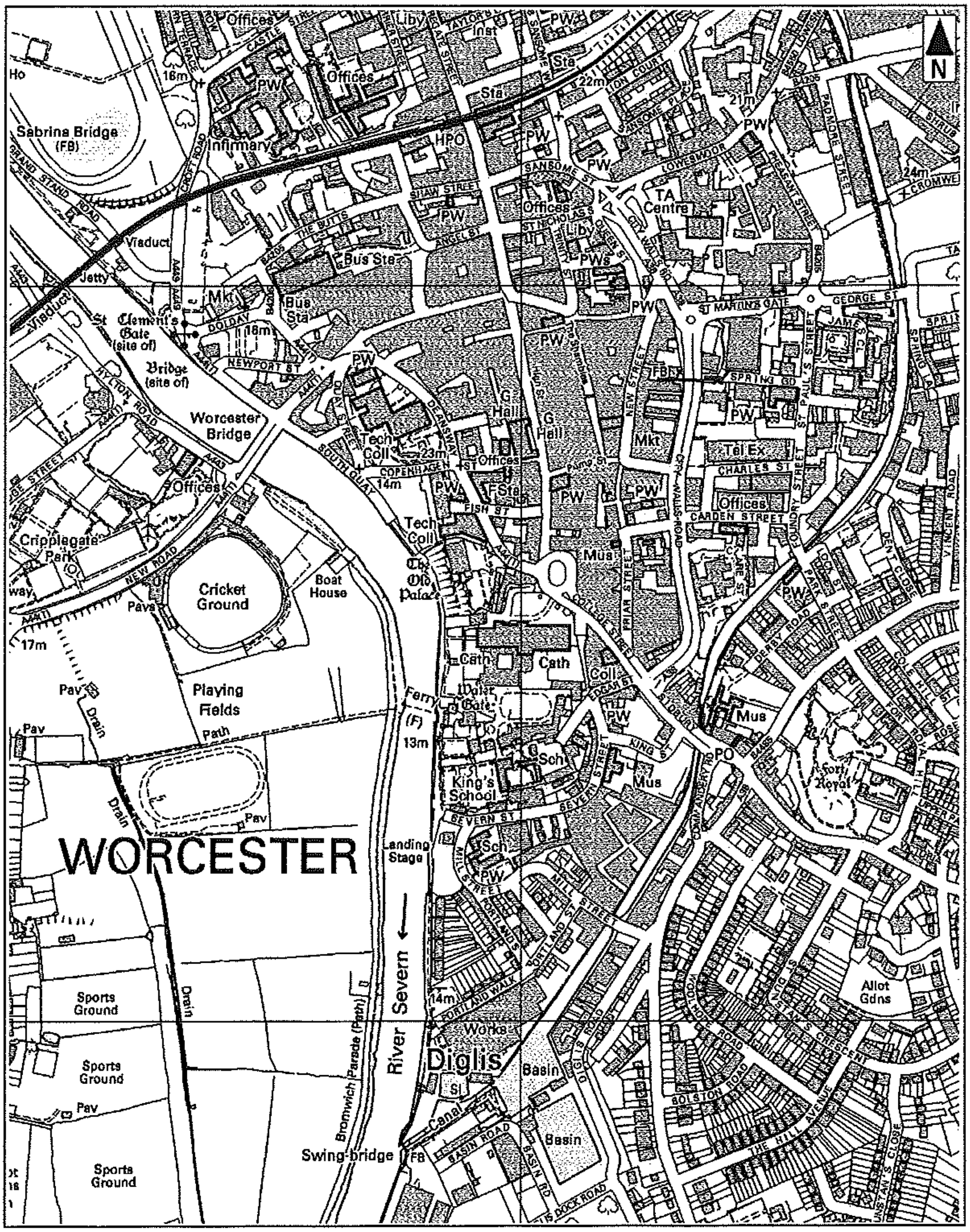


Figure 2: Worcester Cathedral, the high-roof of the Chapter House, showing the location of samples WOR-C215–9 (Christopher Guy)

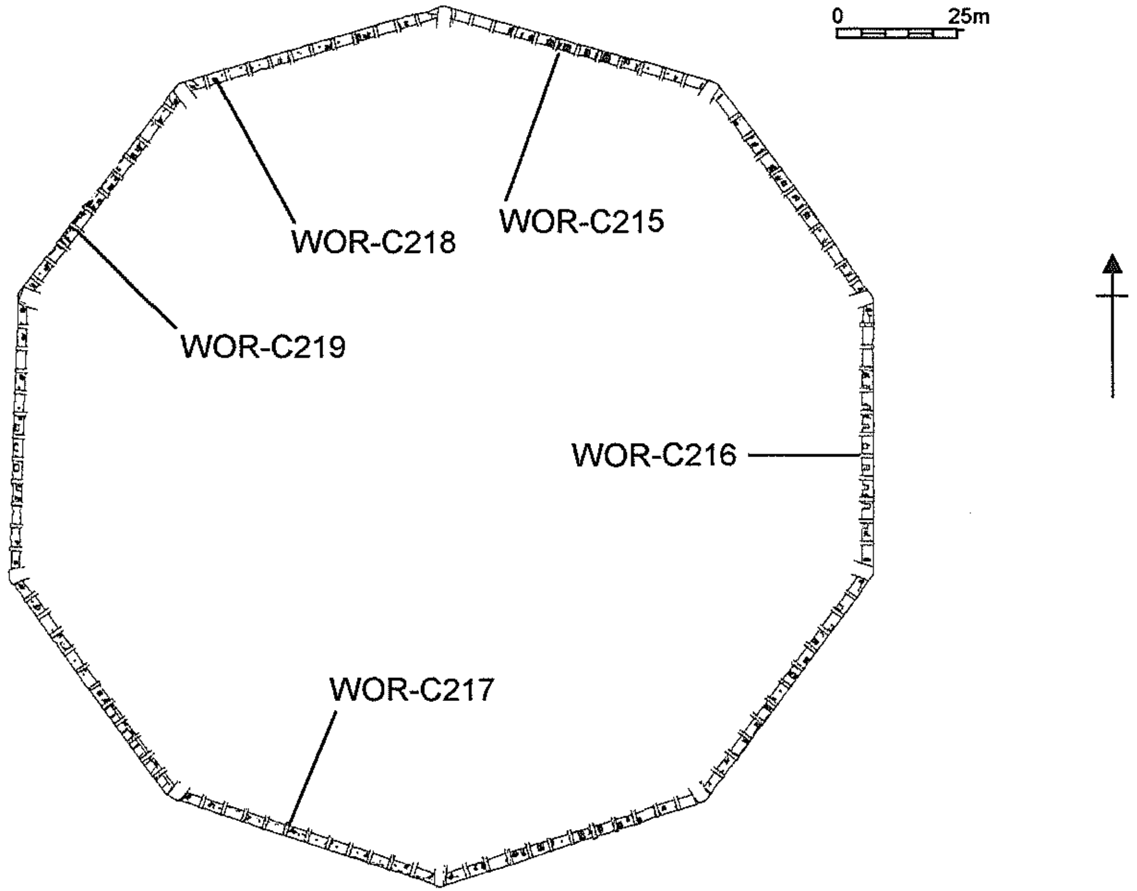
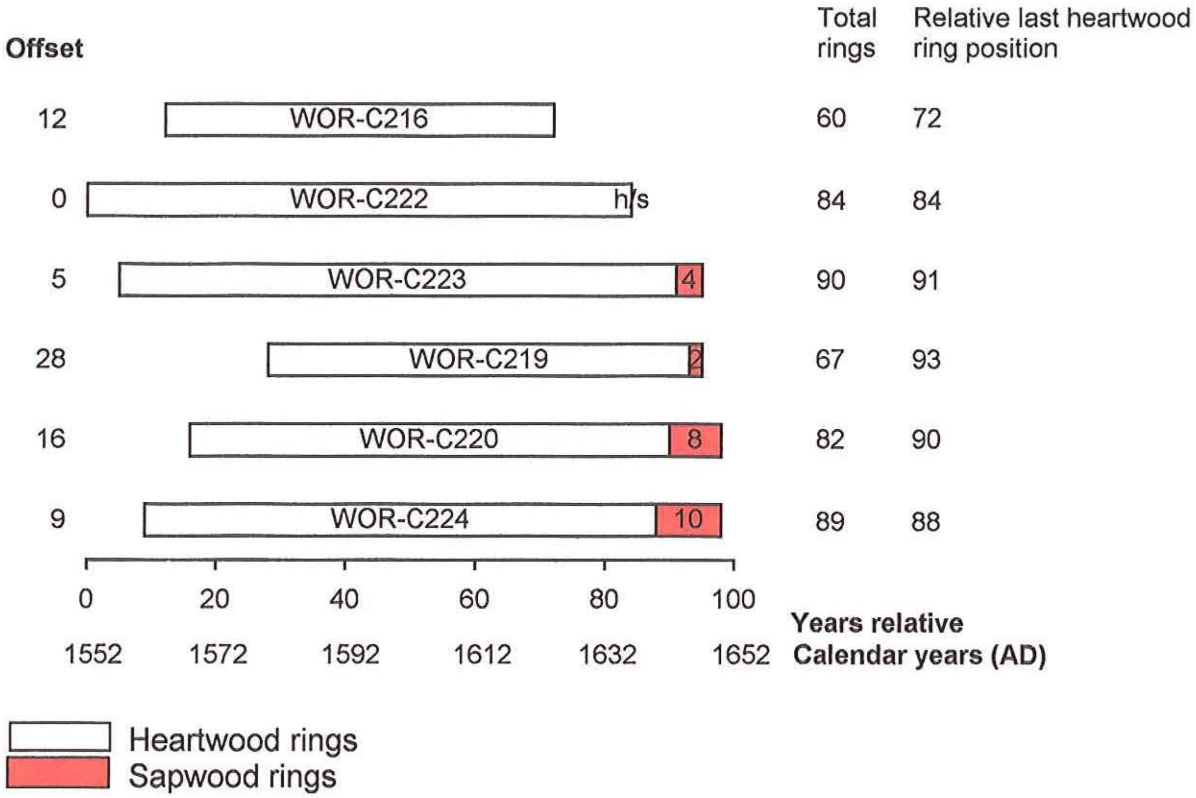
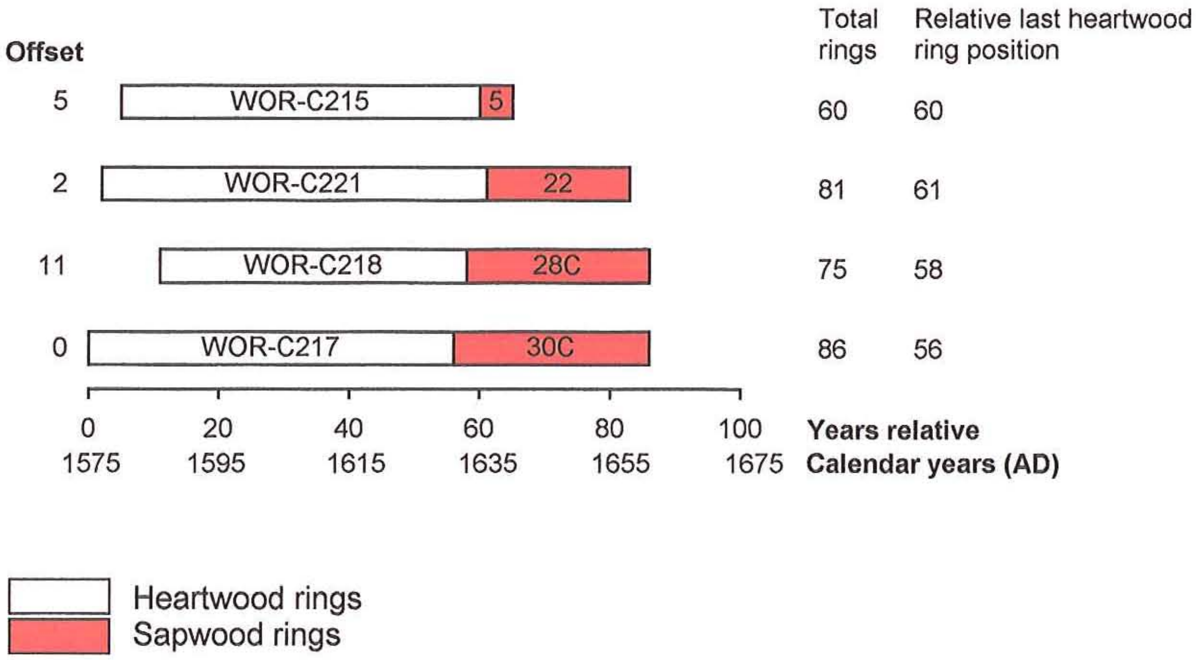


Figure 3: Bar diagram of samples in site sequence WORCSQ06



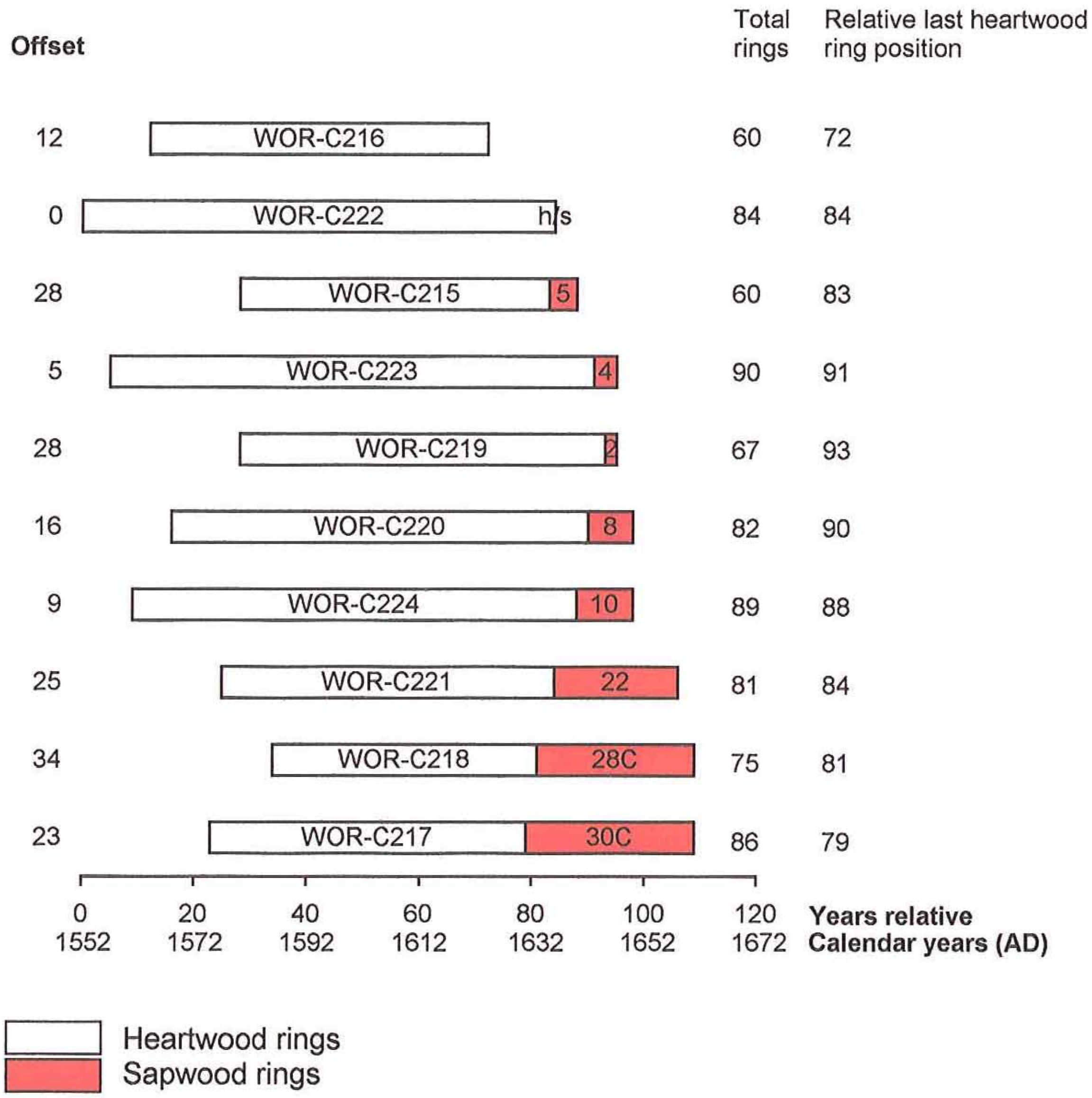
h/s = the heartwood/sapwood boundary is the last measured ring

Figure 4: Bar diagram of samples in site sequence WORCSQ07



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

Figure 5: Bar diagram of samples in site sequence WORCSQ08



C = complete sapwood retained in sample, last measured ring is the felling date
h/s = the heartwood/sapwood boundary is the last measured ring.

Data of measured samples – measurements in 0.01mm units

WOR-215A 60
444 330 310 310 332 291 280 340 220 306 265 344 307 380 376 330 338 281 285 305
208 292 171 249 298 281 309 333 309 246 311 264 260 339 316 350 305 596 451 453
420 367 506 673 530 343 203 385 334 568 314 260 374 311 320 323 156 328 327 177
WOR-215B 60
456 338 289 301 318 303 278 338 238 320 267 319 314 342 379 284 320 274 277 276
183 259 209 264 301 291 299 346 311 250 285 264 288 337 298 323 301 559 461 443
393 360 506 646 547 349 206 385 321 589 300 266 397 285 315 341 161 298 326 195
WOR-216A 60
313 276 261 345 364 381 375 616 521 609 601 544 446 444 425 363 681 441 452 366
528 441 395 407 313 355 196 253 239 357 292 426 299 291 396 375 357 385 369 357
315 279 404 391 320 369 324 366 262 422 322 737 627 441 354 306 445 301 404 329
WOR-216B 60
334 287 262 353 348 388 373 613 521 608 609 536 422 443 432 344 663 425 436 363
548 406 404 409 302 353 216 250 245 357 287 406 296 296 398 373 361 377 370 351
323 272 400 386 326 367 313 342 267 411 333 690 602 420 350 295 473 269 410 327
WOR-217A 86
238 316 302 314 455 523 407 476 441 331 413 387 404 354 400 312 362 362 380 356
338 324 208 194 209 176 236 196 236 178 164 180 179 234 218 250 207 251 177 199
224 176 261 246 208 230 244 221 259 234 151 114 203 188 326 123 153 174 186 142
204 87 122 185 102 94 97 99 98 62 67 86 72 103 102 134 108 109 93 84
79 98 114 89 101 115
WOR-217B 86
264 298 303 312 443 524 386 477 438 326 430 382 417 346 388 302 367 362 380 339
332 353 215 188 227 169 228 184 246 179 154 175 183 234 217 249 218 235 166 173
239 189 259 251 222 212 241 250 248 241 140 110 208 190 322 153 142 165 180 133
198 91 125 217 83 95 97 101 107 63 64 85 79 97 91 144 117 104 102 86
82 102 123 78 96 92
WOR-218A 75
324 437 318 316 290 365 259 323 321 295 247 217 217 253 190 267 255 323 309 313
258 293 276 236 446 508 530 519 478 578 503 547 391 378 372 276 446 422 428 188
149 300 340 477 367 326 344 381 241 298 139 215 319 97 79 80 62 61 55 51
73 81 129 175 151 179 128 128 138 211 220 173 183 226 228
WOR-218B 75
269 440 315 307 287 357 277 324 326 287 245 218 214 251 195 241 279 319 303 299
274 263 270 260 455 510 527 530 487 569 506 574 385 368 359 283 455 452 414 196
166 318 318 478 382 328 347 390 215 265 131 241 285 103 78 84 58 63 47 47
81 80 132 160 149 150 140 146 136 209 221 174 187 235 230
WOR-219A 67
445 298 332 275 396 396 426 357 313 362 193 300 222 324 244 263 216 268 249 303
191 244 213 238 214 260 334 385 297 317 234 257 240 298 189 253 201 168 210 291
241 226 301 261 161 135 184 268 259 470 219 264 363 257 256 242 197 234 244 312
232 240 258 244 289 226 201
WOR-219B 67
446 300 337 267 379 370 435 362 303 362 199 306 205 338 241 274 216 272 242 303
185 241 217 237 214 266 326 392 286 319 236 239 234 306 171 241 199 172 207 288
263 220 331 261 161 157 196 291 228 474 212 234 320 247 234 252 195 223 249 285
231 240 265 227 276 247 242

WOR-220A 82
272 239 294 378 511 466 403 348 345 315 250 247 378 285 189 170 232 286 232 195
202 299 152 244 192 213 220 207 173 156 155 167 165 227 196 184 265 211 385 278
223 256 232 218 238 303 255 764 648 445 296 338 345 186 199 224 202 146 173 271
272 530 252 272 317 249 228 335 221 253 288 348 203 206 163 156 150 177 241 149
245 177
WOR-220B 82
271 224 284 365 521 466 395 339 352 311 247 253 372 287 188 182 243 292 240 186
189 286 139 239 188 203 213 217 207 157 166 198 185 256 230 224 251 210 411 307
262 284 245 196 191 275 176 692 609 401 244 264 227 154 198 239 229 174 195 330
312 582 288 276 283 242 223 286 233 211 243 255 177 182 169 164 149 172 224 136
245 191
WOR-221A 81
244 305 307 376 345 326 264 321 308 275 294 202 232 220 286 242 256 229 264 202
196 229 265 218 240 214 291 277 216 243 234 249 250 323 604 517 448 455 504 470
505 403 372 371 248 361 382 294 145 158 303 294 421 281 272 256 281 186 250 122
220 253 81 60 79 60 56 51 58 85 84 160 157 142 176 122 144 142 211 223
183
WOR-221B 81
263 308 306 385 341 329 263 322 306 287 288 193 236 223 292 246 268 230 249 211
196 226 273 221 231 209 281 278 227 236 233 243 253 323 532 506 429 486 565 460
477 387 357 334 287 348 368 313 180 195 294 342 439 286 306 323 315 190 299 118
218 309 96 80 94 88 80 60 90 121 121 186 178 157 169 120 152 156 211 223
168
WOR-222A 84
150 176 241 304 216 263 265 266 252 220 218 184 252 197 133 213 188 189 292 534
544 490 540 360 270 320 383 245 619 300 330 244 288 367 346 328 258 454 236 369
314 409 449 409 284 273 266 261 232 234 207 244 216 210 305 391 349 392 283 243
257 316 267 275 191 224 212 198 199 177 266 255 135 129 175 275 245 487 192 202
311 215 191 214
WOR-222B 84
163 168 246 288 215 265 250 258 202 193 208 185 298 258 203 209 215 235 297 448
491 488 562 374 287 329 373 277 633 317 315 236 291 430 422 366 285 463 228 363
308 416 438 398 286 284 280 261 231 235 209 248 227 212 298 394 341 394 290 226
259 283 310 281 181 226 212 197 204 182 251 260 146 123 166 293 265 472 200 199
297 222 189 218
WOR-223A 90
289 315 345 345 245 210 198 290 238 233 192 185 238 252 388 428 426 391 314 298
260 272 213 377 248 220 221 404 328 328 324 258 320 188 292 227 323 302 318 244
222 241 262 227 301 194 221 217 180 267 249 185 261 224 263 176 278 308 816 551
367 295 311 477 363 335 335 176 146 256 207 228 342 197 176 255 198 162 158 114
171 177 151 157 181 150 156 119 168 132
WOR-223B 90
301 312 343 353 252 226 205 280 232 214 240 179 271 277 371 409 431 387 287 279
280 277 204 372 263 218 233 380 329 325 316 317 370 204 309 232 349 311 317 232
215 251 273 260 307 193 216 229 169 268 236 175 260 219 260 174 283 321 829 551
364 293 291 469 356 358 311 178 163 245 214 229 355 206 178 259 199 169 138 129
184 182 152 145 197 150 159 121 165 122

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 1 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 1, 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 University of 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 2 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 to 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.

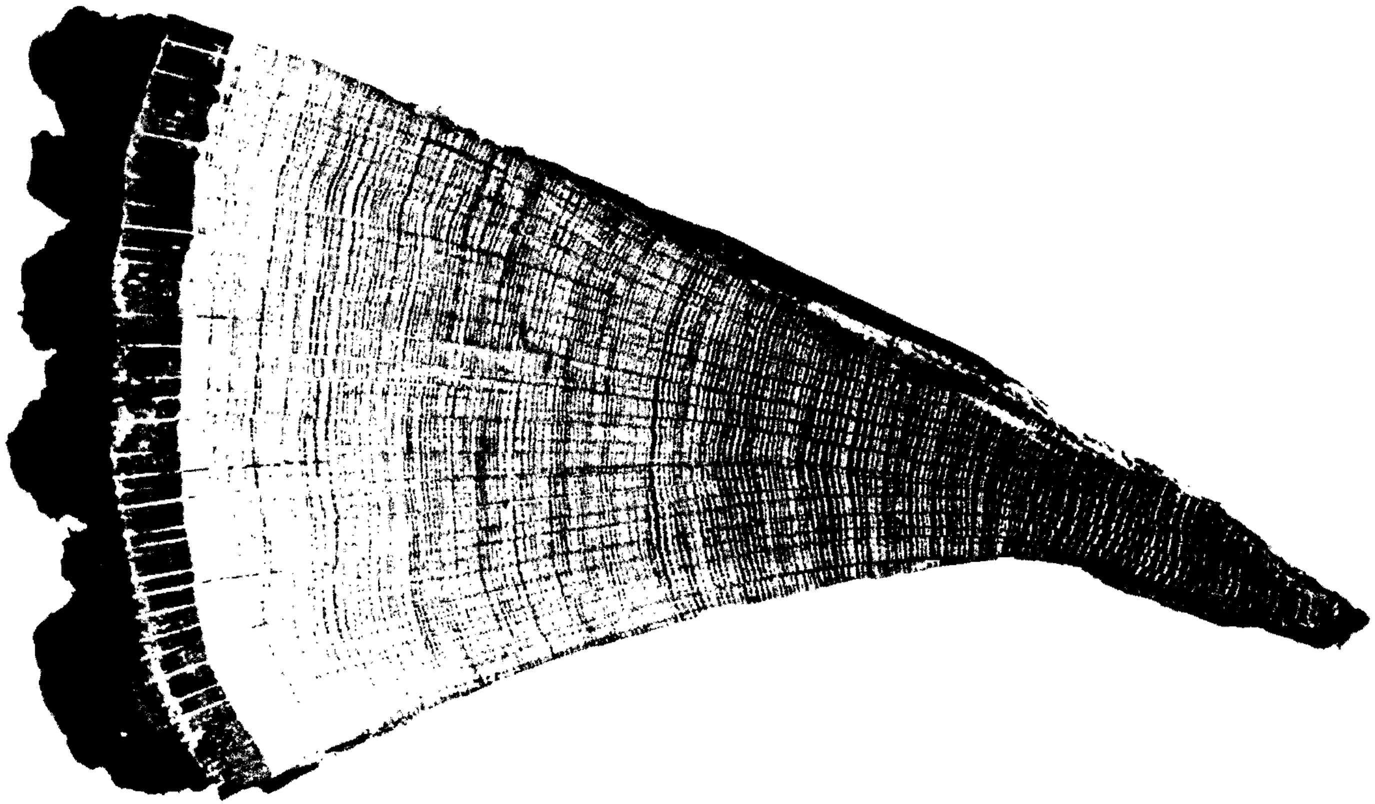


Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can determined by counting back from the outside ring, which grew in 1976.

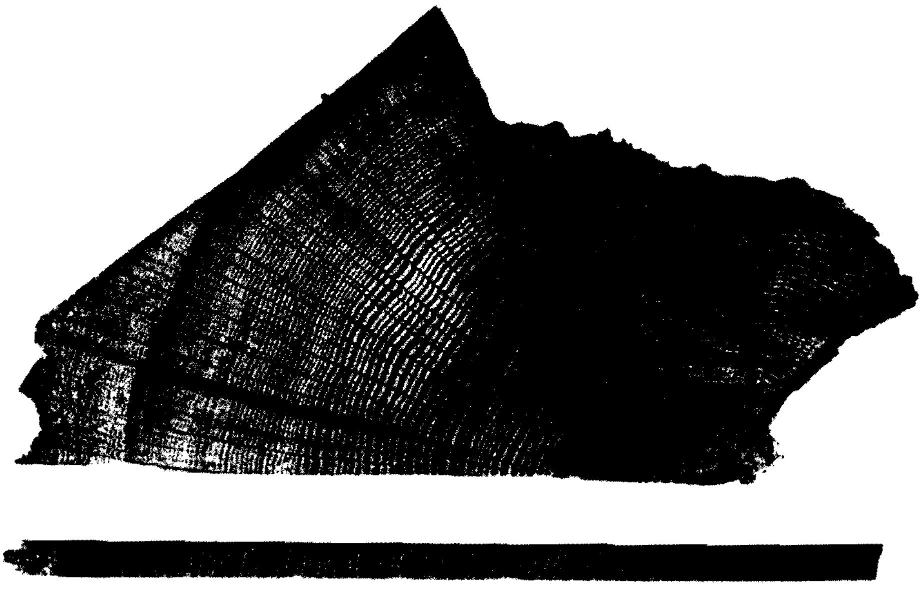


Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the left hand corner, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

Fig. 3 Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measure 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.

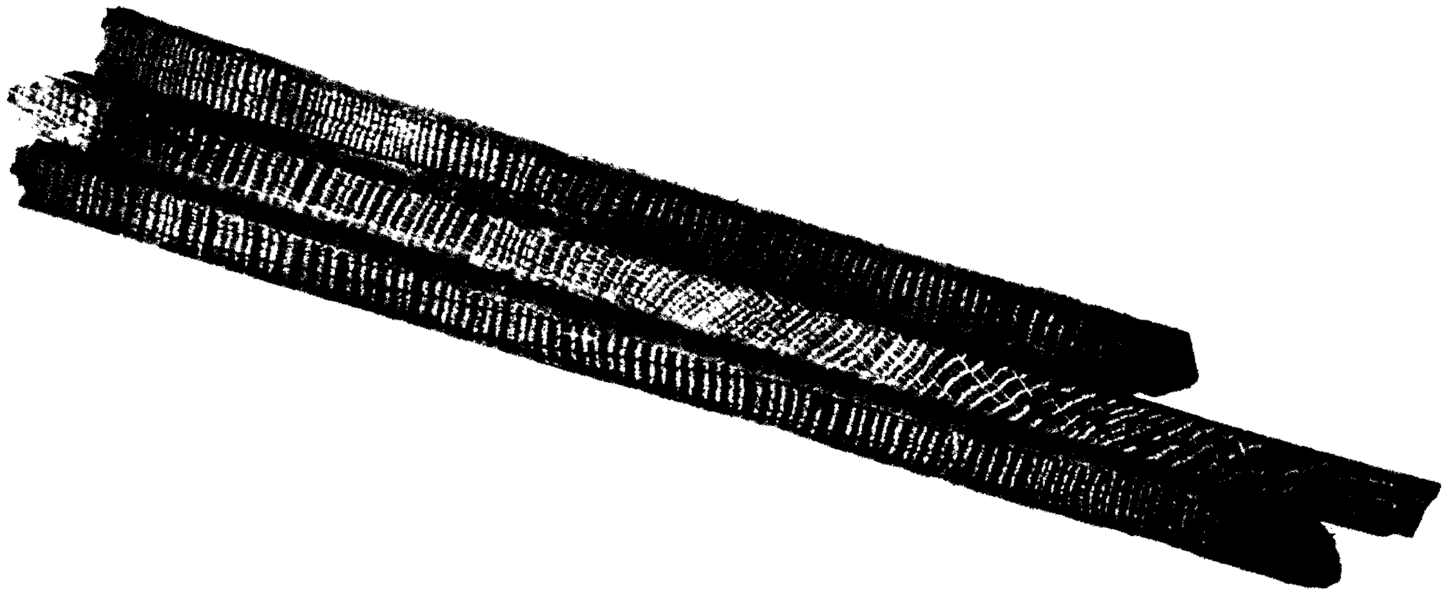


Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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 2; it is about 15cm long and 1cm 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.

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 2. 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 3).

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 4). 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 Fig 5 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 Fig 5. 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 5 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