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Tree-Ring Analysis of Timbers from Gibside Hall, Near Gateshead, Tyne and Wear

A J Arnold, Dr R R Laxton and Dr C D Litton

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Summary

Thirteen samples were obtained from timbers of this building, two of which were discarded before measurement, as they were unsuitable for tree-ring analysis.

No grouping occurred between samples. Attempts to date them individually resulted in sample GSH-A11 being dated to a first-ring date of AD 1419 and a last-ring date of AD 1471. This sample has complete sapwood and so the last measured ring date of AD 1471 is the felling date of the timber represented.

Tree-ring analysis of timbers at Gibside has resulted in the successful dating of only one beam, an inserted lintel, thought to be reused. The poor results are most likely to be due to the short ring-width sequences of a number of the samples and the acknowledged difficulty in dating single samples.

Keywords

Dendrochronology
Standing Building

Author's address
University of Nottingham, University Park, Nottingham, NG7 2RD

Introduction

Gibside Hall is a National Trust property situated just outside Gateshead (Fig 1; NE17615890), set in an early/mid eighteenth-century park. The large house/hall, built between AD 1603-20 for William and Jane Blakiston, overlooks the River Derwent. The building is of three-storeys and five bays with a central, square projecting bay. Contained in this central bay is a three-centred arched door in a Tuscan doorcase with tall plinths. There is a plaque below the entablature inscribed WB 1620 and BS 1805. There are mullioned and transomed six-light windows in the bays to either side and above the door.

When George Bowes took possession of Gibside in AD 1693, rather than building a new house, he made few changes to the existing hall, adding fourteen sash-windows, moving the kitchens, and adding a library. Instead he concentrated on the grounds in which the house is set. Between AD 1729-60 he created impressive landscaped grounds and built a number of garden buildings in a range of styles designed by two of the north-east's leading architects of the time Daniel Garrett and James Paine. These included a Palladian bath house and stables, a Gothic banqueting house, and the Column to Liberty (a monument to demonstrate his loyalty to the Whig party).

On George Bowes' death Gibside passed to his only child, Mary Eleanor, who in an attempt to improve the kitchen offices, added a further wing but again was more interested in developing the grounds. It was Mary Eleanor who built the Orangery in AD 1772-4. Her son, the 10th Earl of Strathmore also tried to improve the kitchens. In addition he removed the top storey, replacing it with a high battlemented parapet and completed the Chapel begun by his grandfather. Gibside then passed to his son John Bowes who did not reside there, preferring to live in France. After John Bowes' death in AD 1885 the estate reverted to the 13th Earl of Strathmore who lived mainly in Scotland and Hertfordshire. (Gibside Guide Book 1999)

During the early twentieth century the house fell into disrepair, culminating in the removal of the roof tiles in the 1950s. The building is now a roofless shell in poor condition. Consolidation of the hall, partly funded by English Heritage, which is currently taking place, included the erection of scaffolding, which allowed access to surviving floor timbers, and roof joists for sampling.

Sampling and analysis by tree-ring dating of Gibside Hall was commissioned and funded by English Heritage. It was requested to provide a precise date for its construction and better understand its later development. The building is a Scheduled Ancient Monument, in addition to being a grade II* listed building, and on the English Heritage Buildings at Risk Register (Priority A).

The Laboratory would like to thank Harry Beamish of the National Trust and Richard Annis of University of Durham Archaeological Services for arranging access and on-site advice, and for providing drawings on which the location of samples could be marked (Figs 2 and 3).

Sampling

The English Heritage brief was to sample a number of embedded floor timbers and roof timbers from the primary AD 1603-20 construction and also a number of inserted timbers, which were thought to relate to the mid eighteenth-century enlargement of the building and reused timbers of unknown date and origin. Sampling was greatly hindered by the poor state of the site, many areas being unsafe to enter. A number of timbers in which interest was shown were embedded in the surviving fabric of the building making sampling difficult and time consuming. Additionally, the majority of the timbers were in a very poor state being exposed to the elements for a number of decades. For these reasons each phase could not be sampled as extensively as would normally be the case. After in-depth discussion with Harry Beamish and Richard Annis twelve core samples were taken from surviving oak timbers. Additionally a thirteenth sample in the form of a slice was taken from an ex-situ timber. Each sample was given the code GSH-A (for Gibside Hall) and numbered 01-13. The positions of all samples were noted at the time of sampling and have been marked on Figures 2 and 3. Further details relating to the samples are recorded in Table 1.

Analysis and Results

After initial sanding two samples were rejected as unsuitable for analysis. GSH-A01 was too broken to be measured and GSH-A03 had too few rings for secure dating. The remaining samples were prepared by further sanding and polishing and their growth-ring widths measured; the data of these measurements are given at the end of the report. The growth-ring widths of the samples were compared with each other by the Litton/Zainodin grouping procedure (see appendix). No grouping occurred between the samples and attempts were made to date the samples individually.

This resulted in sample GSH-A11 being matched at a first-ring date of AD 1419 and a last-ring date of AD 1471. This sample has complete sapwood and so the last-ring date is also the felling date for the timber represented. The evidence for this dating is given by the *t*-values in Table 2.

The remaining samples could not be matched and are undated.

Discussion

Following analysis by tree-ring dating it has only been possible to obtain a date for one of the timbers. This is an inserted lintel, thought to be a reused timber, from a tree felled in AD 1471. Although this is a single sample of only 53 rings, it matches at this date consistently and with high *t*-values, especially against local reference chronologies.

The results have been disappointing and this is most likely due to the short ring width sequences of many of the samples. Additionally with samples being taken from a number of different phases and including reused and inserted timbers the likelihood of in-site grouping occurring is lessened. The chances of successfully dating a site sequence is far greater than trying to individually date samples. As mentioned in the introduction sampling was hindered by the unsafe condition of much of the site. In the future, as further areas are made safe and access to other timbers improved it might be helpful to return and sample these.

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Table 1: Details of tree-ring samples from Gibside Hall, near Gateshead, Tyne and Wear

Sample number	Sample location	Total rings	Sapwood rings*	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
GSH-A01	East beam supporting first-floor floor joists	NM	--	----	----	----
GSH-A02	West beam supporting first-floor joists	67	--	----	----	----
GSH-A03	South window lintel, ground floor	NM	--	----	----	----
GSH-A04	East window lintel, ground floor	60	23C	----	----	----
GSH-A05	Ceiling beam on corbels, F5	94	--	---	----	----
GSH-A06	Ceiling beam (partner to GSH-A05 (not in situ)	62 (+12NM)	01 (+12NM)	----	----	----
GSH-A07	Lintel over cellar (cut through), between G5 and G6	44	19c(+1-2 lost)	----	----	----
GSH-A08	Joist under small lobby, G3	61	01	----	----	----
GSH-A09	Stair	56	10	----	----	----
GSH-A10	Stair	45	--	----	----	----
GSH-A11	Inserted lintel	53	15C	1419		1471
GSH-A12	South lintel above first-floor window, G38 (not in situ)	70 (+10NM)	01 (+10NM)	----	----	----
GSH-A13	Ceiling beam to first-floor bathroom	45	16C	----	----	----

*h/s = the heartwood/sapwood boundary is the last ring on the sample
NM = not measured
C = complete sapwood retained on sample, last measured ring is the felling date
c(+x-y lost) = complete sapwood on timber, some lost in sampling (estimated number of sapwood rings lost in brackets)

Table 2: Results of the cross-matching of sample GSH-A11 and relevant reference chronologies when the first-ring date is AD 1419 and the last-ring date is AD 1471

Reference chronology	*t*-value	Span of chronology	Reference
England	4.8	AD 404-1981	Baillie and Pilcher 1982 unpubl
Sffb01m	4.5	AD 1359-1591	Morgan 1977
East Midlands	4.3	AD 882-1981	Laxton and Litton 1988
Trinity House (rigging loft), Newcastle upon Tyne, Tyne and Wear	7.8	AD 1397-1524	Howard *et al* 2002
Hallgarth Manor Cottages, Hallgarth, Pittington, Co Durham	6.8	AD 1336-1624	Howard *et al* 2001
Witton Hall (house), Witton Gilbert, Tyne and Wear	6.3	AD 1395-1475	Howard *et al* 1996
Seaton Holme, Easington, Durham	6.1	AD 1375-1489	Howard *et al* 1988 unpubl
Horbury Hall, Horbury, Wakefield	5.9	AD 1368-1473	Howard *et al* 1992
Nether Levens Hall, Kendal, Cumbria	5.1	AD 1395-1541	Howard *et al* 1991
Middridge Grange, Shildon Road, Heighington, Durham	5.1	AD 1395-1559	Arnold *et al* 2001
Oakwell House, Birstall, W Yorks	4.8	AD 1380-1583	Howard *et al* 1991

Figure 1: Map showing the location of Gibside Hall (based upon the Ordnance Survey map

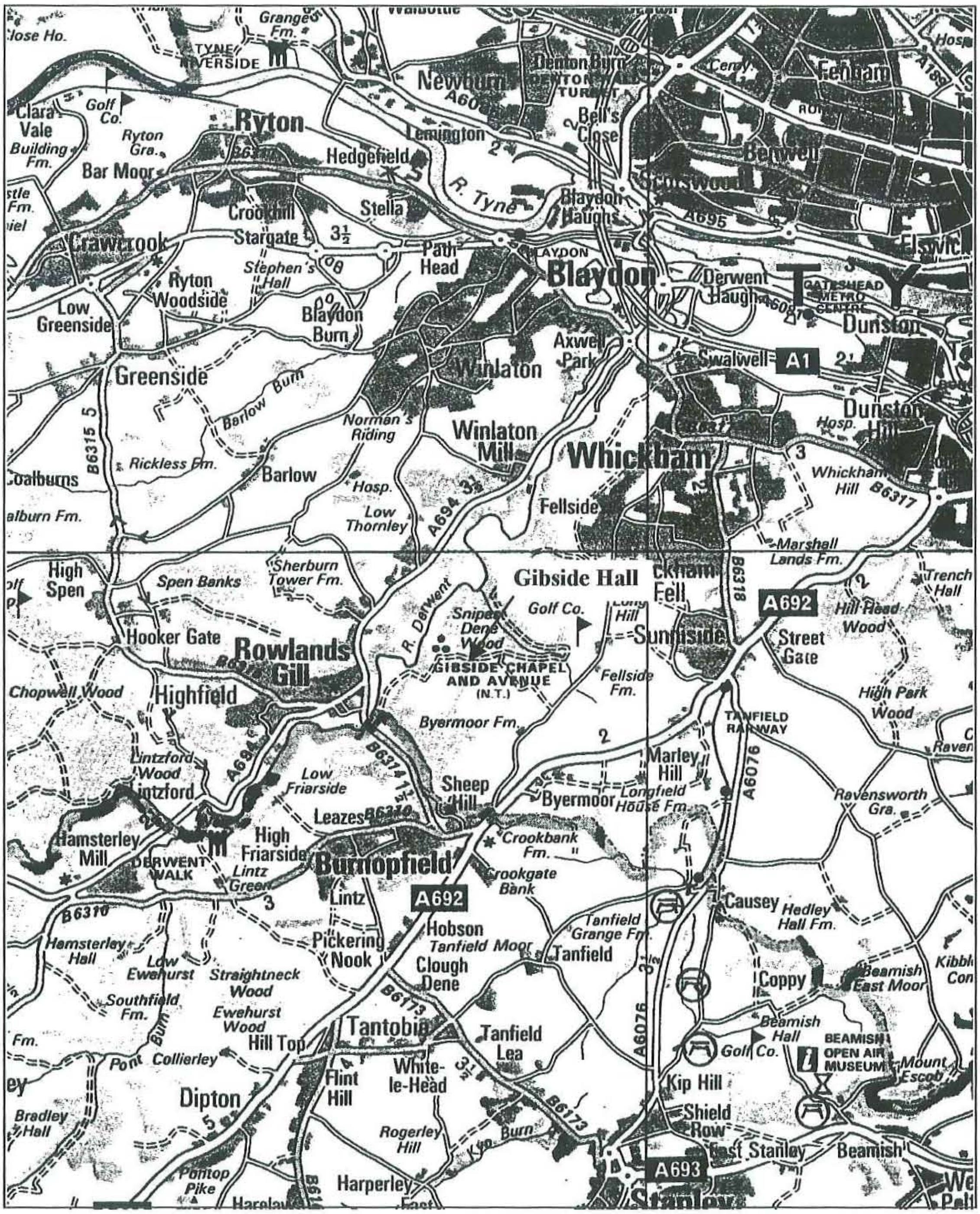
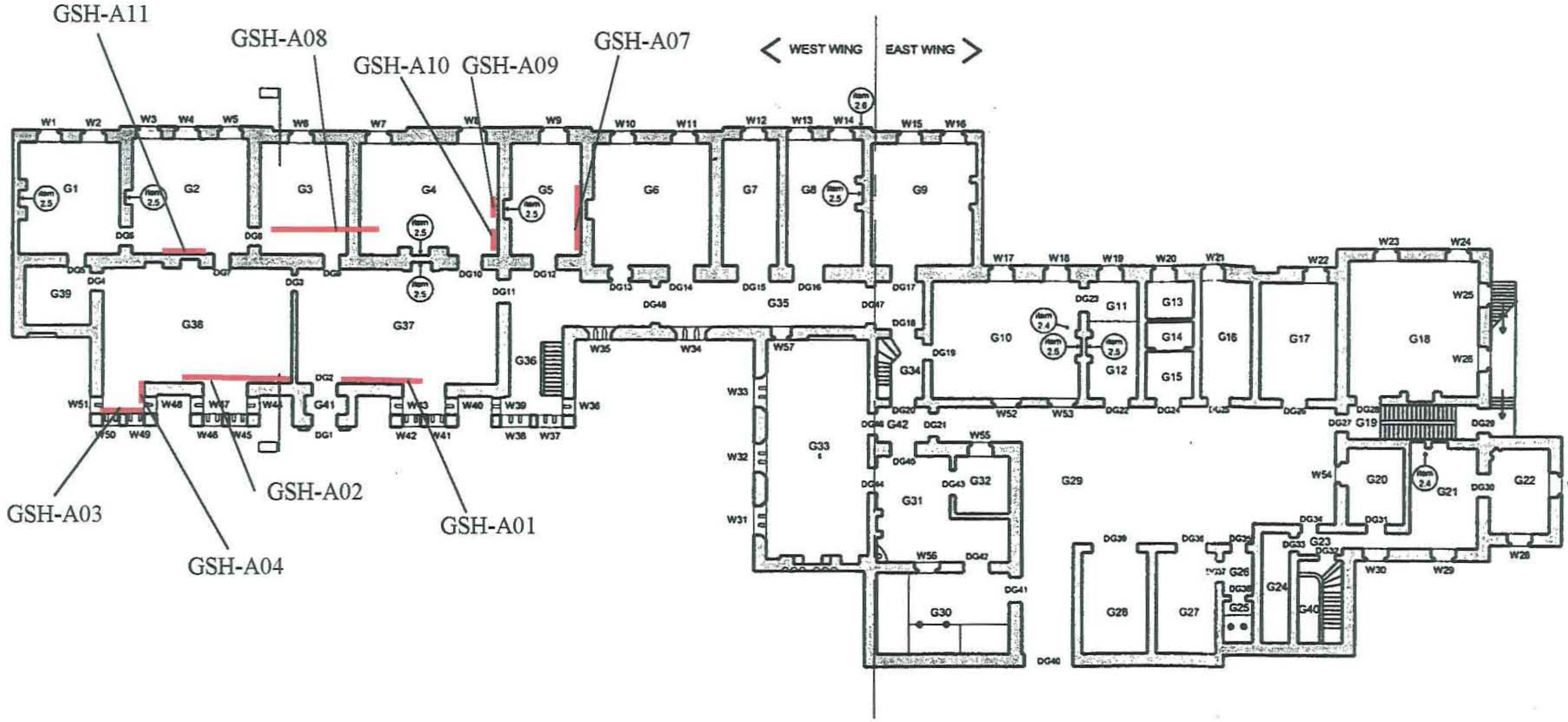
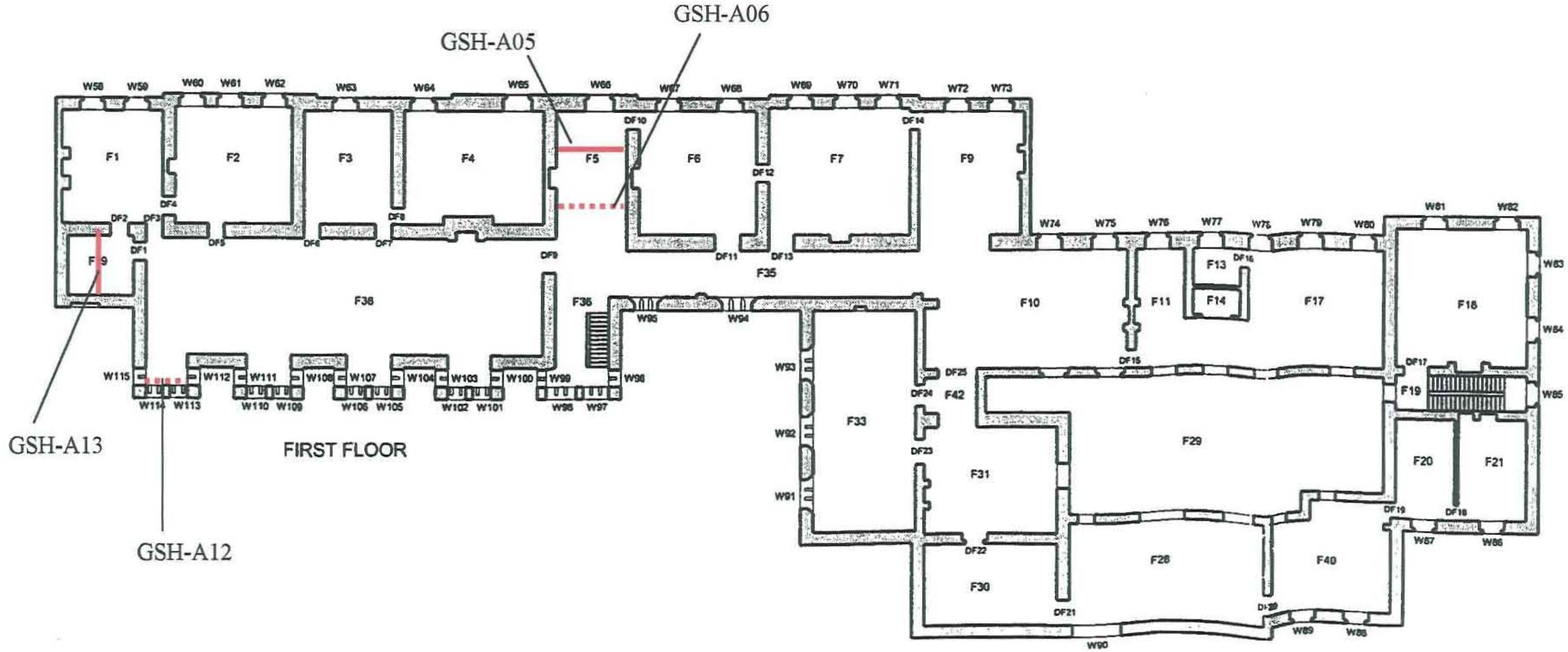


Figure 2: Gibside Hall - Ground floor plan, showing the location of samples GSH-A01-A04, GSH-A07-A11 (after Waring & Netts Chartered Architects Construction Consultants)



Sampled timber – in situ

Figure 3: Gibside Hall - First-floor plan, showing the location of samples GSH-A05-A06 and GSH-A12-A13 (after Waring & Netts Chartered Architects Construction Consultants)



Sampled timber – in situ

Sampled timber – not in situ

Data of measured samples – measurements in 0.01mm units

GSH-A02A 67
280 239 280 306 180 231 292 454 303 245 344 270 230 305 113 176 219 318 424 330
241 243 334 231 272 264 319 247 175 141 182 188 251 339 302 231 175 140 103 156
143 182 205 182 141 135 121 113 145 163 132 145 165 138 115 73 80 119 131 220
189 139 121 118 68 59 55
GSH-A02B 67
270 236 284 329 179 240 282 457 302 249 345 269 229 308 104 173 221 323 429 327
238 254 329 232 279 263 320 273 182 133 173 199 249 338 305 233 170 132 108 160
147 177 199 168 154 124 126 111 161 167 130 142 159 148 108 68 93 108 136 218
195 141 121 117 66 65 56
GSH-A04A 60
244 431 613 493 331 571 535 695 455 551 494 525 416 357 261 434 311 183 256 314
326 239 205 189 233 208 256 235 236 215 183 107 157 127 117 141 159 153 64 125
104 126 98 111 99 75 84 84 68 100 82 92 59 78 79 63 67 79 63 74
GSH-A04B 60
244 442 613 492 330 564 543 686 449 553 489 527 421 358 259 413 280 180 286 310
326 240 205 182 236 205 264 246 235 217 181 107 157 129 111 147 157 153 62 107
144 127 96 109 103 75 85 83 69 96 73 101 49 64 79 62 64 75 62 66
GSH-A05A 94
484 343 483 377 337 256 260 196 168 190 221 202 263 223 262 272 233 252 229 182
173 209 167 149 174 150 172 170 132 115 133 148 160 183 178 194 140 128 120 112
117 119 98 94 91 82 128 129 141 84 113 143 131 169 144 107 92 120 86 89
119 124 155 119 132 130 126 121 118 98 91 108 97 97 68 82 84 143 87 66
73 61 70 70 60 66 40 55 48 45 38 52 40 59
GSH-A05B 94
443 355 493 386 370 248 265 201 175 180 230 209 264 227 264 278 230 275 217 179
166 212 176 140 171 174 169 170 133 124 131 149 170 183 191 192 142 136 135 129
129 96 103 95 93 99 106 124 121 105 122 125 133 177 139 116 93 129 85 93
110 133 158 119 120 124 124 109 124 119 91 123 95 82 85 93 82 129 95 70
73 63 67 78 60 63 43 54 46 46 42 48 44 54
GSH-A06A 62
274 358 278 304 321 371 282 329 299 351 293 343 294 328 331 238 266 220 205 206
249 160 188 289 304 292 217 263 211 238 250 174 194 162 217 187 290 258 226 195
165 137 186 223 213 249 232 220 260 194 233 200 192 182 186 155 244 258 247 204
191 108
GSH-A06B 62
253 352 275 307 324 359 285 327 310 353 302 352 302 330 324 226 273 218 202 211
243 165 208 284 307 287 214 262 216 231 243 166 201 166 217 190 289 250 222 196
156 142 186 228 215 256 234 218 250 200 230 201 193 177 188 153 248 257 249 218
188 119
GSH-A07A 35
347 445 486 465 432 459 479 445 328 301 326 276 243 239 191 212 186 153 162 230
202 246 252 172 217 225 223 216 195 233 233 197 165 214 211
GSH-A07B 38
405 432 215 136 140 125 139 129 93 116 107 81 95 126 114 161 176 132 169 184
173 149 203 208 240 168 160 174 206 211 201 230 193 189 197 179 143 118
GSH-A08A 61
260 258 214 239 280 226 227 192 163 150 106 122 104 130 120 162 144 144 145 157
166 223 203 222 177 177 142 127 148 161 197 143 238 217 193 160 175 191 166 139
147 150 156 152 114 139 174 142 195 117 90 105 141 155 166 108 162 138 158 172
137
GSH-A08B 61
254 255 219 235 302 197 218 193 183 158 109 131 102 131 129 161 156 132 154 161
179 215 203 221 183 175 139 125 151 155 189 137 232 219 198 157 154 185 170 139
151 148 153 153 113 140 166 140 191 119 94 106 136 156 161 106 166 136 152 181
138

GSH-A09A 56
70 85 99 157 128 156 203 337 361 225 300 262 201 203 322 280 250 335 379 346
226 274 371 216 407 263 268 305 479 314 209 169 180 181 255 160 213 212 259 203
129 125 190 177 147 127 110 174 228 214 152 71 86 66 53 94
GSH-A09B 56
68 89 100 156 138 156 205 334 313 253 290 264 197 204 318 277 246 324 379 342
229 286 375 214 410 249 247 292 484 314 206 168 174 185 253 158 214 214 259 201
132 123 187 177 149 123 127 182 215 227 140 75 78 70 64 101
GSH-A10A 45
182 185 297 277 180 179 179 211 167 258 227 278 225 233 162 285 227 198 241 303
355 144 62 50 56 38 53 45 47 46 67 66 104 168 151 166 209 347 448 357
343 329 295 294 471
GSH-A10B 45
160 203 300 258 166 192 178 223 157 255 229 253 225 245 179 265 218 174 242 301
365 142 54 48 58 44 59 49 41 48 68 72 106 158 147 155 219 341 423 326
348 370 265 350 466
GSH-A11A 53
286 534 536 408 458 416 487 319 375 488 613 387 365 501 380 502 490 446 363 405
342 402 448 423 419 456 466 318 518 386 328 367 339 390 284 364 244 314 339 223
232 227 235 238 223 245 205 245 252 262 212 263 167
GSH-A11B 53
278 541 544 412 445 416 484 317 390 481 605 394 372 496 377 503 494 440 366 401
337 396 459 425 422 450 468 317 509 394 334 362 328 396 270 326 238 313 313 211
217 226 217 236 241 190 241 232 241 253 202 274 171
GSH-A12A 70
47 101 145 116 214 142 326 324 239 265 269 341 218 283 174 243 182 216 189 212
176 174 199 230 253 232 225 254 219 212 232 243 206 259 350 369 302 357 314 246
320 315 327 270 300 286 233 380 267 333 222 298 167 249 263 255 231 272 251 166
284 320 410 381 433 456 344 390 266 203
GSH-A12B 70
62 102 146 106 225 145 330 320 240 262 390 341 219 280 174 240 186 215 187 215
170 188 198 229 264 220 248 265 214 206 239 240 181 265 343 352 303 364 301 246
305 311 321 260 267 259 231 350 237 311 215 304 188 239 237 234 223 297 253 176
247 318 399 388 429 456 344 396 265 202
GSH-A13A 44
361 347 325 439 543 445 356 368 293 297 268 287 243 275 261 279 355 227 241 233
236 245 134 124 114 152 247 159 155 149 100 125 125 139 160 128 137 115 110 148
108 95 89 107
GSH-A13B 45
102 325 387 338 426 547 456 371 381 295 308 290 301 248 270 243 256 339 223 231
246 269 257 137 121 115 147 242 164 148 158 98 125 116 120 177 139 159 120 111
147 111 95 88 92

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 Buildings*' (Laxton and Litton 1988b) and, for example, in *Tree-Ring Dating and Archaeology* (Baillie 1982) or *A Slice Through Time* (Baillie 1995). 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 Figure1 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, 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 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. 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 we inspect the timbers in a building 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. Similarly the core has just over 100 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.

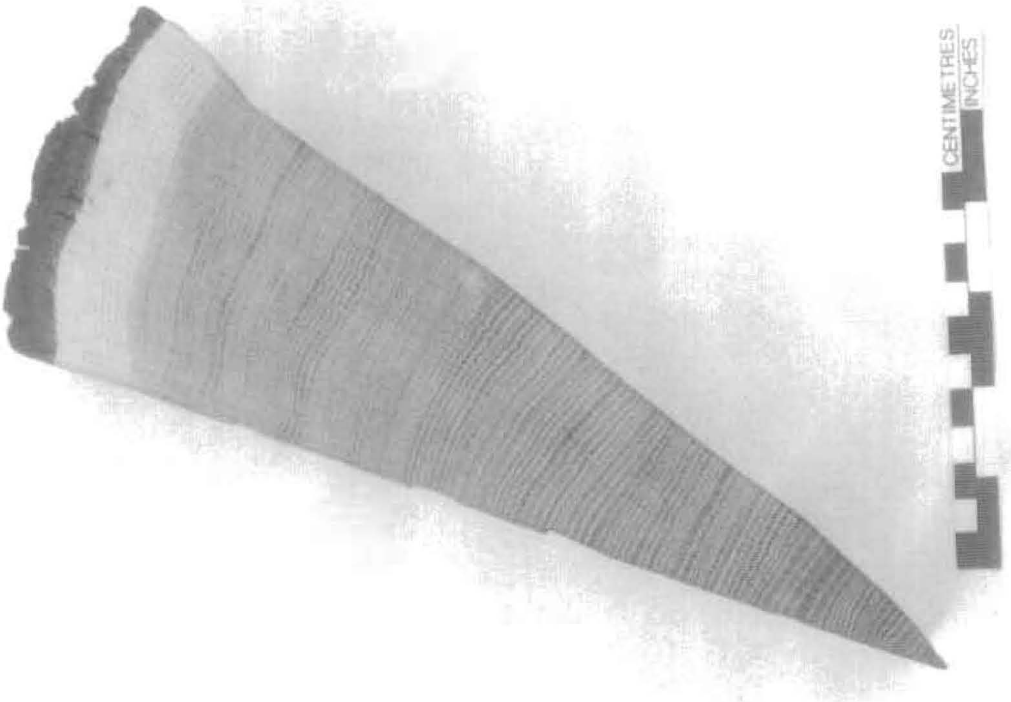


Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

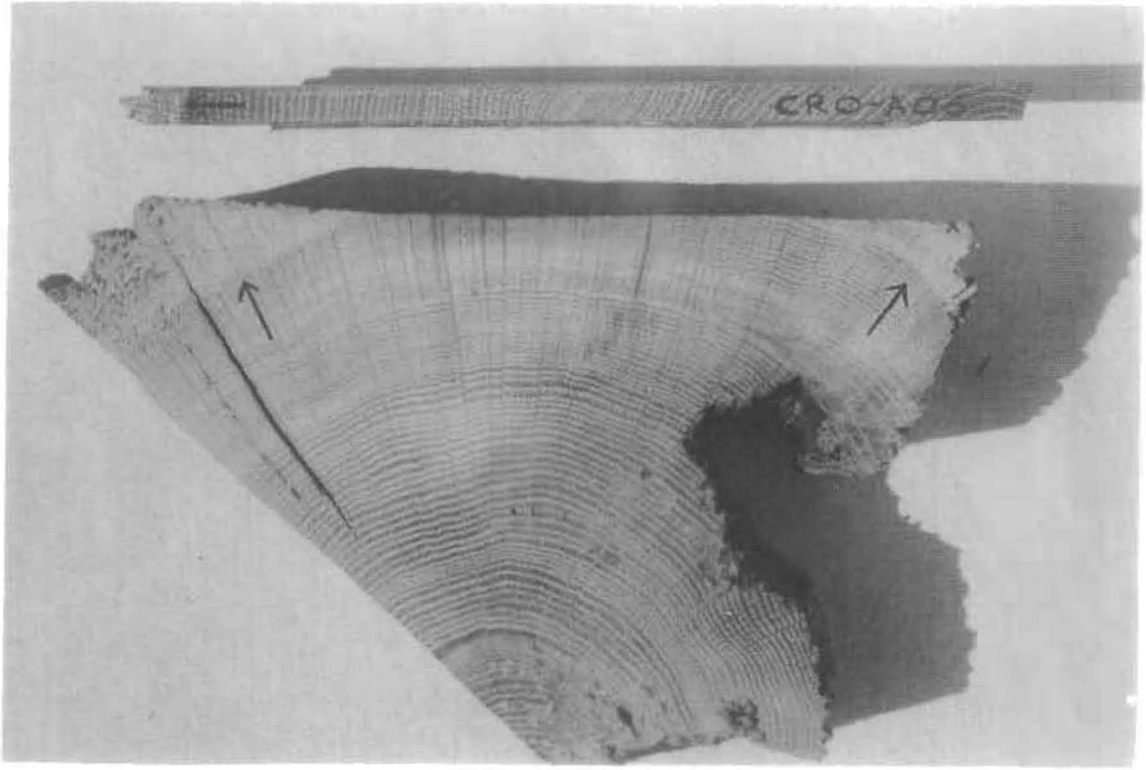


Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

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 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.

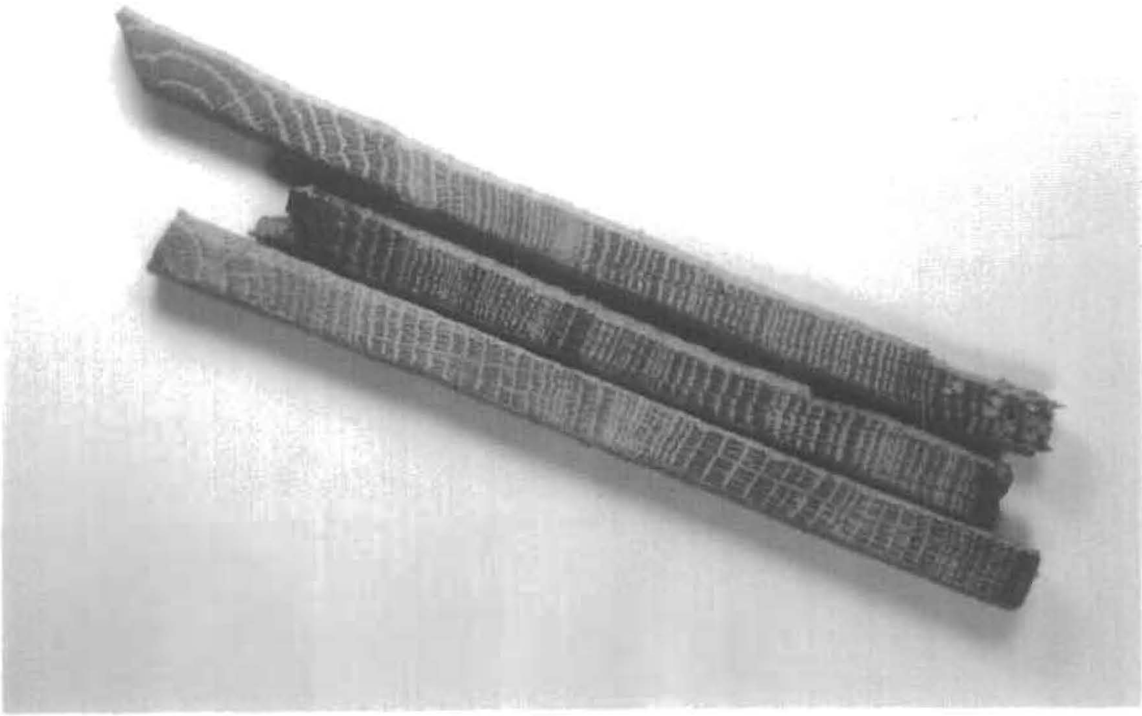


Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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 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 inspecton 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 is insured with the CBA.

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 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton *et al* 1988a,b; 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. C08 matches C45 best when it is at a position starting 20 rings after the first ring of 45. 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 between these two whatever the position of one sequence relative to the other.

   It is standard practice in our Laboratory first to cross-match as many as possible of the 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 from 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. 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.

average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

This 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'. This was developed and tested in the Laboratory and has been published (Litton and Zainodin 1991; Laxton *et al* 1988a). To illustrate the difference between the two approaches with the above example, consider sequences C08 and C05. They are the most similar pair with a t-value of 10.4. Therefore, these two are first averaged with the first ring of C05 at +17 rings relative to C08 (the offset at which they match each other). This average sequence is then used in place of the individual sequences C08 and C05. The cross-matching continues in this way gradually building up averages at each stage eventually to form the site sequence.

4. ***Estimating the Felling Date.*** If the bark is present on a sample, then the date of its last ring is the date of the felling of its tree. Actually it could be the year after if it had been felled in the first three months 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, they can be seen in two upper corners of the rafter and at the outer end of the core in Figure 2. 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 for 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. Thus in these circumstances the date of the present last ring is at least close to the date of the original last ring on the tree, and so to the date of felling.

   Various estimates have been made for the average number of sapwood rings in a mature oak. One estimate is 30 rings, based on data from living oaks. So, in the case of the core in Figure 2 where 9 sapwood rings remain, this would give an estimate for the felling date of 21 (= 30 - 9) years later than of the date of the last ring on the core. Actually, it is better in these situations to give an estimated range for the felling date. Another estimate is that in 95% of mature oaks there are between 15 and 50 sapwood rings. So in this example this would mean that the felling took place between 6 (= 15 - 9) and 41 (= 50 - 9) years after the date of the last ring on the core and is expected to be right in at least 95% of the cases (Hughes *et al* 1981; see also Hillam *et al* 1987).

   Data from the Laboratory has shown that when sequences are considered together in groups, rather than separately, the estimates for the number of sapwood can be put at between 15 and 40 rings in 95% of the cases with the expected number being 25 rings. We would use these estimates, for example, in calculating the range for the common felling date of the four sequences from Lincoln Cathedral using the average position of the heartwood/sapwood boundary (Fig 5). These new estimates are now used by us in all our publications except for timbers from Kent and Nottinghamshire where 25 and between 15 to 35 sapwood rings, respectively, is used instead (Pearson 1995).

   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 2 was taken still had complete sapwood. Sapwood rings were only lost in coring, because of their softness. By measuring in the timber the depth of sapwood lost, say 2 cm., a reasonable estimate can be made of the number of sapwood rings missing from the core, 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 40 years later we would have estimated without this observation.

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

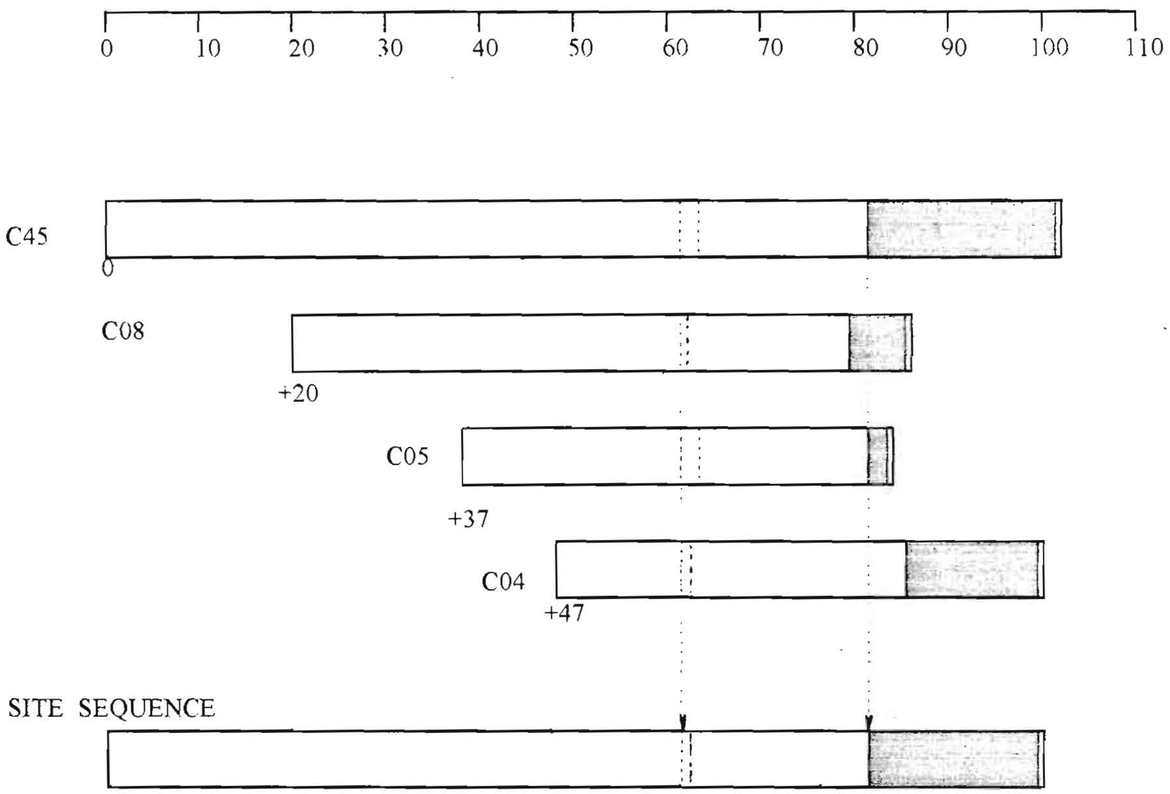


Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.
The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set 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.

Even if all the sapwood rings are missing on all the timbers sampled, an estimate of the felling date is still possible in certain cases. For provided the original last heartwood ring of the tree, called the heartwood/sapwood boundary (H/S), is still on some of the samples, an estimate for the felling date of the group of trees can be obtained by adding on the full 25 years, or 15 to 40 for the range of felling dates.

If none of the timbers have their heartwood/sapwood boundaries, then only a *post quem* date for felling is possible.

5. ***Estimating the Date of Construction.*** There is a considerable body of evidence in the data collected by the Laboratory that the oak timbers used in vernacular buildings, at least, were used 'green' (see also Rackham (1976)). Hence provided the samples are taken *in situ,* and several dated with the same estimated common felling date, then this felling date will give an estimated date for the construction of the building, or for the phase of construction. If for some reason or other we are rather restricted in what samples we can take, then an estimated common felling date may not be such a precise estimate of the date of construction. More sampling may be needed 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 Fig 6 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 Fig 6. 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 1988b, 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* 1988a). 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 (1988b) and is illustrated in the graphs in Fig 7. Here ring-widths are plotted vertically, one for each year of growth. In the upper sequence (a), the generally large early growth after 1810 is very apparent as is the smaller generally later growth from about 1900 onwards. A similar difference can be observed in the lower sequence 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, hopefully corresponding to good and poor growing seasons, respectively. The two corresponding sequences of Baillie-Pilcher indices are plotted in (b) where the differences in the early and late growths have been removed and only the rapidly changing peaks and troughs remain only associated with the common climatic signal and so make cross-matching easier.

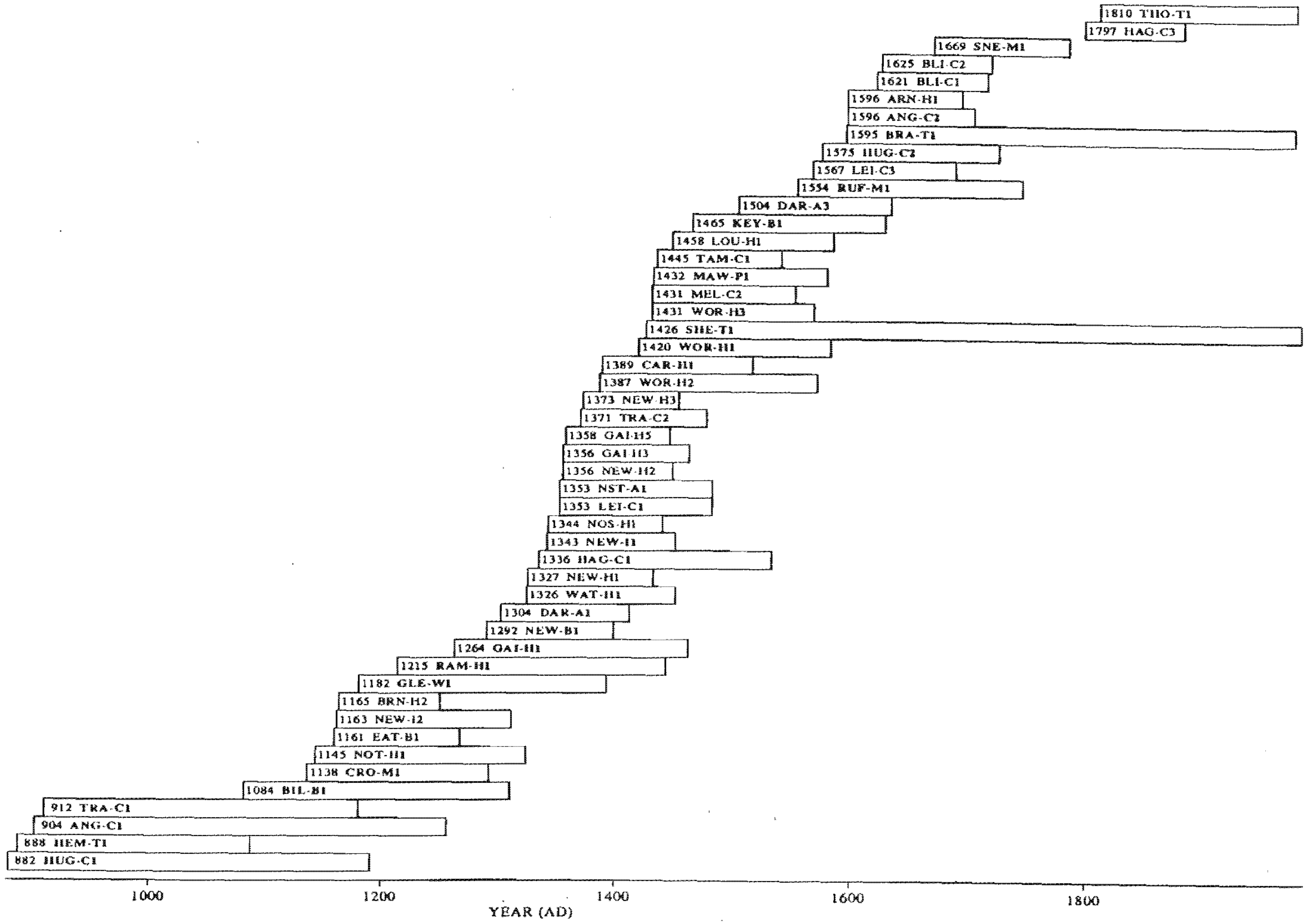


Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

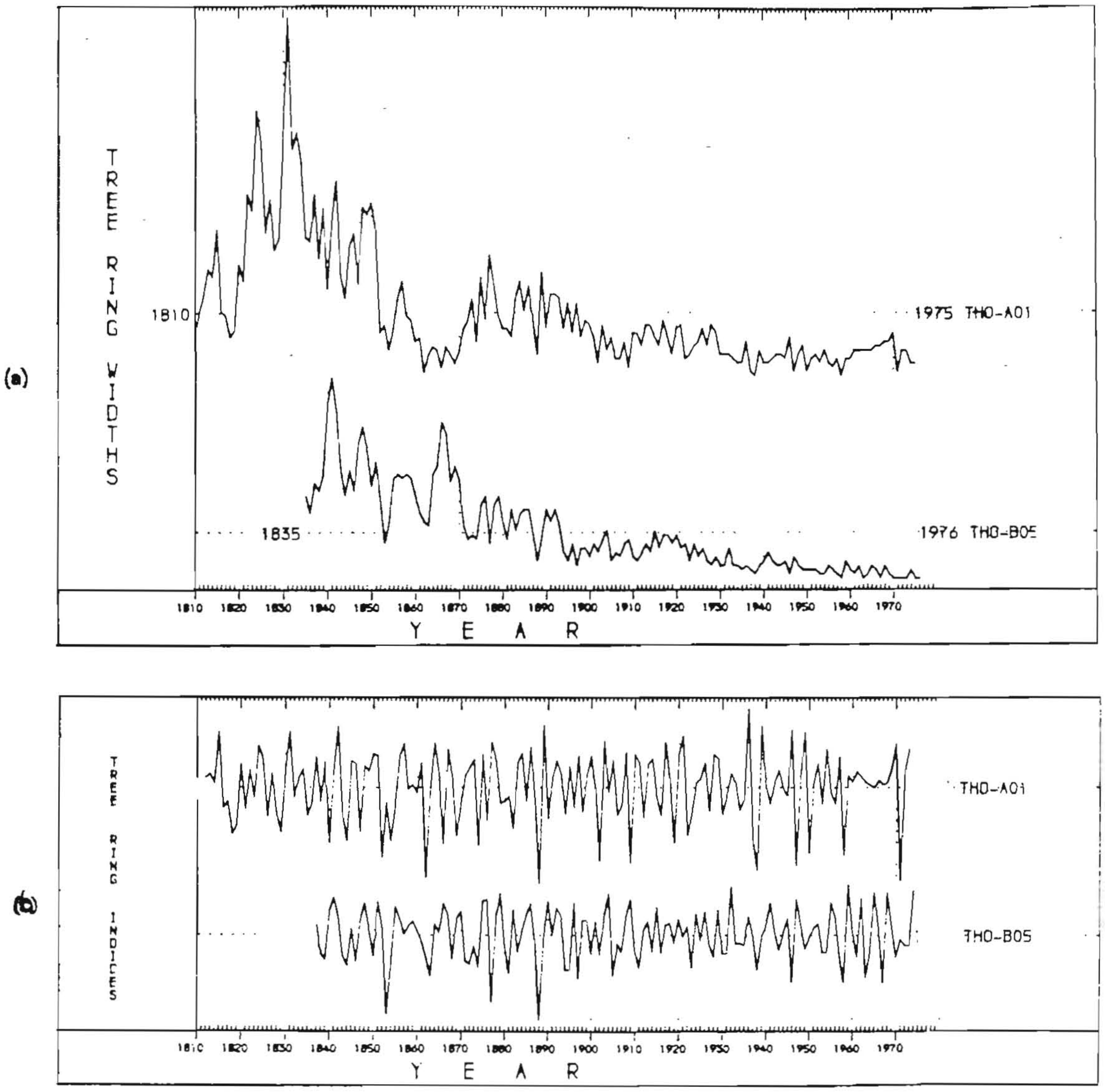


Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree are wider than the later ones of the older tree in both sequences.

(b) The *Baillie-Pilcher indices* of the above widths. The growth-trends have been removed completely.

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