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With an architectural description by Richard Bond

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Summary

Thirty-four samples were obtained from the roofs of six different areas of Southall Manor. The analysis of these produced three site chronologies, STHASQ01, SQ02, and SQ03, consisting of 18, four and three samples, of length 86, 81 and 73 rings, respectively. None of these site chronologies, or the remaining ungrouped single samples, could be dated.

However, while it has not been possible to date any of the elements absolutely, it is possible to demonstrate that the hall, and the north and south cross-wings of the Manor, the stair tower, and the North Range, or 'kitchen wing', all belong to one programme of construction. The timber used in these elements was all cut in a single felling.

Unfortunately, the date and relationship of the 'Link Range' with these elements cannot be demonstrated by tree-ring analysis.

Keywords

Dendrochronology
Standing Building

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Introduction

General description

Southall Manor House is situated to the north of Southall Green, three-quarters of a mile north-west of Southall parish church (TQ 124 784; Figs 1 and 2). The house is timber-framed with tiled roofs and probably dates from the late-sixteenth century. The late-sixteenth century building appears to have consisted of two separate elements: the main house, aligned north - south, comprising a two-storey hall with flanking cross-wings, a rear staircase wing, and gabled entrance porch; and a two-storey 'kitchen-lodgings' range (referred to as the North Range in this report) on its north side, aligned east - west. The carved wooden overmantle above the hall fireplace bears the arms of the Awsiter family and the initials R A (there is a brass to Francis Awsiter, died AD 1624-5, in the Parish Church). The date AD 1587 is carved inside the pediment of one of the windows of the west front of the main house.

Main house (see general plan, Fig 3)

The roof of the main house comprises three separate single-pitched roof structures, the central hall range, the north cross-wing, and the south cross-wing. All three roofs are of the same basic constructional form as the roof of the North Range, ie staggered tenoned purlins, common rafters (with pegged mortice and tenoned joints between them and the purlins), and straight collars, with raking queen struts linking the collars and tie beams. Drawings of parts of the roof are shown in Figure 4. The roofs remain largely intact; however, there is some evidence of later repairs. For example, at the front, west, end of the roof of the north cross-wing the rafters along the north roof slope are not morticed into the purlin, but simply rest upon its back. The purlin is not the original purlin (the empty mortice for the original purlin can still be seen) but a replacement timber that was inserted when the present pair of long rafter braces were inserted, probably in the eighteenth or nineteenth century. In the central hall range, the longitudinal second floor beam seen running along the centre of the attic floor, has an iron bolt running up through it and it has extra timbers and wedges attached to it as a means of strengthening and re-tensioning the beam.

'Brentwood marking', so called after the town in Essex where its use was first recorded, was used in the roofs of the central hall range and north cross-wing of the main house. The rafters are numbered in pairs rather than individually. The numbers are located on the feet of the upper rafters and tops of the lower rafters, and the upper and lower sides of the purlins. In the south cross-wing roof a more conventional system was adopted whereby the rafters are numbered individually.

Above the collar of the east (rear) gable truss of the north cross-wing are still to be seen fragments of the original lath and plaster infilling of the truss. The infilling was applied to both faces of the gable truss, ie there was a skin of lath and plaster on both the inside and outside faces of the truss. The fact that the gable truss was originally closed on both sides all the way up to the apex suggests that when the north cross-wing was first completed the 'Link Range' had yet to be built. However, there may not have been a long time period separating the construction of these two elements. By looking at how the various parts of the house relate to one another structurally, it is clear that the house was constructed not in a single operation, but in stages, with the different elements of the building – the south cross-wing, hall range, north cross-wing, 'Link Range', North Range, staircase bay and entrance porch – being added one at a time, and with some elements depending for at least some of their support on the adjoining parts of the building. Inside the roof space over the main house, for instance, it can be seen that the tie beam at the north end of the hall range abuts and rests upon the edge of the south wall plate of the north cross-wing, meaning that the hall range can only have been constructed once the cross-wing was already built. At the south end of the hall range, by contrast, there is no roof truss, and the hall roof terminates in a common rafter couple that simply abuts the north (internal) wall plate of the south cross-wing. This would suggest that the hall range and south cross-wing were constructed in a single operation, or that, like the north cross-wing, the south cross-wing was built first and the hall range was constructed with its frame partly resting against it. A drawing of the building as it might have appeared at the time of completion *c* AD 1587 is shown in Figure 5.

North Range

The North Range is a two-storey structure aligned on an approximately east-west axis. It is joined to the main house by a narrow range (referred to as the 'Link Range' in this report), which is aligned on a north - south axis running parallel with the central hall range of the main house. The easternmost three bays of the North Range is a timber-framed structure (although largely rebuilt in brick) and probably represents a late-sixteenth century 'kitchen-lodgings' range serving the main house. The North Range was extended westwards in the late-eighteenth century (and perhaps further extended in the nineteenth century). The wing was truncated (leaving just the easternmost bay of the extended section) when the road in front of the house was widened in the early-twentieth century.

The North Range owes much of its present appearance to a restoration of the house carried out in the nineteenth or early-twentieth century. The north elevation has been rebuilt in 'mock-Tudor' style with decorative timber-framing; to what extent (if any) the present elevation reflects the original appearance of the building is unknown. The existing arrangement of twin gables over the west and central bays of the original range wing is certainly inaccurate: the rafters of the late sixteenth-century roof structure extend continuously along both sides of the roof, and within the gables the backs of the rafters are nailed, showing that they were originally clad with tiles. The brick bay window at the east end of the north wall is clearly a late-nineteenth century addition, but may be a replacement for a seventeenth or eighteenth century bay window.

The large gable chimney at the east end of the wing was reconstructed in brick probably in the early- or mid-twentieth century but probably dates from late-sixteenth century. The chimney probably served a kitchen occupying the rear bay of the North Range. The kitchen fireplace was remodelled in the eighteenth or nineteenth centuries and reduced in depth. The present fireplace is framed by a pair of moulded pilasters (the pilasters are painted but appear to be of timber), which may date from the original construction of the house. The use of pilasters in what was essentially a 'service' context seems rather incongruous; however, a similar arrangement can be seen in the ground floor room of the south cross-wing (the Conference Room). It is likely that, in both cases, the main reason for employing pilasters was not so much structural (although in both rooms the pilasters provide direct support for the beams for the floor of the room overhead) as decorative.

The North Range was accessed from within the main house via a short, narrow range, referred to in this report as the 'Link Range'. The 'Link Range' was a two-storey structure and included fireplaces at both ground and first floor. The 'Link Range' adjoined the rear of the north cross-wing and it had a simple pitched roof aligned on a north - south axis. Whereas the other roofs in the building are constructed of oak, the roof of the 'Link Range' contains a large amount of elm. This may indicate that the 'Link Range' was built later than the other parts of the house; alternatively it could simply reflect the fact that the 'Link Range' is a relatively small structure, and it therefore did not warrant using the best quality timbers.

The roof of the North Range is of tenoned-purlin construction. There is a single purlin on each side of the roof and an upper and lower tier of common rafters. The purlins are staggered, ie not in line. There are straight collars linking the principal rafters. Many of the timbers still retain the carpenter's marks that were applied to them during the initial construction of the building. The marks take the form of Roman numerals and the numbering sequence runs from east to west along both roof slopes. The numbering runs from 1 to 10 in the east and middle bays. Over the west bay (the bay with the coved ceiling at first floor – see below) the numbering runs from 1 to 4.

The west end bay incorporates a coved ceiling at first floor, ie tie beam level. The ceiling is supported on a series of common ceiling joists, the inner ends of which are tenoned into a longitudinal central floor beam. The outer ends of the ceiling joists are reduced in width and simply nailed to the east sides of the common rafters. The joists themselves are straight but carry curved timbers at their outer ends; it is these curved timbers that give the ceiling below its coved form. The soffit of the central ceiling beam extends below the line of the plaster ceiling and is visible within the first floor room below. The ends of the beam are supported on decorative moulded brackets of similar type to those found on the front of the building supporting the projecting windows of the north and south cross-wings.

Sampling

A programme of sampling and analysis by tree-ring dating of the timbers of Southall Manor House was commissioned by English Heritage. This was requested to inform a potential listing upgrade from its present grade II status. To obtain optimum information about the dating of the original building and the sequential development of the site, it was decided, after some preliminary inspection and survey by Richard Bond of English Heritage, that samples should be obtained from seven parts of the building.

Primarily, this concerned the sampling of the timbers in the roof of the hall, and of the primary north and south cross-wings. In addition samples were to be taken from the modest number of timbers available in the roof of the stair tower to the east side of the hall. Samples were also required from the roof timbers and a single beam in the ceiling of the North Range, and from the roof of the 'Link Range'.

A total of 34 samples was obtained from these timbers. Each sample was given the code STH-A (for Southall, site 'A'), and numbered 01 - 34. Fifteen samples, STH-A01 - A15, were obtained from the hall and the primary north and south cross-wings. Five samples, STH-A16 - A20, were obtained from the timbers of the stair tower roof, several of the timbers here being unsuitable for analysis by virtue of being too fast grown, and having too few rings, ie less than 54.

Six samples were obtained from the roof of the 'Link Range', STH-A21 - A26. Although potentially containing a sufficient number for sampling, many of the timbers in this roof were of a material other than oak, and thus less suitable for tree-ring analysis, and were excluded from the brief provided. Furthermore, access to parts of this roof was very limited due to both safety and space considerations. The number of samples obtained from this roof is thus slightly less than might otherwise have been the case.

Eight samples, STH-A27 - A34, were obtained from the roof of the North Range. This number is again perhaps slightly less than might otherwise have been the case, given the number of timbers potentially available here. In this case it was seen that many of them appeared to be derived from fast grown trees and thus again contained too few rings for satisfactory analysis.

Furthermore, the ceiling beam of the first floor of the North Range was not sampled. This was due to the fact that it was not of oak but of some form of softwood, and therefore possibly later. There were no timbers available from any of the lower floors, these either possibly being nineteenth-century replacements, or hidden within walls and floors.

The approximate positions of the samples taken are shown in Figure 6, with details of the samples being given in Table 1. In this report timbers and bays have been identified and numbered on a north - south, or east - west basis as appropriate.

The Laboratory would like to take this opportunity to thank Richard Bond of the English Heritage's Historical Areas Research Team for his help in deciphering the phases of the building and for his comments and interpretation. In particular we would like to thank him for his contribution to the architectural description used in the introduction above, and for the use of his plans and drawings. We would also like to thank the staff and occupants of the hall for their help and cooperation during sampling.

Analysis

Each of the 34 samples obtained was prepared by sanding and polishing and their annual growth-ring widths measured. The data of these measurements are given at the end of the report. These data were then compared with each other by the Litton/Zainodin grouping procedure (see appendix). At a minimum *t*-value of 4.5 three groups of cross-matching samples could be formed.

The first group consists of 18 samples cross-matching with each other at relative positions as shown in the bar diagram, Figure 7. These 18 samples were combined at their indicated off-set positions to form site chronology STHASQ01, with a combined overall length of 86 rings. Site chronology STHASQ01 was compared with an extensive range of British and European site chronologies, not only those held by the Nottingham Laboratory but also by other laboratories such as the Sheffield Dendrochronology Laboratory. Despite this extensive comparison there was no satisfactory cross-matching.

The second group consists of four samples, cross-matching with each other at relative positions as shown in the bar diagram, Figure 8. These four samples were combined at their indicated off-set positions to form site chronology STHASQ02, with a combined overall length of 81 rings. Site chronology STHASQ02 was also compared with an extensive range of British and European site chronologies, but again, despite the extensive comparison, there was no satisfactory cross-matching.

The third and final group consists of three samples, cross-matching with each other at relative positions as shown in the bar diagram, Figure 9. These three samples were also combined at their indicated off-set positions, forming site chronology STHASQ03. This has a combined overall length of 73 rings. Site chronology STHASQ03 was likewise compared with British and European site chronologies, but once again, there was no satisfactory cross-matching.

Each of the remaining ungrouped samples was compared individually with the reference chronologies, but there was no satisfactory cross-matching, and these samples must also remain undated.

Interpretation

Analysis by dendrochronology has produced three site chronologies, STHASQ01, SQ02, and SQ03, consisting of 18, four, and three samples, of length 86, 81, and 73 rings, respectively. However, despite their satisfactory composition and length, after being compared to an extensive range of reference chronologies the three site chronologies, and the remaining ungrouped single samples, cannot be dated.

Whilst the lack of precise calendar dates for the felling of the timber is disappointing, the tree-ring analysis nevertheless addresses the key question concerning the relationship of the North Range with the hall complex, and does produce some positive results. Of the 18 samples in site chronology STHASQ01, 12 retain complete sapwood, that is they each have the last growth-ring produced by the tree represented before it was felled. In each case the last, complete, sapwood ring is the same at relative position 86. This indicates that the trees represented by these 12 samples were all felled at the same time. Furthermore, the relative positions of the heartwood/sapwood boundaries on the other seven cross-matching samples, see Figure 7, would suggest that the timbers they represent were all felled at this time as well.

Importantly for interpretive purposes, site chronology STHASQ01 includes samples from five of the six areas examined in this analysis, the north cross-wing, the south cross-wing, and the hall range of the Manor, plus the stair tower, and the North Range. The clear interpretation is that these elements were all built using timber felled at the same time, and are therefore most likely all contemporary, and part of a single programme of construction.

The notable absence from site chronology STHASQ01 is of any samples from the 'Link Range'. Four 'Link Range' samples form site chronology STHASQ02, each one retaining complete sapwood. Unlike the samples with complete sapwood in site chronology STHASQ01, the positions of the last, complete, sapwood rings in site chronology STHASQ02 vary, from relative position 79 on sample STH-A23, to relative position 81, on sample STH-A26. This clearly shows that the timbers represented by these four samples were not felled at the same time as each other.

Conclusion

All three cross-matching groups of timber, and those that remain unmatched, have a series of periodic growth disturbances in the form of three or four very narrow rings followed by a period of recovery. Whilst it cannot be proven, it seems likely that these sudden and severe growth retardation events are a result of anthropogenic influences in the form of woodland management rather than natural environmental factors. Such disturbances are effectively masking the general climatic signal required for absolute dating purposes.

Judging by the *t*-values of the cross-matches between samples it is possible that there is some slight differentiation in the sources of timber used for each element of the building. It is possible that the timbers used in the hall may have come from one stand within a copse, while that used for the primary north and south cross-wings from other, but very nearby stands. The timber used in the North Range may have come from a different, but nearby copse. The highest *t*-values seem to occur between samples from the same roof. Indeed, again judging by the *t*-values, it is possible that some timbers have been derived from the same tree, samples STH-A02 and A04, or STH-A11 and A12 for example.

Those samples included in each of the three groups are likely to be responding to similar management regimes and are hence likely to be derived from the same woodland stands. In this case the lack of cross-matching between the three site chronologies and the unmatched individual samples could simply be due to the trees being subjected to different management regimes.

While it has not been possible to absolutely date any of the elements of Southall Manor under consideration in this programme of analysis, it has been possible to resolve one of the major questions concerning this site. Tree-ring dating has been able to demonstrate quite clearly that the north cross-wing, the south cross-wing, and the hall range of the Manor, about which there was little question, plus the stair tower and the North Range, about which there was greater doubt, are all of one programme of building, being constructed using timber felled in the same year.

Unfortunately tree-ring analysis has not been able to demonstrate, absolutely or relatively, the date of the 'Link Range'. The fact that the samples from the 'Link Range' do not cross-match with those of the rest of the Manor House, does not necessarily mean that the timbers of the 'Link Range' are of a different date.

The differences in the form of the roof, the use of timber with different felling dates, and the use of a mixture of timber types in the 'Link Range' roof, may indicate that it is of a different, probably later date, than the rest of the Manor house. However, this cannot be proven by dendrochronology and will therefore be reliant on structural survey and interpretation undertaken during possible alteration or repairs to the building.

Four samples, all from the roof of the primary south cross-wing, in site chronology STHASQ03, also remain undated. Two of these, STH-A02 and A05 have complete sapwood indicating that the timbers they represent were felled at the same time. The fact that site chronology STHASQ03 does not cross-match with other samples from the roof is most likely to suggest that these timbers are from a different source, rather than of a different date.

Thus, although undated some interpretive benefit has accrued from this programme of tree-ring analysis. Dendrochronology has independently established the contemporaranity of parts of this building with greater certainty, the results thus illustrating the merits of undertaking analysis even where the date of a building is intimated from other sources.

Should work be undertaken at Southall Manor at any time in the future, it would certainly be worthwhile taking further samples, particularly from the roof of the 'Link Range', where access was restricted.

Table 1: Details of samples from Southall Manor House, Ealing, Greater London

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	South cross-wing					
STH-A01	North purlin, truss 2 – east gable	62	3	------	------	------
STH-A02	South purlin, truss 2 – east gable	67	18C	------	------	------
STH-A03	South purlin, west gable – truss 2	58	18C	------	------	------
STH-A04	North principal rafter, truss 2	66	27	------	------	------
STH-A05	North purlin, west gable – truss 2	65	21C	------	------	------
STH-A06	South principal rafter, truss 2	72	25	------	------	------
STH-A07	South common rafter 4, bay 1	54	16	------	------	------
STH-A08	South common rafter 2, bay 1	55	19C	------	------	------
	Hall range					
STH-A09	West purlin, truss 1 – north gable	64	15	------	------	------
STH-A10	East purlin, truss 1 – north gable	68	10C	------	------	------
STH-A11	West principal rafter, truss 1	62	18C	------	------	------
STH-A12	East principal rafter, truss 1	60	18C	------	------	------
	North cross-wing					
STH-A13	South common rafter number 6, bay 2	66	17	------	------	------
STH-A14	South common rafter number 7, bay 2	59	15	------	------	------
STH-A15	South common rafter number 2, bay 1	53	14C	------	------	------

Table 1: continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Stair tower					
STH-A16	North wall plate	79	20C	------	------	------
STH-A17	South wall plate	72	22C	------	------	------
STH-A18	East wall plate	49	13C	------	------	------
STH-A19	South common rafter 4	63	18C	------	------	------
STH-A20	North common rafter 6	60	22C	------	------	------
	'Link Range'					
STH-A21	East common rafter number 6	62	10	------	------	------
STH-A22	East common rafter number 12	75	27C	------	------	------
STH-A23	West common rafter number 14	52	15C	------	------	------
STH-A24	East common rafter number 15	59	26C	------	------	------
STH-A25	East common rafter number 16	54	17C	------	------	------
STH-A26	West common rafter number 16	81	26C	------	------	------
	North range					
STH-A27	South principal rafter, truss 2	55	21C	------	------	------
STH-A28	North purlin, truss 1 – 2	69	9	------	------	------
STH-A29	South purlin, truss 1 – 2	75	30	------	------	------
STH-A30	North purlin, truss 2 – west gable	54	10	------	------	------

Table 1: continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	North range (continued)					
STH-A31	South purlin, truss 2 – west gable	60	18C	------	------	------
STH-A32	North principal rafter, truss 1	75	24C	------	------	------
STH-A33	South principal rafter, truss 1	79	20C	------	------	------
STH-A34	South lower common rafter 8, bay 2	87	h/s	------	------	------

*h/s = the heartwood/sapwood boundary is the last ring on the sample
C = complete sapwood retained on the sample

Figure 1: Map to show general location of Southall

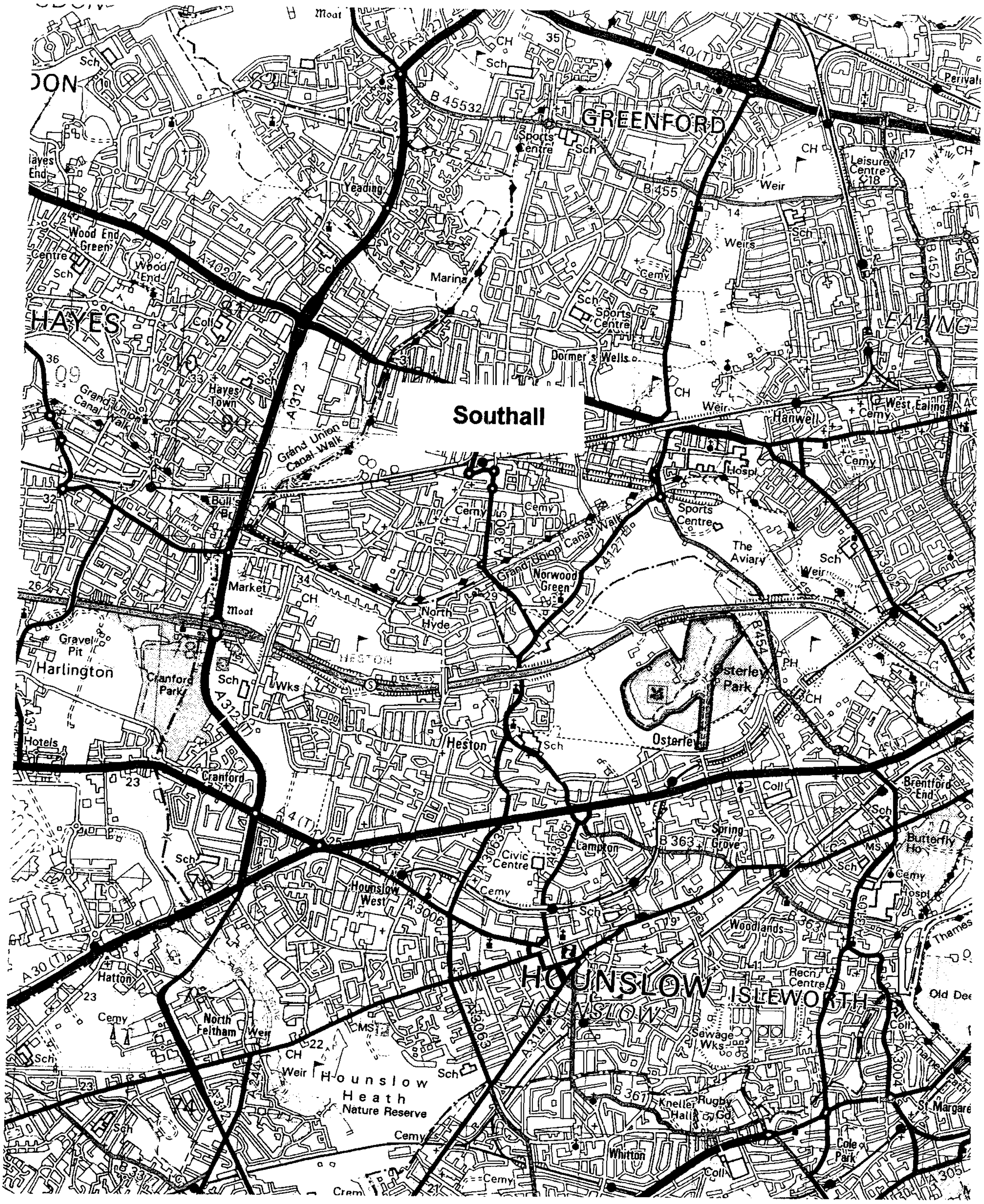


Figure 2: Map to show location of Southall Manor

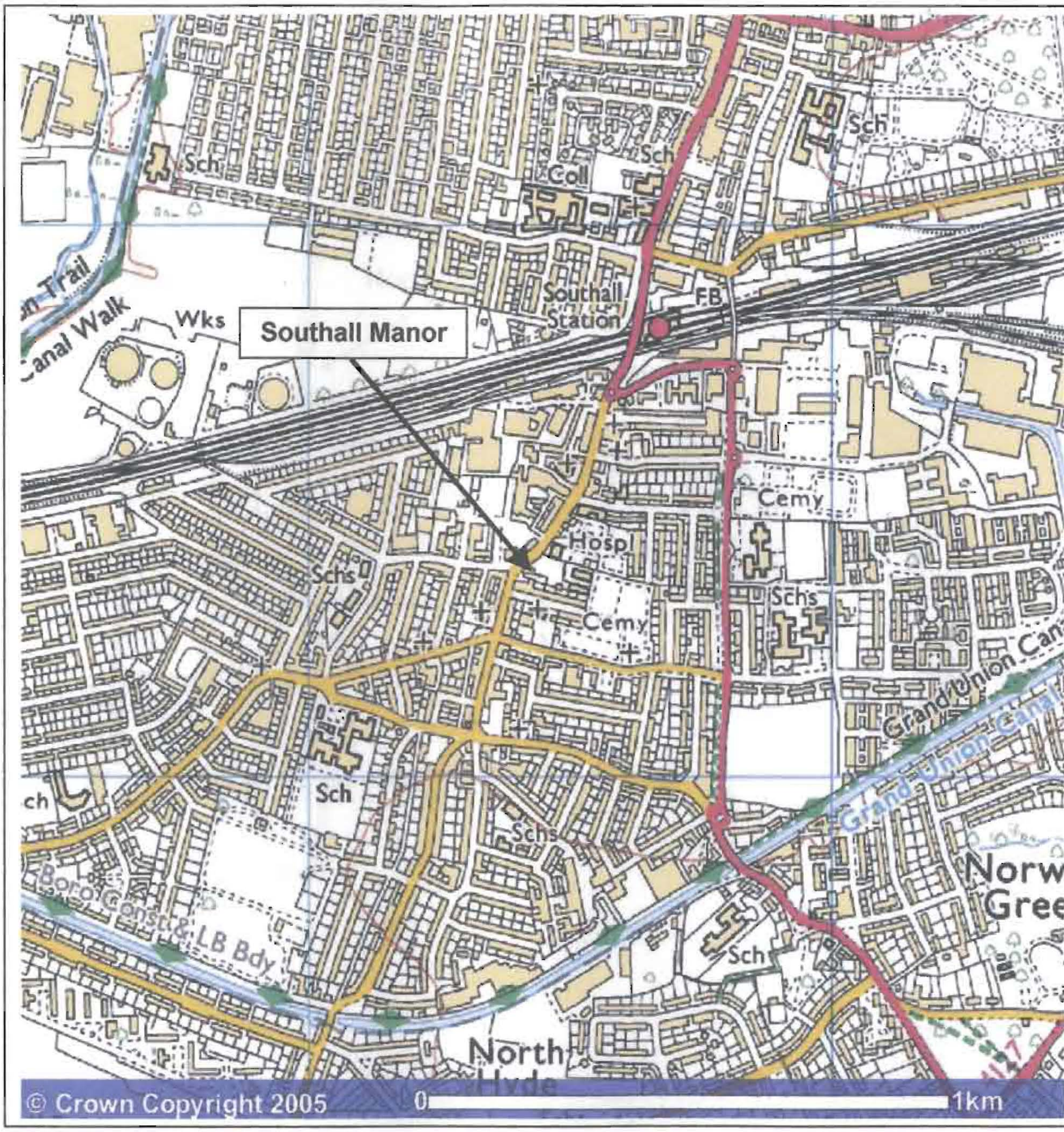


Figure 3: General plan of Southall Manor House (after Richard Bond)

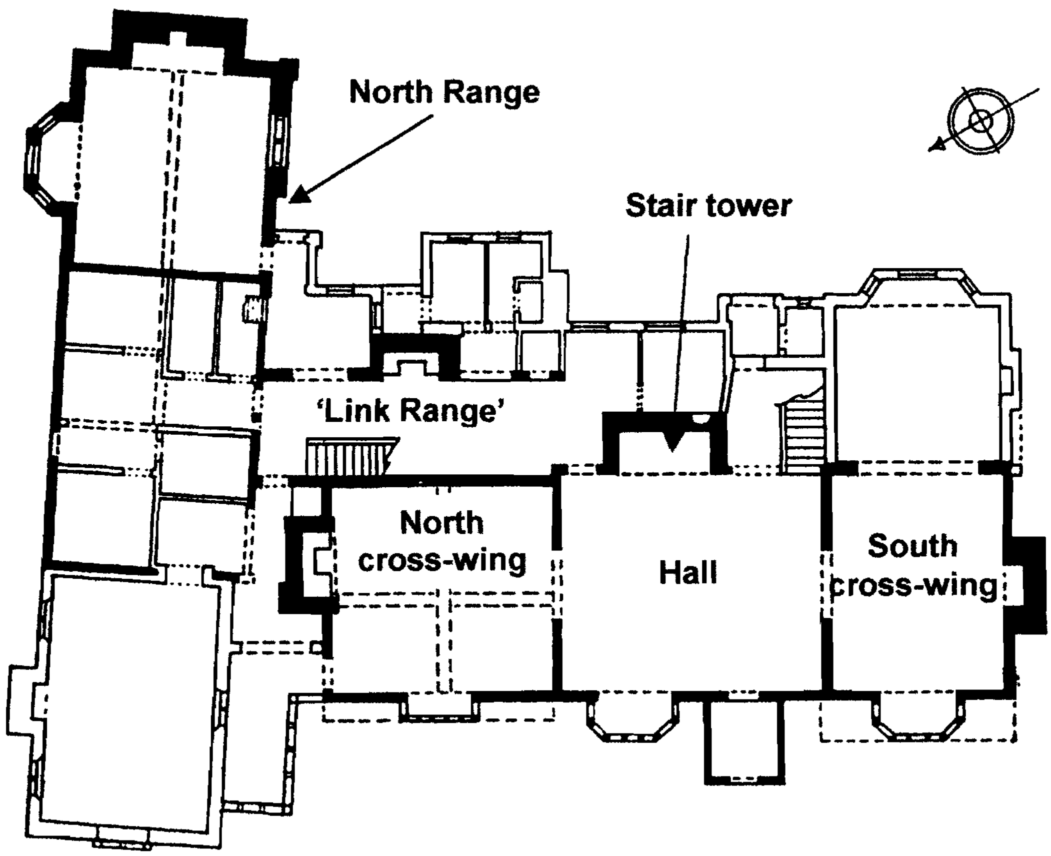


Figure 4: Roof trusses in main house.
Above: central truss in north cross-wing (west elevation)
Below: easternmost truss in south cross-wing (east elevation)
(after Richard Bond)

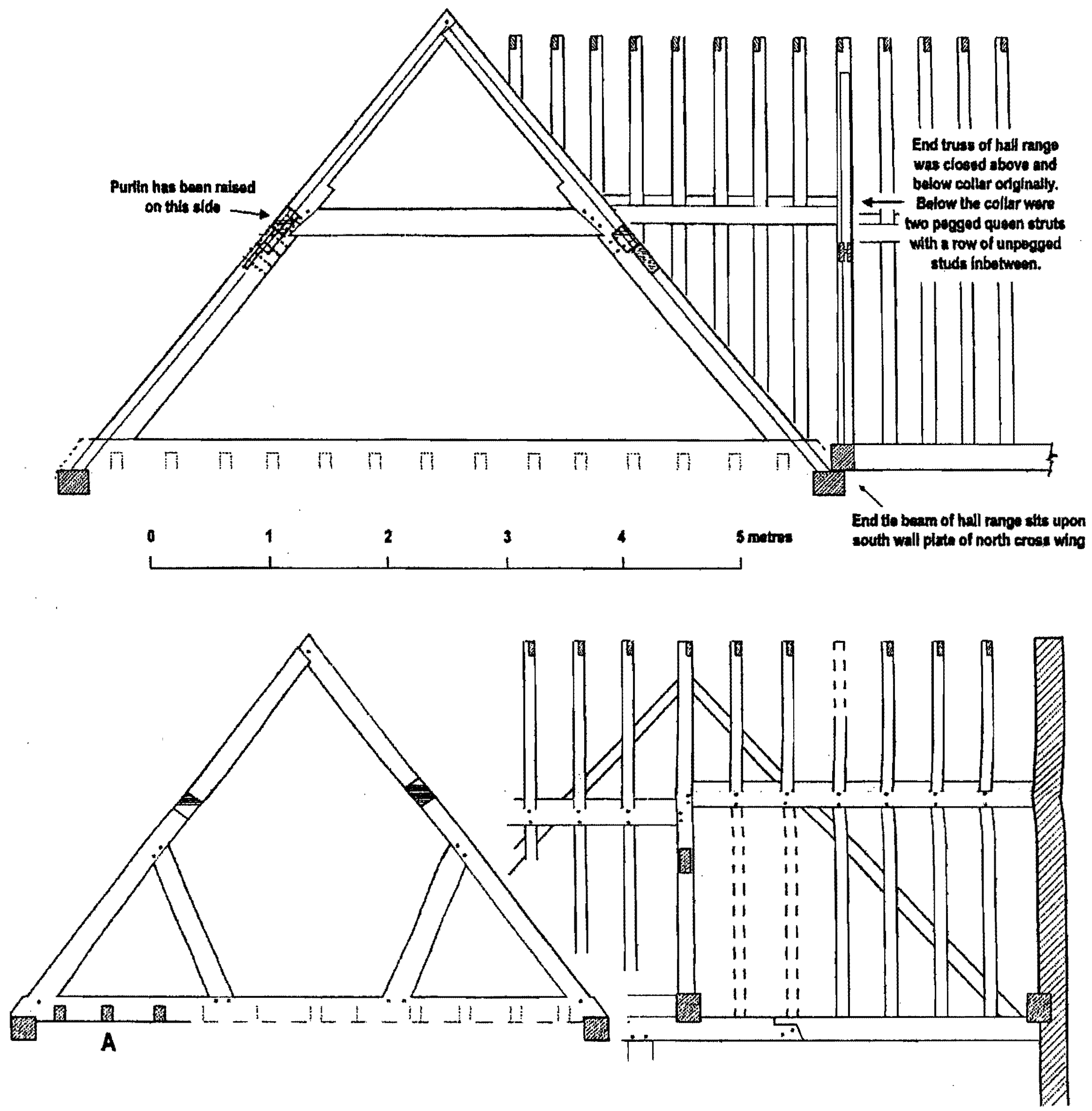


Figure 5: Conjectured reconstruction of Southall Manor as it may have appeared when first built in AD 1587 (after Richard Bond)

Figure 6: Plan to show approximate position of timbers sampled

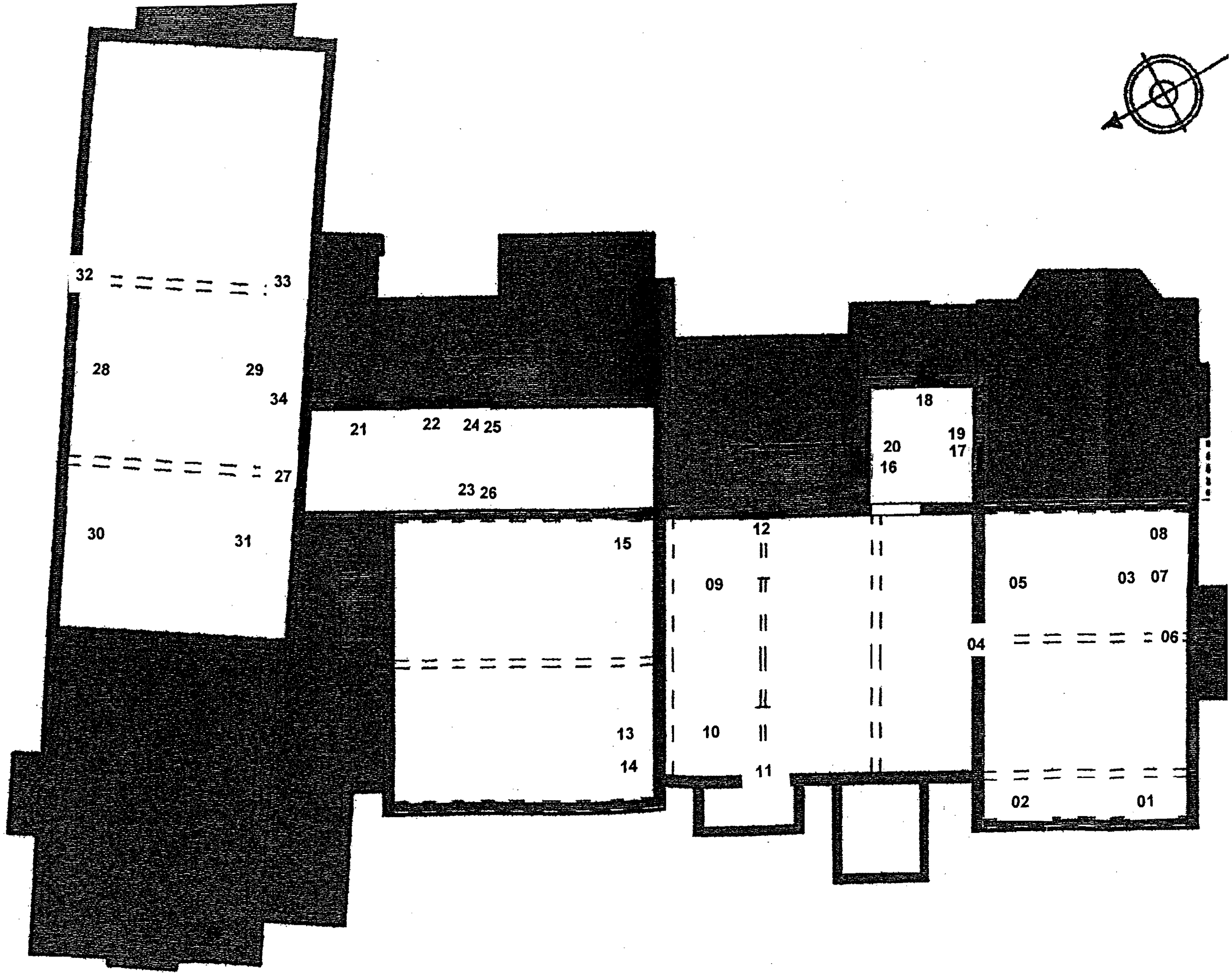
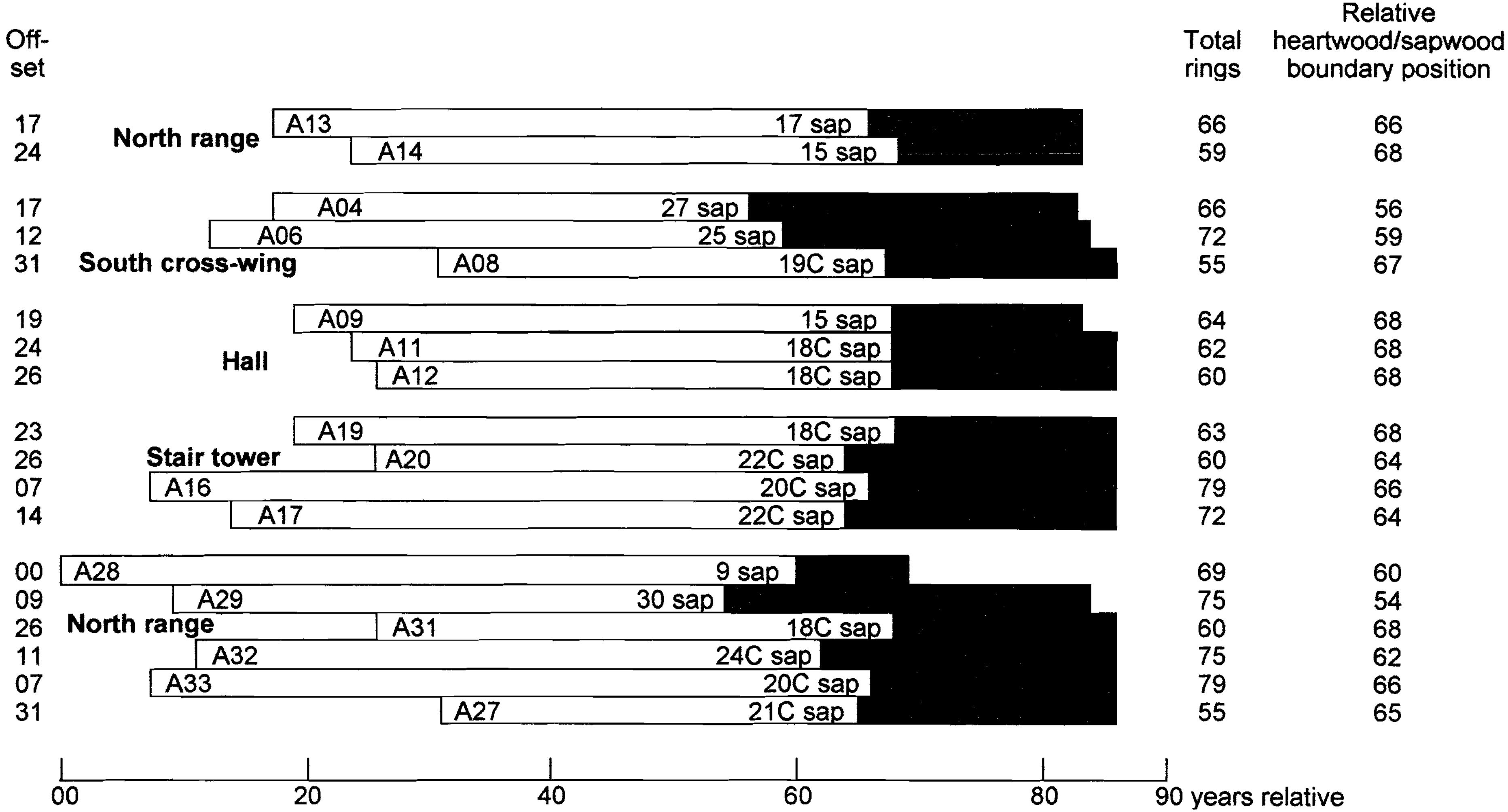


Figure 7: Bar diagram of the samples in site chronology STHASQ01



white bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample
C = complete sapwood retained on the sample

Figure 8: Bar diagram of the samples in site chronology STHASQ02

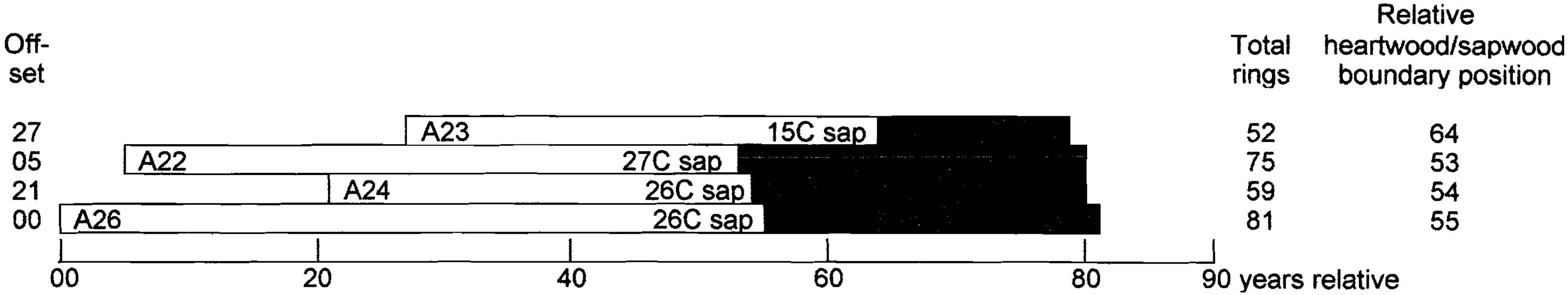
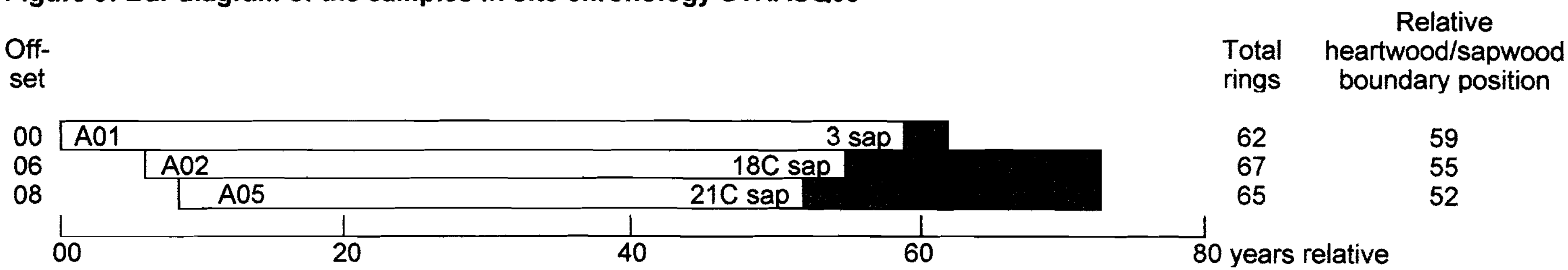


Figure 9: Bar diagram of the samples in site chronology STHASQ03



white bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample
C = complete sapwood retained on the sample

Data of measured samples – measurements in 0.01 mm units

STH-A01A 62
407 200 240 286 345 508 342 437 252 226 414 475 554 634 436 498 483 392 111 127
123 166 214 210 437 463 240 281 383 314 392 428 325 320 92 89 101 166 182 261
334 328 393 293 260 250 88 96 90 92 73 124 150 181 231 123 202 100 120 148
151 195
STH-A01B 62
428 173 249 293 333 504 333 451 246 231 430 461 567 623 455 514 490 389 111 104
137 151 227 218 420 462 287 290 360 330 393 416 338 302 98 91 101 140 190 266
311 345 383 284 255 251 107 101 83 106 72 118 139 194 243 172 204 98 118 138
154 193
STH-A02A 67
229 260 312 331 412 422 575 658 486 407 325 329 96 67 76 89 119 128 228 330
230 226 315 290 355 351 252 272 85 63 103 184 188 194 248 277 196 145 169 281
96 62 68 91 133 191 216 200 155 271 108 60 84 118 134 173 198 165 158 190
86 79 46 137 195 191 172
STH-A02B 67
250 236 314 333 418 421 590 604 482 421 326 335 92 72 67 101 114 131 226 337
221 237 306 281 391 333 236 275 89 63 119 187 199 193 240 249 210 147 189 281
101 62 61 100 125 200 205 191 191 240 112 53 79 118 121 165 184 167 160 194
76 71 58 140 185 171 168
STH-A03A 58
261 296 338 449 697 517 250 219 256 429 403 452 381 179 95 153 187 342 405 475
483 440 361 399 106 136 167 143 174 257 225 48 59 75 79 183 220 151 281 80
64 100 152 145 69 80 62 76 105 204 135 74 40 36 86 85 121 146
STH-A03B 58
282 293 350 459 698 512 232 239 264 432 401 440 369 197 99 156 178 342 396 478
481 448 346 414 109 119 143 134 183 259 214 50 59 83 91 182 209 163 305 81
62 99 157 148 63 78 71 83 99 211 141 53 36 48 62 83 117 109
STH-A04A 66
336 428 460 326 440 458 301 392 497 507 594 531 159 249 327 309 170 270 261 367
103 82 152 329 285 340 332 301 295 407 349 385 75 76 177 228 195 232 210 93
41 74 128 182 85 61 44 71 34 50 61 112 43 79 45 47 86 110 124 67
72 61 52 95 155 126
STH-A04B 66
303 440 472 318 445 449 291 461 495 511 590 530 170 234 317 292 163 295 263 370
116 69 144 326 288 362 343 306 309 378 335 401 70 85 185 215 196 211 198 110
48 87 119 146 114 62 54 74 29 44 75 104 46 71 39 67 81 114 125 72
59 63 60 85 157 128
STH-A05A 65
487 412 649 498 683 901 766 590 625 578 108 116 167 177 219 201 318 517 338 380
418 329 460 520 319 264 93 77 107 149 215 216 307 342 296 221 263 306 99 69
100 98 116 173 226 262 222 244 78 78 49 88 100 166 168 206 182 188 77 60
53 77 75 103 122
STH-A05B 65
449 410 646 499 690 888 764 582 649 584 74 147 177 165 207 190 313 550 362 402
405 337 460 509 324 256 93 66 114 139 219 239 323 311 296 232 249 310 93 72
114 106 126 165 200 251 226 253 101 76 52 79 86 152 178 181 189 206 85 63
41 89 71 101 117

STH-A06A 72
267 257 331 310 276 326 327 428 331 397 403 202 261 382 398 399 404 119 134 166
231 161 263 301 355 105 87 170 355 330 357 398 346 342 427 360 403 106 67 205
227 262 311 317 95 124 149 195 235 186 185 92 55 60 58 78 217 181 74 83
91 122 120 143 125 61 85 58 94 122 194 152
STH-A06B 72
236 241 349 311 268 317 319 408 345 400 400 203 262 378 401 389 417 101 155 163
221 169 266 287 368 85 106 176 337 338 343 408 346 343 405 358 404 96 80 204
218 267 305 314 102 121 147 204 247 178 181 82 68 60 44 90 205 182 71 98
78 119 137 141 107 75 73 62 95 129 187 168
STH-A07A 54
400 198 227 273 398 498 347 425 226 371 350 421 474 451 397 539 343 504 154 70
95 102 81 95 142 57 58 63 63 64 194 216 267 102 89 79 119 295 195 105
90 118 141 96 252 282 84 51 31 58 84 188 254 72
STH-A07B 54
408 193 229 273 373 501 329 411 233 361 361 411 520 468 409 483 368 507 146 73
106 78 91 84 143 70 59 57 53 69 193 211 268 96 87 67 127 294 171 86
85 101 141 107 230 275 86 38 52 63 75 188 268 68
STH-A08A 55
399 199 234 269 367 459 249 270 311 341 400 385 475 228 128 330 279 293 84 200
365 284 215 274 451 108 154 203 162 198 323 338 539 104 98 104 133 197 227 45
62 64 67 194 180 158 66 71 65 134 138 222 274 112 112
STH-A08B 55
401 191 237 270 368 469 241 276 315 343 410 414 470 220 130 344 228 317 78 211
370 264 225 268 464 114 138 230 173 184 335 335 534 104 103 112 120 194 220 61
52 69 81 185 176 161 55 85 69 129 124 202 275 106 94
STH-A09A 64
500 289 386 402 263 278 330 348 378 297 140 196 272 199 360 509 261 265 112 131
162 250 234 295 268 261 245 264 158 136 86 68 111 161 201 252 258 92 94 71
111 120 142 169 187 63 42 65 101 165 177 86 76 69 90 91 122 116 56 78
52 47 58 80
STH-A09B 64
566 275 378 382 236 303 343 355 359 326 128 194 276 216 380 458 296 312 127 122
166 253 231 307 273 267 244 235 170 144 77 69 116 176 192 235 222 88 88 75
114 136 142 156 175 84 62 64 103 166 178 75 80 86 98 83 122 104 60 68
49 47 62 82
STH-A10A 68
243 167 115 153 134 141 156 174 222 397 285 181 216 183 191 215 230 286 200 282
233 352 331 276 224 243 113 132 193 265 206 314 342 198 323 317 174 215 53 89
117 175 159 272 267 49 65 105 103 109 248 259 46 34 61 91 139 140 134 62
64 77 141 110 190 56 51 44
STH-A10B 68
214 164 123 152 130 168 175 163 233 397 304 202 180 199 182 183 224 215 189 284
242 366 330 289 214 252 98 138 211 264 199 314 343 196 323 306 183 212 50 82
107 161 174 265 255 58 66 92 115 132 233 251 58 39 56 98 138 139 133 67
73 87 135 149 185 63 47 38
STH-A11A 62
486 582 505 653 618 189 159 223 284 236 342 241 357 76 96 221 340 307 356 406
284 379 306 216 314 77 142 259 286 278 263 266 77 111 173 216 425 269 184 298
46 98 117 209 259 173 73 97 140 134 180 149 105 67 62 109 225 219 221 243
72 77

STH-A11B 62
457 600 507 643 630 183 159 218 298 234 344 250 352 82 104 192 324 302 378 391
305 362 310 211 316 85 136 253 280 284 269 253 79 116 156 211 389 267 197 308
47 92 95 236 260 170 58 100 142 127 186 150 120 65 71 97 225 222 214 241
70 76
STH-A12A 60
517 614 534 199 221 182 289 244 342 309 322 95 100 142 231 212 357 353 301 401
388 291 349 83 84 157 180 196 213 262 70 82 96 153 213 223 248 275 57 68
89 159 191 180 44 72 71 84 165 183 167 67 48 44 120 128 159 192 51 77
STH-A12B 60
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364 283 328 90 97 161 163 183 234 254 56 97 106 163 217 228 238 296 59 60
111 164 198 161 52 68 67 87 122 179 155 67 56 40 118 119 174 166 78 78
STH-A13A 66
476 454 500 275 300 207 189 247 326 307 316 342 124 102 81 118 198 199 159 201
158 111 164 170 214 248 242 213 202 245 167 221 93 95 125 129 127 181 185 90
90 154 152 183 191 206 262 74 115 79 128 148 177 80 96 87 125 159 114 104
92 79 74 79 97 94
STH-A13B 66
500 490 473 260 297 224 171 249 336 276 326 354 130 105 86 135 198 191 156 189
159 107 151 184 207 239 232 222 215 222 172 210 96 96 126 134 120 183 177 77
118 145 153 171 207 205 243 83 106 103 100 155 194 94 83 92 108 145 127 107
79 106 73 77 83 110
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300 412 335 270 297 106 54 73 118 199 223 175 258 113 141 133 186 207 339 302
272 183 194 128 200 80 111 156 139 130 143 108 61 97 115 116 172 206 160 268
87 90 83 100 158 163 93 85 92 150 137 187 155 100 96 79 74 106 158
STH-A14B 59
314 397 342 289 286 104 54 73 106 196 231 185 250 124 137 137 214 211 309 283
265 191 191 148 203 84 88 160 145 132 142 115 58 115 114 97 172 206 172 274
71 101 65 117 164 161 81 83 92 142 154 164 165 81 110 66 76 96 159
STH-A15A 53
216 219 92 58 58 114 177 166 176 154 147 217 81 87 87 110 150 167 154 150
145 265 245 84 75 80 100 119 129 148 140 187 299 261 270 205 449 147 72 57
73 124 140 224 202 191 241 77 68 43 60 53 71
STH-A15B 53
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161 262 267 81 69 68 103 110 133 173 145 197 322 247 299 180 434 146 79 63
72 117 148 233 199 227 222 149 42 60 47 40 66
STH-A16A 79
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273 288 137 146 119 162 277 260 169 173 162 146 145 198 192 270 278 221 192 201
111 155 81 93 122 158 152 220 244 122 110 105 104 116 89 65 83 40 51 49
65 82 141 72 98 83 128 180 182 193 109 101 79 115 115 145 85 64 90
STH-A16B 79
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291 289 120 153 133 152 271 275 163 189 154 132 144 207 189 272 278 219 189 189
121 135 96 99 120 151 175 204 246 114 110 100 109 126 81 65 71 46 50 45
77 87 147 68 98 71 140 169 189 192 103 96 88 117 112 137 84 65 88
STH-A17A 72
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330 194 146 167 233 224 260 198 312 308 245 244 271 157 165 98 112 155 214 129
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120 155 148 97 59 71 59 113 90 54 78 76

STH-A17B 72
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328 216 153 194 200 206 250 197 337 303 240 237 299 138 178 85 113 165 203 144
142 93 49 67 71 57 53 174 147 193 99 91 74 112 120 108 81 88 99 92
141 152 151 90 73 64 66 92 113 59 75 67
STH-A18A 49
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139 218 225 183 141 175 175 248 93 132 177 194 219 211 217 214 198 205 303 257
195 89 133 92 108 115 161 215 170
STH-A18B 49
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147 216 232 182 147 164 171 262 92 115 161 200 228 206 216 220 194 216 298 261
187 105 101 107 105 101 178 218 164
STH-A19A 63
159 306 280 295 340 353 127 131 109 213 209 233 165 160 129 112 234 227 218 320
315 306 298 251 153 171 55 92 78 142 173 182 166 55 76 87 124 142 170 159
200 72 57 66 134 194 168 67 58 86 98 91 103 78 62 64 41 39 51 69
36 49 40
STH-A19B 63
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191 66 60 70 126 197 171 71 76 79 110 86 103 65 55 53 36 46 57 62
42 55 48
STH-A20A 60
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253 151 174 67 91 103 132 177 202 182 64 78 96 118 137 179 163 186 67 69
79 112 214 190 83 86 79 109 94 102 69 60 60 47 37 61 55 37 34 48
STH-A20B 60
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STH-A21A 62
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225 260 289 95 52 52 67 110 161 284 393 410 325 72 49 43 68 79 82 90
218 193
STH-A21B 62
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50 54 70 62 112 148 146 188 214 316 306 241 336 82 52 38 83 110 145 224
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212 226
STH-A22A 75
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63 32 32 37 44 48 76 102 117 60 43 38 43 49 57
STH-A22B 75
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STH-A23A 52
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72 158 163 190 479 566 89 75 47 69 54 94

STH-A23B 52
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78 165 164 200 471 571 100 68 44 55 79 64
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84 91 109 121 68 42 46 49 48 82 85 129 94 51 45 28 43 53 60
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96 108 76 68 55 70 76 146 118 221 169 192 185 212 66 60 36 37 45 66
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142 105 127 118 102 55 37 36 41 62 52 88 106 87 46 55 46 47 45 38
51
STH-A26B 80
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40 82 74 97 64 66 99 59 48 69 49 76 81 50 48 46 47 40 48 64
68 36 38 40 26 39 47 53 32 44 46 41 63 91 64

STH-A29B 75
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139 188 191 60 103 100 143 164 147 105 56 59 70 71 92 98 65 41 49
STH-A33B 79
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128 180 79 131 167 208 187 235 252 102 112 120 99 97 148 107 77 54 96 117
151 193 206 51 81 107 145 156 145 113 70 66 65 76 83 97 72 54 51
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APPENDIX

Tree-Ring Dating

The Principles of Tree-Ring Dating

Tree-ring dating, or *dendrochronology* as it is known, is discussed in some detail in the Laboratory's Monograph, '*An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Building*' (Laxton and Litton 1988) and, *Dendrochronology; Guidelines on Producing and Interpreting Dendrochronological Dates* (English Heritage 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.

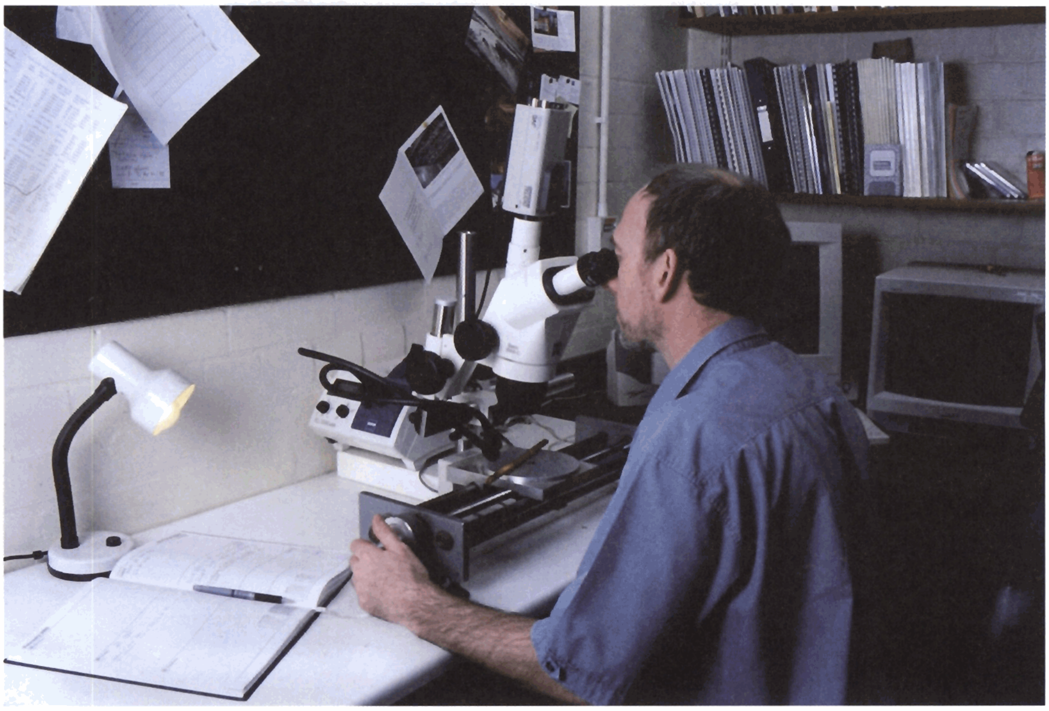


Fig. 3 Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measure twice to ensure that an error has not been made. This type of apparatus is needed to process a large number of samples on a regular basis.

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 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 straight forward 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. 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, sapwood can be seen in the corner of the rafter and at the outer end of the core in Figure 2, 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 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 2 was taken still had complete sapwood but that none of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 2 cm, 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 *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

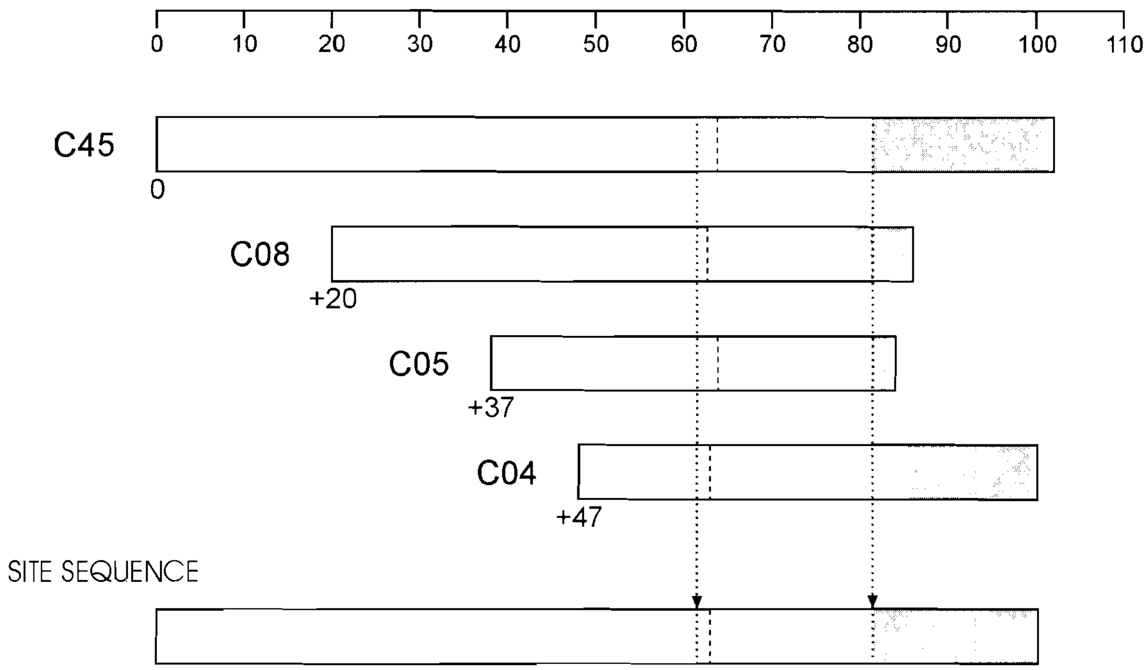


Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

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.

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 and Miles 1997, 50-55). Hence provided 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, figure 8 and pages 34-5 where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storing 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 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 (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 Fig 7. 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 phenomena 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.

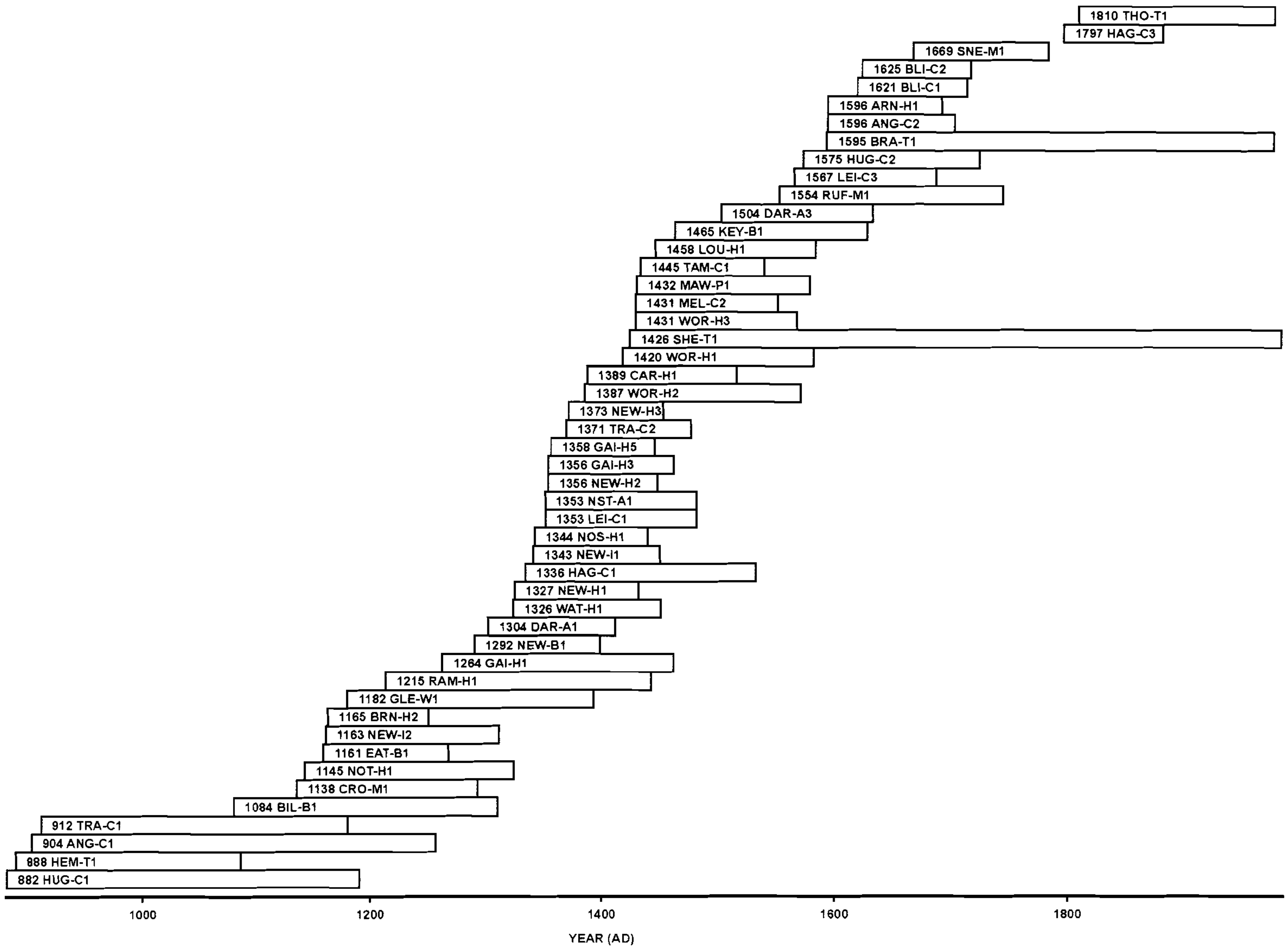
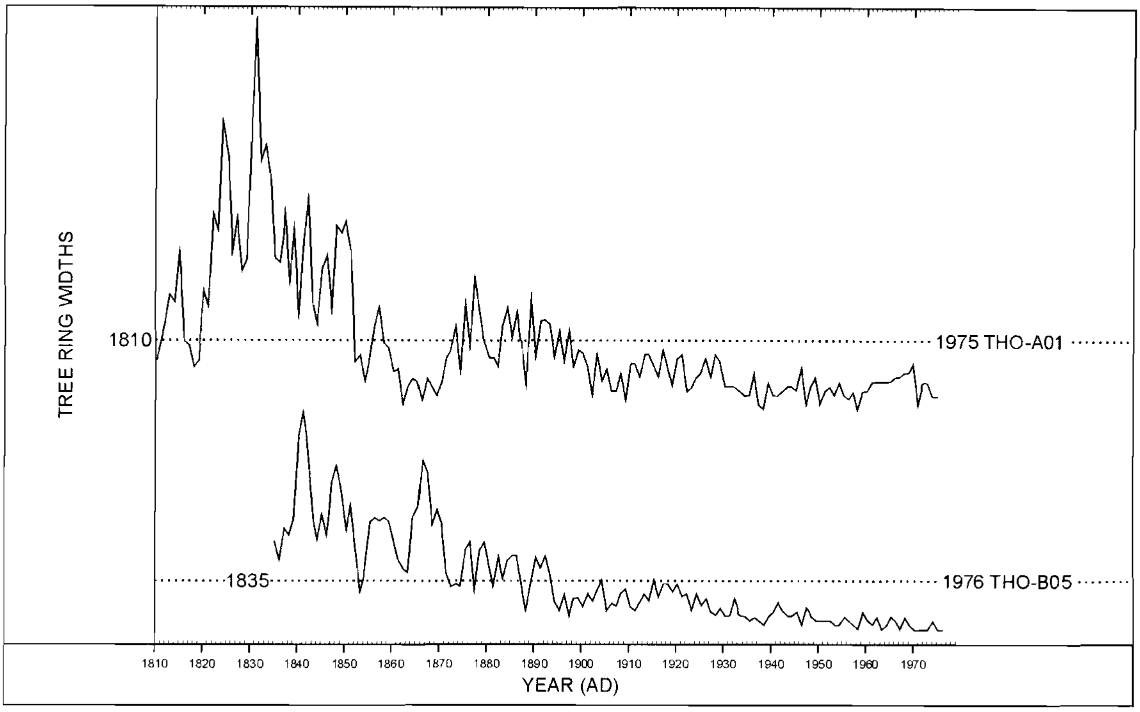


Fig. 6 Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

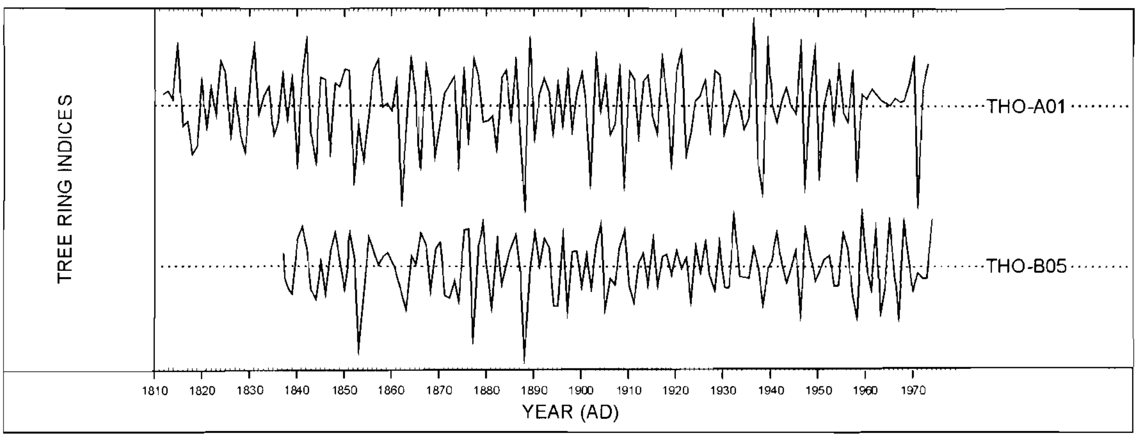


Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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

Fig 7. (b) The *Baillie-Pilcher* indices of the above widths. The growth-trends have been removed completely.

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