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Summary

Sixteen samples were obtained from this building, of which only ten were suitable for tree-ring dating. Analysis by dendrochronology produced two site chronologies, only one of which could be dated. The analysis also dated one sample individually.

The first site chronology, consisting of three samples from the floor frame, is 83 rings long. This site chronology cannot be dated.

The second site chronology consists of two samples from the roof timbers. This is 67 rings long and is dated as spanning the years AD 1403 to AD 1469. Interpretation of the sapwood would suggest that the timbers represented have an estimated felling date in the range AD 1484 - 1509.

The dated individual sample is from a main ceiling beam of the floor frame. This sample has 70 rings and is dated as spanning the years AD 1419 to 1488. This sample does not have the heartwood/sapwood boundary on it, and it is thus not possible to estimate the felling date of the timber except to say that this is unlikely to be before AD 1503.

Keywords

Dendrochronology
Standing Building

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Introduction

Number 10 - 14 Churchgate, Hallaton, is a high quality timber-framed structure, believed to date to the late-fifteenth century. It is located on a prominent site, just opposite the church, at the centre of this village set in south east Leicestershire (SP787966; Figs 1 and 2). It is suggested that, though subsequently reduced in status and subdivided into four cottages, it was once one of the two main manor houses of Hallaton. The location of this second manor house has been lost since it was merged with the other main manor in the early seventeenth century.

The building, of six bays, had timber-framed walls with heavy close-studding throughout. Three bays originally formed an open hall, with a high arch-braced roof truss of an unusual stub tiebeam arch-braced roof form, a rare Midlands type associated with high status houses. Although this was an open hall, the absence of smoke blackening indicates that there must have been a chimney stack from the beginning rather than an open hearth, a remarkably early feature if the presumed late fifteenth-century date is correct. The remaining three bays have always had a first floor.

The original building has three main bays, subdivided into intermediate bays at roof-level. The external walls are all close-studded where evidence survives. The plan is out-of-square at both gable ends, particularly to the west, following the line of the road frontage.

There are two principal trusses, truss 3 and truss 5, these being illustrated in Figures 3 and 4. The most striking feature of the building is the open truss, truss 3. This has sweeping arch braces which cut the line of the tie beam, creating the interrupted or stub tie beam pattern. The braces rise from main posts which are well jowled and have a chamfered rib moulding to the inner face, carved from the solid main post timber, with a further chamfer to the main post section. At the head of the rib-moulding to the posts is a shaped cap, above which rises the continuation of the chamfered moulding, on the arch braces.

The intermediate trusses, trusses 2, 4, and 6, are of a lighter A-frame type, with two cambered collars holding the two sets of clasped purlins. The principal rafters are of small section, and similar in size to the common rafters. The upper collars are strongly curved and chamfered to the undersides. An illustration of the intermediate type is given in Figure 5.

There is a complete absence of smoke-blackening to any of the roof timbers, which are quite clean throughout. Despite evidence for an open hall there must have been an original chimney stack, or no heating at all.

Very little evidence of the original timber-framed structure survives to the ground floor, most of the structure having been replaced in stone or brickwork. The main posts of truss 3 and probably truss 5 survive on the south side. Otherwise, only the south post of intermediate truss 4 and a short section of sill beam remain, with evidence from peg holes in the first floor girding beam for ground-floor walling of close studs. This small surviving section of wall framing contains some interesting evidence. The sill beam sits on a stone plinth wall, now about 500mm high, and the intermediate post tenons into the sill beam in the normal way. However, the foot of the main post of truss 3 has peg holes to each side at its base, indicating that the structure here was of unusual interrupted sill type, with the sill beam jointed into either side of the main post, instead of passing underneath it. The end of the post sits on the stone plinth at the same level as the bottom of the sill beam, and seems never to have run further down towards ground level, unlike most interrupted sill structures.

Part of a timber-framed internal cross partition survives on the ground floor near the intermediate post of truss 4. Only the upper part of this is visible, with two posts framing a wide 1200mm opening. The posts are tenoned and pegged at the top to a head beam, which is chamfered to match the width of the opening. The opening has a timber lintel tenoned and pegged to the side posts, with three close-stud timbers above, unpegged. The partition abuts the front south wall, and its north end is cut off by the later inserted fireplace. As the lintel is around door head height, it seems likely this was a doorway, though it is unusually wide; alternatively, it could have been a hatch. The wall does not seem well integrated with the original framed structure and fails to align with the nearby intermediate post, so it seems likely it is a later insertion, not original. The purpose of such a wide opening in this location is puzzling.

The second principal phase which can be distinguished is the insertion of a first-floor structure into the open hall, probably in the seventeenth century. This is a conspicuous and rather clumsy insertion, with heavy new posts set inside the line of the existing walls, carrying large ceiling beams. The fact that there is no similar inserted structure in the eastern half of the building provides further evidence for this part having been floored originally.

Sampling

Sampling and analysis by tree-ring dating of timbers from this building was commissioned by English Heritage. The purpose of this was to provide a precise date for the original timber frame and to date the insertion of a later floor frame. This work was to help inform a possible listing upgrade of this two-phase building. A further purpose of analysis was to assist in research into the understanding of a rare group of other high-status "stub tiebeam" roofs and to clarify the date of an open hall with an original chimney. Analysis of the inserted floor was to provide information on the subsequent development of the site.

Thus, after discussion with Nicholas Hill, and in conjunction with the English Heritage brief, a total of sixteen core samples was obtained, eight samples from the roof timbers and eight from the timbers of the inserted floor. It was noticed at the time of sampling that many of the timbers were wide grained and thus likely to have too few rings for satisfactory analysis, ie less than fifty-four. This was particularly so of the roof timbers and only the most promising timbers were selected. The timbers of the inserted floor, though being closer grained, were smaller.

Each sample was given the code HAL-D (for Hallaton, site "D") and numbered 01 - 16. The positions of these cores are shown on drawings made by Nicholas Hill and provided by English Heritage. These are reproduced here as Figures 6 - 8. Details of the samples are given in Table 1 and this can be used in conjunction with the drawing to locate the timbers sampled.

The Laboratory would like to take this opportunity to particularly thank the owner of this delightful cottage, Mrs Middleditch. Not only did Mrs Middleditch cooperate wholeheartedly with the project, helped in providing access to otherwise difficult to reach timbers by moving furniture etc, but also, and more importantly, provided a very fine and welcome pot of tea during sampling.

The Laboratory would also like to thank Nicholas Hill of English Heritage East Midlands Office in Northampton. Nicholas Hill not only assisted at the time of sampling, but also provided a clear and precise interpretation as to the phasing of the building and an excellent report on the site from which the introduction above is directly taken. Importantly for prompt publication of results Nicholas Hill also provided a full set of immediately usable drawings which are used as illustrations here to mark the position of the core samples.

Analysis

Each of the sixteen samples was prepared by sanding and polishing. It was seen at this point that five of the eight samples from the roof timbers and one from the ground-floor timbers had too few rings for satisfactory analysis, that is less than fifty-four rings, and these had to be rejected. The data of all ten measured samples is given at the end of the report. These measured samples were compared with each other by the Litton/Zainodin grouping procedure (see appendix). At a minimum t-value of 4.5 two groups of samples formed, the samples cross-matching with each other as shown in the bar diagrams, Figures 9 and 10.

The growth-ring widths of the two cross-matching groups of samples were combined at their indicated relative off-set positions to form site chronologies HALDSQ01 and HALDSQ02. Each site chronology was then compared with a series of relevant reference chronologies for oak. This indicated a date for only one site chronology, HALDSQ02. Evidence for this dating is given in the t-values of Table 2

The two site chronologies were then compared with the five remaining measured but ungrouped samples, but there was no further satisfactory cross-matching. Each of the five ungrouped samples was then compared individually with a full range of reference chronologies. This indicated a cross-match and date for one sample only, HAL-D10 with a first ring date of AD 1419 and a last ring date of AD 1488. Evidence for this dating is given in the t-values of Table 3. This analysis is summarised below:

Site chronology	Number of samples	Number of rings	Date span (where dated)
HALDSQ01	3	83	undated
HALDSQ02	2	67	AD 1403 - 1469
HAL-D10	--	70	AD 1419 - 1488

Interpretation

Analysis by dendrochronology has produced two site chronologies, only one of which can be dated, and dated one sample individually. The heartwood/sapwood date of sample HAL-D02 in the dated site chronology, HALDSQ02, from a roof timber, is AD 1469. If we use a 95% confidence limit for the amount of sapwood on mature oaks of 15 - 40 rings, this timber would have an estimated felling date in the range AD 1484 – 1509. It is probable that the timber represented by sample HAL-D07 is contemporary with that represented by sample HAL-D02.

The dated individual single sample is from a main ceiling beam of the inserted floor frame. This sample has 70 rings and is dated as spanning the years AD 1419 to AD 1488. This sample does not have the heartwood/sapwood boundary on it and it is thus not possible to estimate the felling date of the timber except to say that this is unlikely to be before AD 1503. This interpretation is summarised below

Site chronology	Sampling area	Sample numbers	Estimated felling date
HALDSQ02	Roof timbers	D02, D07	AD 1484 - 1509
	First-floor frame	D10	Not before AD 1503

Conclusion

The dating of two samples from the roof would indicate that these timbers probably are, as believed, of late fifteenth-century date, though there is a possibility that they are of early sixteenth-century date. It is probable that these two timbers represent the primary phase of construction but, given that the dating is based on only two samples, it is best to treat the results with some caution.

The single dated timber of the inserted ground-floor ceiling could, just, also be of the same date as the roof, but this is rather unlikely. It is more likely to have been felled later than those in the roof and is probably part of the supposed seventeenth-century frame. There was no evidence for re-use of this timber, or indeed any of the others in the floor frame. However, the dating and interpretation of the floor frame is based on a single sample and again it should be treated with caution.

Site chronology HALDSQ01 is made up of samples from joists in all three bays and although this site chronology is not dated it would suggest that at least some of the timbers are contemporary with each other. It cannot be said why site chronology HALDSQ01 does not date. With eighty-three rings it is certainly of satisfactory length and there is not usually a problem with this sort of material at its supposed date. Nor can it be said why site chronology HALDSQ01 does not cross-match with the sample, HAL-D10, from the main ceiling beam. Given that the timbers are of quite different sizes it is possible that they are from quite different sources and might therefore have sufficiently distinct growth rings to preclude cross-matching.

Analysis by dendrochronology has not been particularly successful in dating this site. Of the sixteen samples obtained only ten were suitable for tree-ring analysis in having at least fifty-four rings, and of these ten only three have dated. It will be seen from Table 1 that most of the samples have low numbers of rings, the longest sample still having only 70 rings. Such young trees are not conducive to satisfactory cross-matching and dating.

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Table 1: Details of samples from 10 - 14 Churchgate, Hallaton, Leicestershire

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Roof timbers (earlier phase)					
HAL-D01	Collar, truss 6	nm	---	------	------	------
HAL-D02	Collar, truss 5	60	h/s	AD 1410	AD 1469	AD 1469
HAL-D03	South upper brace, truss 5	nm	---	------	------	------
HAL-D04	South lower brace, truss 5	55	7	------	------	------
HAL-D05	South principal rafter, truss 4	nm	---	------	------	------
HAL-D06	North common rafter 1 to east of truss	nm	---	------	------	------
HAL-D07	North purlin, truss 3 - 4	61	no h/s	AD 1403	------	AD 1463
HAL-D08	South principal rafter, truss 2	nm	---	------	------	------
	Ground-floor ceiling joists (later phase)					
HAL-D09	Beam above door in partition wall	nm	---	------	------	------
HAL-D10	Main ceiling beam below truss 3 / 4	70	no h/s	AD 1419	------	AD 1488
HAL-D11	Joist 3 (from south) bay 3 (from west)	60	12	------	------	------
HAL-D12	Joist 5, bay 3	54	11	------	------	------
HAL-D13	Joist 6, bay 2	67	15	------	------	------
HAL-D14	Joist 7, bay 1	58	3	------	------	------
HAL-D15	Joist 8, bay 1	54	15	------	------	------
HAL-D16	Joist 9, bay 1	70	5	------	------	------

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

Table 2: Results of the cross-matching of chronology HALDSQ02 and relevant reference chronologies when the date of the first ring is AD 1403 and the last ring date is AD 1469

Reference chronology	Span of chronology	*t*-value	
Doncaster/Wakfield, Yorks	AD 1360 - 1564	6.4	(Morgan 1982)
High Street, Bruton, Somerset	AD 1318 - 1461	6.1	(Miles *et al* 1997)
Prior's Hall, Widdington, Essex	AD 1361 - 1578	5.6	(Tyers 2001)
England London	AD 413 - 1728	5.0	(Tyers 1999 unpubl)
Hill Wooton, Warwicks	AD 1392 - 1469	4.9	(Alcock *et al* 1989)
Lodge Park, Aldsworth, Glos	AD 1324 - 1587	4.8	(Howard *et al* 1995)
26 Westgate Street, Gloucester	AD 1399 - 1622	4.7	(Howard *et al* 1998)
Gotham Manor, Gotham, Notts	AD 1391 - 1590	4.6	(Howard *et al* 1991)
Mercer's Hall, Gloucester	AD 1289 - 1541	4.3	(Howard *et al* 1997a)
MC10---H	AD 1386 - 1585	4.2	(Fletcher 1978 unpubl)
Leicester Castle, Leicester	AD 1337 - 1486	4.1	(Howard *et al* 1986)
England	AD 401 - 1981	3.7	(Baillie and Pilcher 1982 unpubl)

Table 3: Results of the cross-matching of chronology HAL-D10 and relevant reference chronologies when the date of the first ring is AD 1419 and the last ring date is AD 1488

Reference chronology	Span of chronology	*t*-value	
Gotham Manor, Gotham, Notts	AD 1391 - 1590	6.5	(Howard *et al* 1991)
East Midlands	AD 882 - 1981	6.1	(Laxton and Litton 1988)
St Hugh's Choir, Lincoln Cathedral	AD 882 - 1391	5.5	(Laxton and Litton 1988)
Lodge Park, Aldsworth, Glos	AD 1324 - 1587	5.4	(Howard *et al* 1995)
Leicester Castle, Leicester	AD 1337 - 1486	5.2	(Howard *et al* 1986)
Thatched Cottage, Melbourne, Derbys	AD 1372 - 1530	5.2	(Howard *et al* 1997b)
Mansfield Woodhouse, Notts	AD 1432 - 1579	5.0	(Howard *et al* 1987)
Wales and West Midlands	AD 1341 - 1636	4.5	(Siebenlist-Kerner 1978)
MC10---H	AD 1386 - 1585	4.1	(Fletcher 1978 unpubl)

Figure 1: Map to show general location of Hallaton

Figure 2: Map to show location of 10 – 14 Churchgate

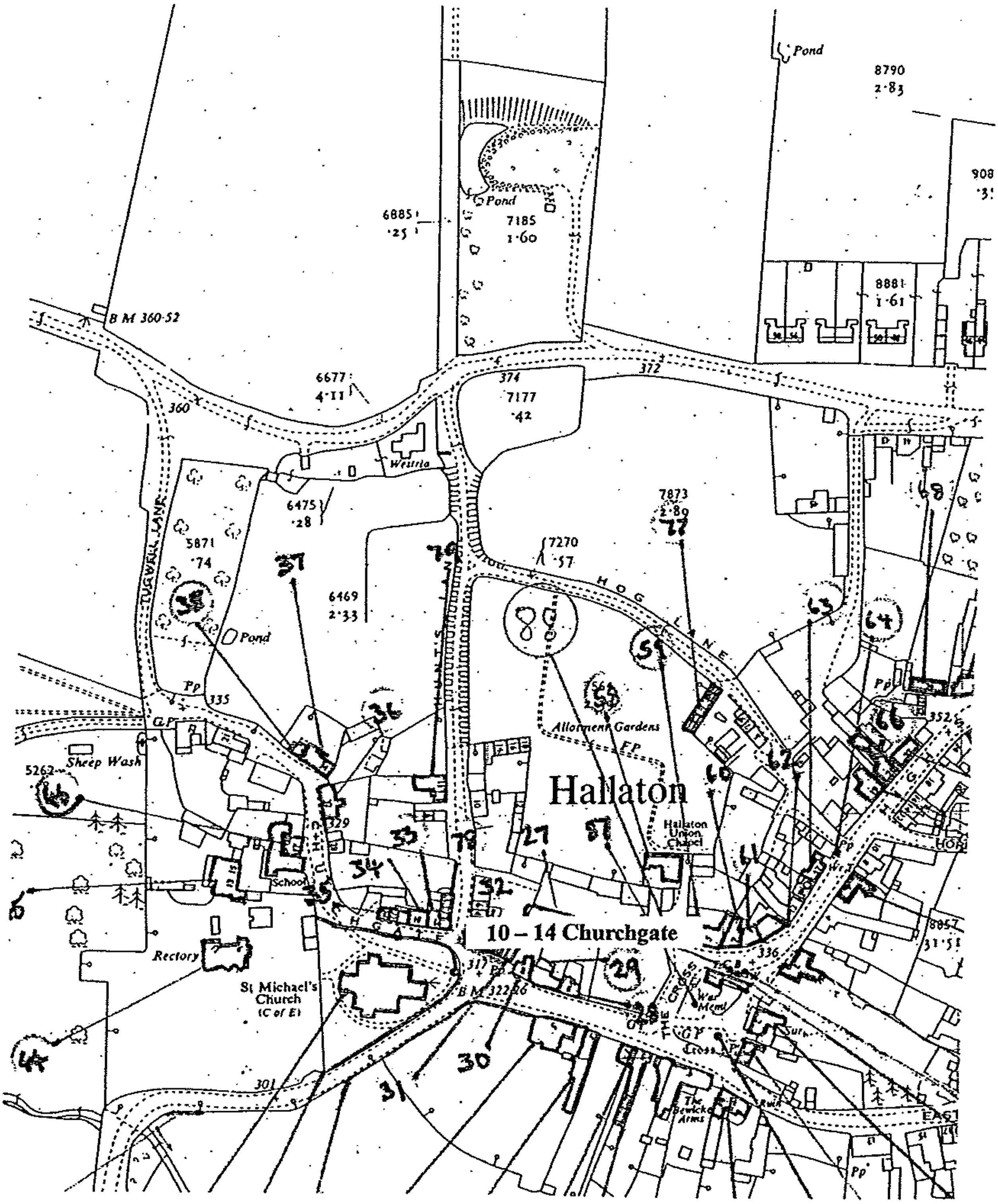


Figure 3: Drawing to illustrate truss 3, stub tiebeam form (viewed from the west)

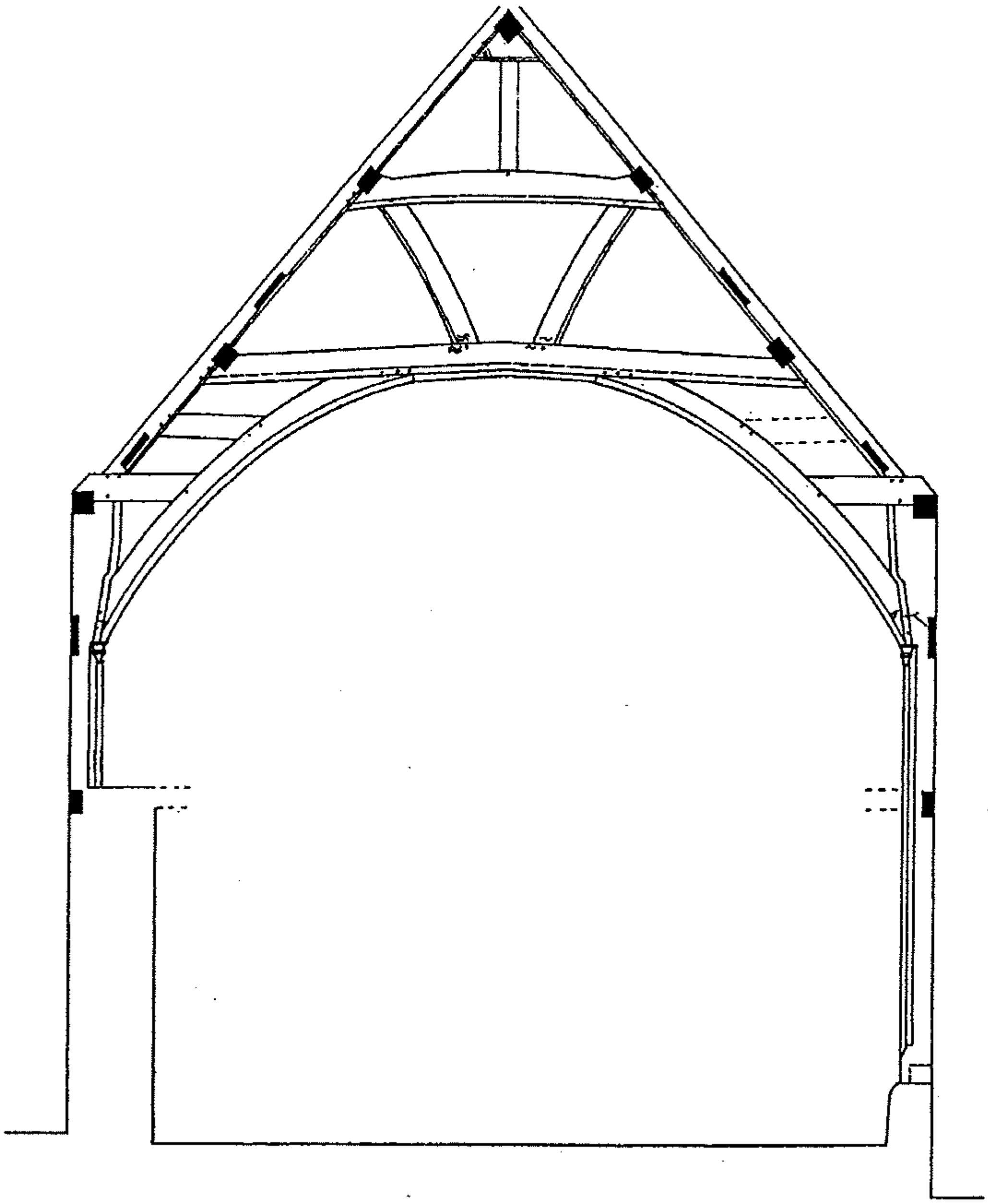


Figure 4: Drawing to illustrate truss 5
(viewed from the east)

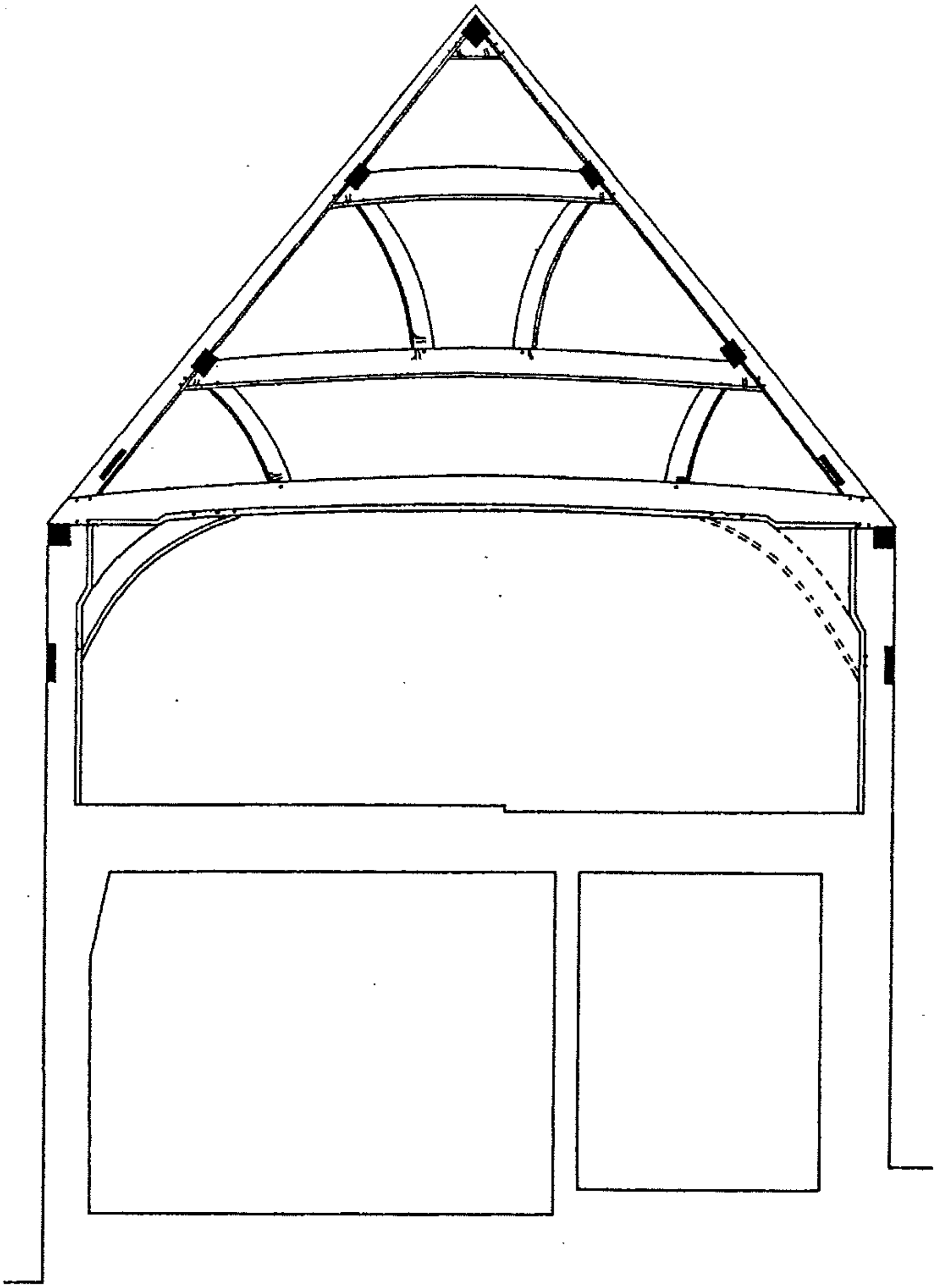


Figure 5: Drawing to illustrate truss 6, intermediate form (viewed from the west)

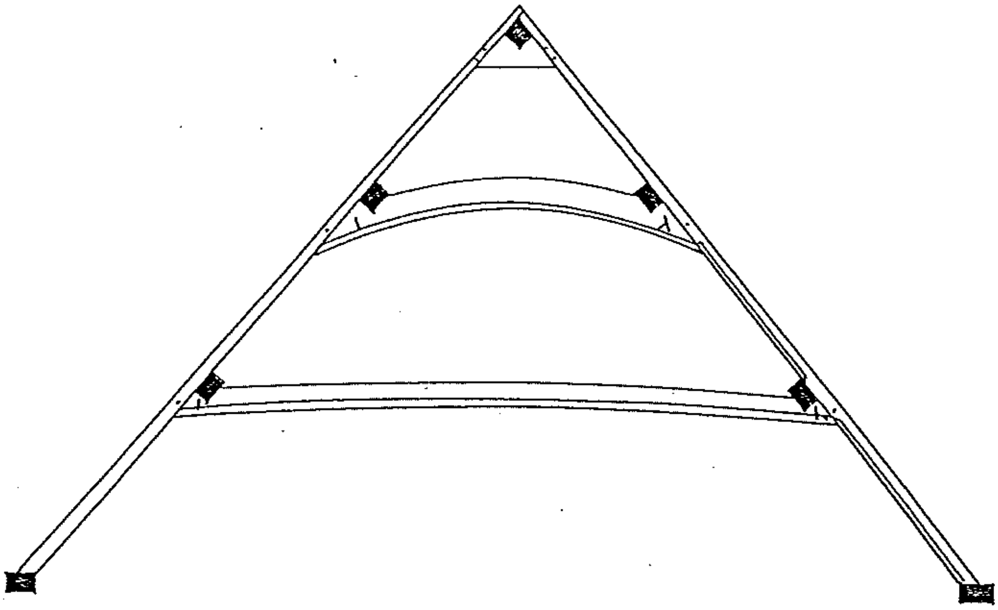


Figure 6: Long section to show timbers sampled
(viewed from the north looking south)

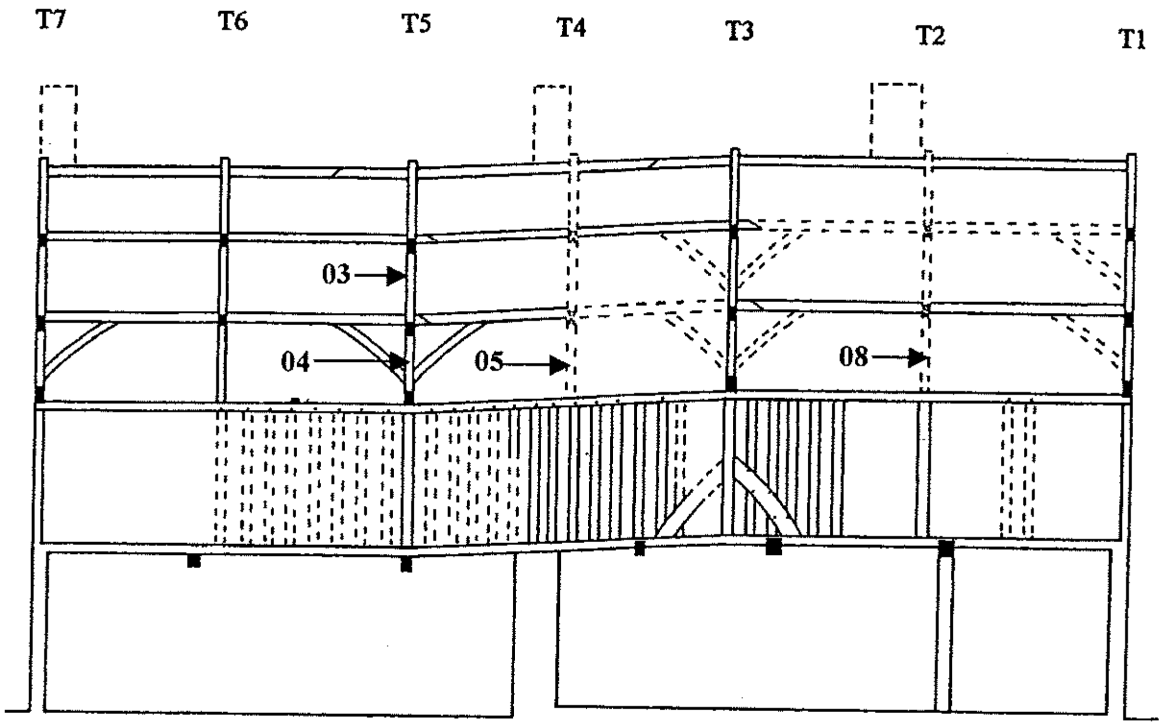


Figure 7: Long section to show timbers sampled (viewed from the south looking north)

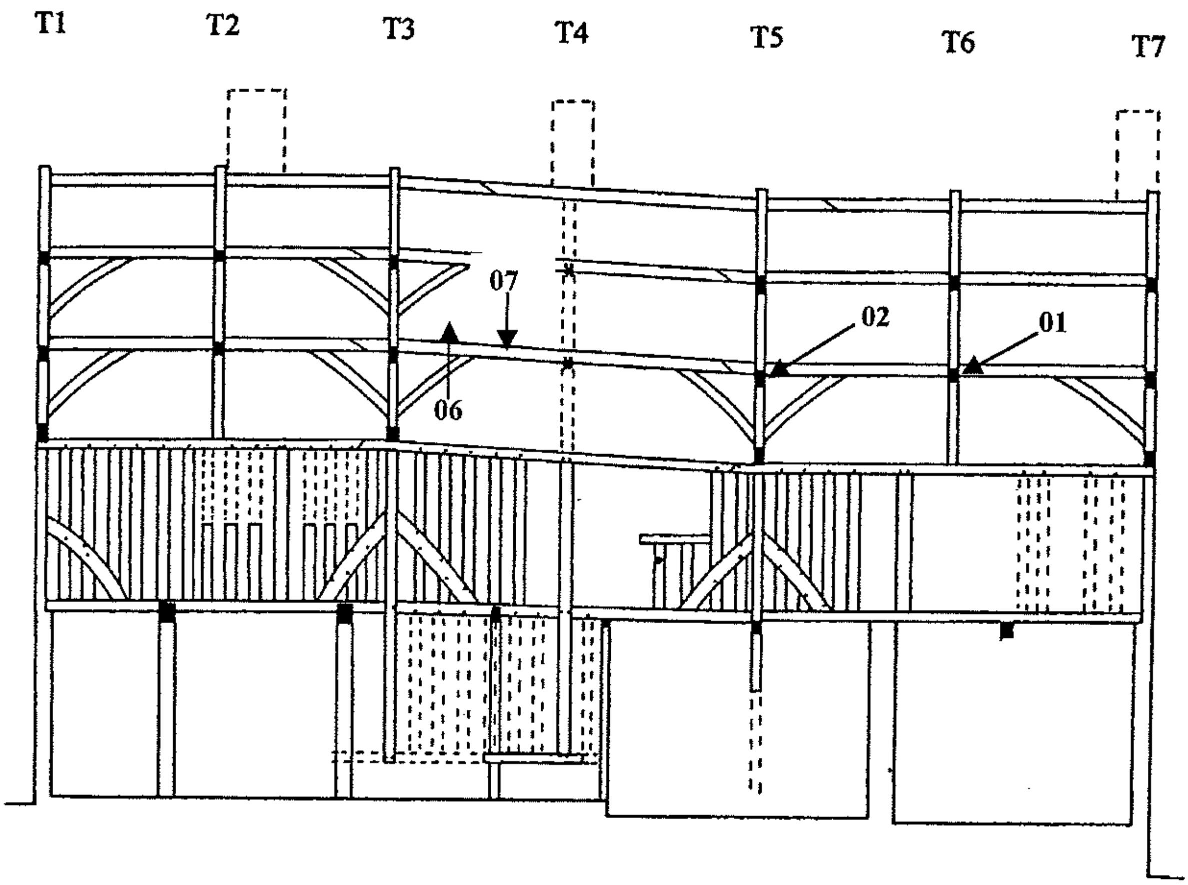


Figure 8: Plan to show position of sampled timbers from the ground-floor ceiling joists

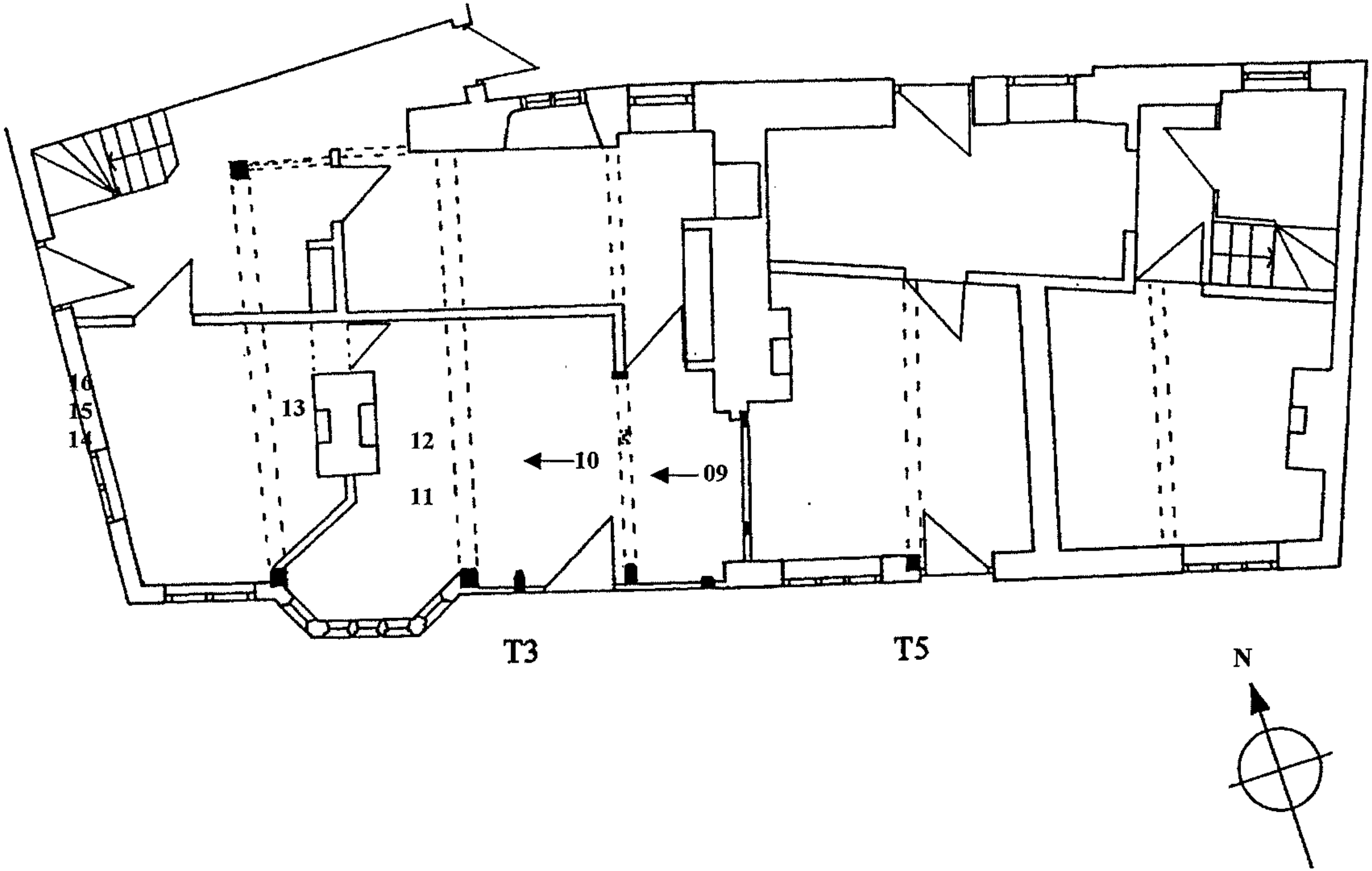


Figure 9: Bar diagrams of the samples in site chronology HALDSQ01

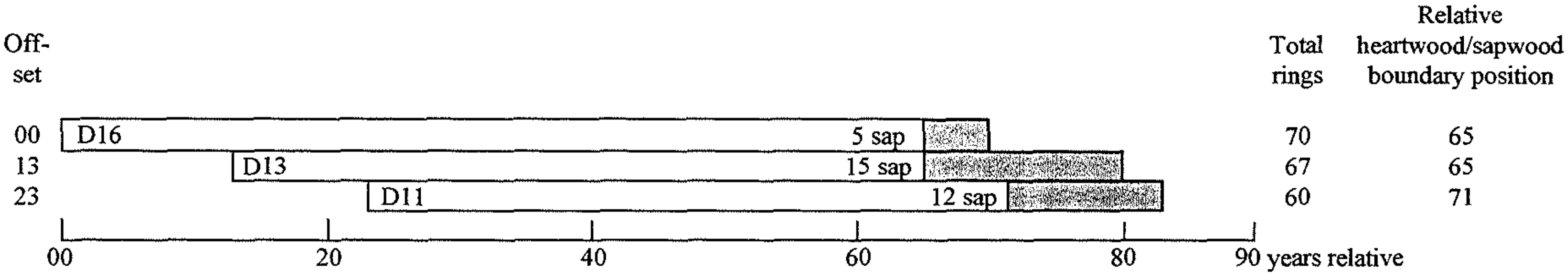
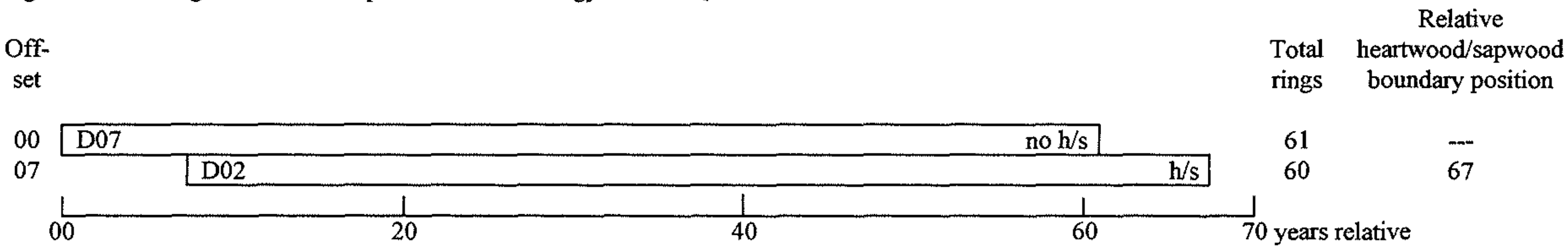


Figure 10: Bar diagrams of the samples in site chronology HALDSQ02



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

Data of measured samples – measurements in 0.01 mm units

HAL-D02A 60
192 232 275 213 314 247 335 318 272 137 315 274 164 205 212 227 152 149 204 164
110 171 267 109 125 123 180 140 115 136 114 143 113 155 128 113 312 267 284 330
353 478 333 273 276 392 353 298 265 315 256 214 124 143 104 112 146 134 143 131
HAL-D02B 60
199 231 259 207 313 246 330 325 266 141 305 276 164 204 220 207 147 152 208 160
111 163 269 129 115 115 164 137 93 133 107 142 106 145 150 116 315 257 263 325
351 483 340 266 267 394 367 294 263 240 250 210 128 144 105 112 140 116 147 177
HAL-D04A 55
301 376 327 409 227 192 303 271 338 189 500 357 325 189 222 256 269 297 369 217
194 239 296 310 196 265 189 248 190 183 195 188 159 151 166 176 140 132 115 85
86 121 140 147 138 137 238 207 182 224 231 285 288 231 200
HAL-D04B 55
319 363 298 413 226 200 296 195 339 190 505 358 331 192 219 256 269 291 370 227
206 235 302 301 206 258 194 234 200 182 201 194 150 155 164 178 136 128 117 74
109 121 160 144 131 155 215 214 196 224 218 274 280 228 201
HAL-D07A 61
351 473 372 363 211 289 221 163 185 219 186 224 285 218 282 279 201 202 214 152
201 207 187 159 271 264 221 151 193 250 207 232 242 270 223 188 186 178 156 169
277 271 191 293 277 246 264 271 366 349 284 239 231 340 287 336 298 360 305 199
252
HAL-D07B 61
296 479 373 397 191 289 189 150 176 214 192 223 274 231 288 283 212 203 205 164
195 213 184 164 241 256 234 144 173 255 218 230 248 269 233 165 197 174 150 163
263 300 192 250 247 253 271 258 356 357 272 239 266 316 300 335 312 357 297 219
198
HAL-D10A 70
179 191 166 186 263 187 112 86 154 188 157 104 186 177 157 170 146 168 158 142
91 128 196 156 206 140 124 112 115 129 174 136 157 187 156 198 162 162 117 88
127 148 161 110 146 100 113 117 149 159 115 136 127 127 103 123 138 131 116 98
143 112 162 146 106 115 119 114 167 140
HAL-D10B 70
145 190 172 191 266 196 110 87 156 193 144 107 187 220 162 174 143 189 152 131
108 133 203 161 203 143 127 111 113 128 158 117 160 179 159 202 134 163 119 92
126 161 129 132 151 93 110 116 145 161 105 146 124 127 103 124 144 132 106 134
127 114 164 144 106 102 134 112 162 151
HAL-D11A 60
210 143 117 179 276 211 139 146 147 120 181 201 186 145 233 199 203 198 239 200
230 382 429 259 230 231 148 228 206 137 211 309 217 250 237 291 277 298 362 336
376 464 323 252 392 279 253 253 298 164 256 263 245 236 306 213 204 200 154 182
HAL-D11B 60
238 148 114 174 305 205 135 146 145 126 175 199 190 159 232 197 203 206 240 204
219 376 421 268 218 253 137 225 208 145 201 307 223 249 233 297 278 288 357 354
373 441 338 274 381 285 245 299 274 208 262 260 238 229 286 262 209 190 133 212
HAL-D12A 54
223 320 291 263 172 165 276 231 182 218 201 210 327 275 215 147 226 253 205 264
282 268 203 195 171 244 377 297 261 253 214 284 155 286 224 197 173 187 183 209

173 183 184 231 300 165 276 291 172 280 231 187 218 200
HAL-D12B 54
282 321 296 244 187 160 283 231 187 217 199 228 316 287 216 141 210 251 224 274
261 258 211 194 173 225 379 301 274 247 204 277 164 281 238 201 165 183 187 205
180 173 187 222 310 244 187 296 160 283 230 182 217 198
HAL-D13A 67
263 294 271 158 132 123 219 200 540 275 215 181 107 193 243 169 108 119 84 102
103 130 148 117 190 168 152 128 172 173 142 156 231 155 116 168 102 234 266 183
283 253 266 266 208 234 219 244 263 202 391 196 184 218 312 211 189 248 238 141
229 150 176 222 199 164 139
HAL-D13B 67
257 301 283 181 136 123 245 207 536 269 222 169 130 186 212 164 108 115 92 97
109 133 133 128 183 172 151 113 185 163 147 159 222 142 117 177 111 223 241 200
291 260 272 272 211 228 242 249 245 204 376 193 180 197 340 193 191 236 235 143
219 182 192 197 198 175 144
HAL-D14A 58
179 80 63 81 82 102 104 87 109 90 117 133 144 168 165 153 163 216 91 84
66 84 80 81 115 150 175 160 185 220 209 195 208 216 316 271 339 392 300 297
289 258 236 280 269 229 252 267 362 317 398 451 401 317 269 213 136 197
HAL-D14B 58
187 75 79 81 88 113 88 96 105 89 113 132 135 171 164 146 179 214 96 87
63 88 82 76 120 148 170 162 198 213 219 192 188 230 323 279 343 398 300 309
282 252 243 283 219 226 253 265 362 264 404 452 391 325 270 225 146 178
HAL-D15A 54
201 308 378 268 358 312 253 230 225 296 319 360 348 311 510 375 357 405 389 329
363 330 376 469 387 418 441 431 362 315 309 275 320 209 260 341 257 270 259 256
250 311 256 258 203 246 218 236 173 150 228 166 193 215
HAL-D15B 54
189 283 382 272 361 325 251 219 207 314 288 350 331 296 481 362 363 395 390 327
354 349 382 448 400 409 452 434 334 317 312 277 307 217 261 333 279 252 255 276
232 295 257 238 211 265 220 220 154 170 244 173 196 230
HAL-D16A 70
183 228 194 184 219 214 156 141 77 106 93 176 262 210 194 104 113 149 113 158
138 539 220 159 148 127 205 228 135 105 110 89 101 137 120 141 101 142 134 122
106 146 125 128 130 230 160 126 157 115 203 223 151 221 241 230 212 176 197 234
245 216 190 356 205 140 149 274 150 145
HAL-D16B 70
201 228 191 190 224 216 161 129 83 107 106 168 270 196 209 92 116 144 113 171
120 543 220 159 148 123 210 230 128 101 117 99 93 145 132 135 99 153 134 116
107 154 130 118 143 232 157 117 153 109 188 206 160 219 243 239 204 167 194 219
245 204 175 359 181 158 159 275 163 157

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.

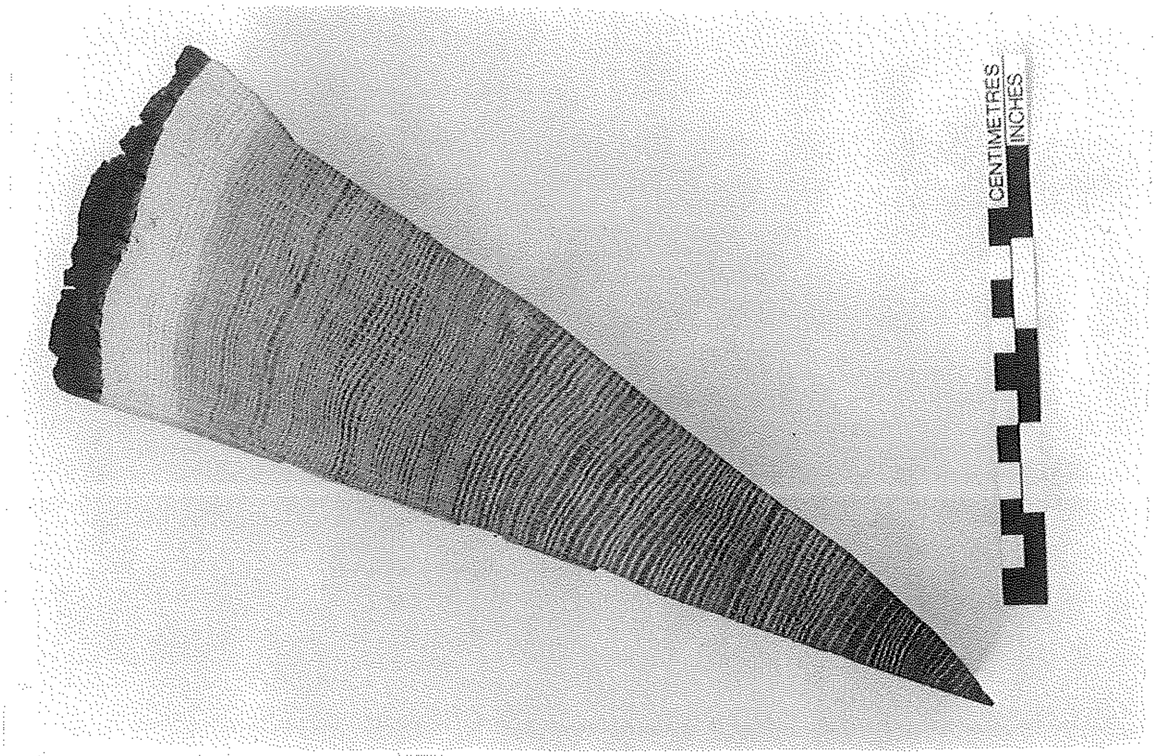


Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

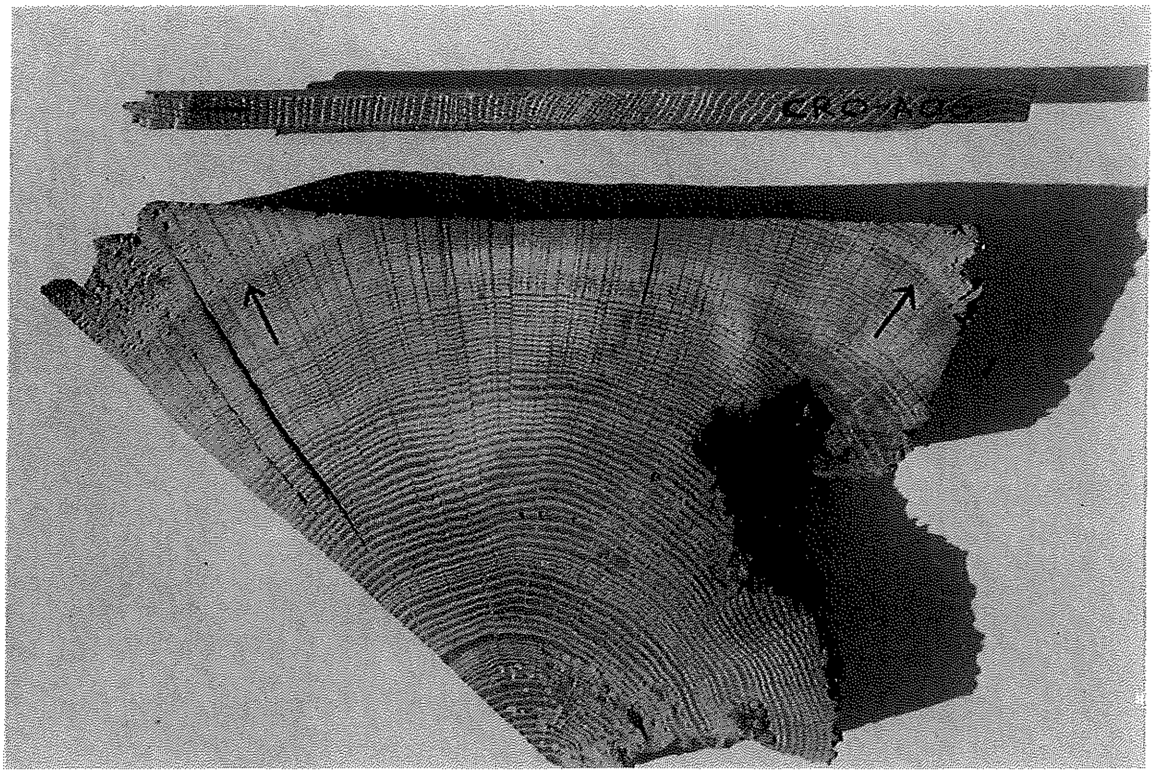


Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners; the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

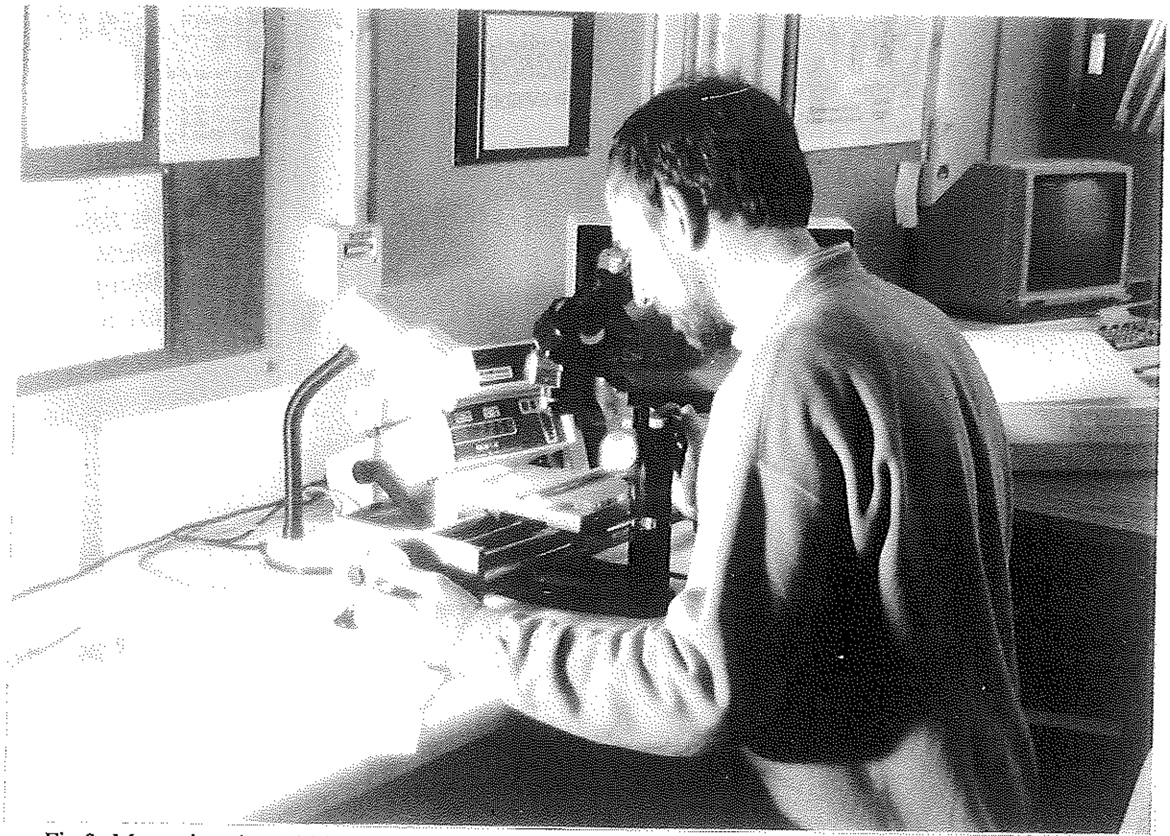


Fig 3. Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measured twice to ensure that an error has not been made. This type of apparatus is needed to process a large number of samples on a regular basis.

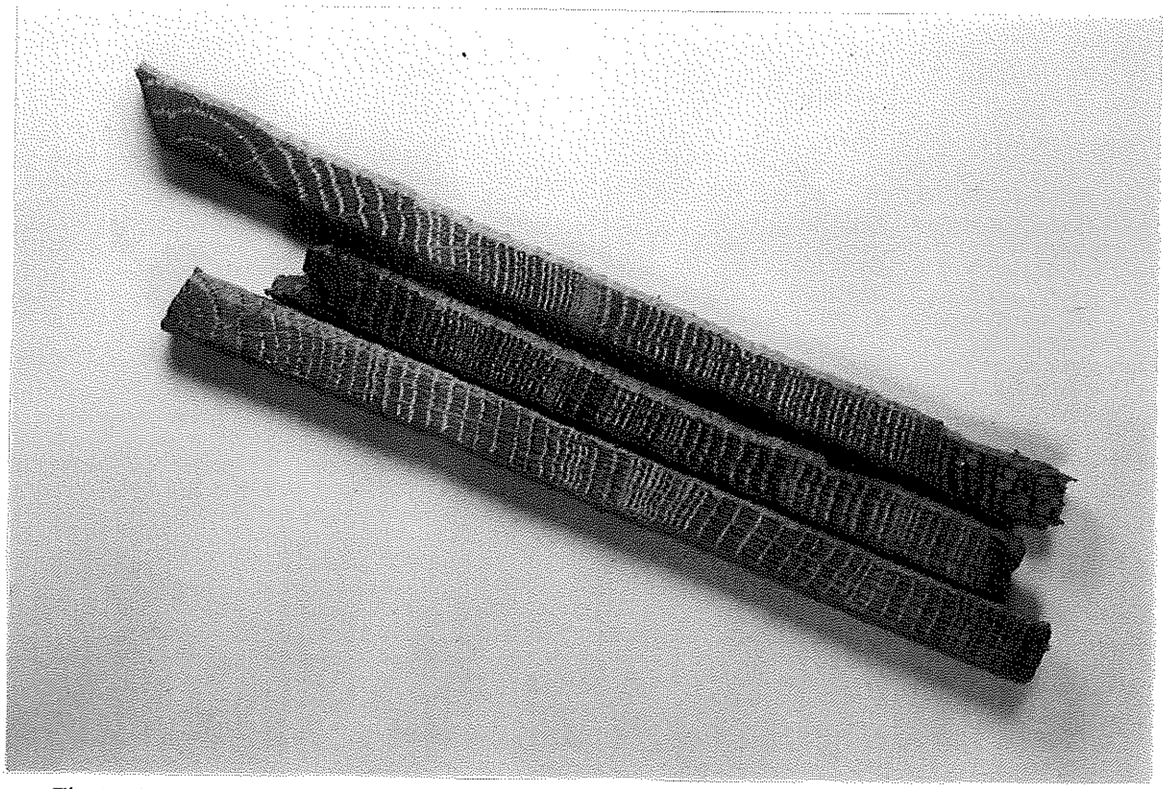


Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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.

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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

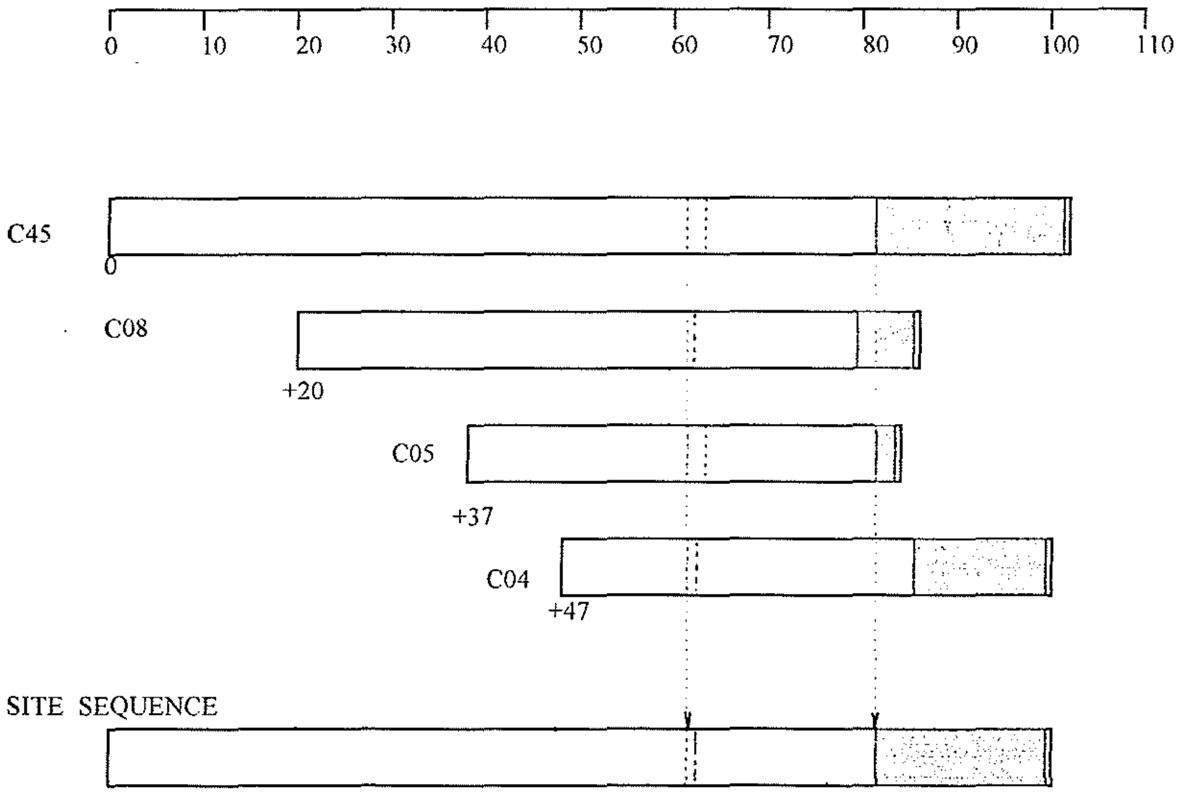

Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.
The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set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

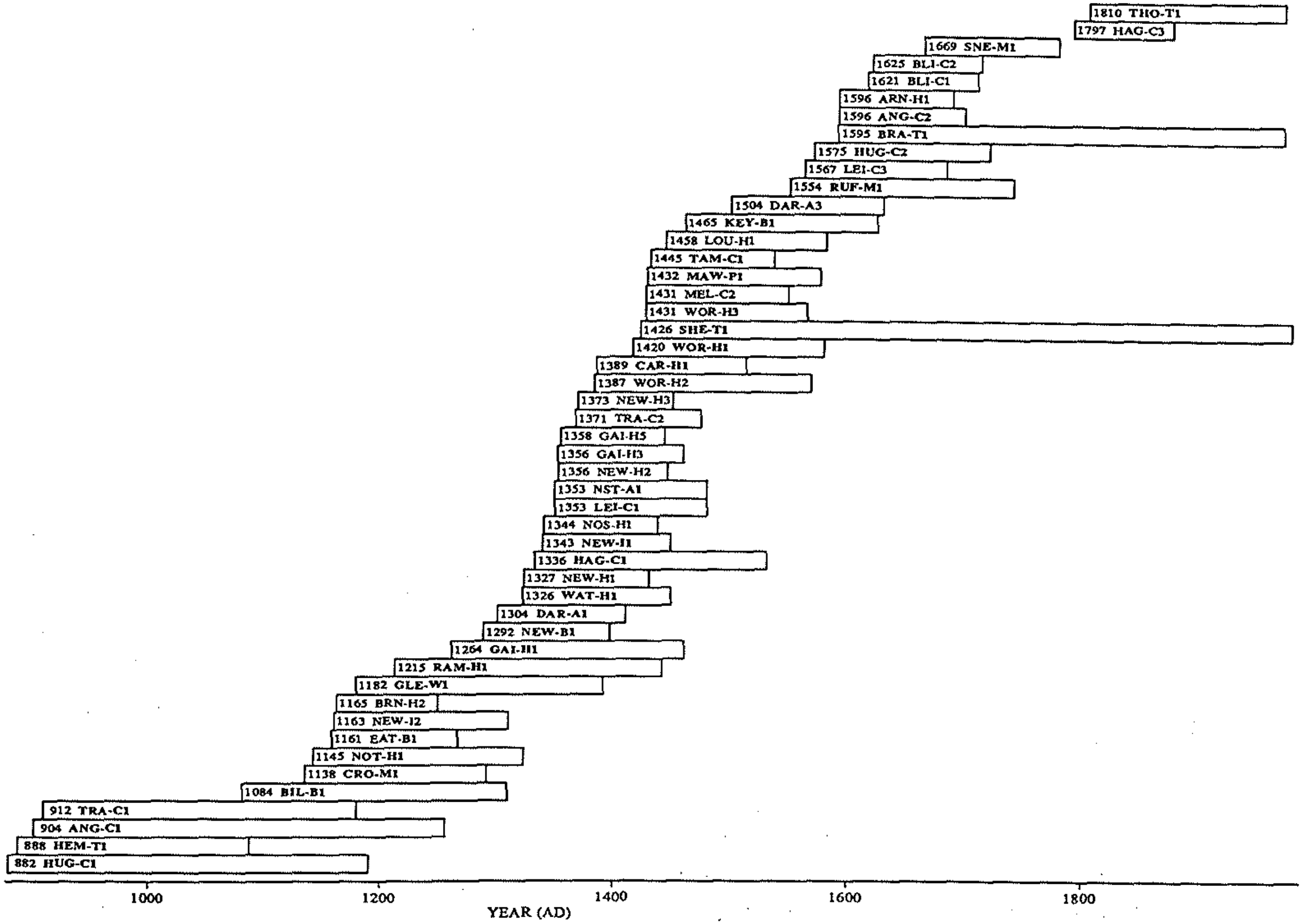

Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

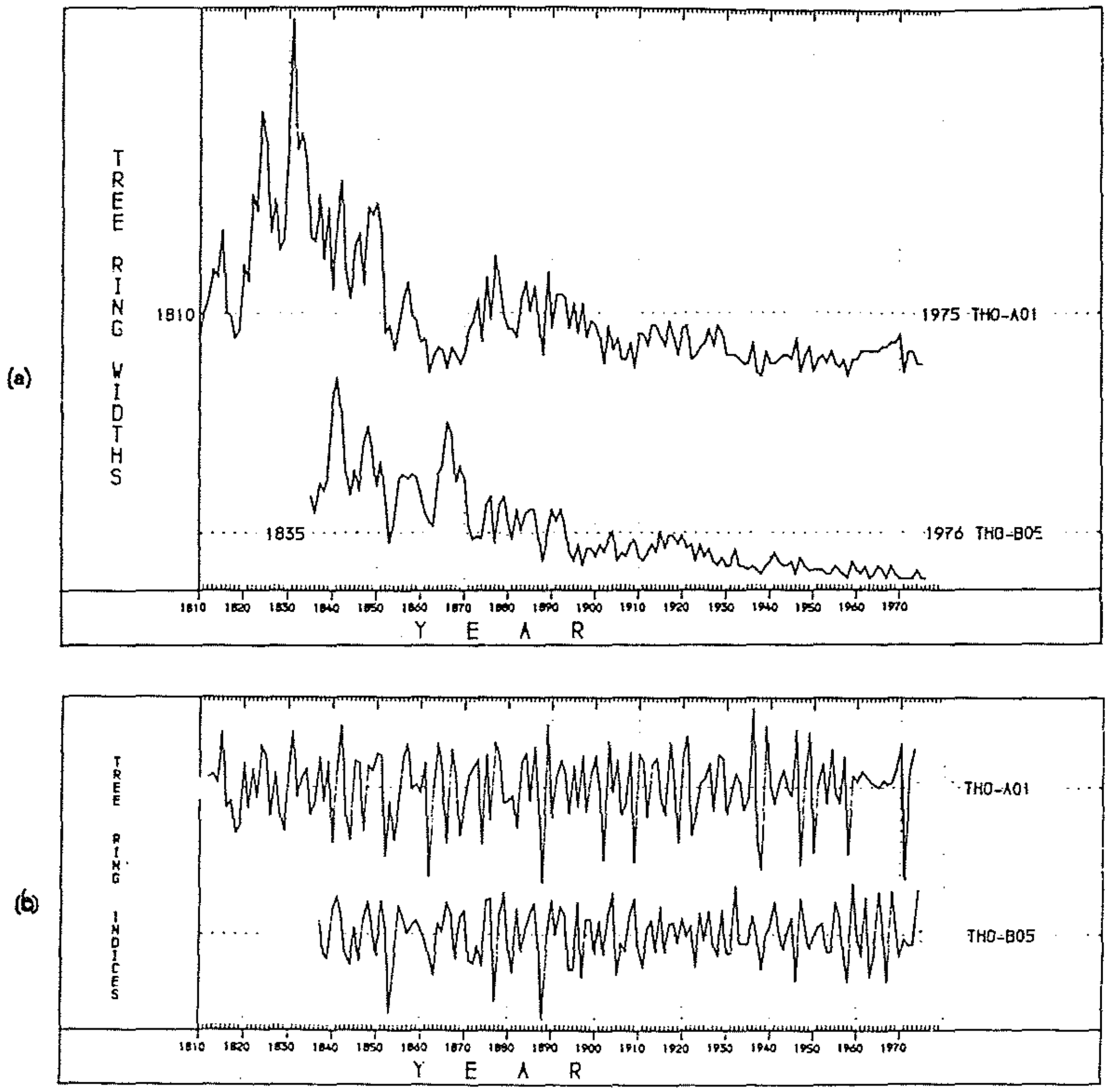

Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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