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with an introduction by Richard Bond



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# Tree-Ring Analysis of Timbers from Clothall Bury Barn, Wallingford, near Baldock, Hertfordshire

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**Summary**

A total of sixteen samples was obtained from a wide range of timbers at this barn at Clothall Bury, Hertfordshire. The analysis of these produced a single site chronology consisting of twelve samples having an overall combined length of 115 rings. This site chronology was dated as spanning the years AD 1253 to AD 1367.

Interpretation of the sapwood, and the relative positions of the heartwood sapwood boundaries on the dated samples, would suggest that all of them represent timbers with a felling date of AD 1367.

**Keywords**

Dendrochronology
Standing Building

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## Introduction

Clothall Bury Barn, Wallingford, is situated near Baldock in Hertfordshire (TL 289320; Figs 1 and 2). The barn is presently listed grade II and described as dating from the sixteenth century. The building is timber-framed and the side and end wall frames are infilled with brick. The walls are weatherboarded externally and the roof is clad in corrugated metal sheeting. The barn is aisled and divided internally into seven bays by six intermediate cross frames. Each cross frame comprises a pair of arcade posts linked by a tie beam, above which are two angled struts clasping a pair of side purlins. An illustrative example of a truss is given in Figure 3. There are two gabled cart entrances on the western side, and on the east side, opposite the northern cart entrance, is a late nineteenth- century threshing bay with white brick walls and a low-pitched slate roof.

The timber frame of the barn includes a large number of reused elements salvaged from an earlier barn on the site, or brought from elsewhere. A number of arcade posts and tie beams include empty mortices redundant in the context of the present building, suggesting that the timbers themselves are probably reused. Potentially, a number of the less obviously reused timbers in the barn could also be reused. Some of the reused tie beams include a halving for a lap-jointed timber at, or close to, their centre. There is only ever one such halving per beam, and these are always for a timber that intersected from the east side of the tie beam, never the west side. Whether the empty halvings relate to a former arrangement of passing braces in the present barn or some other building to which the tie beams belonged, is not known. The present barn includes softwood passing braces extending from the aisle wall posts to the tie beam on the east side only, and these appear to be of fairly recent date. It is clear that the building from which the existing reused arcade posts were salvaged had passing braces (the empty halvings for these can be seen on the faces of the posts). Just below the level of the empty halvings can be seen an empty mortice in the rear (outer) face of the reused arcade posts. These mortices were for an earlier set of aisle tie beams serving the same purpose as the existing aisle ties, but which were situated at a lower level in relation to the tie beams.

The feet of the arcade posts of the intermediate cross frames are morticed into transverse timber sill beams sitting on brick plinths. The external wall frames originally had a fairly high brick plinth, but large parts of the original brickwork has been lost or replaced. The external walls have brick infilling between the vertical timbers of the wall frames. Many of the brick infill panels have been replaced, however the earliest areas of brickwork which appear to be original *in situ* panels, have 2" bricks of probable sixteenth- or seventeenth-century date.

The arcade plates and wall plates have edge-halved scarf joints (two pegs at each end, one above the other), stylistically dateable to the late-sixteenth or seventeenth centuries. The timbers are scarfed together at every cross frame. The side purlins in the roof frame are similarly joined together at each roof truss with simple splay-halved scarf joints.

As was common practice, the timbers were numbered (using a modified style of Roman numerals) in the carpenter's yard during the pre-fabrication stage to ensure the correct matching together of the various framing elements during the final assembly of the roof frame on site. Whereas normally a reused timber might exhibit two different sets of carpenter's marks – one relating to the present use of the timber and the other to its previous use – in this building the more obviously reused timbers (the arcade posts, for example) appear to exhibit just one set of carpenter's marks relating to the current configuration of the timber frame. Whether there was an earlier pattern of carpenter's marks on the reused timbers, but these have been lost through timber decay or the timbers being truncated prior to their use in the present building, is not known. The carpenter's numbers applied to the timbers during the construction of the present barn are small, chisel-cut marks. All of the arcade braces and their corresponding mortices in the arcade posts on the east side of the barn are numbered. The numbering runs in correct order from north to south. There is no equivalent set of marks on the west side of the building. Where the timber frame has come apart at the north-west corner of the building, it can be seen that the underside of the aisle ties were also numbered. The aisle tie here is marked with the number IIII (ie 4) suggesting that the numbering sequence of the aisle ties on the west side ran in the opposite direction to the arcade braces on the east side.

The two cart entrances on the west side of the barn are original to the construction of the present building. The wall plates of the gabled entrances take the place of aisle tie beams, and are set at a slightly higher level. The pattern of carpenter's marks found on the aisle ties (see above) also agrees with the present arrangement of cart entrances along the west side, ie there are only four aisle ties (as such) on this side of the building – the north-west aisle tie being marked number IIII – whereas along the east side there are eight aisle tie beams, all set at the same height above ground level.

A plan drawn by Richard Bond of English Heritage showing the position of reused or repositioned timbers is given in Figure 4.

## Sampling

Sampling and analysis by tree-ring dating of timbers from the barn were commissioned by English Heritage. The purpose of this was to provide a precise date for the primary construction phase, and any subsequent alterations or repairs, to inform a potential listing upgrade.

After on-site discussions with Richard Bond, and in conjunction with the English Heritage brief, a total of sixteen core samples was obtained from the available timbers. Both those timbers that were obviously reused or repositioned, as well as those which showed no evidence for reuse were sampled. Each sample was given the code CLB-A (for Clothall Bury, site "A"), and numbered 01 – 16. Timbers were selected for sampling on the basis of their appearing to have sufficient rings for satisfactory analysis by tree-ring dating. In this respect a number of them, both those with evidence of reuse and those without, had to be rejected because, although being large timbers, they appeared to have too few rings for satisfactory analysis. Timbers were also selected on the basis of their having at least the heartwood/sapwood boundary.

The positions of the timbers sampled are shown in Figures 5a to 5e, using a drawing of a typical cross frame provided by Richard Bond. Details of the samples are given in Table 1. In this report the trusses have been numbered from north to south, with individual timbers being described on a north - south, or east - west basis, as appropriate.

The Laboratory would like to take this opportunity of thanking the owners of the barn, Mr and Mrs Haltom, for allowing sampling, for being so enthusiastic about the project, and for the hospitality during a few cold days sampling in December. The Laboratory would also like to thank Richard Bond for not only providing much of the introductory paragraph above, but also for his clear advice and discussion about the possible phasing of the timbers. Richard Bond also provided immediately useable drawings upon which to show sample locations.

## Analysis

Each of the sixteen samples was prepared by sanding and polishing and their annual growth-ring widths were 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 a single site chronology, CLBASQ01, consisting of twelve samples of combined overall length 115 rings was formed. A bar diagram showing the relative positions of the samples in this site chronology is given in Figure 6. Site chronology CLBASQ01 was then compared with a large number of relevant reference chronologies for oak. This indicated a consistent cross-match with a number of these when the date of its first ring is AD 1253 and the date of its last measured ring is AD 1367. The *t*-values for this cross-matching are given in Table 2.

Site chronology CLBASQ01 was then compared with the four remaining ungrouped samples but there was no further satisfactory cross-matching. Each of the four remaining ungrouped samples was then compared individually with the reference chronologies, but again there was no satisfactory cross-matching, and these samples must remain undated.

## Interpretation and conclusion

Analysis by dendrochronology has produced a single site chronology made up of material obtained from a wide spread of locations within the barn at Clothall Bury. This site chronology consists of twelve samples and is 115 rings long, these rings being dated as spanning the period AD 1253 to AD 1367.

Only one of the samples, CLB-A13, in site chronology CLBASQ01 retains complete sapwood, this having a last measured, complete, sapwood ring date of AD 1367. The relative positions of the heartwood/sapwood boundaries on all the other dated samples, including those from both reused and apparently non-reused timbers, is indicative of a group of timbers with a single felling date and all these others were almost certainly felled in AD 1367 too.

Such a felling date would thus not immediately appear consistent with the supposed sixteenth-century date ascribed to the barn in the site listing description, but would indicate that many of the timbers, at least, are perhaps as much as two hundred years older. Given the evidence of empty mortices and lap joints etc, it is almost certain that the barn has been substantially altered with some timbers also being moved, possibly, on the basis of its current stylistic form, in the sixteenth century.

What tree-ring dating has not been able to demonstrate is when this major alteration occurred, as all dated timbers are dated to the late fourteenth century. This may be a result of the sample selection process in that only those timbers with sufficient rings, which may only be the earlier ones, were selected. The timbers with wider and fewer rings, which were rejected, might belong to the later alteration phase. It is felt that the sampling of such wide-ringed timbers would not be worthwhile. It might be pointed out though that some timbers with clear evidence for an earlier use were also rejected as having too few rings. In any case, the results obtained here thus reinforce the benefits of applying tree-ring analysis to buildings which are thought to be reliably tightly dated on the basis of architectural styles but the timbers of which show evidence of reuse.

Four samples remain undated, all four having low numbers of rings, with three of them also having complacent ring-growth as well. It is probably these features that makes cross-matching and dating difficult.

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Table 1: Details of samples from Clothall Bury Barn, Wallingford, near Baldock, Hertfordshire

| Sample number | Sample location | Total rings | *Sapwood rings | First measured ring date | Last heartwood ring date | Last measured ring date |
|---|---|---|---|---|---|---|
| CLB-A01 | West arcade post, truss 1 ® | 91 | h/s | AD 1258 | AD 1348 | AD 1348 |
| CLB-A02 | West arcade post, truss 6 | 83 | h/s | AD 1259 | AD 1341 | AD 1341 |
| CLB-A03 | West arcade post, truss 2 ® | 64 | no h/s | AD 1257 | ------ | AD 1320 |
| CLB-A04 | East strut, stub tiebeam - wall post, truss 2 | 69 | no h/s | AD 1262 | ------ | AD 1330 |
| CLB-A05 | South arcade brace, east arcade post, truss 2 | 69 | h/s | AD 1273 | AD 1341 | AD 1341 |
| CLB-A06 | East arcade post, truss 5 ® | 74 | h/s | AD 1269 | AD 1342 | AD 1342 |
| CLB-A07 | West arcade post, truss 5 ® | 62 | no h/s | AD 1270 | ------ | AD 1331 |
| CLB-A08 | North arcade brace, west arcade post, truss 7 | 85 | 14 | AD 1272 | AD 1342 | AD 1356 |
| CLB-A09 | Collar, truss 5 ® | 87 | h/s | AD 1253 | AD 1339 | AD 1339 |
| CLB-A10 | South arcade brace, east arcade post, truss 5 | 54 | 4 | ------ | ------ | ------ |
| CLB-A11 | West strut, stub tiebeam - wall post, truss 5 | 54 | 2 | ------ | ------ | ------ |
| CLB-A12 | Collar, truss 7 ® | 80 | h/s | AD 1264 | AD 1343 | AD 1343 |
| CLB-A13 | South arcade brace, east arcade post, truss 7 | 87 | 22C | AD 1281 | AD 1345 | AD 1367 |
| CLB-A14 | North arcade brace, east arcade post, truss 2 | 65 | no h/s | AD 1271 | ------ | AD 1335 |
| CLB-A15 | East arcade post, truss 2 ® | 60 | h/s | ------ | ------ | ------ |
| CLB-A16 | West arcade post, truss 7 | 56 | h/s | ------ | ------ | ------ |

*h/s = the heartwood/sapwood boundary is the last ring on the sample
C = complete sapwood retained on sample, last measured ring date is the felling date of the timber
® = timber shows evidence of reuse / repositioning

Table 2: Results of the cross-matching of site chronology CLBASQ01 and relevant reference chronologies when first ring date is AD 1253 and last ring date is AD 1367

| Reference chronology | Span of chronology | *t*-value | |
|---|---|---|---|
| Chicksands Priory, Beds | AD 1200 - 1541 | 7.9 | ( Howard *et al* 1998 ) |
| Reading Waterfront, Berks | AD 1160 - 1407 | 7.5 | ( Groves *et al* 1997 ) |
| Ramsey, Cambs | AD 1215 - 1443 | 6.5 | ( Laxton and Litton 1988 ) |
| Lacock Abbey, Wilts | AD 1314 - 1448 | 6.1 | ( Esling *et al* 1990 ) |
| Stowmarket Church, Suffolk | AD 1251 - 1363 | 5.5 | ( Howard *et al* 1994 ) |
| Thame Park House, Thame, Oxon | AD 1234 - 1319 | 5.2 | ( Howard *et al* 1993 ) |
| East Midlands | AD 882 - 1981 | 5.1 | ( Laxton and Litton 1988 ) |
| England London | AD 413 - 1728 | 4.8 | ( Tyers and Groves 1999 unpubl ) |

**Figure 1: Map to show general location of Clothall Bury**

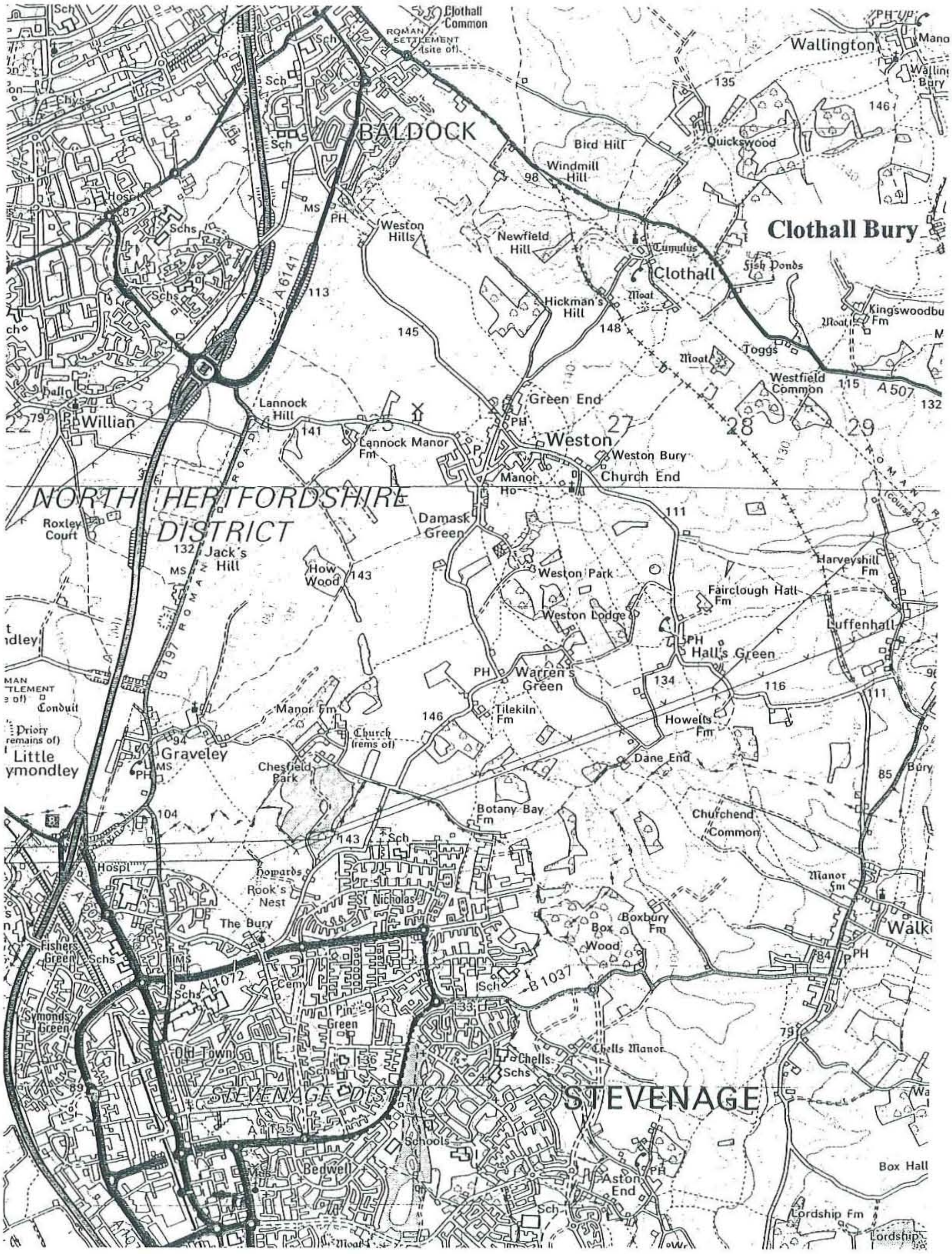


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**Figure 2: Map to show specific location of Clothall Bury Barn**

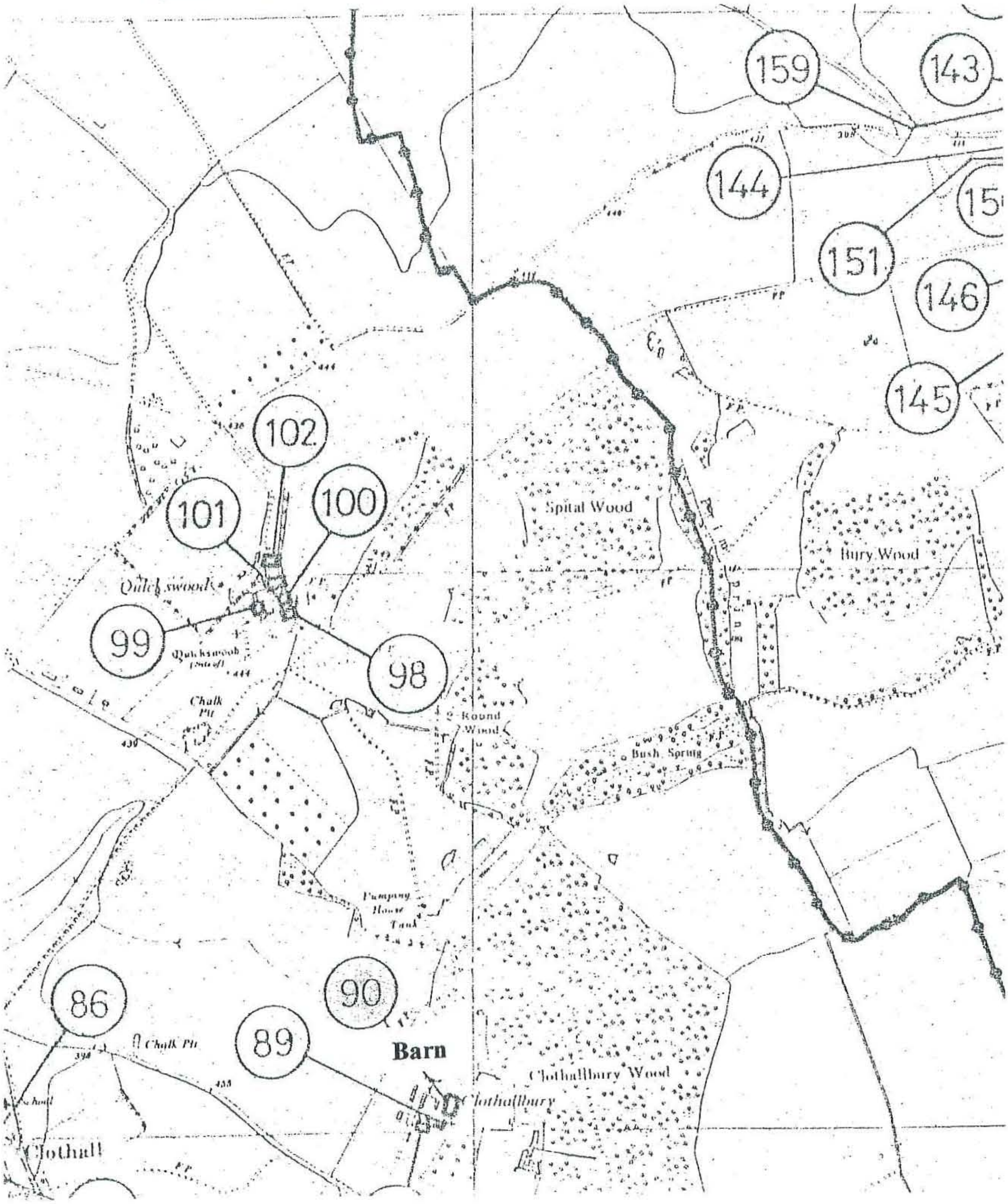


**Figure 3: Illustrative example of a typical truss**

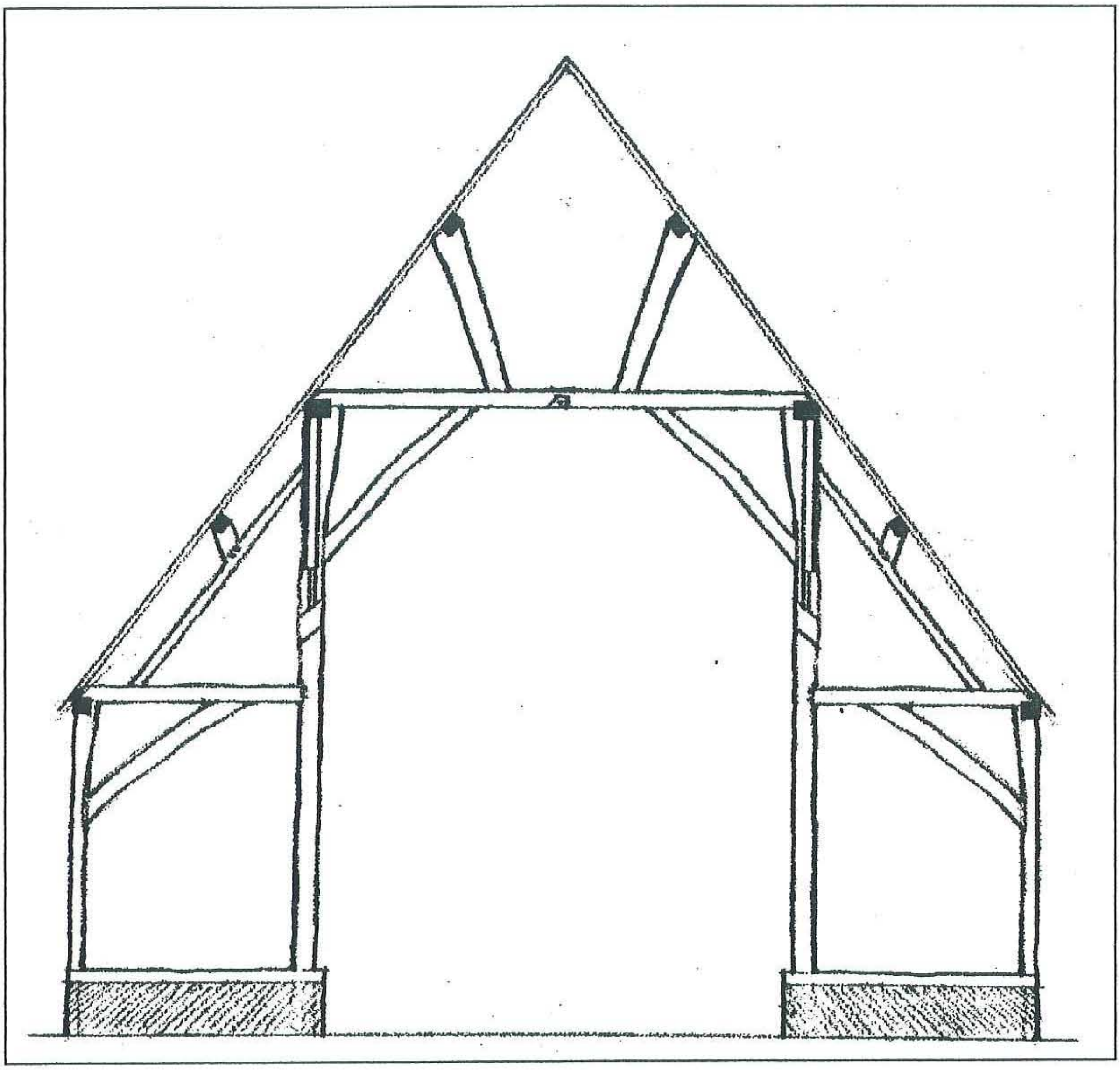
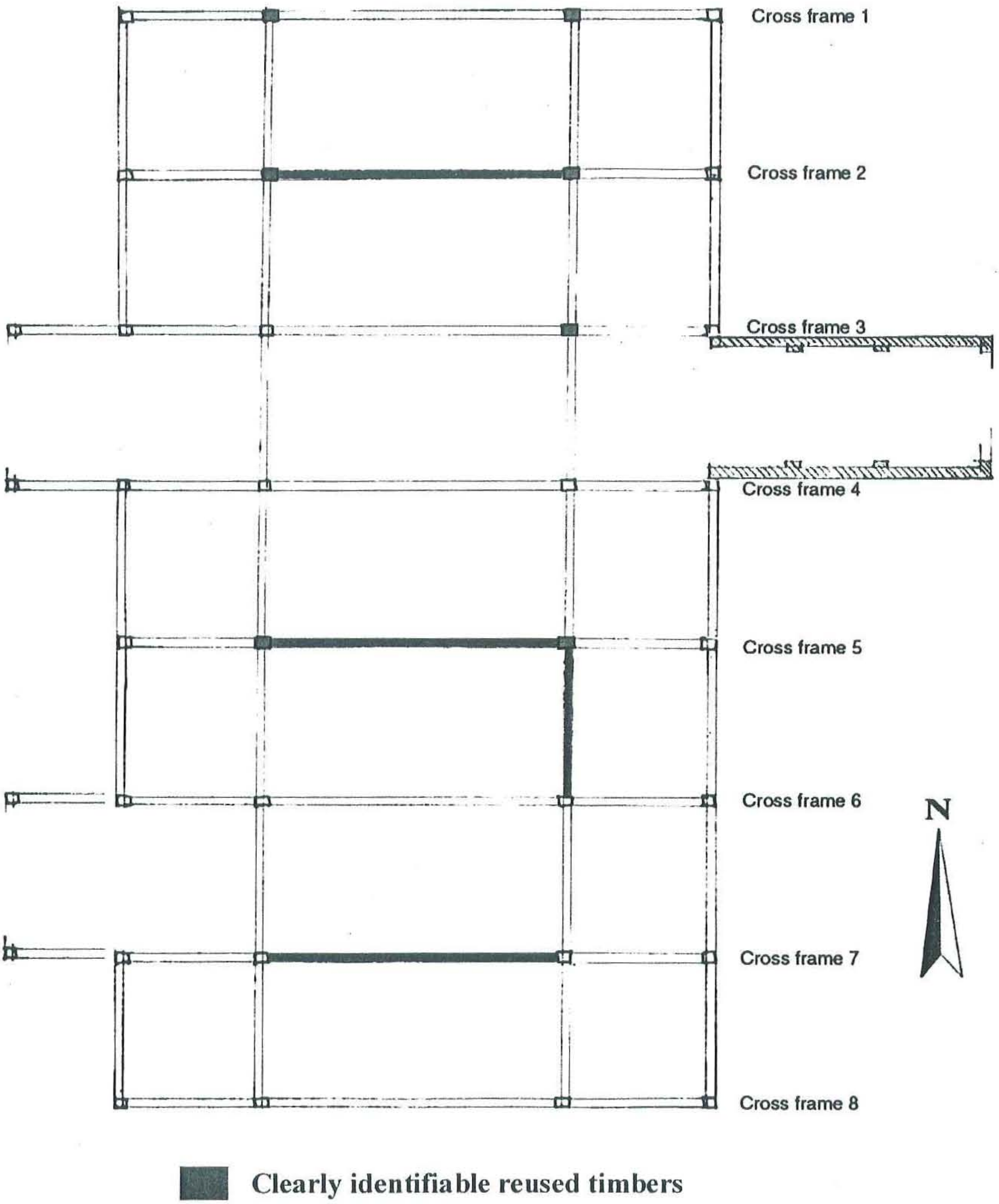


**Figure 4: Plan to show reused timbers**




Sketch Plan (not to scale)

**Figure 5a: Drawing to show position of timbers sampled from truss 1 (drawing based on a typical truss viewed from the south looking north)**

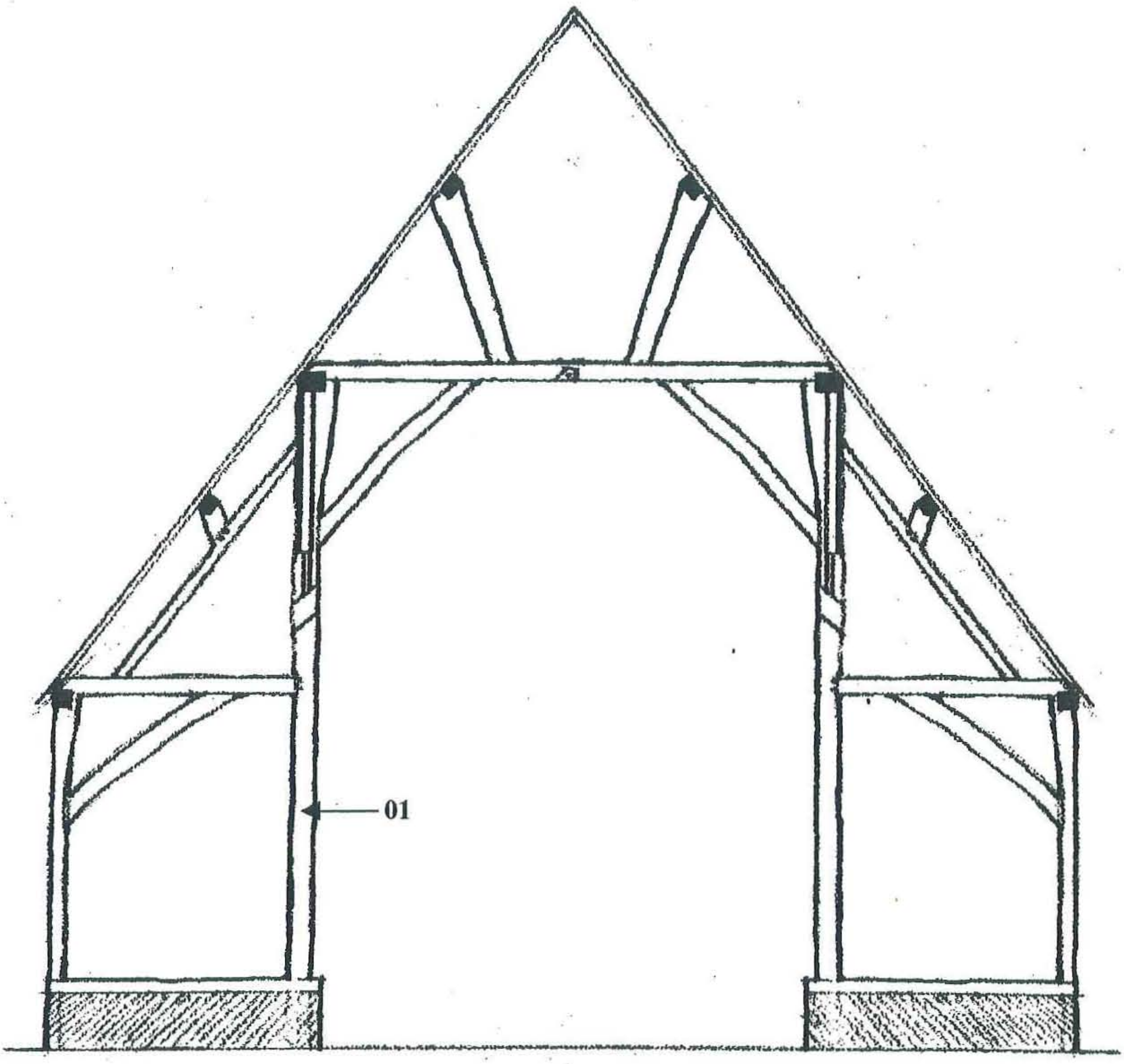


**Figure 5b: Drawing to show position of timbers sampled from truss 2 (drawing based on a typical truss viewed from the south looking north)**

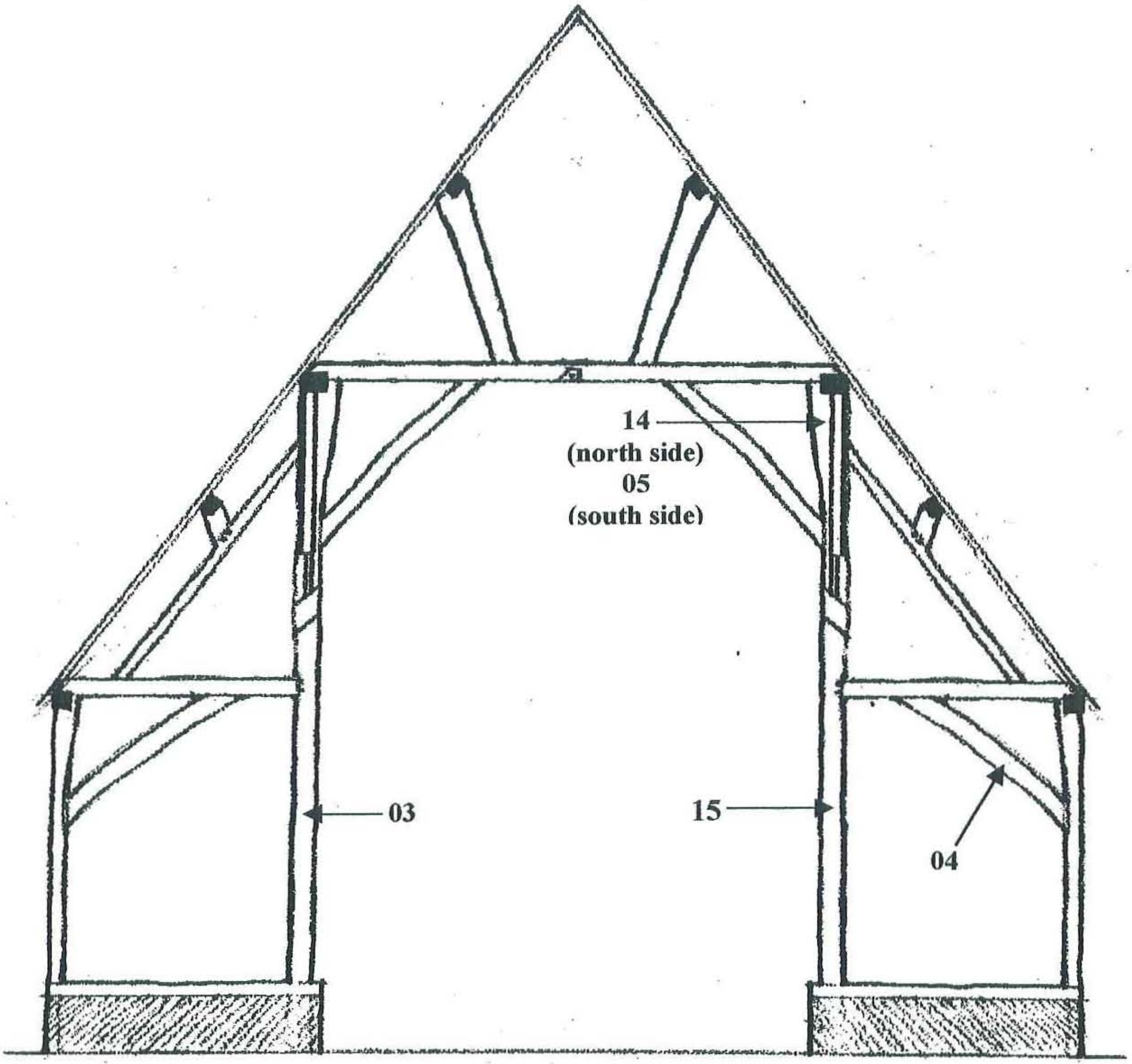


**Figure 5c: Drawing to show position of timbers sampled from truss 5 (drawing based on a typical truss viewed from the south looking north)**

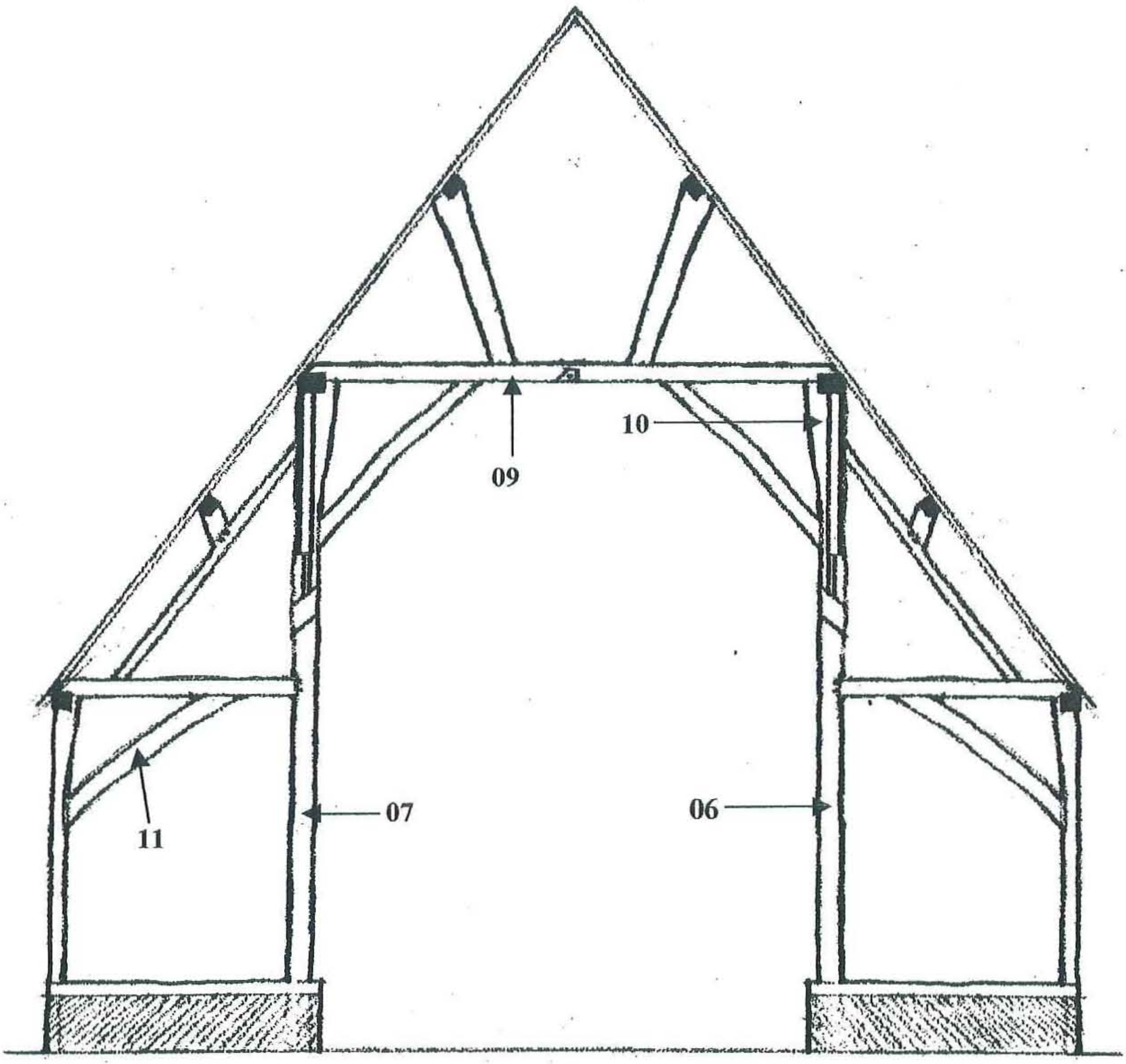


**Figure 5d: Drawing to show position of timbers sampled from truss 6 (drawing based on a typical truss viewed from the south looking north)**

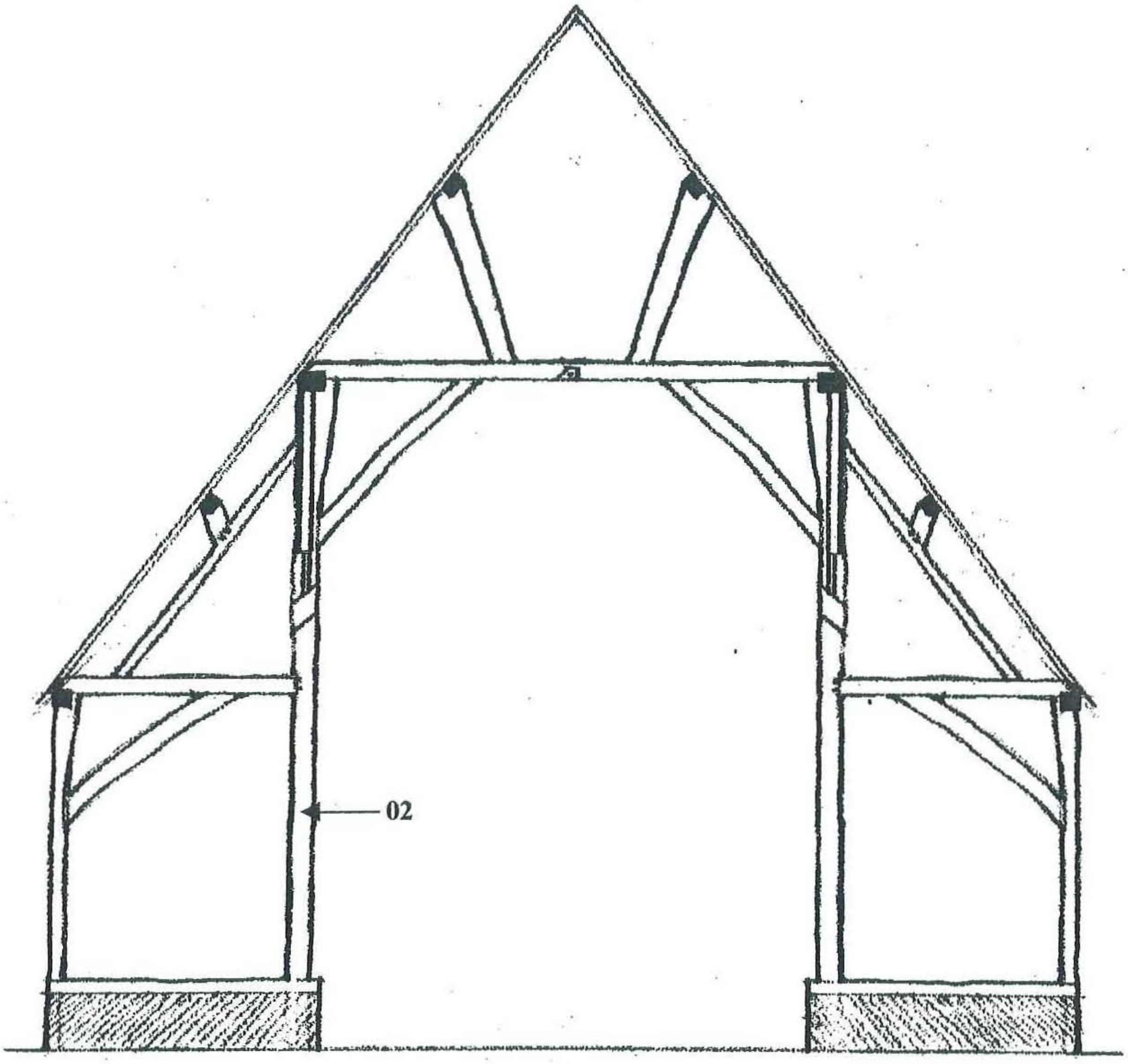


**Figure 5e: Drawing to show position of timbers sampled from truss 7 (drawing based on a typical truss viewed from the south looking north)**

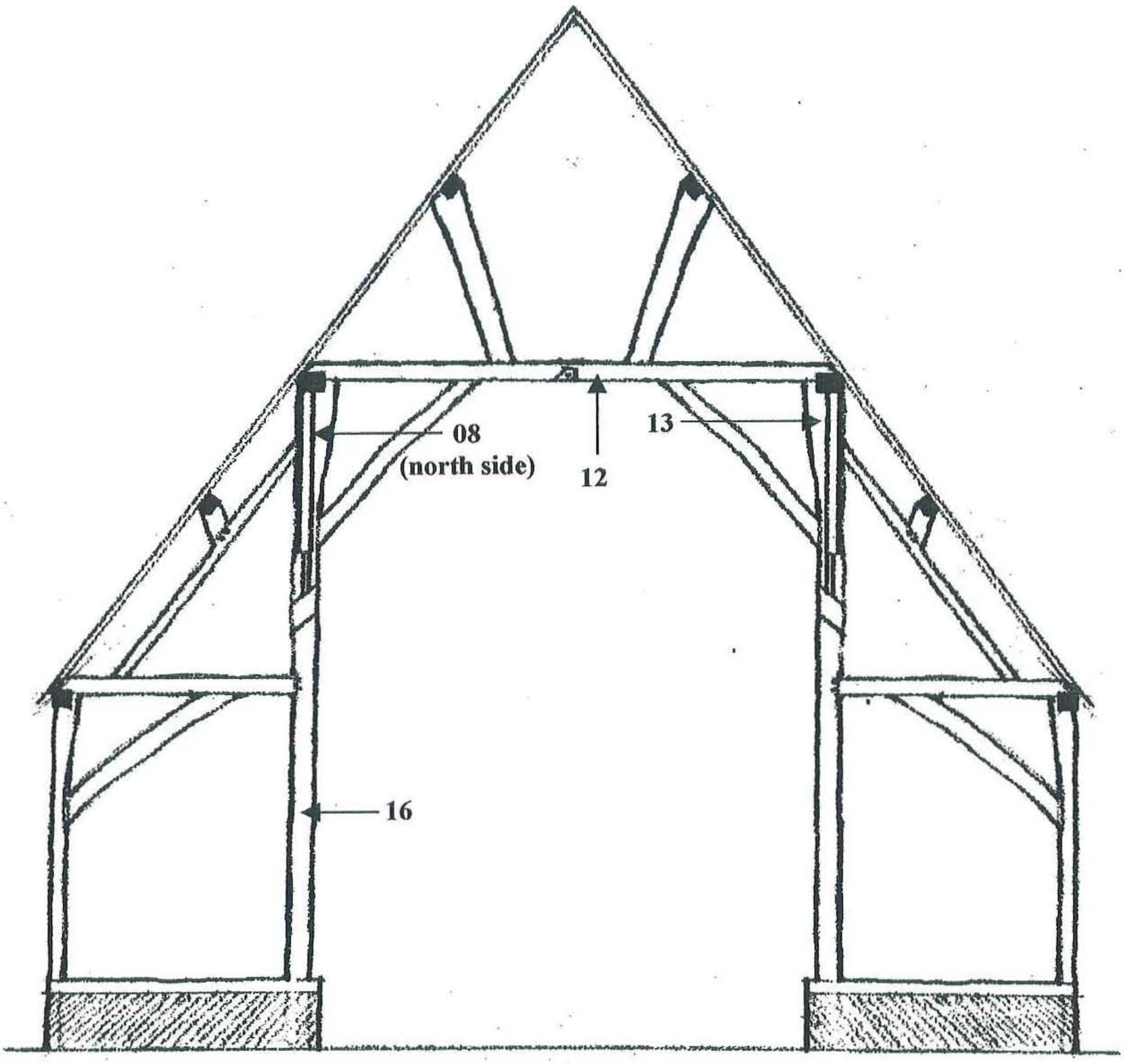
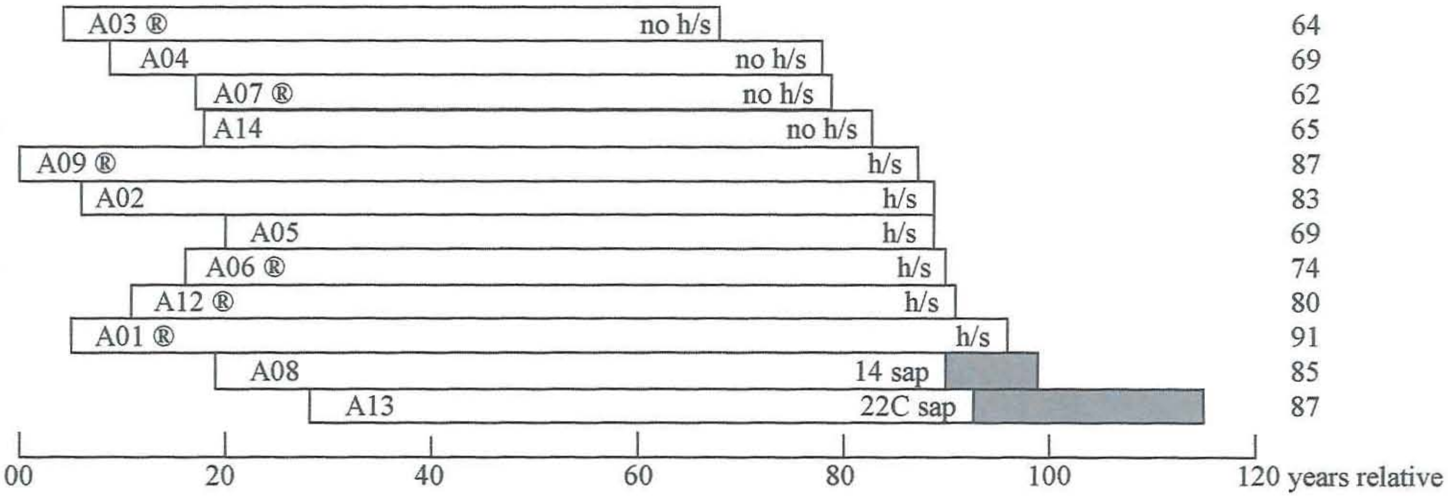


**Figure 6: Bar diagram of the samples in site chronology CLBASQ01**




| Off-set | Sample | | Total rings | Relative heartwood/sapwood boundary position |
|---|---|---|---|---|
| 04 | A03 ® | no h/s | 64 | --- |
| 09 | A04 | no h/s | 69 | --- |
| 17 | A07 ® | no h/s | 62 | --- |
| 18 | A14 | no h/s | 65 | --- |
| 00 | A09 ® | h/s | 87 | 87 |
| 06 | A02 | h/s | 83 | 89 |
| 20 | A05 | h/s | 69 | 89 |
| 16 | A06 ® | h/s | 74 | 90 |
| 11 | A12 ® | h/s | 80 | 91 |
| 05 | A01 ® | h/s | 91 | 96 |
| 19 | A08 | 14 sap | 85 | 90 |
| 28 | A13 | 22C sap | 87 | 93 |

white bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample
C = complete sapwood retained on sample, last measured ring date is the felling date of the timber
® = reused / repositioned timber

Data of measured samples – measurements in 0.01 mm units

CLB-A01A 91
262 497 423 505 489 322 205 194 316 200 201 287 255 242 187 198 142 133 128 173
192 96 162 193 221 192 175 192 137 123 79 171 187 216 179 184 168 193 172 166
147 126 157 135 128 97 112 130 94 104 118 155 121 117 177 127 205 163 102 139
128 155 158 135 150 160 147 111 110 162 214 190 145 122 99 112 175 156 136 114
78 193 193 156 144 150 144 234 216 196 233
CLB-A01B 91
225 486 433 503 477 310 205 193 326 201 196 285 236 247 189 190 140 126 131 175
202 98 163 185 224 180 178 194 140 112 98 168 182 207 182 171 173 201 168 160
159 118 146 137 119 97 112 122 101 94 133 150 117 127 168 129 195 172 112 150
114 161 162 129 154 164 144 111 103 159 217 180 148 112 100 106 174 154 127 105
75 182 194 155 140 156 145 219 218 179 213
CLB-A02A 83
246 377 292 475 367 321 344 311 272 307 385 274 320 246 262 152 151 140 173 200
138 182 211 190 219 204 240 187 169 114 183 199 164 177 173 146 180 150 162 135
118 133 134 164 105 71 84 90 96 122 109 75 91 84 86 122 109 78 61 48
66 71 106 89 100 77 101 78 128 138 104 127 104 113 118 117 93 65 58 44
86 75 115
CLB-A02B 83
210 365 301 447 360 325 341 347 276 328 373 265 293 244 252 173 143 135 172 194
124 184 189 185 228 192 215 229 157 109 167 219 165 169 189 129 183 151 169 126
117 130 135 162 98 71 81 97 98 118 119 75 77 85 88 128 96 63 60 43
73 77 111 75 101 82 89 85 119 151 100 131 97 117 114 122 93 60 58 47
90 74 91
CLB-A03A 64
351 409 558 509 566 720 610 310 319 373 373 447 462 350 292 225 251 221 143 130
187 166 127 133 146 161 105 114 104 91 68 77 125 170 157 178 181 112 147 114
125 72 70 63 59 75 67 73 117 101 82 102 110 77 83 70 82 86 108 86
61 70 77 91
CLB-A03B 64
369 346 514 498 577 666 536 332 310 376 361 452 464 363 281 225 230 212 124 122
173 156 137 143 135 162 114 118 101 94 64 75 126 170 155 174 184 114 142 112
142 75 75 58 56 82 61 71 120 89 94 86 114 83 76 83 77 90 87 87
70 55 68 106
CLB-A04A 69
458 389 421 222 250 192 257 243 336 283 204 189 163 145 136 230 173 151 218 210
239 197 228 226 175 73 76 190 208 183 240 169 144 133 171 158 75 62 91 52
64 44 66 91 77 68 101 115 96 75 73 69 83 74 83 62 54 67 81 114
91 94 90 84 58 75 76 123 94
CLB-A04B 65
419 379 397 221 251 202 246 234 348 274 200 189 167 146 154 244 175 149 218 200
240 201 189 204 170 91 79 178 202 214 233 163 137 131 175 158 67 60 88 59
66 40 67 87 77 63 95 114 111 66 77 65 82 77 90 57 50 70 88 109
96 98 129 71 90
CLB-A05A 69
279 181 210 259 298 350 188 187 264 256 251 283 352 210 193 189 259 224 258 252
216 216 176 201 222 140 120 172 121 100 69 82 98 90 73 115 87 94 68 95
72 107 135 97 73 76 82 121 119 96 104 93 96 96 95 119 123 88 112 94
82 128 95 70 72 57 133 115 100

CLB-A05B 69
266 178 197 238 373 355 195 195 253 260 241 273 387 195 188 179 275 210 258 248
187 228 174 197 232 128 126 169 115 107 66 82 97 92 62 106 107 73 71 90
80 116 128 93 74 65 80 113 125 100 94 106 88 93 96 124 116 84 110 92
92 124 85 77 67 70 112 129 140
CLB-A06A 74
134 174 268 177 191 92 146 132 258 171 66 167 292 305 281 331 380 288 213 281
413 370 400 355 339 266 320 348 295 179 241 235 210 221 149 123 160 156 99 132
113 66 81 86 77 147 124 109 54 55 77 126 122 80 71 76 61 64 86 96
89 66 63 61 61 83 95 54 57 62 135 117 115 155
CLB-A06B 74
175 168 268 171 193 82 153 133 256 164 65 168 273 311 281 320 381 296 212 273
420 357 403 343 344 271 317 338 293 167 240 220 195 218 154 130 153 149 100 125
123 67 83 86 73 146 118 109 53 56 72 128 113 77 80 75 68 52 81 107
90 62 55 58 54 88 83 65 59 52 131 113 120 176
CLB-A07A 62
298 246 231 249 177 185 206 231 239 172 209 281 288 235 253 193 191 137 161 186
216 184 264 249 215 215 229 198 146 137 177 151 103 77 78 123 154 167 216 177
184 124 180 139 194 181 144 121 93 148 176 180 128 159 154 106 123 156 157 167
144 150
CLB-A07B 62
322 243 221 262 149 183 201 240 220 176 210 283 268 228 245 210 199 146 145 206
217 180 243 234 214 222 209 200 131 135 181 152 108 68 79 125 146 176 204 174
176 122 179 146 208 165 150 111 87 161 165 164 119 173 138 112 123 116 155 149
142 150
CLB-A08A 85
254 351 248 328 300 457 345 143 176 278 354 271 272 386 354 250 227 317 321 241
247 230 225 193 172 228 145 118 143 103 124 94 126 163 139 98 156 119 118 93
105 72 104 135 122 86 77 84 117 132 98 112 97 79 78 87 119 85 92 102
94 90 102 104 60 65 45 133 122 111 128 98 81 140 124 114 80 86 120 136
90 111 74 73 100
CLB-A08B 85
182 399 214 318 288 462 350 173 183 317 389 295 266 376 334 238 194 337 324 242
238 216 233 194 165 233 144 131 145 93 136 96 113 152 135 106 156 117 112 94
101 76 112 137 110 85 83 82 119 139 94 112 104 74 75 83 127 96 90 100
88 79 114 96 58 68 68 110 137 110 117 119 79 117 138 115 79 80 128 139
100 86 94 75 100
CLB-A09A 87
291 253 223 233 288 357 467 458 324 479 277 226 218 225 214 277 245 197 195 163
149 102 130 156 190 152 110 126 128 139 165 130 116 144 109 124 182 193 185 191
201 186 186 151 156 89 92 121 92 135 85 109 133 83 105 105 131 115 100 76
99 145 124 156 113 63 122 144 154 120 182 137 112 92 120 110 119 71 80 82
76 133 119 94 94 72 111
CLB-A09B 87
312 261 223 234 280 367 473 465 316 478 280 245 204 221 218 266 260 202 194 162
133 115 159 168 221 167 100 147 137 150 171 132 118 152 78 118 178 183 170 189
198 187 183 153 155 92 90 121 89 139 87 107 136 88 104 111 124 110 102 83
100 143 130 151 119 63 121 142 153 131 162 151 115 89 111 112 112 65 90 75
72 135 126 109 82 64 93
CLB-A10A 54
319 403 357 452 324 463 343 291 149 104 165 143 173 305 522 317 367 339 312 364
391 316 279 223 190 128 128 100 140 129 140 181 232 220 302 246 305 278 241 260
196 221 255 221 290 249 135 152 172 208 150 213 174 202

CLB-A10B 54
339 407 346 402 326 415 382 280 163 115 168 139 161 309 535 334 402 389 356 364
397 314 284 217 195 125 127 102 136 120 130 185 210 208 282 234 318 279 263 283
206 216 234 225 278 251 139 145 166 173 154 187 184 208
CLB-A11A 54
170 164 164 201 162 142 197 172 187 188 286 294 207 210 216 184 244 222 195 145
115 125 165 149 159 159 193 161 152 134 136 175 154 88 101 79 153 118 149 140
141 102 86 77 95 97 95 92 67 45 63 72 83 70
CLB-A11B 54
167 165 154 210 170 136 199 185 196 179 279 292 209 247 195 186 244 223 196 145
112 116 167 141 167 166 189 190 145 131 147 179 155 98 90 74 149 121 170 144
129 97 89 74 100 93 94 96 67 48 70 53 85 86
CLB-A12A 80
141 119 181 129 176 178 194 181 177 148 181 204 138 169 136 96 120 119 135 172
164 168 201 162 140 197 170 184 187 172 173 141 123 135 92 90 131 95 120 85
104 162 118 98 144 156 121 100 91 97 151 148 156 124 86 151 149 192 109 155
120 128 91 125 151 165 100 100 69 96 141 138 103 76 70 175 150 141 155 190
CLB-A12B 80
100 119 174 132 180 177 185 181 175 154 185 198 148 186 136 97 118 130 124 169
165 158 210 170 134 199 183 193 179 183 167 136 119 145 89 100 116 104 126 81
96 158 120 111 123 154 127 106 86 98 158 144 164 116 80 146 145 184 107 163
129 120 101 136 130 172 97 95 78 94 136 135 111 73 77 163 159 131 165 199
CLB-A13A 87
203 278 254 262 288 324 223 202 267 322 271 305 220 228 258 185 223 166 126 167
152 178 124 99 145 115 91 114 124 91 86 65 65 104 121 111 81 79 94 136
205 147 137 133 108 94 108 116 104 75 118 69 94 108 103 84 82 80 160 145
122 117 125 120 142 149 143 116 104 139 113 125 110 99 84 106 105 98 90 109
74 96 109 112 61 67 90
CLB-A13B 87
211 286 258 283 281 329 178 202 333 305 264 306 208 233 209 191 275 151 144 182
139 169 135 103 142 118 92 123 111 83 94 74 70 94 129 137 95 77 115 153
202 133 155 140 108 82 106 135 124 91 113 86 88 108 101 85 84 85 164 156
101 118 115 115 121 163 136 95 124 136 120 116 103 98 83 116 105 91 94 103
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196 253 185 171 215 152 211 146 94 145 205 179 177 152 147 131 99 92 160 183
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143 138 130 231 206 153 108 100 198 166 183 179 149 137 116 105 131 143 150 128
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CLB-A16A 56
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120 122 172 148 225 118 83 256 198 67 155 246 320 268 358 407 458 416 315 313
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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 Buildings*' (Laxton and Litton 1988b) and, for example, in *Tree-Ring Dating and Archaeology* (Baillie 1982) or *A Slice Through Time* (Baillie 1995). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The *width* of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring..

If the bark is still on the sample, as in Figure 1, then the date of the last ring will be the date of felling of the oak from which it was cut. There is much evidence that in medieval times oaks cut down for building purposes were used almost immediately, usually within the year or so (Rackham 1976). Hence if bark is present on several main timbers in a building, none of which appear reused or are later insertions, and if they all have the same date for their last ring, then we can be quite confident that this is the date of construction. If there is no bark on the sample, then we have to make an estimate of the felling date; how this is done is explained below.

**The Practice of Tree-Ring Dating at the University of Nottingham Tree-Ring dating Laboratory**

1. ***Inspecting the Building and Sampling the Timbers.*** Together with a building historian we inspect the timbers in a building to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can sample *in situ* timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer rings than this, 50 for example, sequences of widths become difficult to match to a unique position within a master sequence of ring widths and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure 2 has about 120 rings; about 20 of which are sapwood rings. Similarly the core has just over 100 rings.

   To ensure that we are getting the date of the building as a whole, or the whole of a phase of construction if there is more than one, about 8 to 10 samples per phase are usually taken. Sometimes we take many more, especially if the construction is complicated One reason for taking so many samples is that, in general, some will fail to give a date. There may be many reasons why a particular sequence of ring widths from a sample of timber fails to give a date even though others from the same building do. For example, a particular tree may have grown in an odd ecological niche, so odd indeed that the widths of its rings were determined by factors other than the local climate! In such circumstances it will be impossible to date a timber from this tree using the master sequence whose widths, we can assume, were predominantly determined by the local climate at the time.

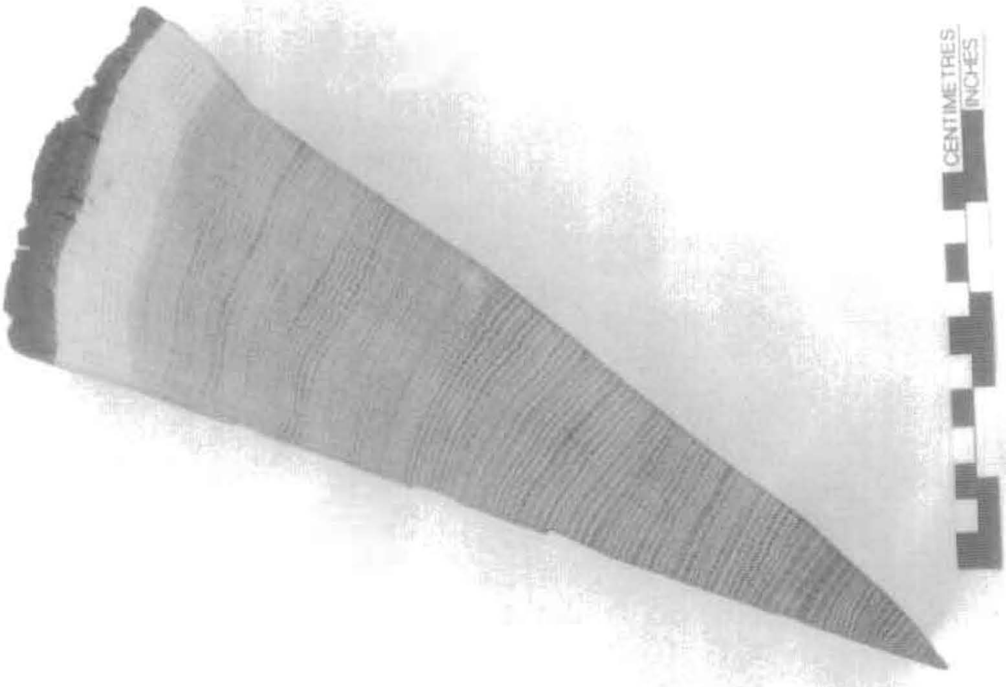


Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

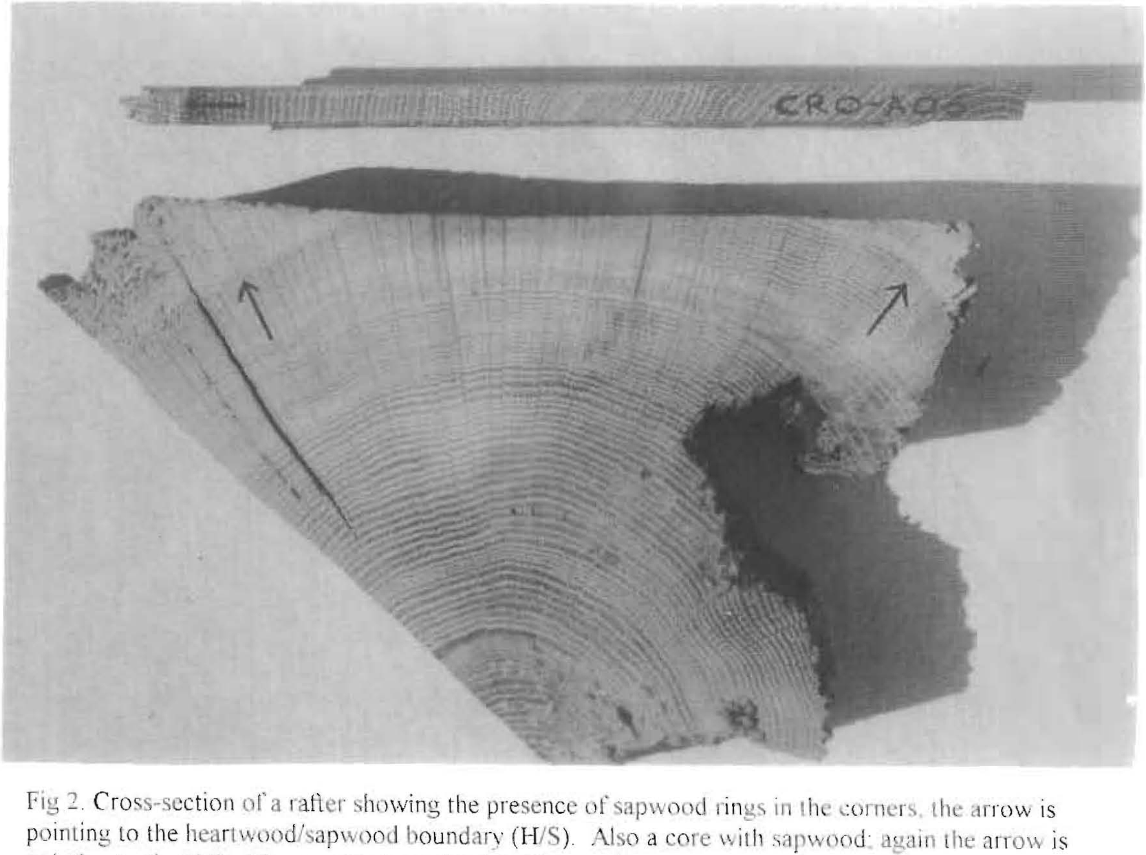

Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

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

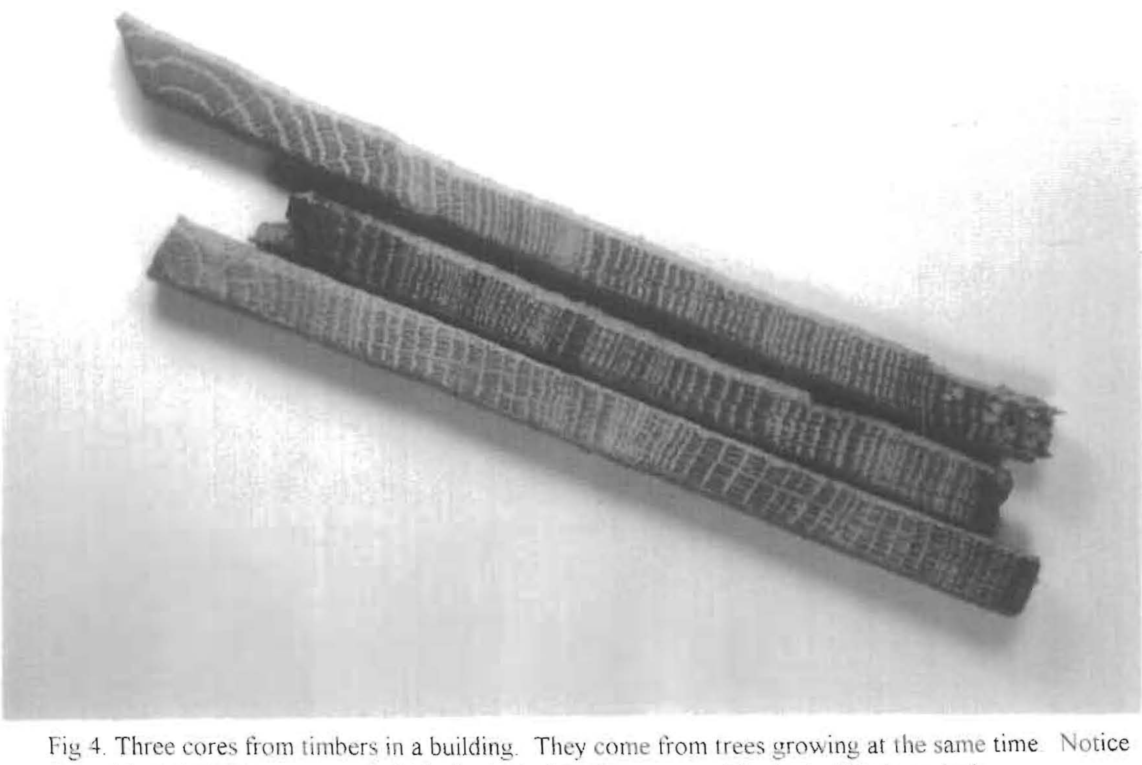

Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

Sampling is done by coring into the timber with a hollow corer attached to an electric drill and usually from its outer rings inwards towards where the centre of the tree, the pith, is judged to be. An illustration of a core is shown in Figure 2; it is about 15cm long and 1cm diameter. Great care has to be taken to ensure that as few as possible of the outer rings are lost This can be difficult as these outer rings are often very soft (see below on sapwood) Each sample is given a code which identifies uniquely which timber it comes from, which building it is from and where the building is located. For example, CRO-A06 is the sixth core taken from the first building (A) sampled by the Laboratory in Cropwell Bishop. Where it came from in that building will be shown in the sampling records and drawings. No structural damage is done to any timbers by coring, nor does it weaken them.

During the initial inspecton of the building and its timbers the dendrochronologist may come to the conclusion that, as far as can be judged, none of the timbers have sufficient rings in them for dating purposes and may advise against sampling to save further unwarranted expense.

All sampling by the Laboratory is undertaken according to current Health and Safety Standards.
The Laboratory is insured with the CBA.

2. ***Measuring Ring Widths.*** Each core is sanded down with a belt sander using medium-grit paper and then finished by hand with flourgrade-grit paper. The rings are then clearly visible and differentiated from each other with a result very much like that shown in Figure 2. The core is then mounted on a movable table below a microscope and the ring-widths measured individually from the innermost ring to the outermost. The widths are automatically recorded in a computer file as they are measured (see Fig 3).

3. ***Cross-matching and Dating the Samples.*** Because of the factors besides the local climate which may determine the annual widths of a tree's rings, no two sequences of ring widths from different oaks growing at the same time are exactly alike (Fig 4). Indeed, the sequences may not be exactly alike even when the trees are growing near to each other. Consequently, in the Laboratory we do not attempt to match two sequences of ring widths by eye, or graphically, or by any other subjective method. Instead, it is done objectively (ie statistically) on a computer by a process called cross-matching. The output from the computer tells us the extent of correlation between two sample sequences of widths or, if we are dating, between a sample sequence of widths and the master, at each relative position of one to the other (offsets). The extent of the correlation at an offset is determined by the *t-value* (defined in almost any introductory book on statistics). That offset with the maximum t-value among the t-values at all the offsets will be the best candidate for dating one sequence relative to the other. If one of these is a master chronology, then this will date the other. Experiments carried out in the past with sequences from oaks of known date suggest that a t-value of at least 4.5, and preferably 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton *et al* 1988a,b; Howard *et al* 1984 - 1995).

   This is illustrated in Fig 5 with timbers from one of the roofs of Lincoln Cathedral. Here four sequences of ring widths, LIN- C04, 05, 08, and 45, have been cross-matched with each other. The ring widths themselves have been omitted in the *bar-diagram*, as is usual, but the offsets at which they best cross-match each other are shown; eg. C08 matches C45 best when it is at a position starting 20 rings after the first ring of 45, and similarly for the others. The actual t-values between the four at these offsets of best correlations are in the matrix. Thus at the offset of +20 rings, the t-value between C45 and C08 is 5.6 and is the maximum between these two whatever the position of one sequence relative to the other.

   It is standard practice in our Laboratory first to cross-match as many as possible of the sequences of the samples in a building and then to form an average from them. This average is called a site sequence of the building being dated and is illustrated in Fig 5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences from four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

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

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

4. ***Estimating the Felling Date.*** If the bark is present on a sample, then the date of its last ring is the date of the felling of its tree. Actually it could be the year after if it had been felled in the first three months before any new growth had started, but this is not too important a consideration in most cases. The actual bark may not be present on a timber in a building, though the dendrochronologist who is sampling can often see from its surface that only the bark is missing. In these cases the date of the last ring is still the date of felling.

Quite often some, though not all, of the original outer rings are missing on a timber. The outer rings on an oak, called sapwood rings, are usually lighter than the inner rings, the heartwood, and so are relatively easy to identify. For example, they can be seen in two upper corners of the rafter and at the outer end of the core in Figure 2. More importantly for dendrochronology, the sapwood is relatively soft and so liable to insect attack and wear and tear. The builder, therefore, may remove some of the sapwood for precisely for these reasons. Nevertheless, if at least some of the sapwood rings are left on a sample, we will know that not too many rings have been lost since felling. Thus in these circumstances the date of the present last ring is at least close to the date of the original last ring on the tree, and so to the date of felling.

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

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

More precise estimates of the felling date and range can often be obtained using knowledge of a particular case and information gathered at the time of sampling. For example, at the time of sampling the dendrochronologist may have noted that the timber from which the core of Figure 2 was taken still had complete sapwood. Sapwood rings were only lost in coring, because of their softness. By measuring in the timber the depth of sapwood lost, say 2 cm., a reasonable estimate can be made of the number of sapwood rings missing from the core, say 12 to 15 rings in this case. By adding on 12 to 15 years to the date of the last ring on the sample a good tight estimate for the range of the felling date can be obtained, which is often better than the 15 to 40 years later we would have estimated without this observation.

**T-value/Offset Matrix**

| | C45 | C08 | C05 | C04 |
|---|---|---|---|---|
| C45 | | +20 | +37 | +47 |
| C08 | 5.6 | | +17 | +27 |
| C05 | 5.2 | 10.4 | | +10 |
| C04 | 5.9 | 3.7 | 5.1 | |

**Bar Diagram**

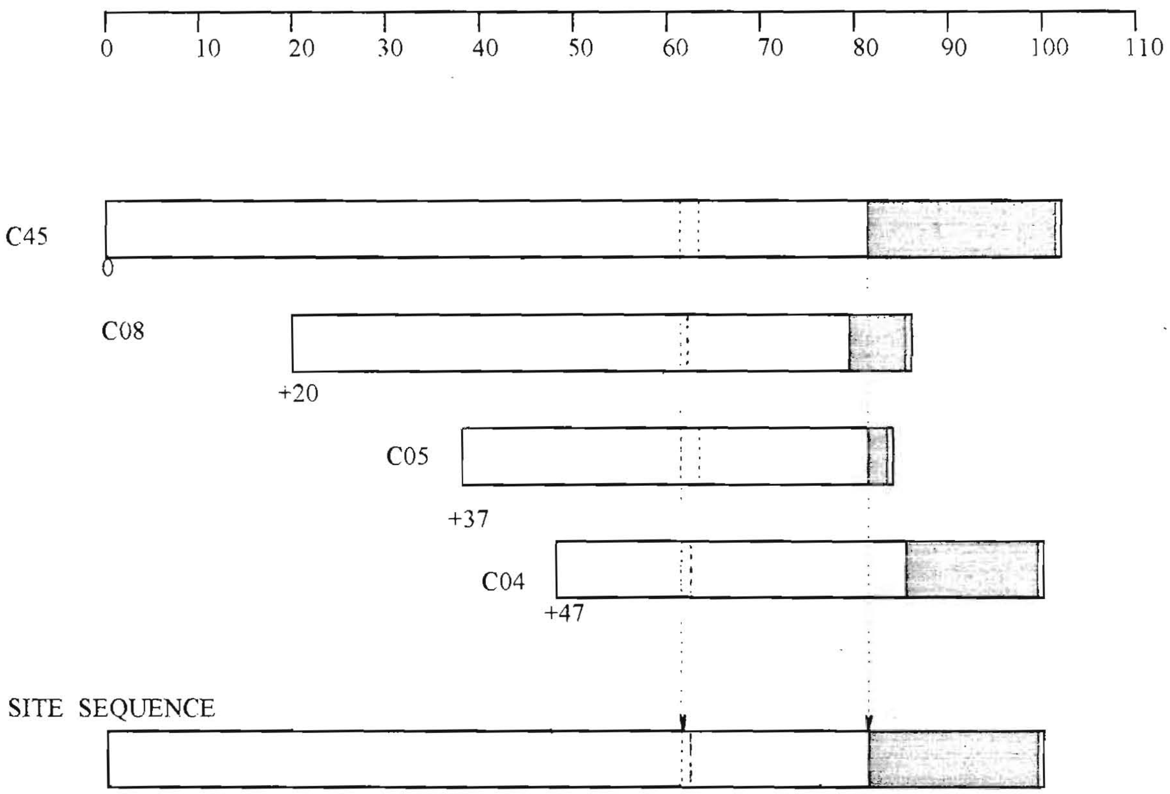


Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.
The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set at relative positions *(offsets)* to each other at which they have maximum correlation as measured by the *t-values*.
The *t-value/offset* matrix contains the maximum t-values below the diagonal and the offsets above it. Thus, the maximum t-value between C08 and C45 occurs at the offset of +20 rings and the t-value is then 5.6.
The *site sequence* is composed of the average of the corresponding widths, as illustrated with one width.

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

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

5. ***Estimating the Date of Construction.*** There is a considerable body of evidence in the data collected by the Laboratory that the oak timbers used in vernacular buildings, at least, were used 'green' (see also Rackham (1976 )). Hence provided the samples are taken *in situ,* and several dated with the same estimated common felling date, then this felling date will give an estimated date for the construction of the building, or for the phase of construction. If for some reason or other we are rather restricted in what samples we can take, then an estimated common felling date may not be such a precise estimate of the date of construction. More sampling may be needed for this.

6. ***Master Chronological Sequences.*** Ultimately, to date a sequence of ring widths, or a site sequence, we need a master sequence of dated ring widths with which to cross-match it, a Master Chronology. To construct such a sequence we have to start with a sequence of widths whose dates are known and this means beginning with a sequence from an oak tree whose date of felling is known. In Fig 6 such a sequence is SHE-T, which came from a tree in Sherwood Forest which was blown down in a recent gale. After this other sequences which cross-match with it are added and gradually the sequence is 'pushed back in time' as far as the age of samples will allow. This process is illustrated in Fig 6. We have a master chronological sequence of widths for Nottinghamshire and East Midlands oak for each year from AD 882 to 1981. It is described in great detail in Laxton and Litton 1988b, but the components it contains are shown here in the form of a bar diagram. As can be seen, it is well replicated in that for each year in this period there are several sample sequences having widths for that year. The master is the average of these. This master can now be used to date oak from this area and from the surrounding areas where the climate is very similar to that in the East Midlands. The Laboratory has also constructed a master for Kent (Laxton and Litton 1989). The method the Laboratory uses to construct a master sequence, such as the East Midlands and Kent, is completely objective and uses the Litton-Zainodin grouping procedure (Laxton *et al* 1988a). Other laboratories and individuals have constructed masters for other areas and have made them available. As well as these masters, local (dated) site chronologies can be used to date other buildings from nearby. The Laboratory has hundreds of these site sequences from many parts of England and Wales covering many short periods.

7. ***Ring-width Indices.*** Tree-ring dating can be done by cross-matching the ring widths themselves, as described above. However, it is advantageous to modify the widths first. Because different trees grow at different rates and because a young oak grows in a different way from an older oak, irrespective of the climate, the widths are first standardized before any matching between them is attempted. These standard widths are known as ring-width indices and were first used in dendrochronology by Baillie and Pilcher (1973). The exact form they take is explained in this paper and in the appendix of Laxton and Litton (1988b) and is illustrated in the graphs in Fig 7. Here ring-widths are plotted vertically, one for each year of growth. In the upper sequence (a), the generally large early growth after 1810 is very apparent as is the smaller generally later growth from about 1900 onwards. A similar difference can be observed in the lower sequence starting in 1835. In both the widths are also changing rapidly from year to year. The peaks are the wide rings and the troughs are the narrow rings, hopefully corresponding to good and poor growing seasons, respectively. The two corresponding sequences of Baillie-Pilcher indices are plotted in (b) where the differences in the early and late growths have been removed and only the rapidly changing peaks and troughs remain only associated with the common climatic signal and so make cross-matching easier.

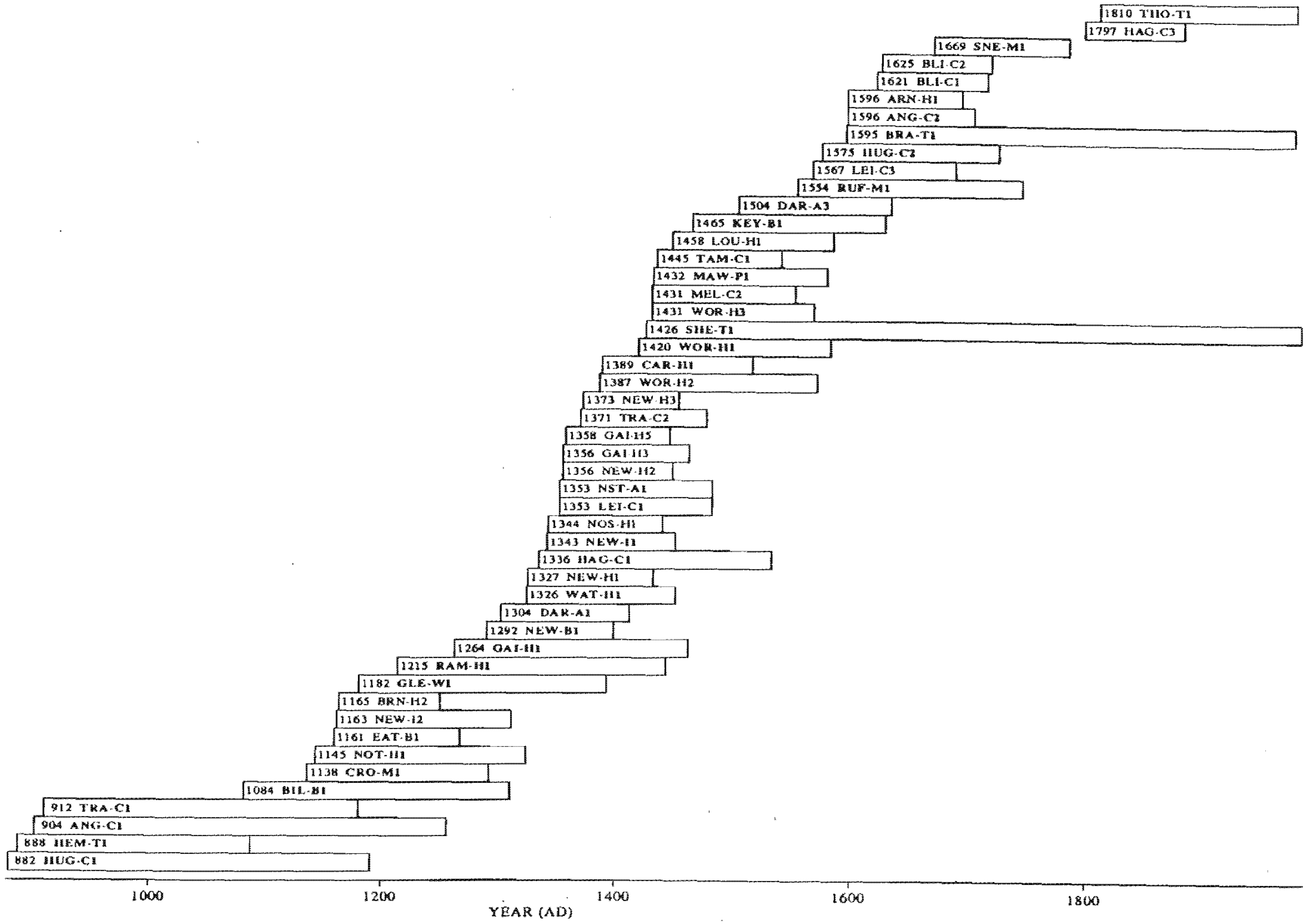


Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

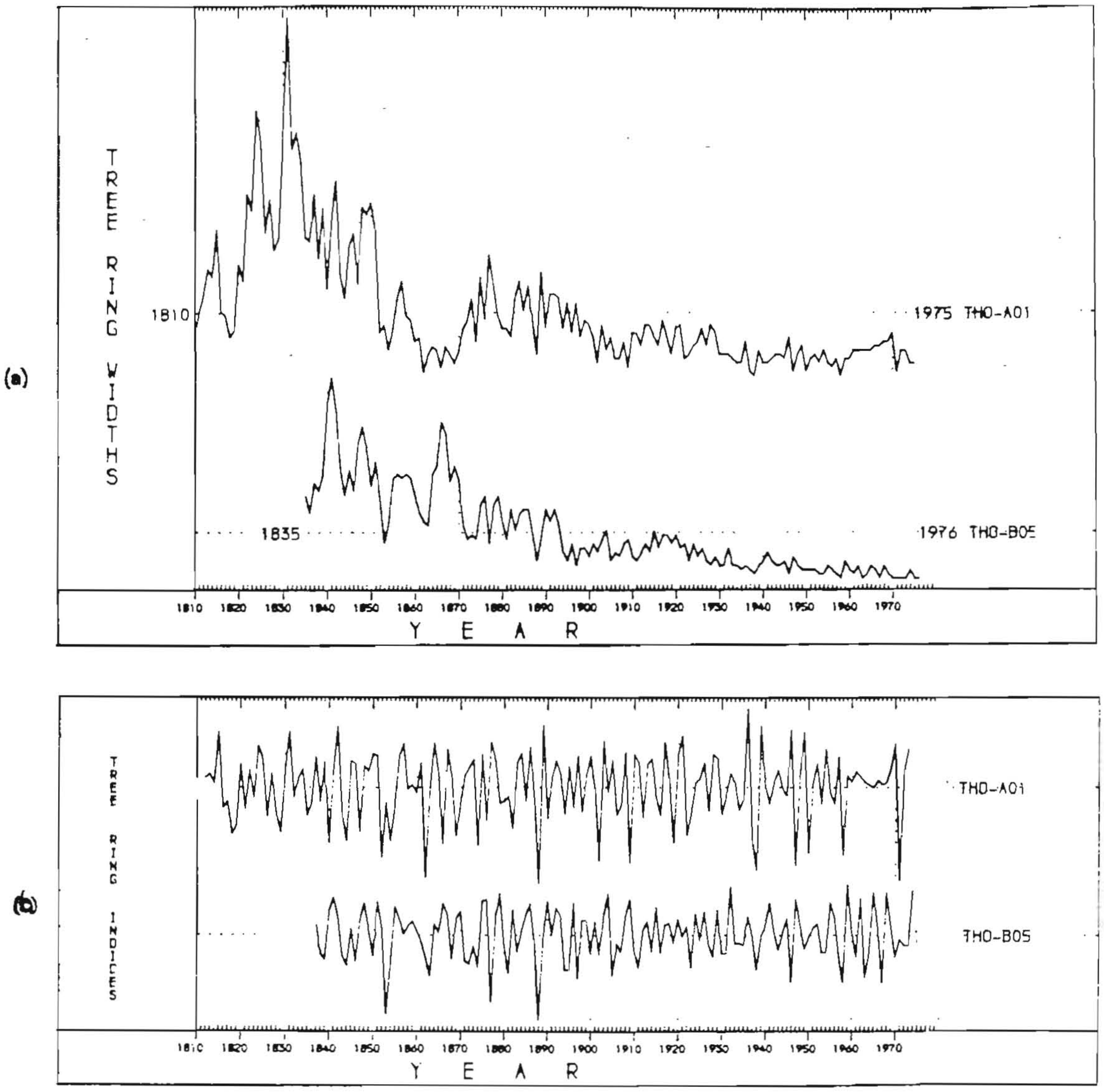


Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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

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

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