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Summary

Core samples were obtained from 21 different oak timbers from within numbers 7 and 9 Stourport Road, Bewdley, all sampled timbers appearing to belong to the primary phase of construction. The analysis of these cores produced a single site chronology, BWDASQ01, comprising 16 samples, and having a combined overall length of 242 rings. This site chronology was dated as spanning the years AD 1060 to AD 1301.

Interpretation of the sapwood would indicate that all the dated timbers were cut in a single phase of felling between AD 1302 and AD 1324.

Keywords

Dendrochronology
Standing Building

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Introduction

The building which is now numbers 5 – 9 Stourport Road, Bewdley, sometimes collectively known as 'Severn View' or 'Riverside', and which is in three separate ownerships, is situated on the north bank of the River Severn (SO 787 754, Figs 1 and 2) on the B4195 Bewdley to Stourport road, about half a kilometre from the centre of the town. Externally, apart from a section of low roofline, the brick and rendered street frontage of three gables provides little indication of the possible antiquity of the site, and it is unlikely that most passers-by would give the buildings more than a second glance.

However, encased within eighteenth, nineteenth, and twentieth-century alterations, the site appears to have originally comprised an early-medieval two-bay open hall (number 7, now listed Grade II*) with a two-bay cross-wing at the east end (number 9) and a single-bay cross-wing at the west end (number 5). Indeed, the under-stated nature of the exterior makes the unexpected timber framing within, which is often moulded, very squarely cut, and well carpentered, all the more spectacular and breathtaking. A simple plan of the site is given in Figure 3, with views to front and rear being shown in Figure 4.

The central truss of the open hall is of base-cruck type, the cruck blades jointed to a cambered tiebeam with cusped and moulded arch braces (Fig 5). The upper portion of the roof, above the tiebeam, consists of a crown post and collar purlin, the crown post supported by concave braces from the tiebeam, with straight struts from crown post to collar purlin. There is also a pair of scissor-braced rafters. Cusped and moulded arch braces also hold the purlins between the trusses from the cruck blades.

The truss forming the partition wall between the hall and the cross-wing at the east end is only slightly less moulded (Fig 6), the beams being plain and undecorated. The principal posts of the truss are held by a straight tiebeam with a central stud post below and a crown post above, the crown post supported by convex braces. The panels below show paired convex braces. Cusped arch braces again run from the posts to purlins. The truss between the hall and the cross-wing at the west end is similarly framed (Fig 7).

The cross-wing at the east end is also of two bays. Again, the central truss has a crown post with scissor-braced rafters sitting atop a slightly cambered tiebeam (Fig 8). The braces from tiebeam to crown post are concave and plain, while those from crown post to collar purlin are straight but chamfered and stopped. The braces from wall posts to tiebeam, and from wall posts to wall plates, are curved, though not cusped or chamfered. The trusses at each end are almost entirely hidden, only being visible within a cupboard, or externally in the north gable wall (Fig 9).

An exhaustive survey of the whole building, with full drawings, has never been undertaken, although The Worcestershire Archaeological Society has carried out a very useful preliminary examination of numbers 7 and 9. There are no survey drawings or notes for number 5, the western single-bay cross-wing, though it is believed to be framed in a generally similar manner. Stylistically, the framing of numbers 7 and 9 dates to the fourteenth century.

Some later alterations have been undertaken at this site, particularly the insertion of a first-floor frame in number 7, the hall range. It is believed that this was done in the eighteenth century, with further changes being made in the nineteenth century. The extent of these changes is unclear. The timbers relating to these alterations are generally of small size and derived from fast-grown trees. As such, they appeared unsuitable for tree-ring analysis and they were excluded from this programme of research.

Sampling

Sampling and analysis by tree-ring dating of the timbers of 5 – 9 Stourport Road were commissioned by English Heritage, to establish more reliably and accurately the date of the buildings in order to inform listed building consent for works being proposed for the central hall portion of the site, number 7. It was hoped that analysis would determine whether the entire building represents a single phase of construction, or whether there was a more complicated developmental history to the site.

Sampling at this site was complicated by the fact that the building is in three separate ownerships. Sadly, consent for sampling at number 5 could not be obtained and samples were thus obtained from numbers 7 and 9 only. Each sample was given the code BWD-A (for Bewdley, site "A") and numbered 01 – 21.

Twelve samples, BWD-A01 – A12 were obtained from the roof timbers of number 7, the hall range, with a further nine samples, BWD-A13 – A21, being obtained from the eastern two-bay cross-wing, in which a smaller number of timbers was available. All the timbers sampled appeared to be primary and integral to the original construction, all being jointed and pegged together.

Other timbers could have been sampled, such as, for example, those of truss 4, between the hall range and the east cross-wing. The timbers of this truss, however, appeared to be derived from faster-grown trees, and thus to have fewer rings, than the timbers of the other trusses. There were also timbers in the floor-frames of number 7, but many of these appeared to be more recent, possibly related to eighteenth-century alterations, to be of small scantling, and again to be derived from fast-grown trees. As such, they appeared to have too few rings for reliable analysis.

Where possible the positions of the samples are marked on Figures 3 – 8, which, along with Figure 9, were very kindly provided by the Worcestershire Archaeological Society, and by Birmingham Museum and Art Gallery. Details of the samples are given in Table 1. In this Table, all frames and timbers are identified on a north - south or east - west basis as appropriate.

The Laboratory would particularly like to thank to Lorna Burman, of number 7 Stourport Road, and her partner, for their help in arranging access to the building, for their enthusiasm for the project, and for their hospitality during sampling. We would also like to thank their neighbours, Mr and Mrs Giles, for allowing the Laboratory to sample the timbers at number 9. We must also thank Worcestershire

Archaeological Society and Birmingham Museum and Art Gallery for the use of their descriptions and drawings.

Analysis

Each of the 21 samples obtained was prepared by sanding and polishing, and its annual growth-ring widths were measured. The growth-ring widths of all 21 samples were then compared to each other by the Litton/Zainodin grouping procedure (see appendix). At a minimum value of t=4.5 a single group of 16 samples was formed, cross-matching with each other at the positions shown in the bar diagram, Figure 10. The samples were combined at these off-sets to form BWDASQ01, a site chronology of 242 rings. Site chronology BWDASQ01 was then satisfactorily dated, by comparison to a number of relevant oak reference chronologies, as spanning the years AD 1060 to AD 1301. Evidence for this dating is given in the t-values of Table 2.

Site chronology BWDASQ01 was then compared to the five remaining unmatched samples, but there was no further satisfactory cross-matching. Each of the five remaining ungrouped samples was then compared individually to a full series of reference chronologies, but again there was no further satisfactory cross-matching. These samples must, therefore, remain undated.

Interpretation and conclusion

Analysis by dendrochronology has produced a single site chronology, BWDASQ01, comprising 16 samples, its 242 rings dated as spanning the years AD 1060 to AD 1301. Given the moulded and carved nature of many of the timbers at this site, few of the samples retain any sapwood. Sapwood was found on only two samples, BWD-A01 and A11, with the heartwood/sapwood boundary being found on only four others, BWD-A12, A14, A16, and A17. The average date of the heartwood/sapwood boundary on all the samples where it exists is AD 1284. Using a 95% confidence limit of 15 to 40 rings for the amount of sapwood on mature oaks, and allowing that the last measured ring date of any sample is AD 1301, would give the timbers an estimated felling date in the range AD 1302 to AD 1324.

There appears to be little difference, if any, in the relative positions and dates of the heartwood/sapwood boundary on samples from the hall range (number 7) and the east cross-wing (number 9) (Fig 11). This would indicate that both ranges might be considered parts of a single programme of construction, even if the timbers for the two ranges were not felled at exactly the same time. The exact constructional relationship between the two might be determined by careful structural analysis.

The estimated range of AD 1302 – 24 for the felling date of the timber is in keeping with the general fourteenth-century date suggested on the basis of stylistic evidence. The tree-ring date, however, narrows the likely construction date to the first quarter of that century and suggests, perhaps, that the style of framing and moulding seen here is older than had previously been thought. Furthermore, tree-ring analysis clearly shows that the hall and east cross-wing are likely to represent a single programme of building.

Judging by the cross-matching between some of the samples, with values in excess of t=7.0 and t=8.0 being seen, it is very likely that a number of the timbers represent trees growing very close to each other in the same copse or stand of woodland. Indeed, some samples, such as BWD-A16, A18, and A20, cross-match with each other with values ranging from t=9.5 to t=12.7, suggesting that the timbers they represent, a brace, a crown post, and a wall post, are derived from the same tree. A cross-match with a value of t=10.2 is found between samples BWD-A13 and A14, suggesting that the two timbers represented, both braces to a crown post, are also probably derived from a single tree.

Five samples, BWD-A02, A04, A10, A15, and A19, remain ungrouped and undated. Although a couple of these are a little shorter, all the samples have sufficient numbers of rings for reliable analysis. Some of them do have distorted or erratic rings, with some compaction also being shown, as on samples BWD-A10 and A15 for example. Sample BWD-A19 possibly shows some periodicity in its growth regime, with one or two rings of wide growth followed by years of narrower growth. It is possible that these anomalies have had some impact on the climatic signal resulting in difficulty in dating, although none of them appear to be particularly severe.

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Table 1: Details of samples from 7 – 9 Stourport Road, Bewdley, Worcestershire

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Number 7 (open hall)					
BWD-A01	South purlin, truss 5 - 6	144	24	AD 1158	AD 1277	AD 1301
BWD-A02	East brace to south purlin, truss 6	97	h/s	——	——	——
BWD-A03	Tiebeam, truss 6	103	no h/s	AD 1142	——	AD 1244
BWD-A04	Central stud post, truss 6	93	no h/s	——	——	——
BWD-A05	North brace, crown post to tiebeam, truss 6	55	no h/s	AD 1215	——	AD 1269
BWD-A06	West brace to north purlin, truss 5	71	no h/s	AD 1182	——	AD 1252
BWD-A07	West brace, crown post - collar purlin, truss 5	57	no h/s	AD 1151	——	AD 1207
BWD-A08	Tiebeam, truss 5	148	no h/s	AD 1060	——	AD 1207
BWD-A09	Crown post, truss 5	99	no h/s	AD 1160	——	AD 1258
BWD-A10	South brace, crown post - tie beam, truss 5	63	h/s	——	——	——
BWD-A11	East brace to north purlin, truss 5	106	14	AD 1195	AD 1286	AD 1300
BWD-A12	North purlin, truss 4 - 5	137	h/s	AD 1158	AD 1294	AD 1294
	Number 9 (east cross-wing)					
BWD-A13	South brace, crown post - collar purlin, truss 2	81	no h/s	AD 1170	——	AD 1250
BWD-A14	North brace, crown post - collar purlin, truss 2	77	no h/s	AD 1170	——	AD 1246
BWD-A15	East brace, crown post - collar purlin, truss 2	56	no h/s	——	——	——
BWD-A16	West brace, crown post - collar purlin, truss 2	112	h/s	AD 1166	AD 1277	AD 1277
BWD-A17	Tiebeam, truss 2	102	h/s	AD 1183	AD 1284	AD 1284
BWD-A18	Crown post, truss 2	56	no h/s	AD 1166	——	AD 1221
BWD-A19	Collar purlin, truss 1 - 2	106	h/s	——	——	——
BWD-A20	East Wall post, truss 2	62	no h/s	AD 1174	——	AD 1235
BWD-A21	East wall plate, truss 1 - 2	74	h/s	AD 1212	AD 1285	AD 1285

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

Table 2: Results of the cross-matching of site chronology BWDASQ01 and relevant reference chronologies when first ring date is AD 1060 and last ring date is AD 1301

Reference chronology	Span of chronology	*t*-value	
Chichester Cathedral, West Sussex	AD 1173 – 1295	9.0	(Howard *et al* 1992)
186/7 Horniglow St, Burton upon Trent, Staffs	AD 1101 – 1345	8.8	(Howard *et al* 1995)
East Midlands	AD 882 – 1981	8.6	(Laxton and Litton 1988)
Reading Waterfront, Berks	AD 1160 – 1407	8.5	(Groves *et al* 1997)
Gloucester Blackfriars	AD 1024 – 1347	8.2	(Howard *et al* 2002)
England	AD 401 – 1981	8.1	(Baillie and Pilcher 1982 unpubl)
England, London	AD 413 – 1728	8.0	(Tyers and Groves 1999 unpubl)
Hansacre Hall, Staffs	AD 965 – 1279	7.4	(Esling *et al* 1990)

Figure 1: Map to show general location of Bewdley

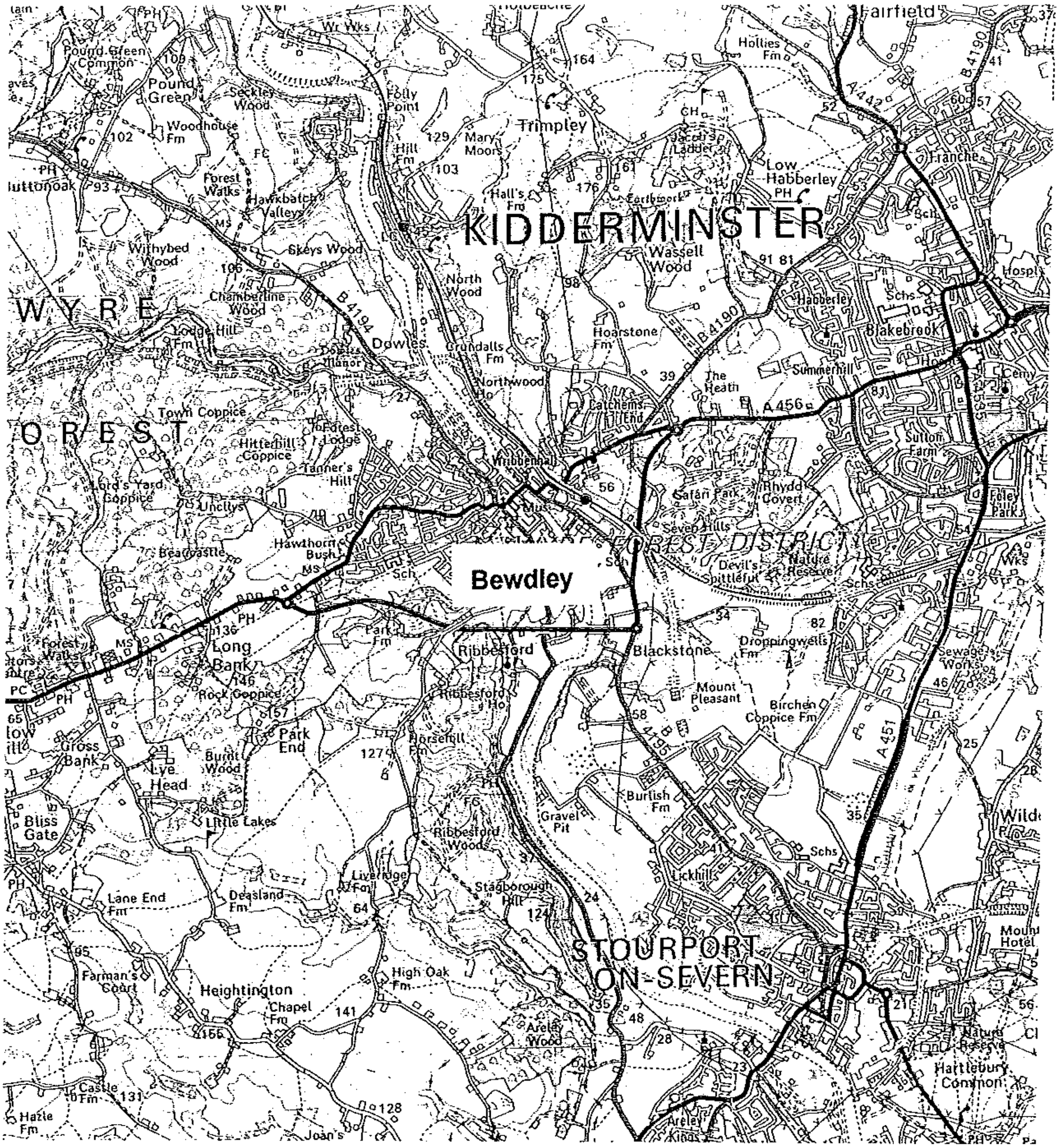


Figure 2: Map to show more specific location of 7 – 9 Stourport Road

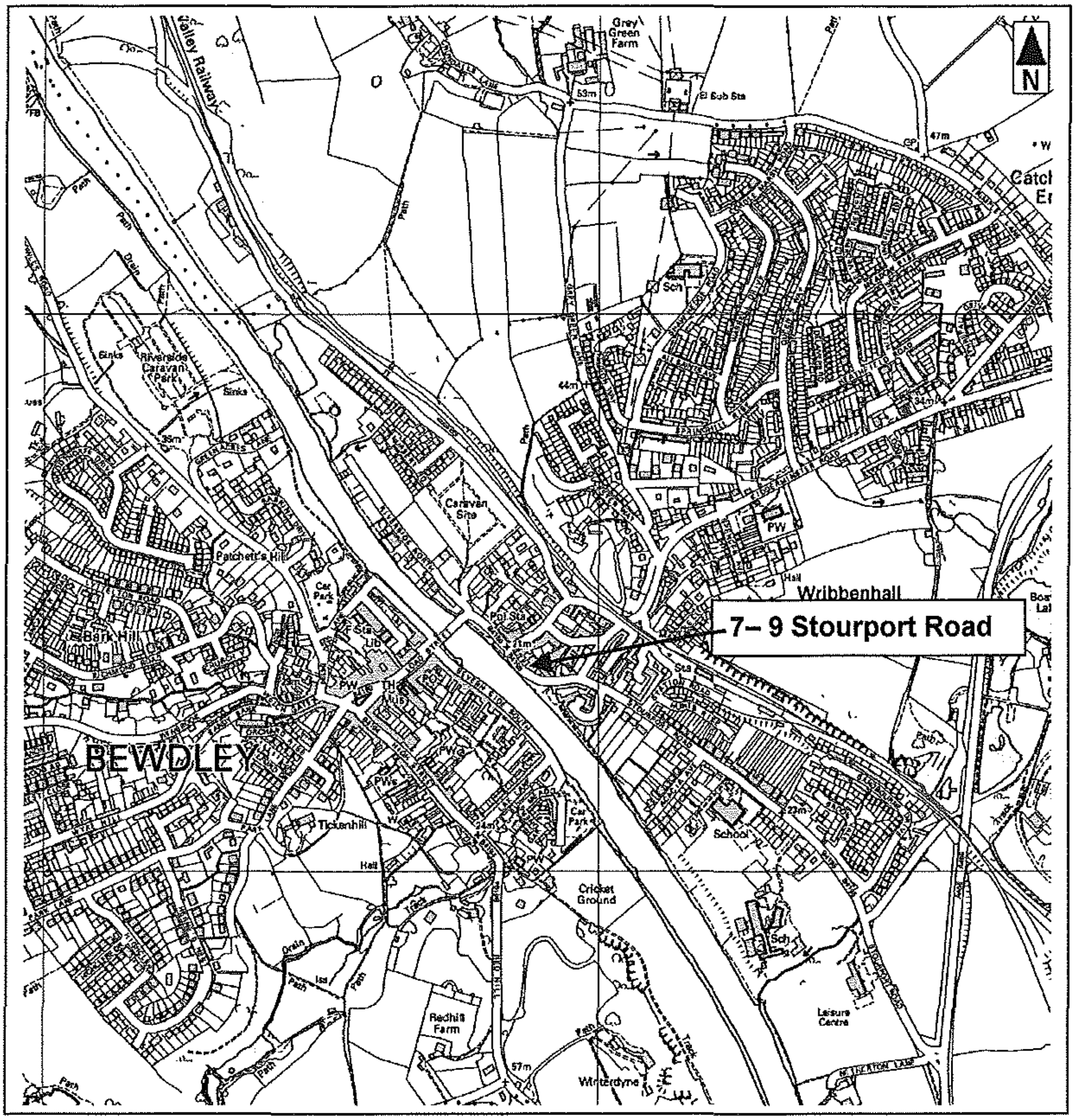


Figure 3: Simple plan of 5 – 9 Stourport Road, Bewdley showing approximate position of sampled timbers

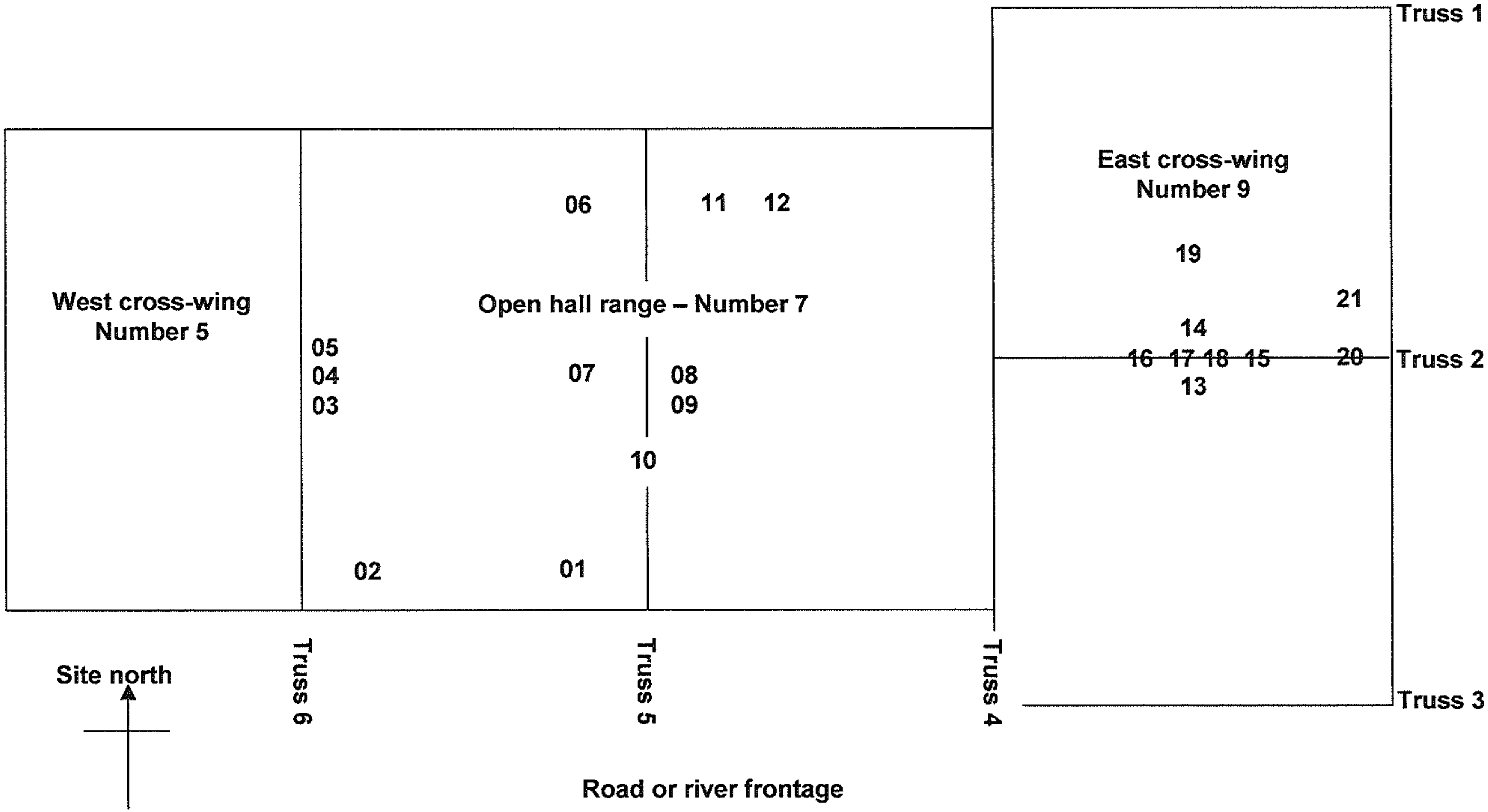


Figure 4: Above, front view of 5 – 9 Stourport Road, rear view below (by kind permission of Steven Price)

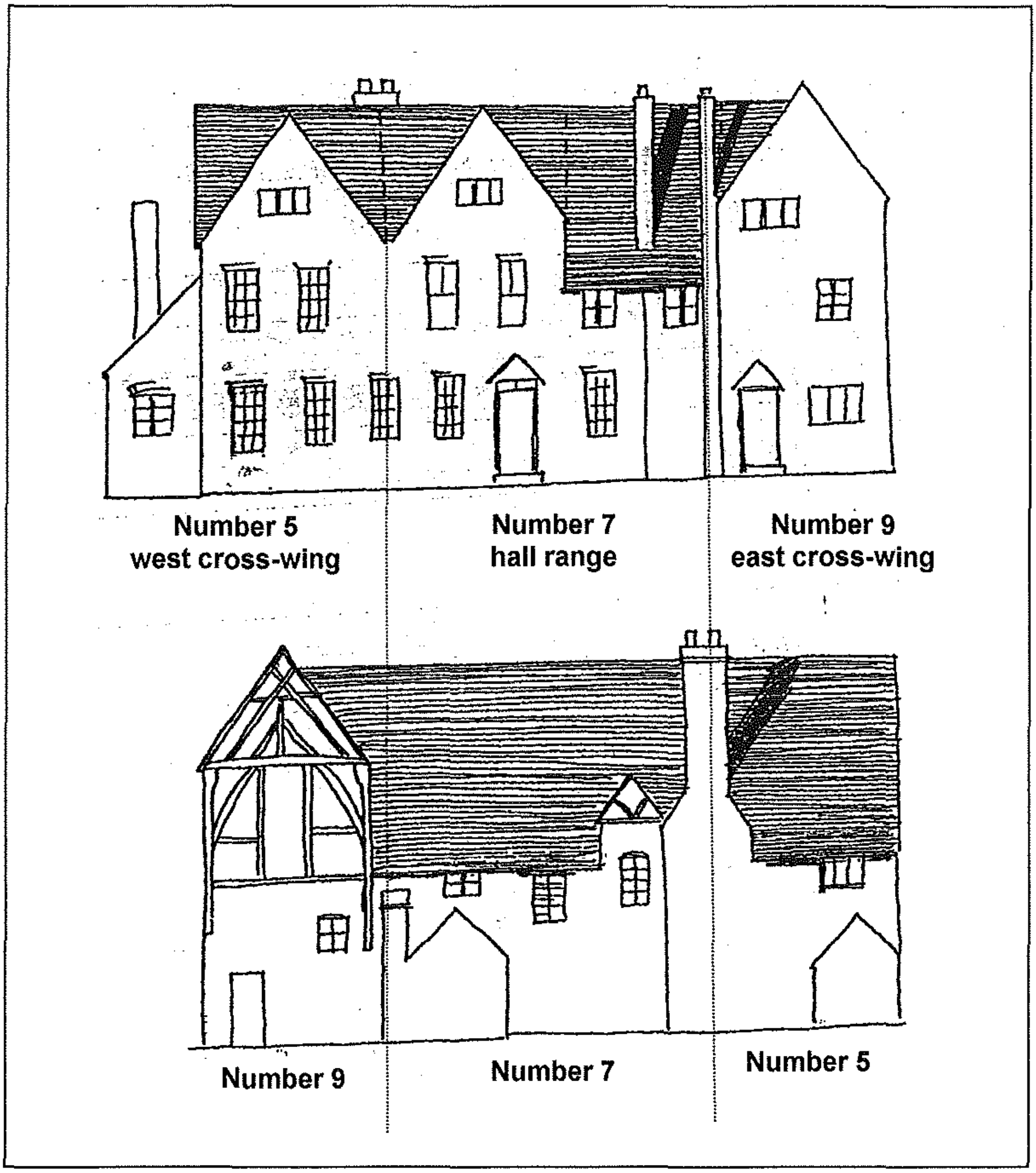


Figure 5: Drawing showing truss 5 (central truss) of the open hall range to show sample positions (viewed from the west looking east) (by kind permission of Steven Price)

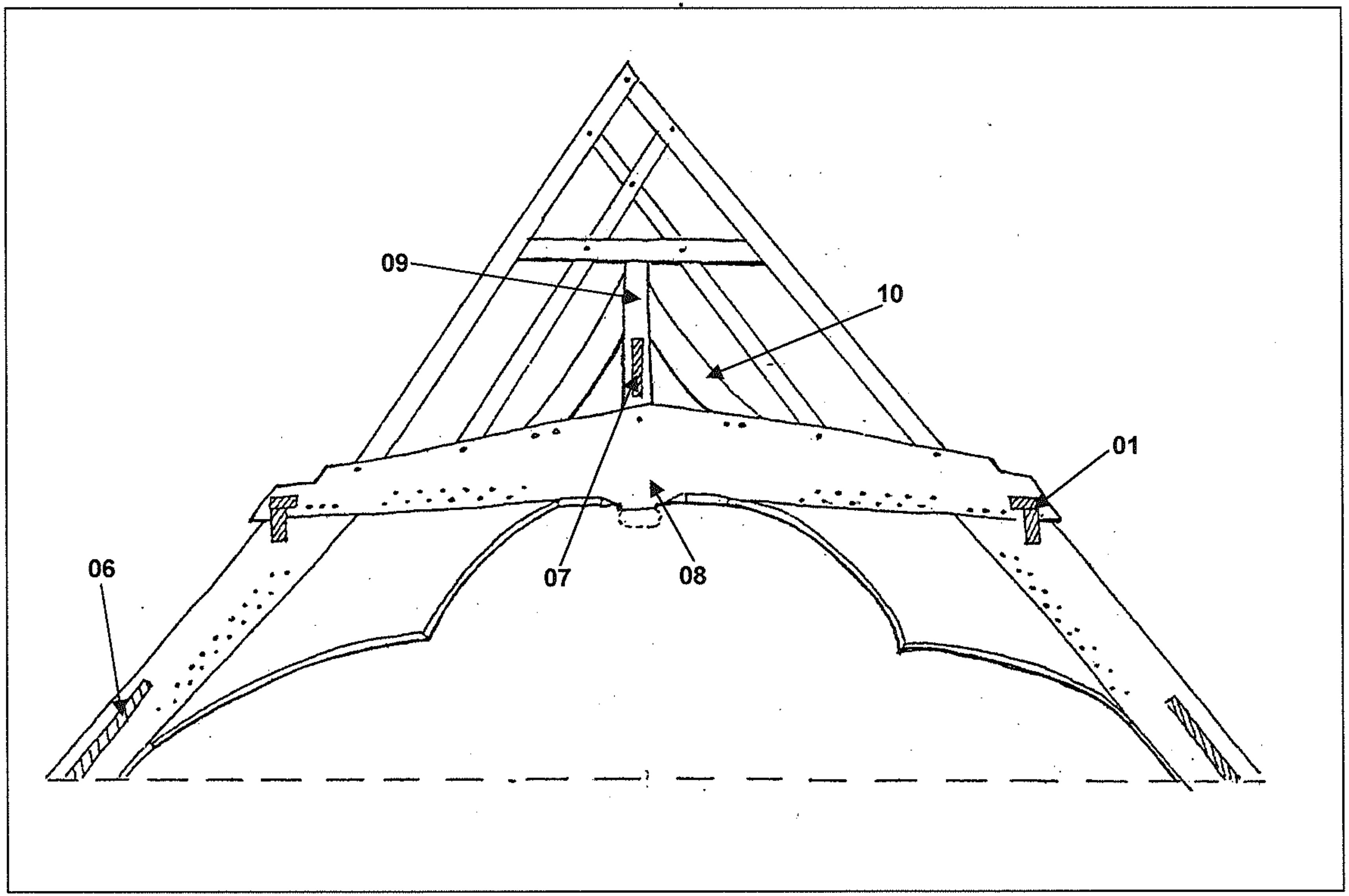


Figure 6: Illustration of truss 4 between the hall range and the east cross-wing (viewed from the west looking east) (by kind permission of Steven Price)

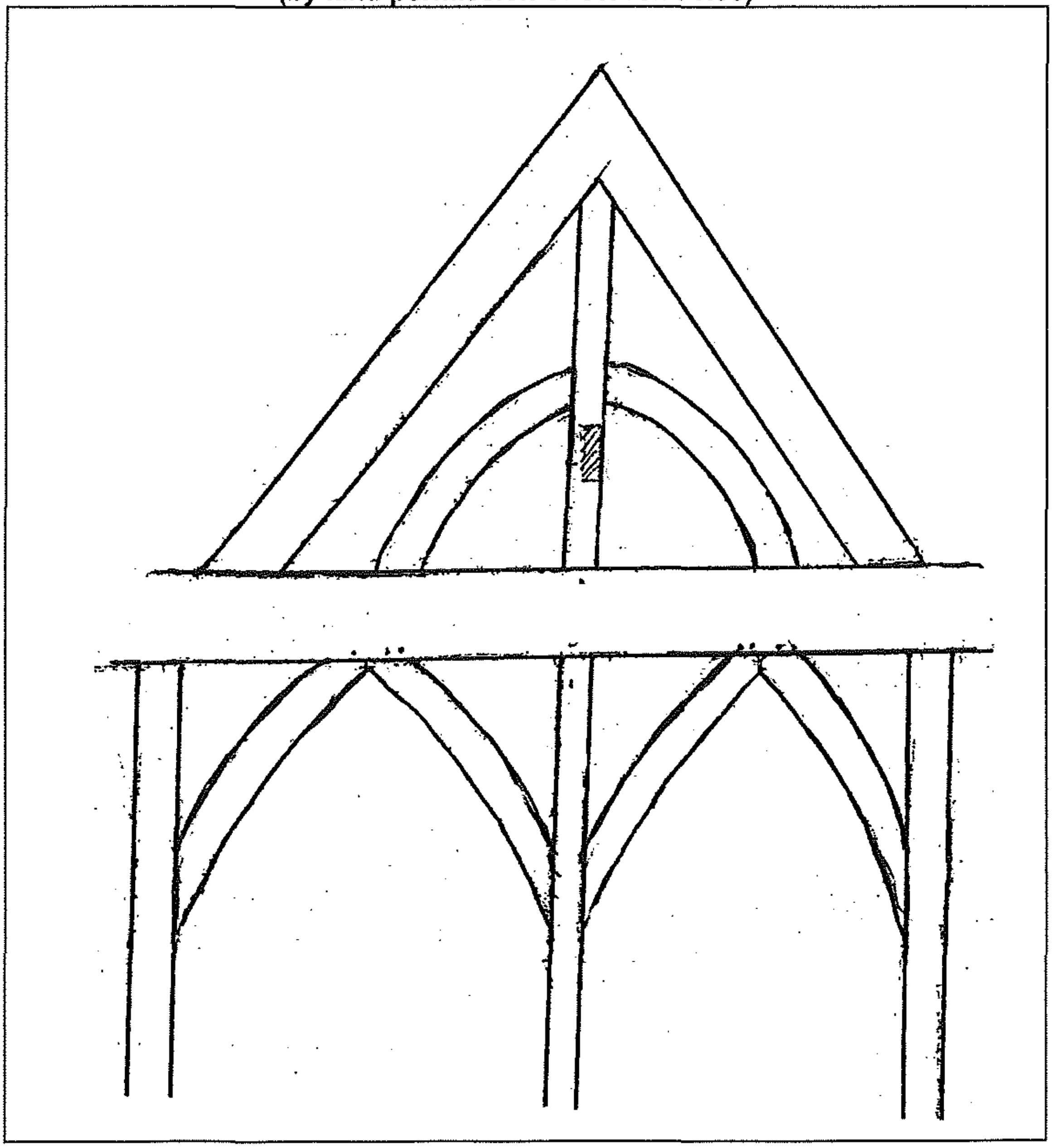


Figure 7: Drawing to illustrate truss 6 between hall range and west cross-wing to show sample positions (viewed from the east looking west) (by kind permission of Steven Price)

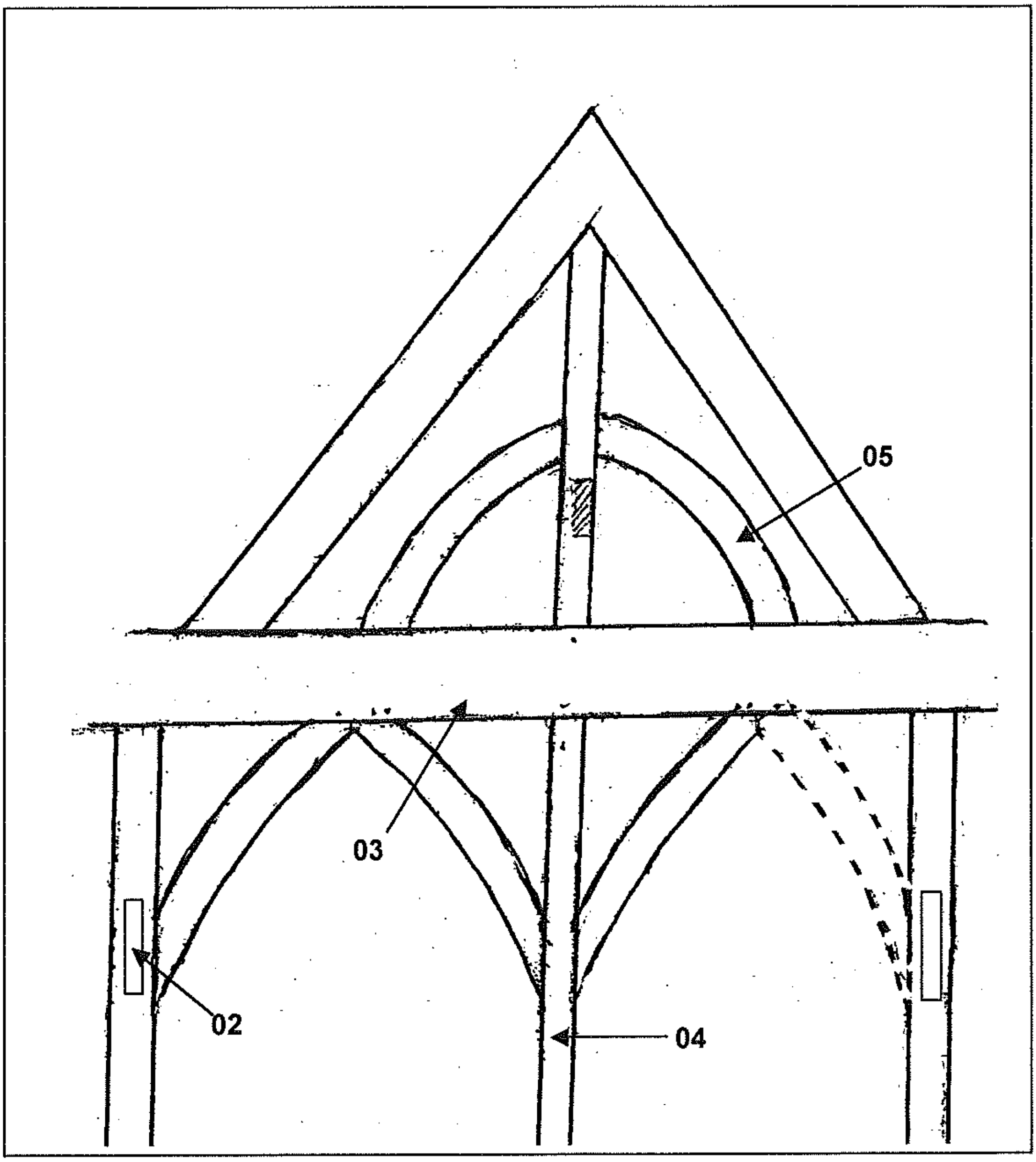


Figure 8: Drawing of truss 2 (central truss) of the east cross-wing to show sample positions (viewed from the south looking north) (by kind permission of Steven Price)

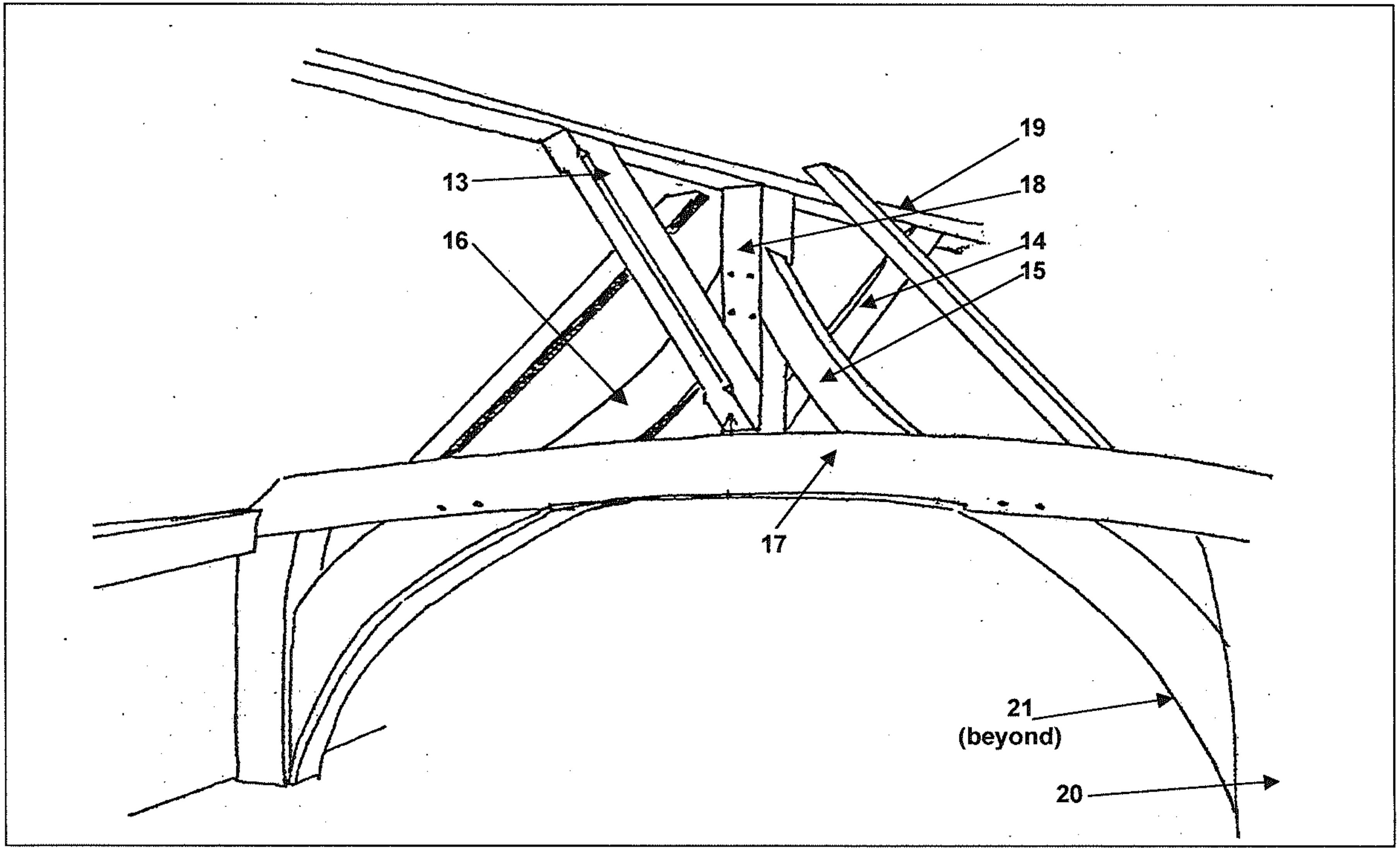


Figure 9: Illustration of truss 1, visible in the north gable wall of the east cross-wing (by kind permission of Steven Price)

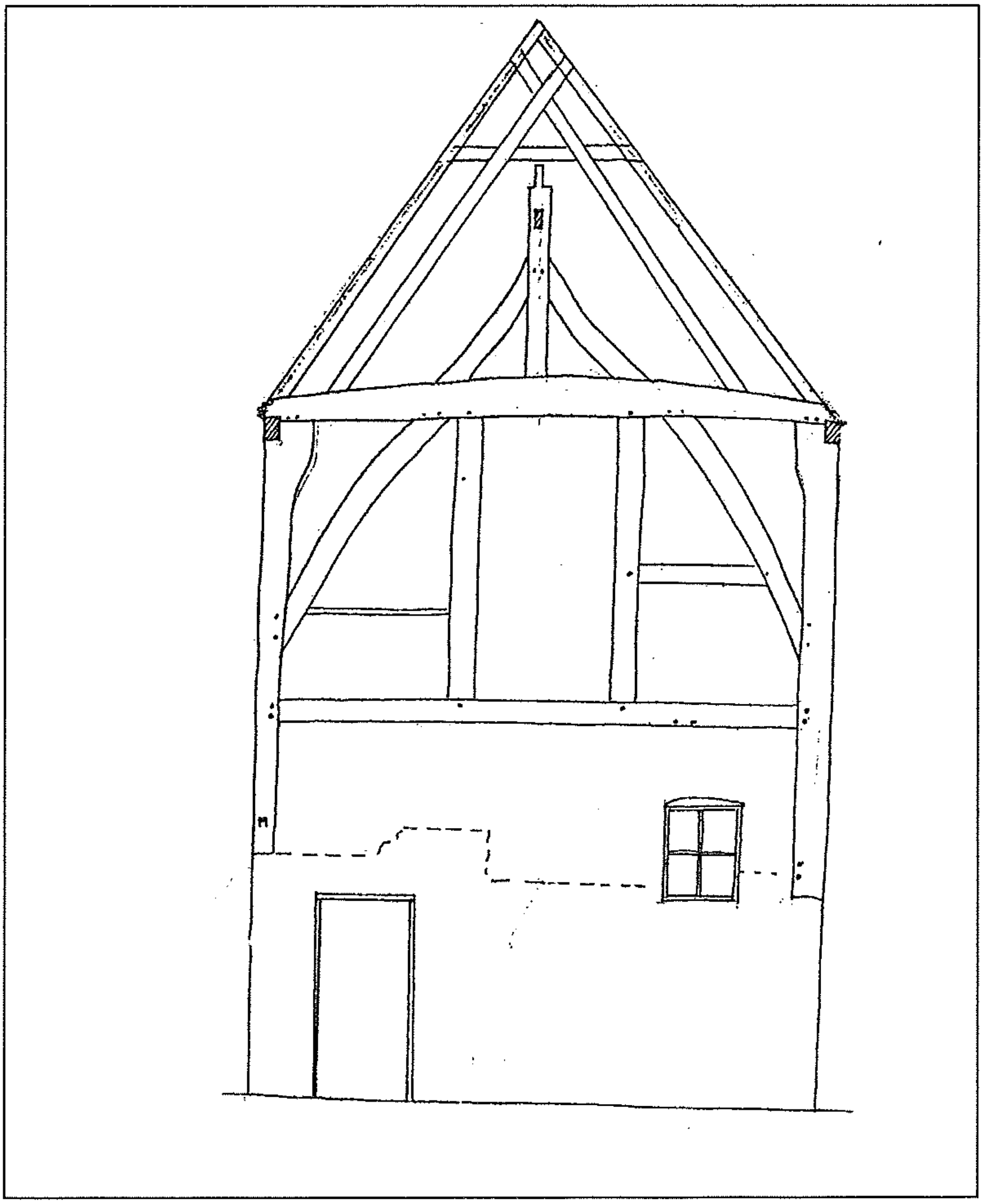
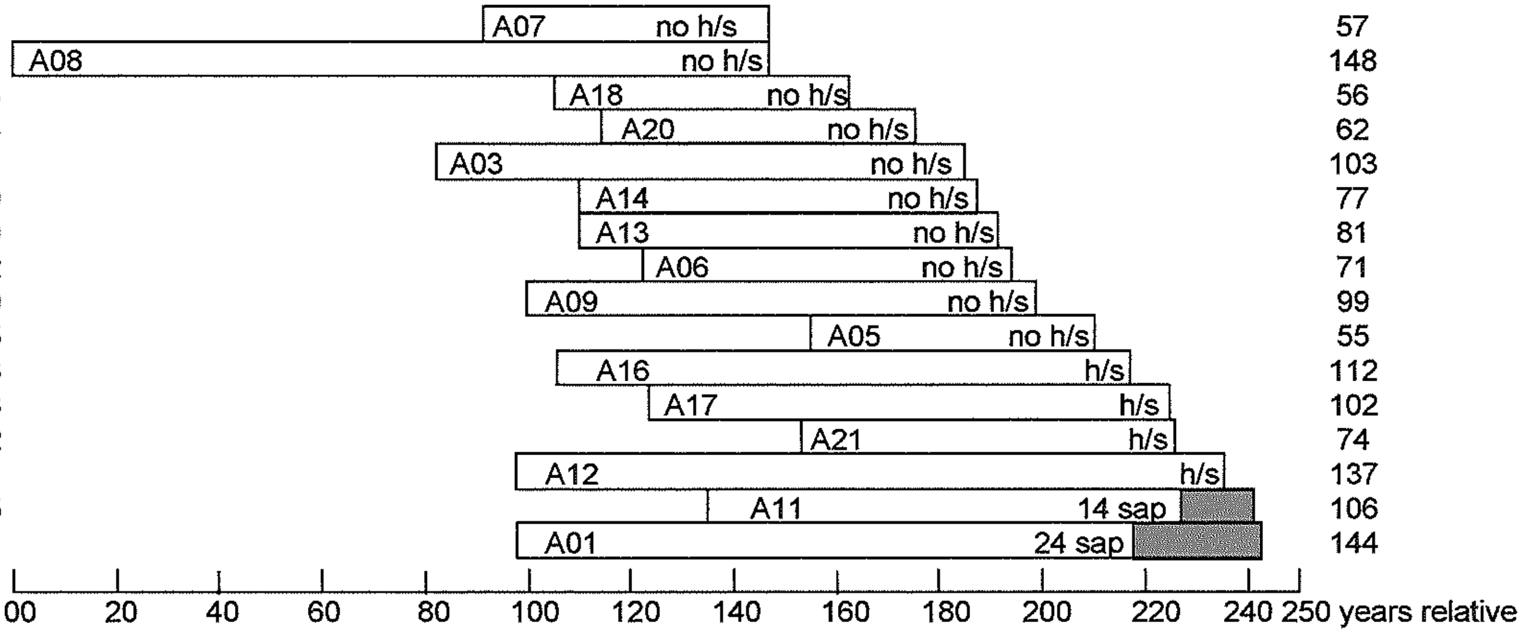


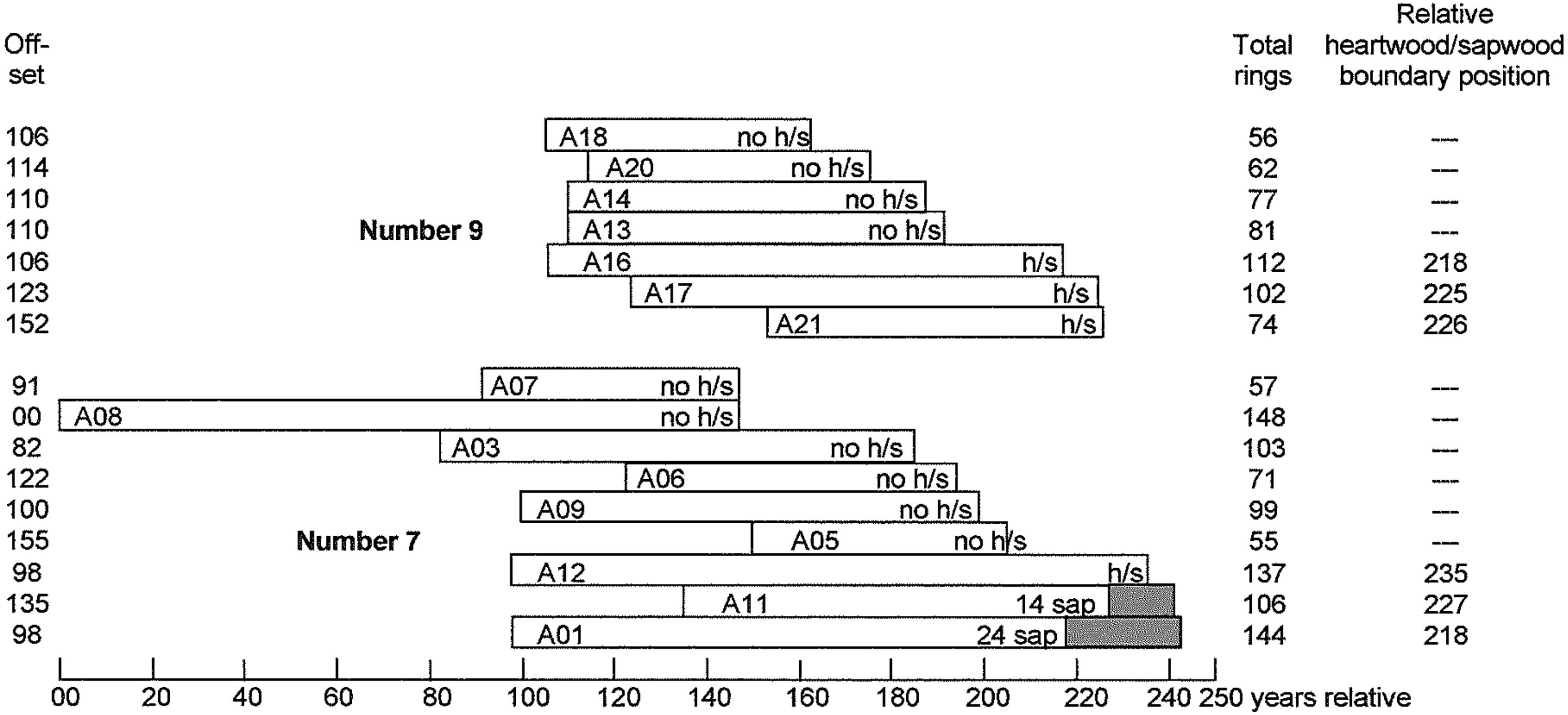
Figure 10: Bar diagram of the samples in site chronology BWDASQ01



Off-set	Sample	Total rings	Relative heartwood/sapwood boundary position
91	A07	57	---
00	A08	148	---
106	A18	56	---
114	A20	62	---
82	A03	103	---
110	A14	77	---
110	A13	81	---
122	A06	71	---
100	A09	99	---
155	A05	55	---
106	A16	112	218
123	A17	102	225
152	A21	74	226
98	A12	137	235
135	A11	106	227
98	A01	144	218

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

Figure 11: Bar diagram of the samples in site chronology BWDASQ01 sorted by sample location



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

BWD-A01A 144
160 192 235 238 218 207 245 240 170 198 239 172 136 156 175 113 67 103 215 141
150 183 151 189 217 151 130 207 333 260 122 166 214 141 143 163 167 211 267 248
159 186 358 285 225 216 144 161 229 185 216 215 147 184 211 151 227 166 173 197
143 165 114 77 51 47 82 141 210 168 374 192 183 136 108 129 269 327 295 331
351 309 194 89 53 54 93 93 133 145 115 69 81 103 95 113 116 99 78 100
52 39 114 98 114 79 96 168 120 95 86 82 43 47 73 95 87 94 99 92
69 57 97 100 93 114 163 127 115 66 43 78 102 141 106 125 113 99 151 96
70 52 123 174
BWD-A01B 144
186 180 229 247 171 203 265 241 179 199 222 180 141 153 178 106 70 114 211 130
146 194 149 195 233 155 123 198 306 253 111 172 208 159 143 160 150 213 291 251
175 187 355 263 230 235 131 173 230 162 225 204 137 158 210 152 228 161 160 190
137 175 111 73 55 40 90 126 222 179 326 181 182 123 119 136 225 324 233 370
307 279 139 89 72 65 81 102 146 174 123 70 77 102 103 115 108 98 78 99
59 40 114 101 108 85 85 172 122 95 90 78 41 39 81 99 81 98 102 91
79 49 90 105 88 114 171 127 98 69 41 88 96 143 98 131 110 102 138 97
63 49 140 167
BWD-A02A 97
329 249 403 241 209 166 287 276 340 131 152 176 177 319 544 492 290 205 188 77
90 133 298 299 276 175 209 232 261 268 245 212 156 192 273 167 208 241 410 205
125 179 152 141 270 238 281 503 323 419 341 264 176 145 149 153 154 147 289 330
496 333 163 170 403 285 155 220 247 395 358 134 201 160 157 159 189 197 197 238
149 290 343 304 172 139 118 127 168 177 224 182 187 144 212 246 191
BWD-A02B 84
376 260 368 211 200 186 251 261 318 144 153 181 172 341 554 490 282 225 184 65
100 127 297 313 283 186 201 234 242 284 256 203 159 172 255 167 215 264 289 161
126 197 150 149 263 253 268 525 337 422 337 238 171 153 127 167 190 159 287 318
478 335 169 166 428 278 144 211 252 393 353 128 192 172 154 164 186 182 198 241
152 285 347 306
BWD-A03A 103
89 95 78 105 108 125 120 126 91 113 127 121 152 143 149 152 134 188 171 112
128 94 124 140 149 187 163 308 235 172 94 120 114 167 238 140 148 151 121 124
217 344 177 259 191 225 117 132 166 111 96 150 167 185 204 193 184 124 144 151
182 228 158 186 195 148 236 131 147 148 86 114 203 246 191 249 226 245 234 221
143 119 208 244 219 172 237 274 264 155 122 133 202 195 167 255 166 211 193 172
263 354 306
BWD-A03B 103
110 100 66 108 104 119 131 125 87 131 127 127 148 138 159 153 135 187 162 109
122 103 112 151 147 186 167 238 256 168 92 115 133 150 276 139 141 149 122 122
219 347 184 286 174 215 132 131 148 101 113 138 157 190 211 199 177 130 135 152
183 223 160 184 195 133 210 151 157 143 94 118 187 233 212 257 220 251 253 227
146 129 205 244 218 170 217 284 284 146 112 138 220 190 178 249 160 204 197 167
318 351 338
BWD-A04A 93
446 482 342 346 196 288 238 238 239 162 167 159 188 127 147 83 120 68 105 126
175 219 199 245 241 218 233 238 300 248 209 278 264 240 283 201 171 136 122 140
132 147 186 197 197 178 152 123 114 95 119 116 128 128 109 130 141 117 120 117
150 141 201 143 131 151 152 252 186 235 163 140 116 118 149 101 117 102 133 116
138 144 143 89 100 115 139 139 132 129 128 139 132

BWD-A04B 93
437 481 363 346 179 296 253 223 249 151 169 158 184 115 157 87 117 69 105 125
171 231 204 254 249 209 236 239 299 259 186 279 249 242 290 177 165 114 109 142
115 151 201 190 195 173 155 112 125 97 117 118 133 114 118 121 142 113 137 110
136 147 180 156 136 152 162 249 193 255 156 134 124 113 141 103 117 100 129 132
139 135 150 93 86 126 136 136 120 142 132 134 134
BWD-A05A 55
151 174 150 100 138 139 134 111 113 131 170 159 133 100 94 81 85 78 73 79
75 82 83 78 85 130 90 93 108 113 109 171 166 222 170 331 377 336 414 197
273 206 303 175 181 236 324 274 246 201 191 270 241 309 334
BWD-A05B 55
149 175 151 103 137 139 140 113 118 135 167 171 130 97 99 83 78 86 78 74
81 74 90 67 89 116 95 96 123 123 105 176 159 232 176 314 363 393 393 218
280 222 265 159 169 211 254 339 230 197 188 277 231 298 362
BWD-A06A 71
301 281 113 297 183 378 185 228 298 254 237 293 253 245 333 271 317 250 264 336
325 318 247 268 242 117 177 160 211 230 123 156 173 185 196 209 183 168 199 265
262 294 323 305 321 191 185 154 121 81 101 72 124 111 90 148 97 133 165 125
150 135 112 119 94 100 125 94 100 89 108
BWD-A06B 71
407 341 163 269 174 366 186 227 306 225 246 291 257 280 356 262 305 242 276 322
304 310 241 265 245 112 175 155 216 231 137 178 170 180 186 194 162 163 202 254
254 307 341 297 306 213 179 156 130 81 105 80 110 127 107 143 104 119 168 131
136 165 135 112 94 115 127 100 97 113 85
BWD-A07A 57
170 189 287 153 168 121 115 140 143 249 191 213 141 220 155 197 205 270 317 281
261 224 154 147 156 265 191 228 234 276 208 247 226 112 276 270 198 148 135 365
184 264 273 145 280 225 215 214 227 147 198 112 137 150 152 155 173
BWD-A07B 57
150 190 276 149 156 127 128 118 144 221 164 193 150 252 141 177 176 223 345 238
244 231 164 141 199 260 197 219 249 248 193 241 242 150 285 244 229 128 185 333
178 241 236 153 282 211 202 216 223 162 185 114 136 151 152 159 178
BWD-A08A 148
292 268 144 214 272 130 230 325 257 190 172 155 159 217 211 193 181 175 158 130
175 141 118 135 111 119 102 88 65 115 71 70 96 148 104 125 90 84 76 69
67 78 75 105 60 83 104 115 112 145 112 78 102 122 135 127 163 126 89 86
101 152 159 158 175 163 155 103 107 83 103 119 95 112 84 91 81 68 84 97
83 108 97 99 110 134 117 109 90 96 72 108 89 146 132 132 136 129 148 155
177 170 180 150 154 141 160 167 156 195 169 166 126 127 116 139 145 140 133 122
136 159 221 208 133 196 152 160 99 108 159 84 75 118 111 132 132 143 109 113
112 130 110 135 149 150 152 172
BWD-A08B 148
313 292 150 169 245 143 252 333 252 213 181 124 141 222 209 194 191 176 167 121
186 136 115 138 107 122 94 93 87 97 81 69 91 135 105 136 91 86 71 75
62 73 77 97 70 83 99 113 120 148 110 70 108 110 147 134 152 127 84 72
111 152 153 162 168 170 146 109 103 77 111 119 96 114 77 96 77 78 78 92
88 107 99 100 104 138 115 99 102 96 69 96 91 143 132 125 134 128 154 140
181 174 183 157 150 149 182 175 178 188 174 162 130 114 116 149 147 131 134 125
144 154 229 189 149 197 153 149 92 114 154 96 70 113 118 134 136 137 109 112
119 131 104 132 160 162 139 171

BWD-A09A 99
313 369 282 253 301 294 275 263 268 232 185 247 238 195 231 237 308 220 174 187
228 282 262 243 161 239 192 242 118 139 187 213 214 222 240 207 223 170 128 117
177 186 179 202 139 141 151 124 102 103 89 121 104 105 118 124 128 112 110 98
112 110 72 63 95 113 141 131 138 155 117 128 92 206 128 164 112 171 127 97
107 66 66 112 93 80 101 80 87 64 61 94 66 89 79 82 74 75 82
BWD-A09B 99
321 376 272 266 301 296 254 231 275 233 187 235 244 190 229 236 332 230 205 189
231 276 282 262 154 247 180 220 119 124 175 213 192 221 218 213 231 177 126 119
188 185 178 192 125 146 161 111 100 103 98 114 109 89 123 118 144 110 110 116
120 108 64 63 89 113 140 122 148 147 129 119 104 191 125 172 113 173 128 120
97 63 70 110 89 85 102 86 81 70 68 80 82 79 77 76 77 80 81
BWD-A10A 63
480 178 236 304 223 314 206 205 180 195 165 147 182 187 316 240 416 312 347 396
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APPENDIX

Tree-Ring Dating

The Principles of Tree-Ring Dating

Tree-ring dating, or *dendrochronology* as it is known, is discussed in some detail in the Laboratory's Monograph, '*An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Building*' (Laxton and Litton 1988) and, *Dendrochronology; Guidelines on Producing and Interpreting Dendrochronological Dates* (English Heritage 1988). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The *width* of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure 1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths for oaks, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of oak timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring.

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

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

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

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

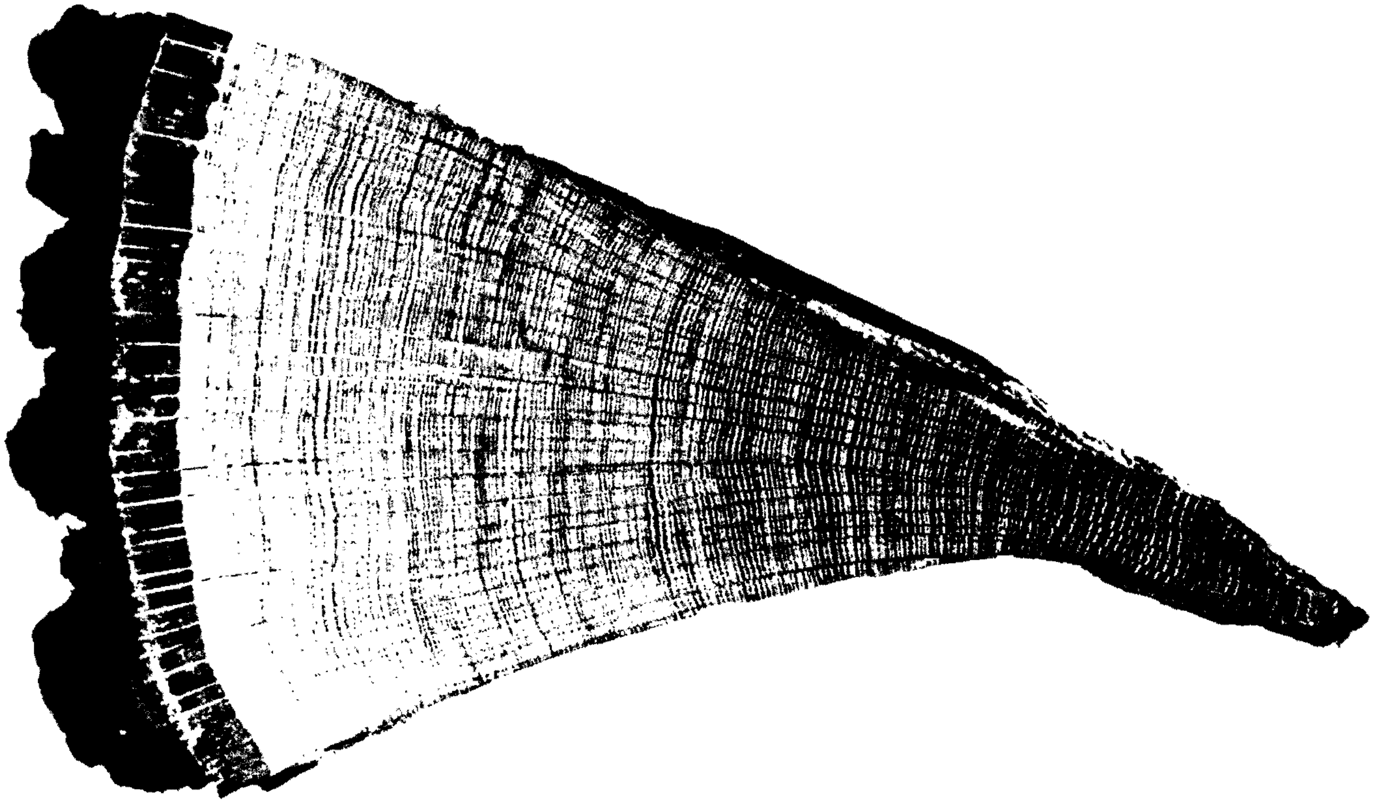


Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can determined by counting back from the outside ring, which grew in 1976.

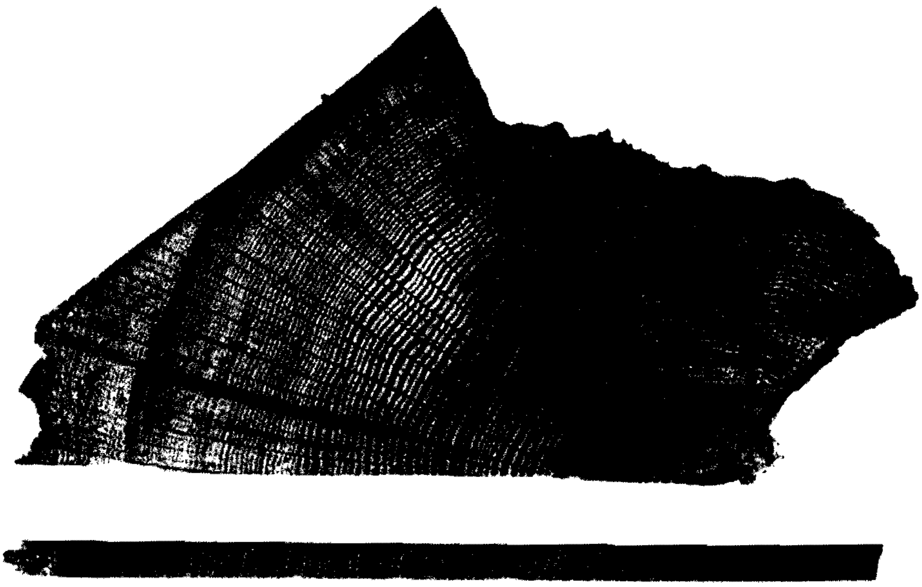


Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the left hand corner, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

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

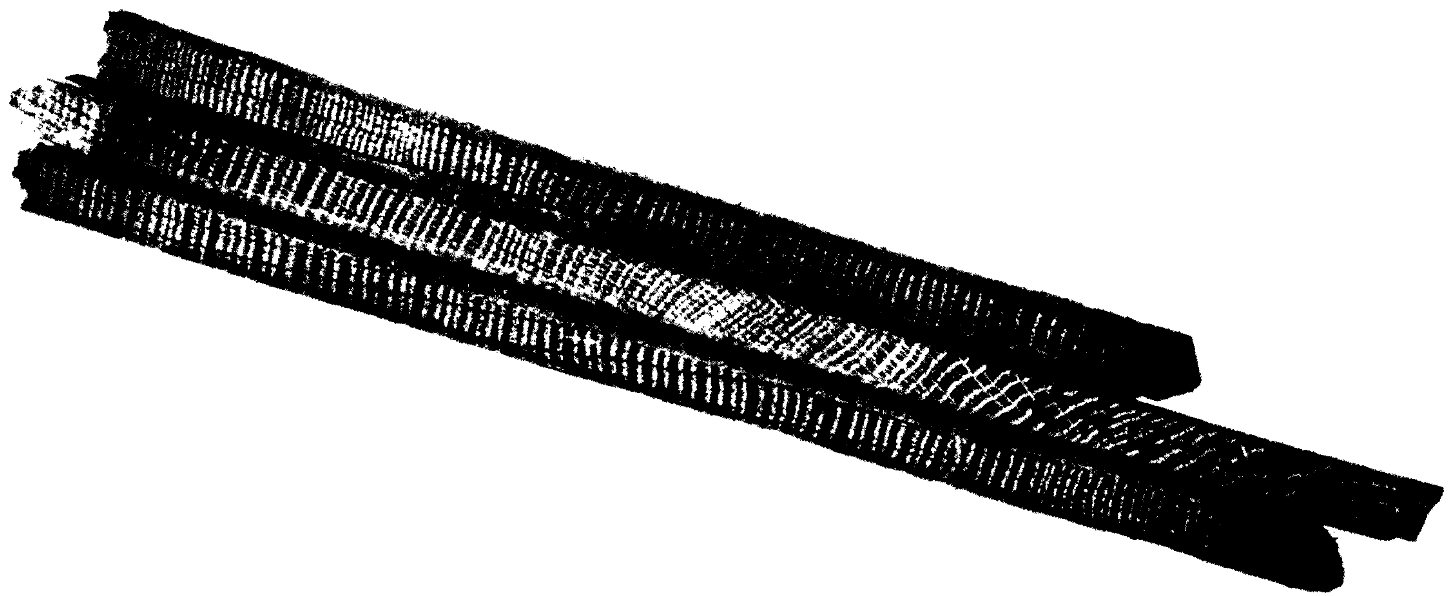


Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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

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

All sampling by the Laboratory is undertaken according to current Health and Safety Standards. The Laboratory's dendrochronologists are insured.

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

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

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

It is standard practice in our Laboratory first to cross-match as many as possible of the ring-width sequences of the samples in a building and then to form an average from them. This average is called a *site sequence* of the building being dated and is illustrated in Fig 5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences of the four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. Thus in Fig 5 if the widths shown are 0.8mm for C45, 0.2mm for C08, 0.7mm for C05, and 0.3mm for C04, then the corresponding width of the site sequence is the average of these, 0.55mm. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

The straightforward method of cross-matching several sample sequences with each other one at a time is called the 'maximal *t*-value' method. The actual method of cross-matching a group of sequences of ring-widths used in the Laboratory involves grouping and averaging the ring-width sequences and is called the 'Litton-Zainodin Grouping Procedure'. It is a modification of the straight forward method and was successfully developed and tested in the Laboratory and has been published (Litton and Zainodin 1991; Laxton *et al* 1988).

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

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

Various estimates have been made and used for the average number of sapwood rings in mature oak trees (English Heritage 1998). A fairly conservative range is between 15 and 50 and that this holds for 95% of mature oaks. This means, of course, that in a small number of cases there could be fewer than 15 and more than 50 sapwood rings. For example, the core CRO-A06 has only 9 sapwood rings and some have obviously been lost over time – either they were removed originally by the carpenter and/or they rotted away in the building and/or they were lost in the coring. It is not known exactly how many sapwood rings are missing, but using the above range the Laboratory would estimate between a minimum of 6 (=15-9) and a maximum of 41 (=50-9). If the last ring of CRO-A06 has been dated to 1500, say, then the estimated felling-date range for the tree from which it came originally would be between 1506 and 1541. The Laboratory uses this estimate for sapwood in areas of England where it has no prior information. It also uses it when dealing with samples with very many rings, about 120 to the last heartwood ring. But in other areas of England where the Laboratory has accumulated a number of samples with complete sapwood, that is, no sapwood lost since felling, other estimates in place of the conservative range of 15 to 50 are used. In the East Midlands (Laxton *et al* 2001) and the east to the south down to Kent (Pearson 1995) where it has sampled extensively in the past, the Laboratory uses the shorter estimate of 15 to 35 sapwood rings in 95% of mature oaks growing in these parts. Since the sample CRO-A06 comes from a house in Cropwell Bishop in the East Midlands, a better estimate of sapwood rings lost since felling is between a minimum of 6 (=15-9) and 26 (=35-9) and the felling would be estimated to have taken place between 1506 and 1526, a shorter period than before. (Oak boards quite often come from the Baltic and in these cases the 95% confidence limits for sapwood are 9 to 36 (Howard *et al* 1992, 56)).

Even more precise estimates of the felling date and range can often be obtained using knowledge of a particular case and information gathered at the time of sampling. For example, at the time of sampling the dendrochronologist may have noted that the timber from which the core of Figure 2 was taken still had complete sapwood but that none of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 2 cm, a reasonable estimate can be made of the number of sapwood rings lost, say 12 to 15 rings in this case. By adding on 12 to 15 years to the date of the last ring on the sample a good tight estimate for the range of the felling date can be obtained, which is often better than the 15 to 35 years later we would have estimated without this observation. In the example, the felling is now estimated to *t*-value/offset Matrix

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

Bar Diagram

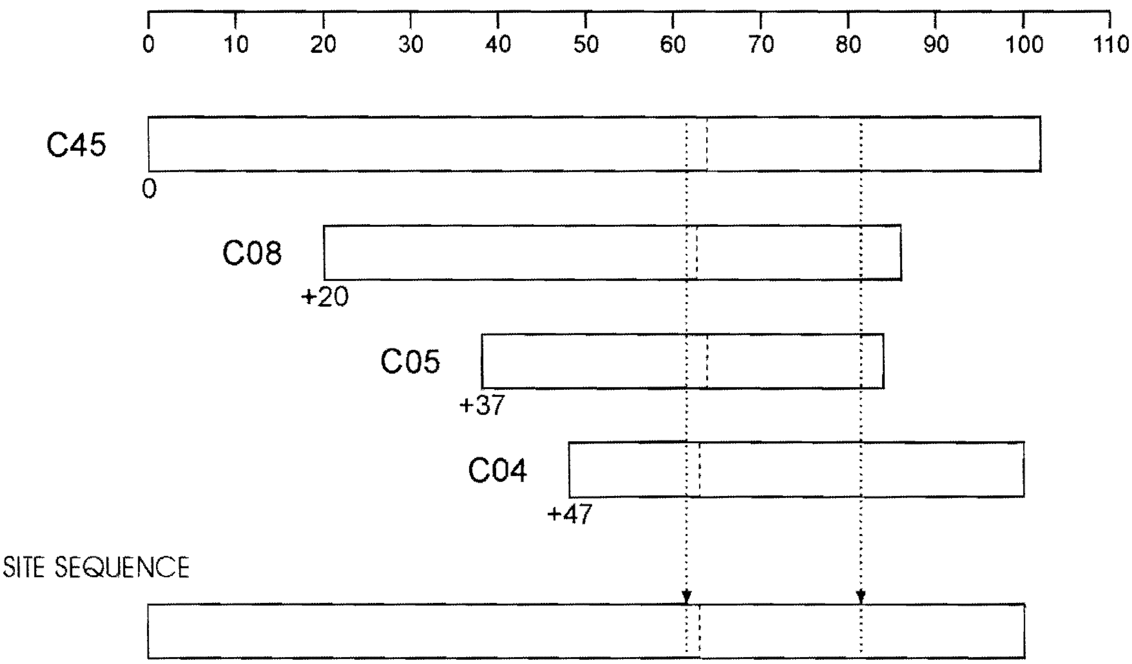


Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set at relative positions (*offsets*) to each other at which they have maximum correlation as measured by the *t*-values.

The *t*-value/offset matrix contains the maximum *t*-values below the diagonal and the offsets above it. Thus, the maximum *t*-value between C08 and C45 occurs at the offset of +20 rings and the *t*-value is then 5.6.

The *site sequence* is composed of the average of the corresponding widths, as illustrated with one width.

have taken place between AD 1512 and 1515, which is much more precise than without this extra information.

Even if all the sapwood rings are missing on a sample, but none of the heartwood rings are, then an estimate of the felling-date range is possible by adding on the full compliment of, say, 15 to 35 years to the date of the last heartwood ring (called the heartwood/sapwood boundary or transition ring and denoted H/S). Fortunately it is often easy for a trained dendrochronologist to identify this boundary on a timber. If a timber does not have its heartwood/sapwood boundary, then only a *post quem* date for felling is possible.

5. ***Estimating the Date of Construction***. There is a considerable body of evidence collected by dendrochronologists over the years that oak timbers used in buildings were not seasoned in medieval or early modern times (English Heritage 1998 and Miles 1997, 50-55). Hence provided all the samples in a building have estimated felling-date ranges broadly in agreement with each other, so that they appear to have been felled as a group, then this should give an accurate estimate of the period when the structure was built, or soon after (Laxton *et al* 2001, figure 8 and pages 34-5 where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storing before use or if there is evidence the oak came from abroad (eg Baltic boards), then some allowance has to be made for this.

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

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

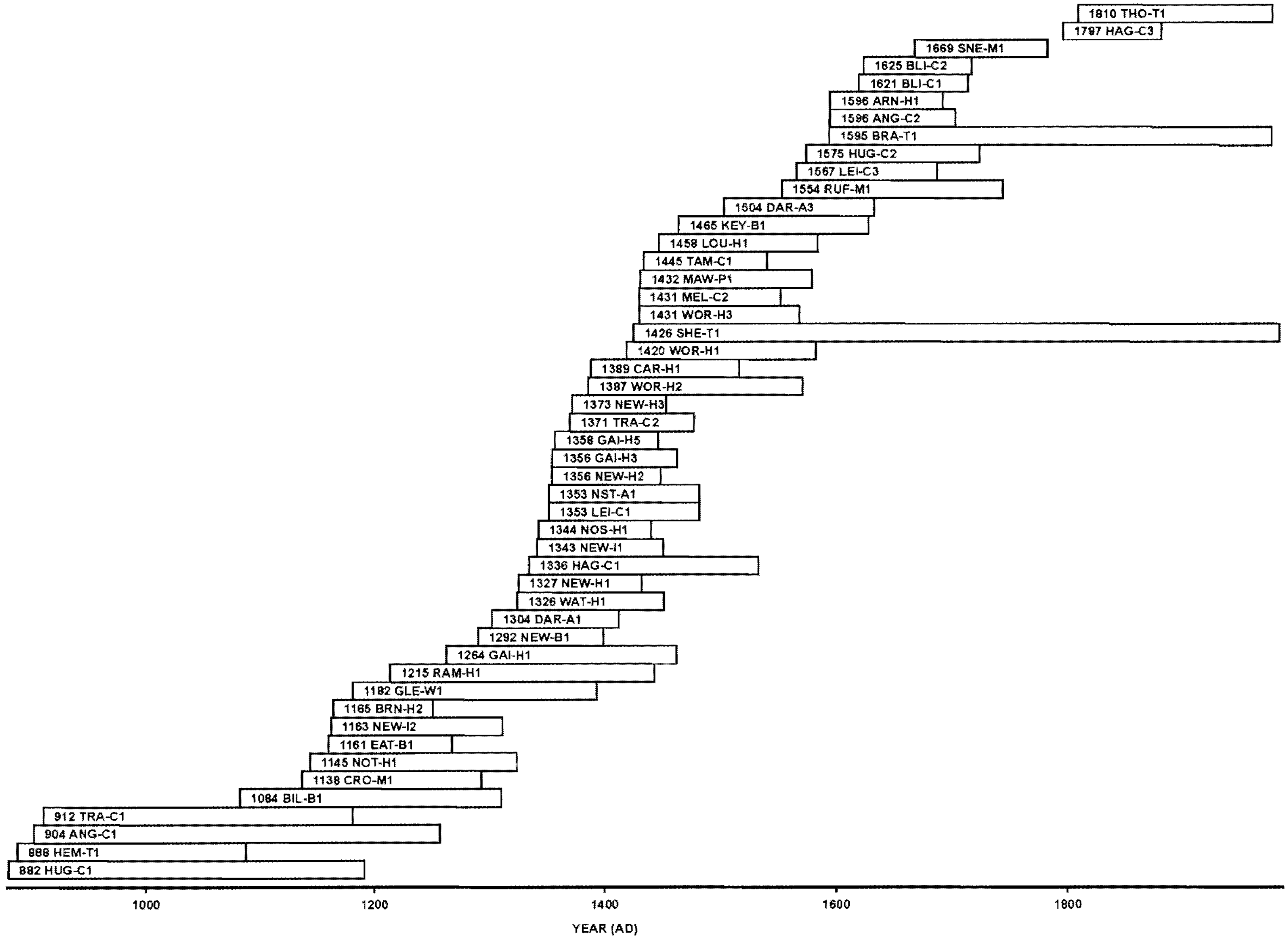
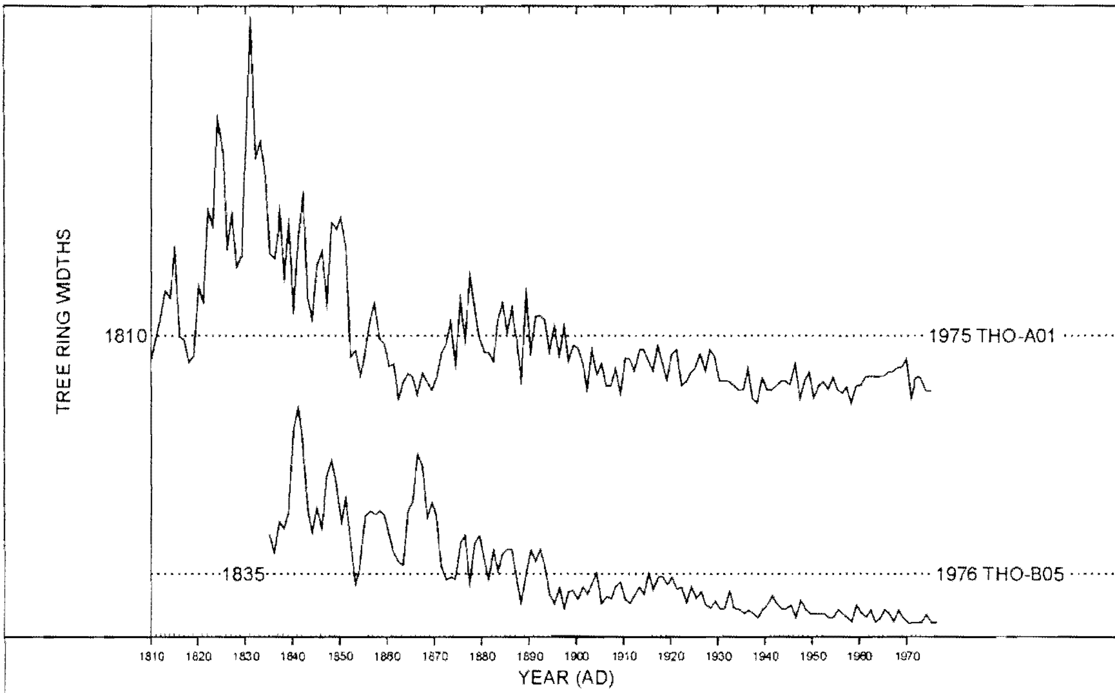


Fig. 6 Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

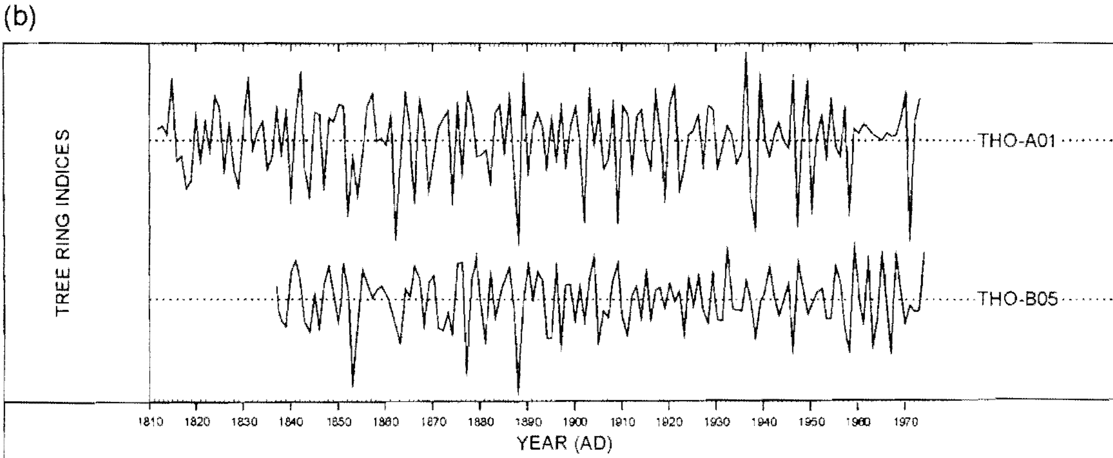


Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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

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

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