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Scientific Dating

Little Toller Farmhouse, Toller Fratrum, West Dorset

Tree-ring Analysis of Oak Timbers

Alison Arnold and Robert Howard

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LITTLE TOLLER FARMHOUSE, TOLLER FRATRUM, WEST DORSET

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SUMMARY
Dendrochronological analysis was undertaken on 23 of the 25 core samples obtained from timbers of the main range roof at Little Toller Farmhouse. This analysis produced a single dated site chronology comprising 15 samples with an overall length of 161 rings. These rings were dated as spanning the years AD 1379–1539. Interpretation of the sapwood on the dated samples, which represent timbers from the entire length of the roof, suggests that they represent a single phase of construction, the timbers probably being cut in a single episode of felling at some point in the mid–AD 1550s. The eight measured but ungrouped samples remain undated.

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INTRODUCTION

Little Toller Farmhouse, a grade II* listed building, stands to the south of the River Hooke approximately 2km west of Maiden Newton in Dorset (Fig 1a–c). The National Heritage List for England (www.historicengland.org.uk/listing/the-list/list-entry/1228875) indicates that the main range is of mid-sixteenth century origin with a nineteenth century range at right angles at the south-west corner. It is believed to have originally been built for John Samways of Winterborne St Martin, which itself lies just to the south-west of Dorchester (Fig 1a). The main range walls are predominantly limestone ashlar with Ham Stone dressings, though the western end and the nineteenth century wing are of shallow-coursed rubble-stone. Various modifications were undertaken prior to what is thought to have been a major refashioning in the nineteenth century. The roof over the main range comprises coupled rafters with collar and archbraces, forming a wagon-style which is more commonly associated with ecclesiastical buildings rather than secular buildings. The building is considered remarkable for its stone carvings, which include a pair of barley twist chimney stacks on either side of a figure of a monkey and a figure of a griffin on a finial on top of an octagonal buttress.

In June 2015 an accidental fire ripped through the property destroying much of the interior floors and fittings and severely damaging the roof (Fig 2a–b). The resulting programme of repair and restoration has enabled outline survey and recording to be undertaken. This raised the possibility, on the basis of differing assembly marks, that the east and west halves of the roof to the main range could potentially be of different dates.

SAMPLING

A dendrochronological survey was requested by Francis Kelly to obtain precise independent dating evidence for the roof construction and hence inform the programme of repair and restoration following the fire. It was hoped that this analysis would establish the date of the main range roof with greater precision and reliability and ascertain if there were indeed any differences in date between the east and west halves, as well as establishing whether the extant roof elements were associated with the original construction.

Thus, after an initial assessment of the timbers as to their suitability for tree-ring analysis, particularly in respect of their condition after the fire, a total of 25 samples were obtained by coring, the samples being distributed as evenly as possible between the two halves of the roof. Each sample was given the code TOL-F (for Little Toller Farmhouse) and numbered 01–25 (Table 1). In this report the front of the house is deemed to be facing south, with the rear facing north (Fig 3). The roof frames have been numbered consecutively 1 to 44 from the east gable westwards along the entire main range (Figures 3 and 4 with individual timbers then being located on a north-south basis as appropriate). The approximate location of each sample on the relevant timber is illustrated in Figures 5a–q.

ANALYSIS AND RESULTS

Each of the 25 samples obtained from Little Toller Farmhouse was prepared by sanding and polishing, at which time it was seen that two samples had less than the 40 rings here deemed necessary for reliable dating and they were rejected from this programme of analysis. The annual growth ring widths of the remaining 23 samples were measured, the data of these measurements being given at the end of this report.

The data of the 23 measured samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix). This comparative process resulted in the production of a single group of 15 cross-matching samples, these matching with each other as shown in Figure 6.

These 15 cross-matching samples were combined at their indicated offset positions to form site chronology TOLFSQ01, this having an overall length of 161 rings. Site chronology TOLFSQ01 was then compared to an extensive corpus of reference material for oak, this indicating a consistent and repeated match with a series of these when the date of its first ring is AD 1379 and the date of its last measured ring is AD 1539 (Table 2).

INTERPRETATION

None of the 15 dated samples in site chronology TOLFSQ01 retain sapwood complete to the bark and it is thus not possible to determine precisely when any individual tree was cut. However, one of the timbers, represented by sample TOL-F02, had complete sapwood present but due to its highly fragile nature all the sapwood (*c* 20mm) was lost from the sample during coring. Given that the heartwood/sapwood boundary on this sample is dated to AD 1535 and allowing for the number of sapwood rings lost, based on the average ring width and overall trends within the measured sequence, suggests that the tree from which this timber was derived was felled in the mid-AD 1550s.

Seven other samples retain the heartwood/sapwood boundary (Table 1; Fig 6) demonstrating that it is only the sapwood that has been lost. The average date of this boundary is AD 1529. Using a sapwood estimate of 15–40 rings (the usual 95% confidence interval) would thus give these seven timbers an estimated felling date in the range AD 1544–69, a span which neatly brackets the likely felling date of the timber represented by TOL-F02. The date of the heartwood/sapwood boundary on all eight dated samples that have it varies by 19 years and this, combined with some very high levels of cross-matching between the 15 dated individual samples, suggests that they are all coeval and were thus all likely to have been felled at, or about, the same time in the mid-AD 1550s.

DISCUSSION AND CONCLUSION

The analysis indicates that the dated samples, representing timbers from both halves of the roof over the main range, were all felled as part of a single episode of felling in the AD 1550s. This therefore suggests that these timbers were associated with the original construction of the main range in the mid-sixteenth century for John Samways and refutes the recent suggestion that the two halves of this roof were of potentially different dates. This interpretation is supported by the similar variation in the heartwood/sapwood boundary date between the two halves of the roof and also by the high level of similarity noted between various individual ring sequences including a value of t=10.5 between samples TOL-F05 and TOL-F14. This is sufficiently high to suggest that the two timbers, both archbraces but one in the east end and one in the west end, have potentially been derived from the same tree.

The level of cross-matching between samples also indicates that the dated timbers are likely to have been sourced from a single woodland. Site chronology TOLFSQ01 has high levels of similarity with reference chronologies across the country suggesting that the trees are responding to a generic climatic signal (Table 2), and while it shows repeated high level cross-matching with reference chronologies from south-west, south-east and mid-west England, these are too geographically dispersed to provide a clear indication of where this source woodland was. However the status of the building and the common practice at the time suggests that the dated timbers from Little Toller Farmhouse were derived from a local regional source. Given that there is currently relatively little contemporary reference material for west Dorset, the well-replicated chronology produced here will prove useful as further dendrochronological work is undertaken in the area.

Despite having sufficient rings for analysis, eight measured samples remain ungrouped and undated. Three of these samples, TOL-F03, TOL-F06, and TOL-F12, show some distortion and disturbance to their growth, and it is likely that this prevents them from grouping and dating by masking the common climatic signal. The other five samples show no such problems. It is, however, a frequent feature of tree-ring analysis to find that some samples will not group or date and in this respect this group of material is fairly typical in that approximately 65% of the measured samples were successfully dated.

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TABLES

Table 1: Details of tree-ring samples from Little Toller Farmhouse, Toller Fratrum, West Dorset

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	Main roof, east end					
TOL-F01	North rafter, frame 1	54	h/s	------	------	------
TOL-F02	North upper archbrace, frame 2	90	h/s (+20mm nm c)	1446	1535	1535
TOL-F03	South rafter, frame 3	55	h/s	------	------	------
TOL-F04	South upper archbrace, frame 4	112	no h/s	1379	------	1490
TOL-F05	South lower archbrace, frame 4	91	h/s	1447	1537	1537
TOL-F06	North upper archbrace, frame 6	58	no h/s	------	------	------
TOL-F07	South rafter, frame 6	78	h/s	1445	1522	1522
TOL-F08	North rafter, frame 7	100	h/s	1421	1520	1520
TOL-F09	North upper archbrace, frame 7	54	no h/s	------	------	------
TOL-F10	North upper archbrace, frame 9	86	no h/s	1413	------	1498
TOL-F11	South rafter, frame 9	55	h/s	1476	1530	1530
TOL-F12	South rafter, frame 10	75	h/s	------	------	------
TOL-F13	South lower archbrace, frame 14	100	no h/s	1420	------	1519
	Main roof, west end					
TOL-F14	North lower archbrace, frame 24	105	h/s	1435	1539	1539
TOL-F15	North rafter, frame 27	nm	---	------	------	------
TOL-F16	South rafter, frame 29	64	h/s	1469	1532	1532
TOL-F17	South rafter, frame 31	65	no h/s	1419	------	1483
TOL-F18	North rafter, frame 32	69	no h/s	------	------	------

Table 1: (cont)

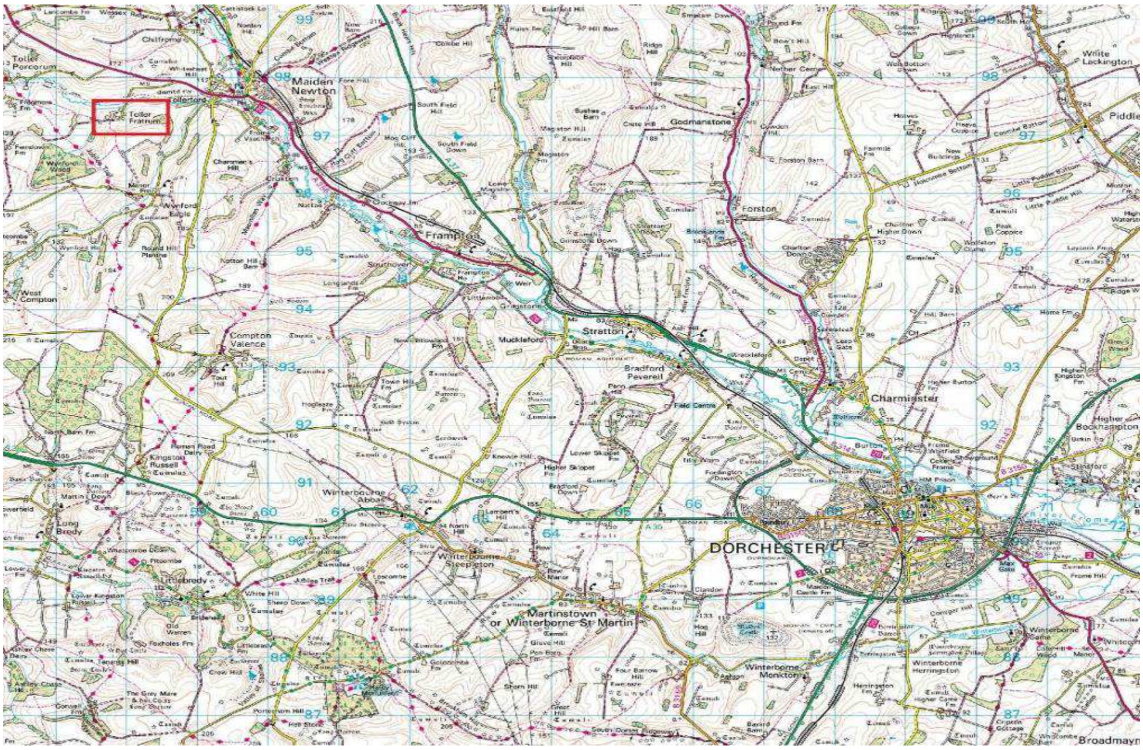
Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	Main roof, west end continued					
TOL-F19	South rafter, frame 32	nm	---	------	------	------
TOL-F20	North rafter, frame 34	88	no h/s	1407	------	1494
TOL-F21	South rafter, frame 34	66	no h/s	1445	------	1510
TOL-F22	North upper archbrace, frame 35	44	h/s	------	------	------
TOL-F23	South rafter, frame 35	74	no h/s	1435	------	1508
TOL-F24	South rafter, frame 36	54	h/s	1469	1522	1522
TOL-F25	South upper archbrace, frame 36	71	no h/s	------	------	------

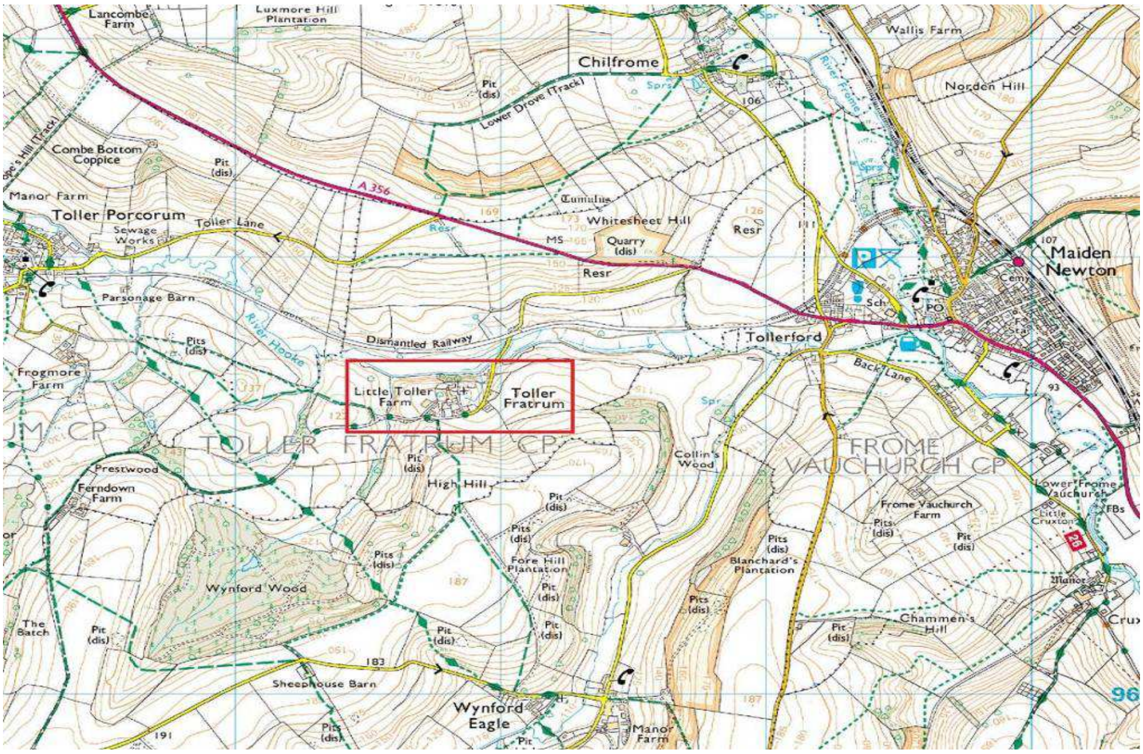
h/s = the heartwood/sapwood ring is the last ring on the sample
c = complete sapwood is found on the timber, but all or part has been lost from the sample in coring
nm = not measured

Table 2: Results of the cross-matching of site sequence TOLFSQ01 and relevant reference chronologies when the first-ring date is AD 1379 and the last-ring date is AD 1539

Reference chronology	Span of chronology	*t*-value	Reference
Holcombe Court, Holcombe Rogus, Devon	AD 1349 – 1536	8.4	(Miles and Bridge 2012)
Sinai Park, Burton on Trent, Staffordshire	AD 1227 – 1750	8.4	(Tyers 1997)
Tusmoore Park, Oxfordshire	AD 1359 – 1545	8.1	(Howard *et al* 1992)
Manor Farm barn, Winterborne Clenston, Dorset	AD 1339 – 1515	7.8	(Bridge 2014)
Gotham Manor, Gotham, Nottinghamshire	AD 1391 – 1590	7.6	(Howard *et al* 1991)
Poltimore House, Poltimore, Devon	AD 1380 – 1559	7.3	(Arnold *et al* 2005)
Manor Court House, Chard, Somerset	AD 1408 – 1517	7.2	(Arnold *et al* 2004)
Holy Cross Church, Crediton, Devon	AD 1317 – 1536	7.0	(Tyers 2004)

FIGURES





Figures 1a and 1b: Maps showing the location of Toller Fratrum. © Crown Copyright and database right 2016. All rights reserved. Ordnance Survey Licence number 100024900

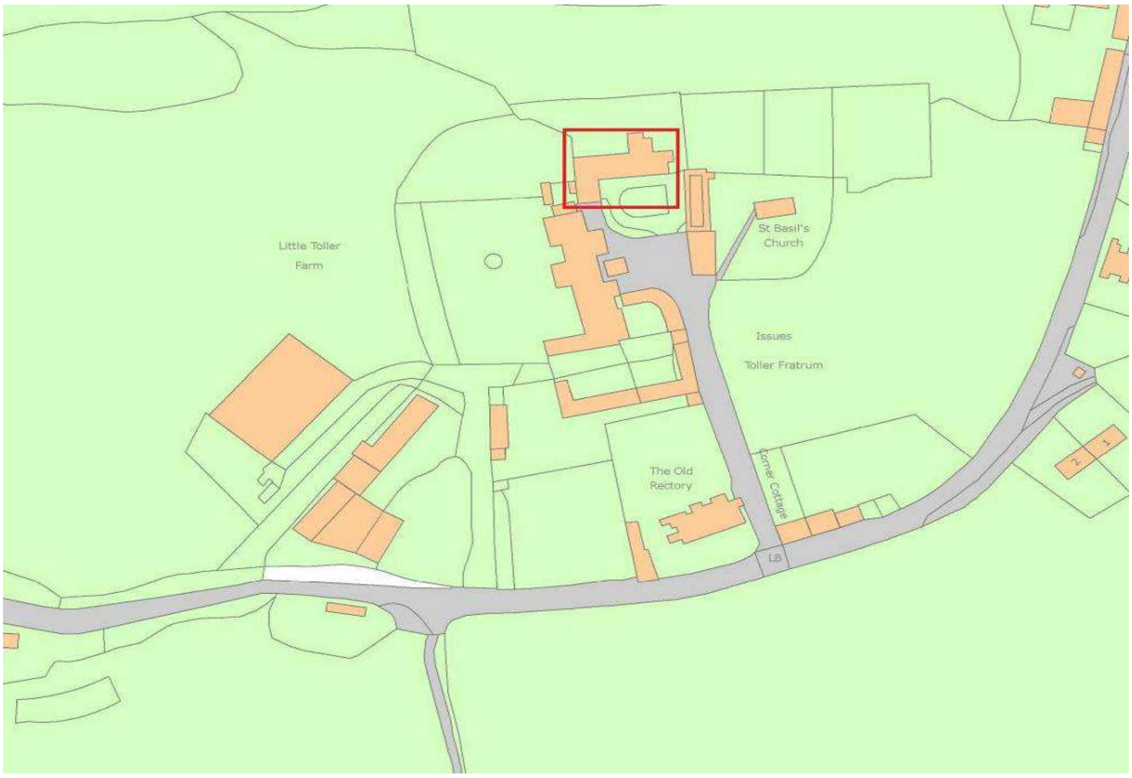


Figure 1c: Map to show the location of Little Toller Farmhouse. © Crown Copyright and database right 2016. All rights reserved. Ordnance Survey Licence number 100024900

Figure 2a: View of part of the roof post-fire (photograph Francis Kelly)

Figure 2b: View of the interior and part of the roof post-fire (photograph Francis Kelly)

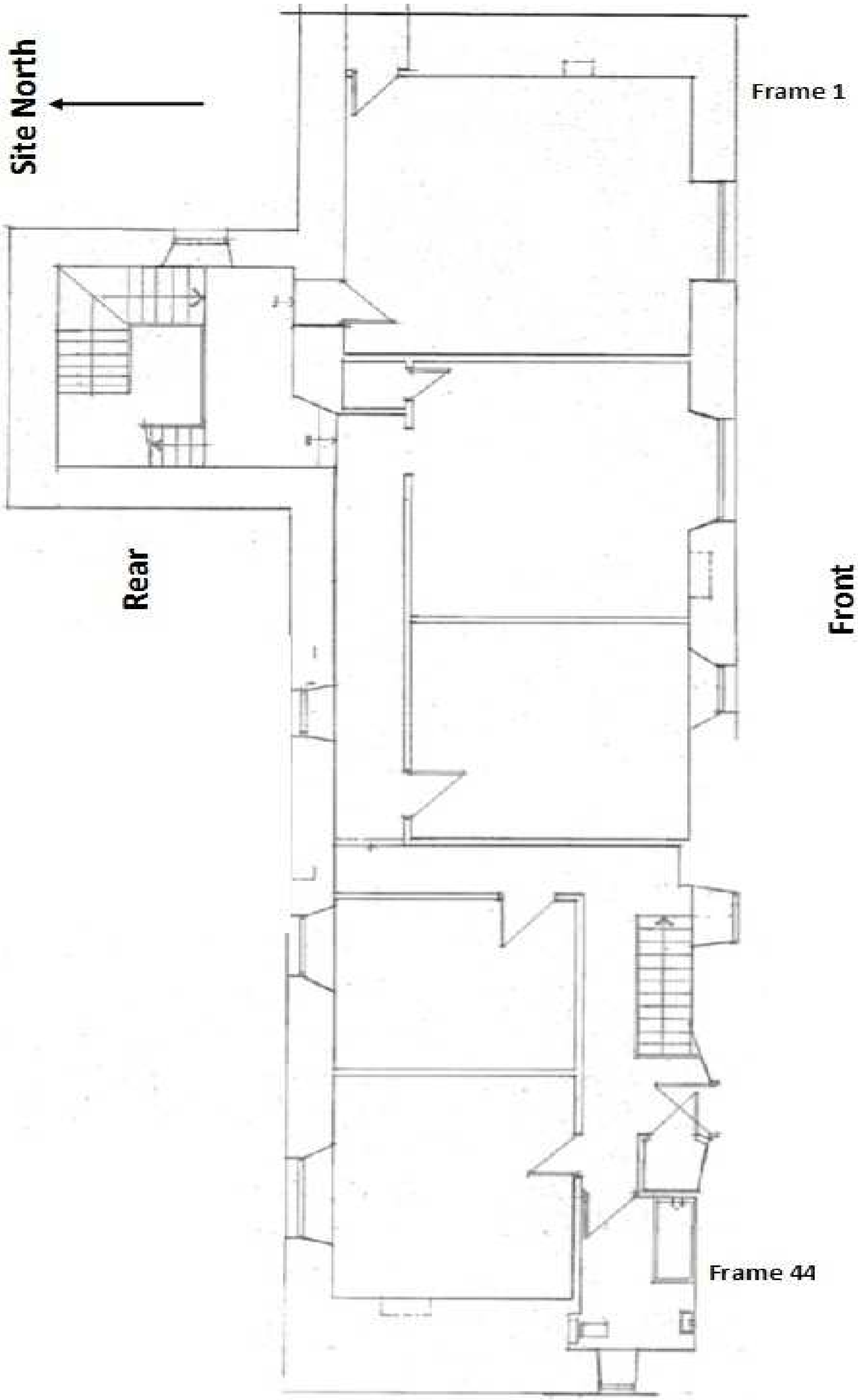


Figure 3: Plan showing the approximate locations of frames 1 and 44 (after Beauchamps Chartered Surveyors)

Figure 4: View of the roof timbers looking southeast (top) (photograph Robert Howard)

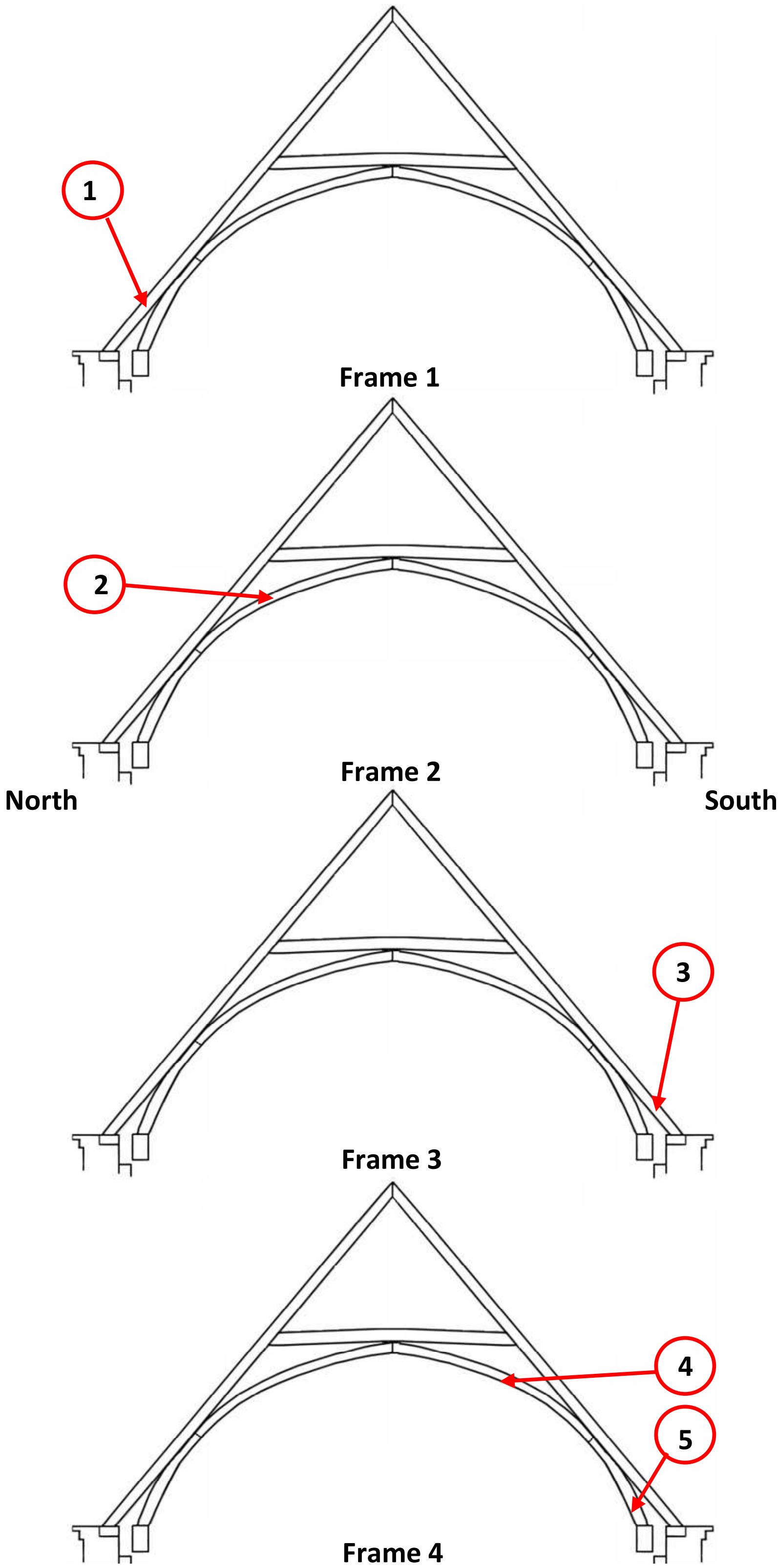


Figure 5a–d: Drawings of the frames to locate sampled timbers (after Beauchamps Chartered Surveyors)

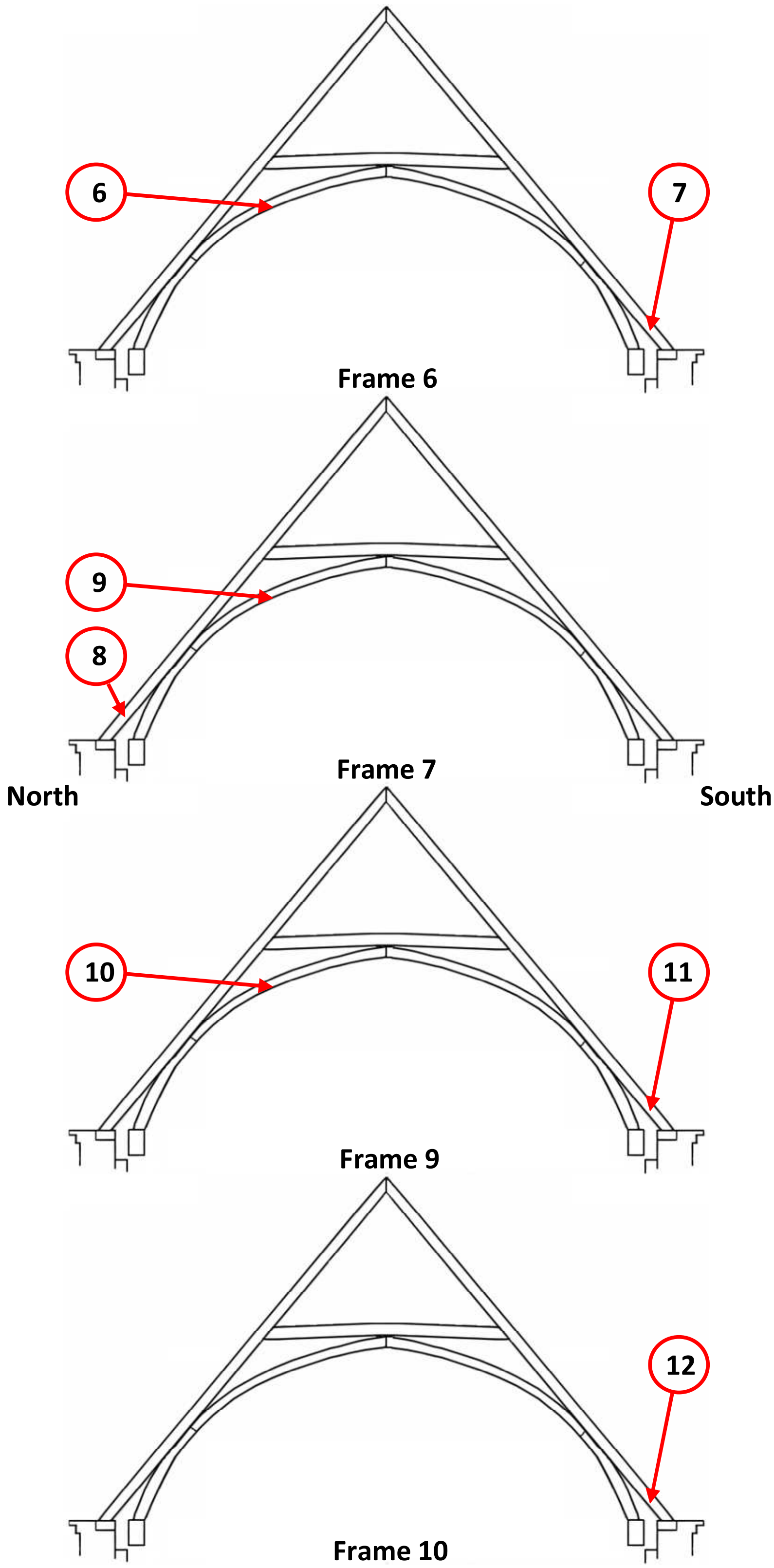


Figure 5e–h: Drawings of the frames to locate sampled timbers (after Beauchamps Chartered Surveyors)

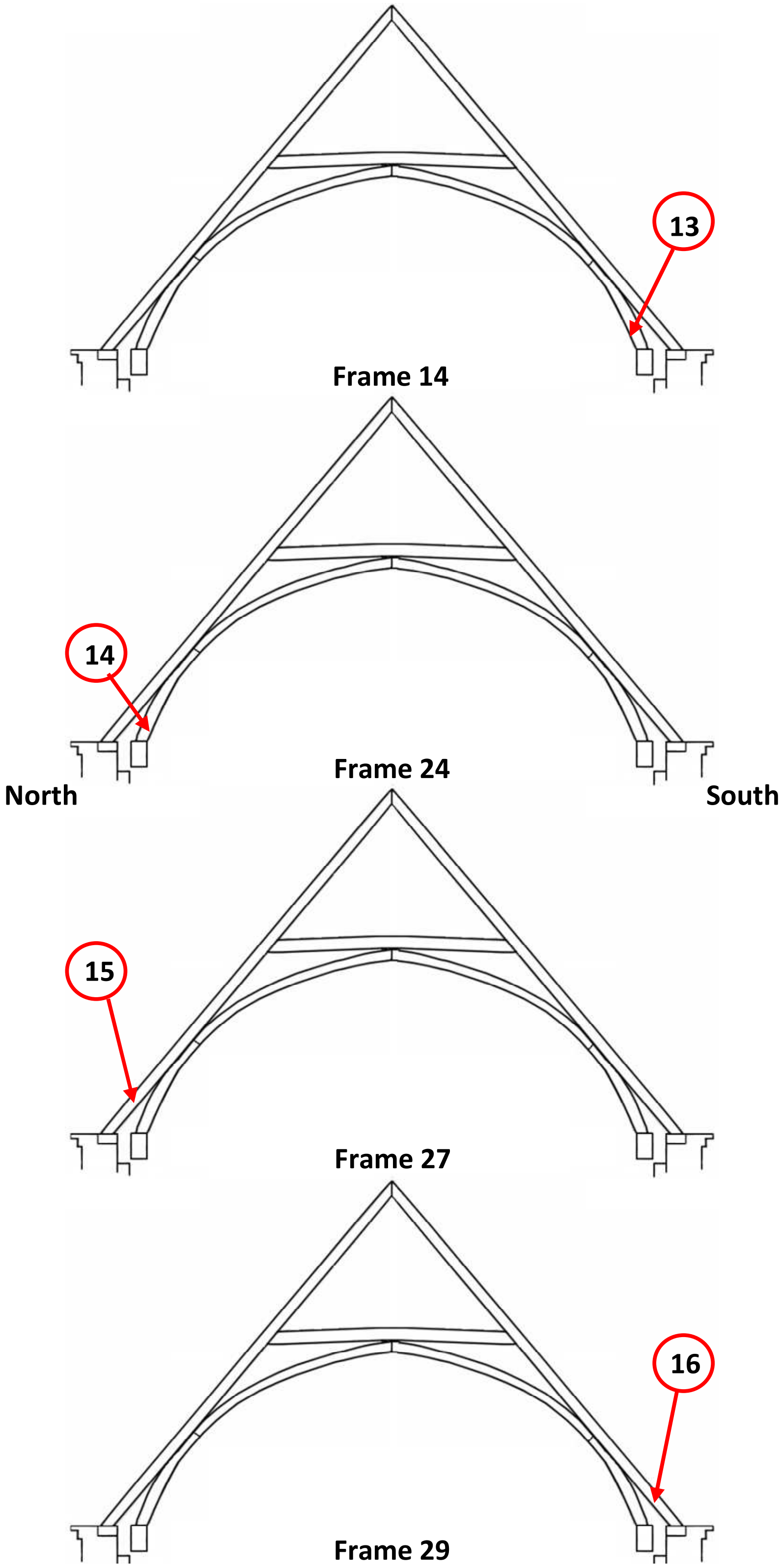


Figure 5i–l: Drawings of the frames to locate sampled timbers (Beauchamps Chartered Surveyors)

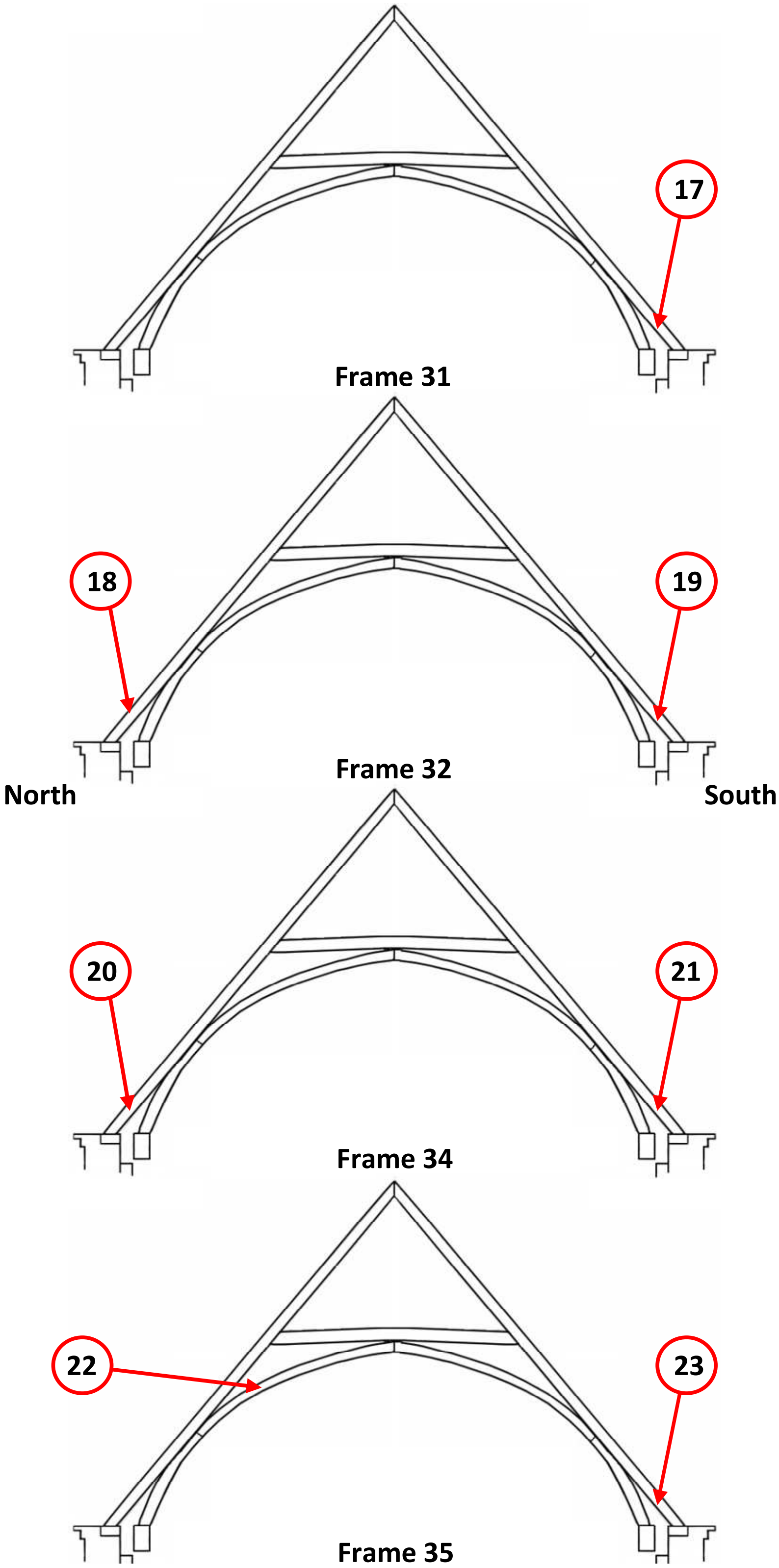


Figure 5m–p: Drawings of the frames to locate sampled timbers (after Beauchamps Chartered Surveyors)

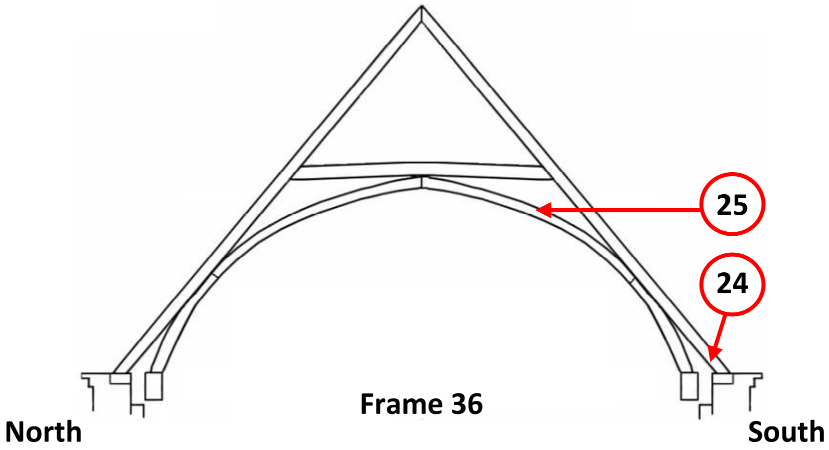
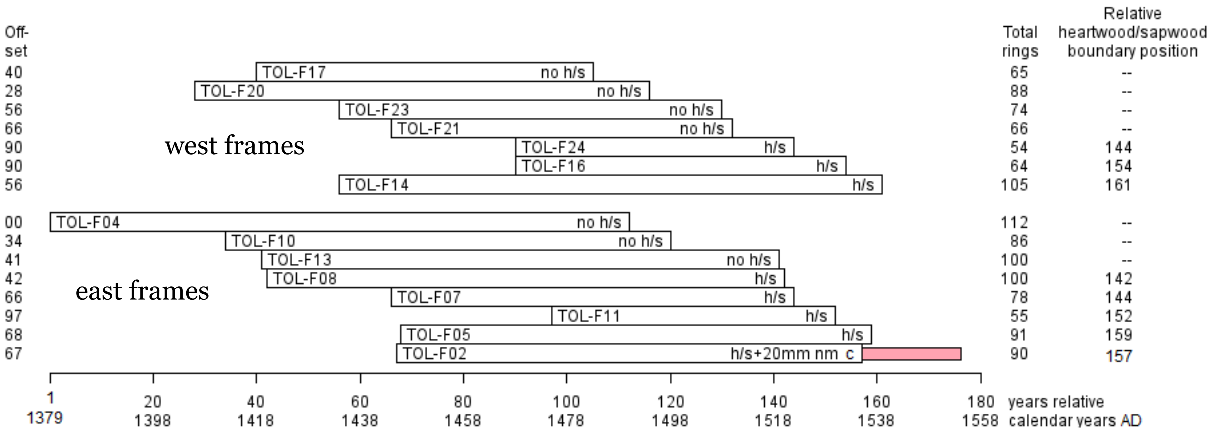


Figure 5q: Drawing of the frame to locate sampled timbers (after Beauchamps Chartered Surveyors)



white bars = heartwood rings,
shaded bars = estimated lost sapwood rings
h/s = heartwood/sapwood boundary;
nm = not measured
c = complete sapwood is found on the timber, but all or part has been lost from the sample in coring

Figure 6: Bar diagram of the dated samples in site chronology TOLFSQ01 sorted by roof area

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

TOL-F01A 54
246 282 267 381 350 367 327 454 443 345 391 433 444 350 382 496 491 400 166 189
201 201 282 278 299 142 194 199 185 121 125 56 158 98 137 64 179 142 207 123
142 209 104 58 82 128 180 109 148 160 165 178 262 221
TOL-F01B 54
243 262 265 401 359 396 339 487 469 334 384 415 447 343 382 482 487 404 170 209
215 223 282 273 300 132 199 197 176 106 118 57 165 89 143 56 181 148 225 129
136 215 115 60 71 146 175 90 153 181 170 165 257 214
TOL-F02A 90
137 169 148 172 100 128 132 157 184 138 124 111 60 46 56 41 54 69 67 102
133 126 128 88 89 91 78 106 98 209 160 76 82 77 125 161 139 121 105 131
137 150 144 144 182 188 150 112 148 155 178 132 107 125 82 79 87 84 93 79
67 43 78 137 89 135 151 135 122 93 89 63 70 134 68 60 82 58 69 53
79 102 100 109 90 118 103 98 104 143
TOL-F02B 90
143 176 144 169 117 127 130 143 172 140 130 117 68 46 54 46 49 67 69 112
126 125 121 70 81 91 69 98 116 202 162 75 91 68 128 153 121 124 119 135
140 150 136 146 195 200 159 115 142 163 197 132 105 132 76 60 93 95 120 95
81 50 85 135 95 146 154 129 117 95 95 59 80 118 78 65 84 66 73 65
70 90 103 112 59 115 101 89 98 145
TOL-F03A 55
65 48 70 68 77 64 63 39 54 71 102 134 97 120 175 274 149 217 253 202
204 155 250 198 140 124 103 128 117 63 139 165 127 192 132 153 265 248 270 158
206 300 182 166 127 242 154 163 107 103 168 206 193 228 196
TOL-F03B 55
59 44 65 77 74 60 54 42 54 70 96 140 77 125 173 265 154 234 239 192
191 178 255 214 137 114 106 131 105 64 140 147 157 206 132 164 298 237 244 152
213 319 180 155 129 241 151 178 118 87 162 209 191 233 200
TOL-F04A 112
157 166 210 174 148 142 246 358 232 228 171 212 284 146 203 161 146 184 111 93
104 147 132 78 114 117 87 91 58 57 46 57 75 74 82 82 65 55 76 65
76 123 93 100 171 146 82 60 50 66 94 189 206 167 119 95 135 85 132 80
69 115 109 106 93 64 92 89 81 120 123 109 78 63 95 142 85 96 81 68
101 59 60 73 100 85 89 121 98 81 54 64 64 103 122 103 127 130 85 96
87 134 139 123 142 157 156 115 104 153 124 129
TOL-F04B 112
169 164 212 179 143 141 233 389 218 228 166 210 280 155 205 157 142 196 110 91
110 146 129 70 112 115 78 89 62 60 42 50 69 65 78 80 62 59 77 65
71 119 87 103 173 145 85 60 57 58 104 212 187 175 138 105 126 84 129 84
66 118 101 103 85 71 85 83 91 105 134 95 62 76 96 154 82 97 87 67
104 50 64 76 90 89 82 129 96 79 57 59 58 109 137 96 122 124 93 89
95 131 144 126 135 165 156 118 118 150 116 130
TOL-F05A 91
142 112 134 81 88 98 94 90 83 104 76 100 69 100 65 50 83 70 68 71
75 51 53 53 63 75 68 83 155 87 48 37 33 35 63 36 57 42 58 55
61 63 74 71 70 46 97 167 107 192 112 69 66 61 59 96 95 99 95 76
46 81 85 89 82 142 132 86 85 92 62 127 296 204 203 175 190 155 103 124
157 144 121 137 218 216 125 196 267 203 224
TOL-F05B 91

140 109 134 75 92 96 86 88 90 86 90 98 73 96 68 58 71 73 68 85
75 53 49 63 56 71 75 80 148 90 46 48 32 40 55 46 50 44 64 53
60 66 76 65 73 48 96 160 110 192 94 73 69 55 59 100 96 99 92 72
53 74 93 85 85 128 136 91 71 98 64 118 275 213 195 190 200 140 114 129
157 157 117 135 251 204 143 190 262 217 226
TOL-F06A 58
162 223 242 235 243 228 256 247 398 110 130 119 118 154 131 229 99 52 78 90
82 81 67 89 71 73 66 86 112 152 169 144 167 112 140 206 167 174 150 242
204 391 335 368 231 210 259 253 323 220 248 262 203 301 235 356 320 322
TOL-F06B 58
168 212 245 240 224 252 254 235 400 110 128 118 121 159 129 228 111 61 76 99
89 74 60 93 61 82 67 79 109 133 157 134 157 114 157 208 167 177 153 213
214 410 317 371 242 202 264 250 325 211 240 265 193 311 220 353 306 332
TOL-F07A 78
147 82 141 112 159 113 149 145 123 170 154 138 123 88 128 176 92 77 97 112
94 71 62 93 75 97 104 101 114 82 146 104 112 117 137 239 188 246 179 201
219 167 167 182 114 139 153 182 201 210 245 367 303 200 251 252 134 151 193 229
148 164 150 281 193 208 131 204 195 157 187 196 154 167 196 156 139 167
TOL-F07B 78
151 88 145 109 152 112 153 144 115 180 156 141 117 87 128 171 91 75 114 112
80 82 55 101 77 98 105 101 107 85 156 104 110 113 132 256 197 230 176 214
218 178 159 181 114 150 139 181 202 217 247 377 279 211 237 267 126 168 190 225
143 161 154 270 193 212 135 192 198 164 206 190 151 171 185 162 139 165
TOL-F08A 100
413 312 394 428 305 277 241 292 282 290 242 246 188 208 227 201 238 189 176 183
172 228 167 183 173 117 156 119 114 108 140 151 146 143 117 110 79 76 118 121
96 56 89 77 61 56 59 92 69 76 86 92 95 68 121 85 94 109 71 162
145 159 121 151 121 139 120 129 89 132 144 130 160 168 115 115 135 95 81 109
82 87 130 100 107 86 63 148 92 80 135 146 142 134 126 145 93 118 144 171
TOL-F08B 100
399 280 422 420 322 285 275 288 263 274 245 236 199 196 212 198 232 179 181 185
179 232 151 189 174 98 155 120 97 96 165 137 157 150 116 108 83 79 104 131
92 59 87 80 65 58 59 95 59 82 90 95 90 66 131 77 95 98 78 167
115 168 103 148 132 129 109 135 70 139 139 128 162 165 118 129 128 93 86 107
81 92 137 107 101 90 76 143 97 81 125 146 134 122 142 132 100 104 150 170
TOL-F09A 54
158 121 169 169 184 189 154 219 199 193 114 164 221 148 144 155 199 216 236 283
279 351 323 297 248 231 256 160 178 240 236 273 435 271 210 275 296 247 277 284
198 175 195 221 202 221 217 195 279 226 181 264 226 295
TOL-F09B 54
164 115 170 163 196 189 171 200 188 200 105 162 216 137 150 166 165 230 235 282
272 349 335 300 221 244 257 155 189 233 242 264 442 254 214 273 295 268 281 270
207 175 196 223 220 210 207 190 278 227 172 266 214 285
TOL-F10A 86
107 105 77 71 88 81 127 184 136 181 293 188 92 80 64 107 110 159 250 201
150 119 169 118 149 118 87 128 100 113 136 107 125 146 135 147 238 134 100 106
113 181 128 168 171 129 187 124 117 137 212 187 145 217 165 132 79 79 89 143
135 160 187 115 98 71 79 171 87 125 112 168 193 119 131 143 116 150 207 206
160 154 184 206 126 175
TOL-F10B 86
106 112 71 71 77 90 132 192 148 165 316 184 101 73 69 103 103 157 290 207
148 130 163 116 142 128 89 123 111 109 137 134 115 146 135 153 228 142 103 100
121 194 156 181 168 143 194 117 129 123 228 198 134 214 167 118 71 71 84 146

139 166 189 129 92 70 78 176 100 125 115 170 191 119 138 129 120 141 213 207
150 167 182 217 123 172
TOL-F11A 55
237 245 250 216 251 273 277 300 278 241 231 251 265 209 234 224 182 268 256 218
401 239 163 211 147 91 109 234 253 214 167 156 190 248 190 240 271 359 250 168
179 167 265 292 206 132 253 210 156 96 175 200 157 146 139
TOL-F11B 55
231 248 256 217 250 270 254 293 280 239 233 248 262 198 247 218 182 262 210 228
373 238 170 198 140 90 138 247 248 206 158 173 182 268 196 215 279 400 239 190
183 185 264 300 186 132 242 218 156 91 164 187 160 120 189
TOL-F12A 75
399 359 251 284 246 213 239 179 287 262 171 103 92 71 60 79 113 72 66 45
64 89 71 103 117 45 71 60 76 64 71 113 193 182 157 98 113 99 230 96
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148 129 118 110 79 137 107 115 221 184 114 156 120 117 190
TOL-F12B 75
379 382 266 293 213 204 238 191 291 248 169 86 104 55 48 69 100 80 43 35
60 82 69 133 116 50 69 61 77 73 85 107 182 182 153 120 141 119 217 109
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157 137 96 96 86 157 89 107 231 193 117 145 130 117 200
TOL-F13A 100
152 104 107 136 132 75 112 90 124 133 84 104 108 105 77 98 85 105 92 65
82 82 60 89 42 61 78 76 67 66 52 61 59 78 72 87 71 72 60 69
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185 178 175 154 230
TOL-F14B 105
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TOL-F16A 64
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303 174 250 203 242 295 337 275 207 115 137 193 316 197 251 342 307 284 171 248
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TOL-F23A 74
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206 191 193 188 161 164 123 134 150 117 142 190 213 182 108 122 118 127 142 107
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180 146 180 208 189 195 190 163 158 189 213 164 179 266
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180 185 175 153 178 169 142 268 193 142 153 125 107 151 182 187 134 132 91 132
178 139 181 202 189 192 184 171 159 179 197 180 185 263
TOL-F25A 71
241 202 156 155 250 182 188 282 326 246 235 203 169 190 273 212 169 185 225 192
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114 120 132 146 79 96 137 136 181 146 110 104 122 123 121 112 89 73 85 105
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TOL-F25B 71
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76 70 60 82 73 70 63 72 66 75 100

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 A1 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 A1, 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 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 A2 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 8–10 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.

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 A2; it is about 150mm long and 10mm 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.

Figure A1: 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

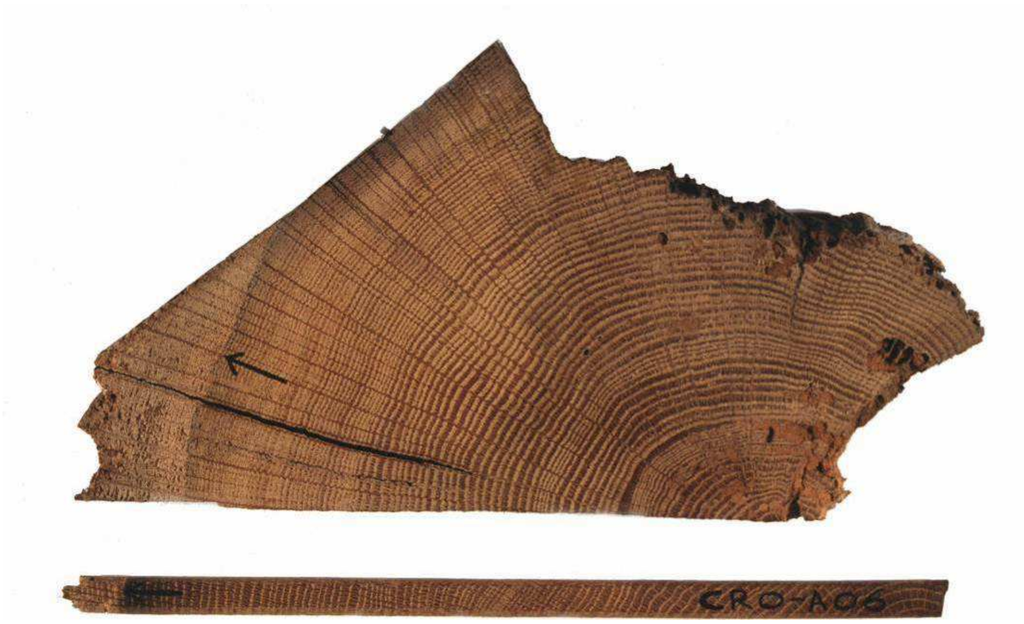


Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

Figure A3: 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

Figure A4: 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

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 A2. 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 A3).

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 A4). 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 Figure A5 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 Figure A5. 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 Figure A5 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 straightforward 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 (or the last full year before felling, if it was felled in the first three months of the following calendar year, 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 A2, 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 region 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 A2 was taken still had complete sapwood but that some of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 20mm, 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 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; Miles 1997, 50–5). Hence, provided that 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, Fig 8; 34–5, where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storage 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 Figure A6 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 Figure A6. 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 Figure A7. 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 phenomenon 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.

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	

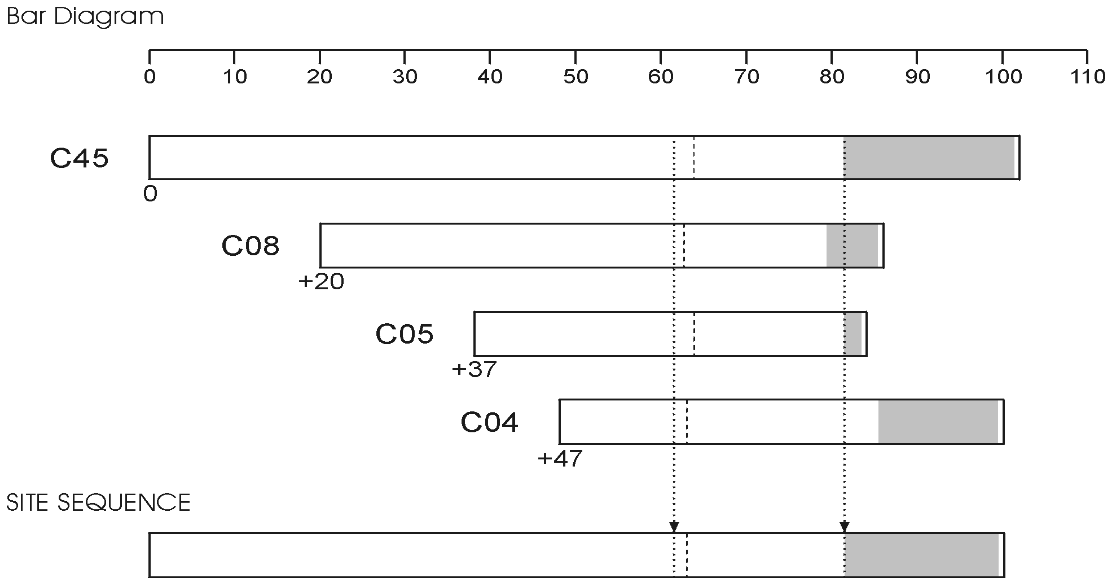


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

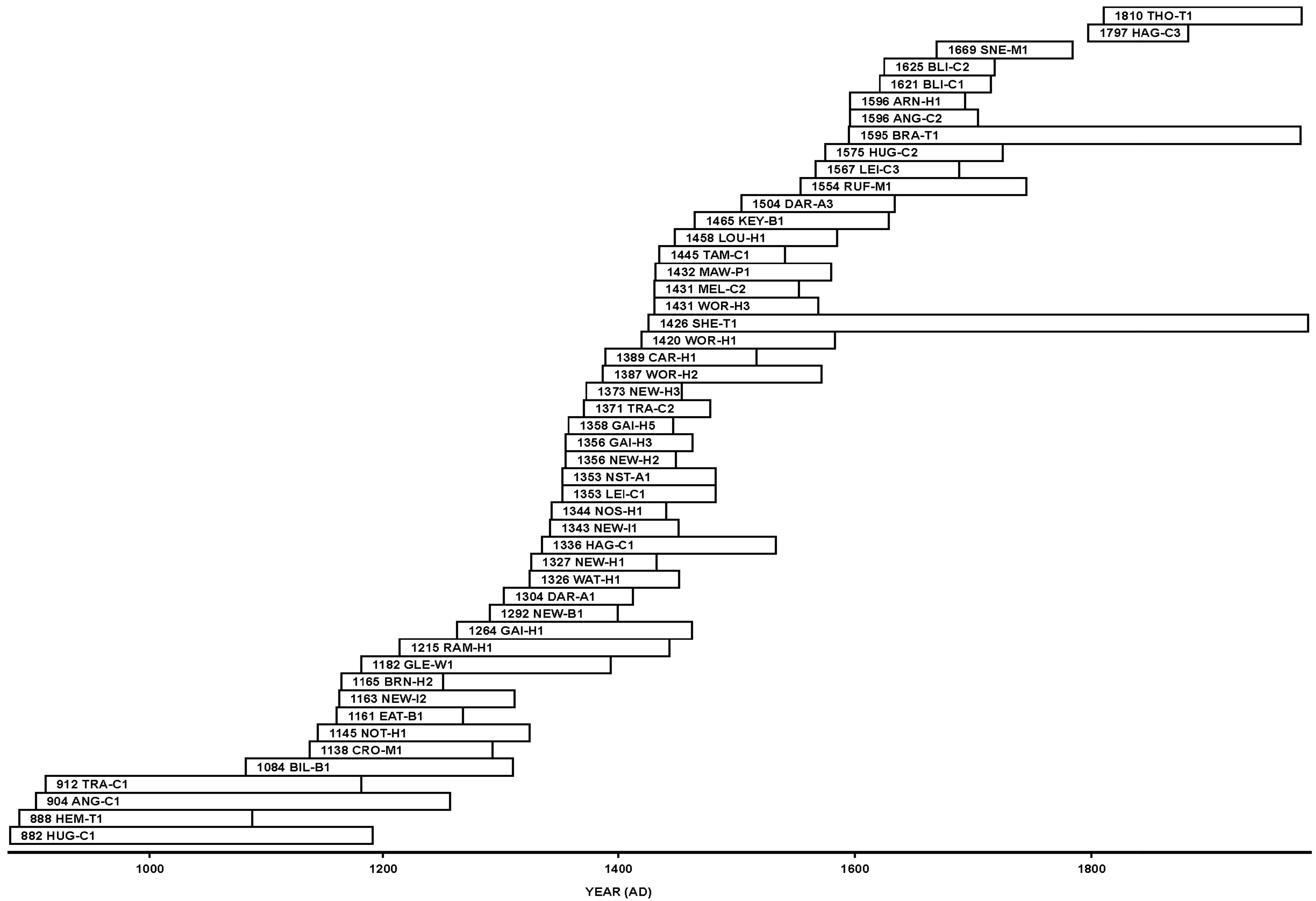
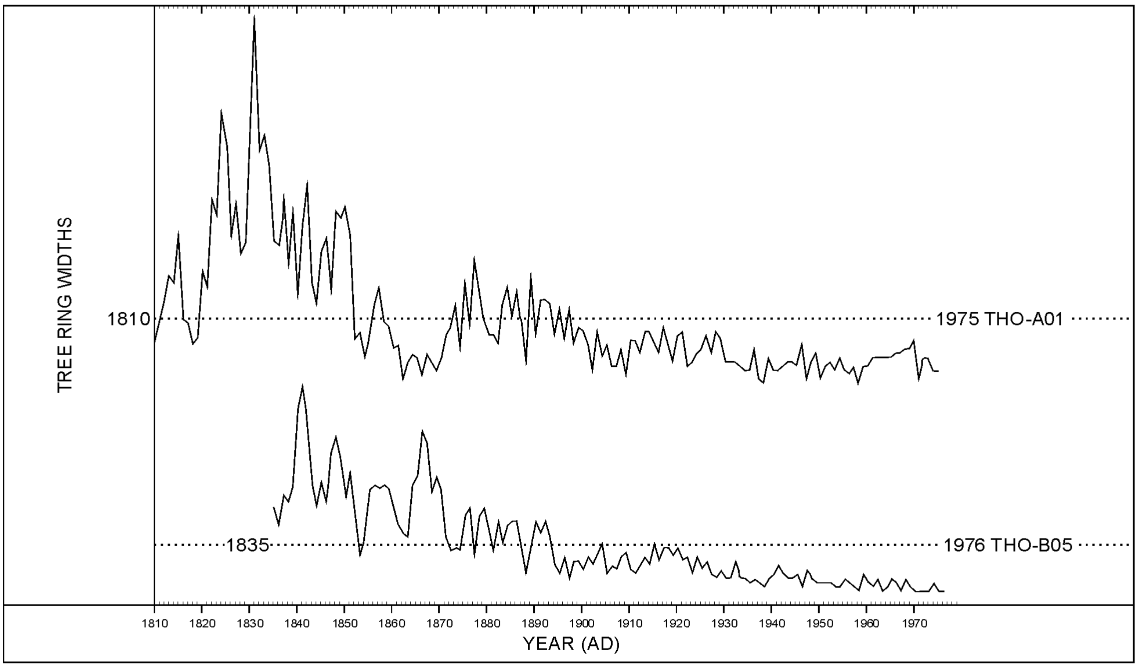


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

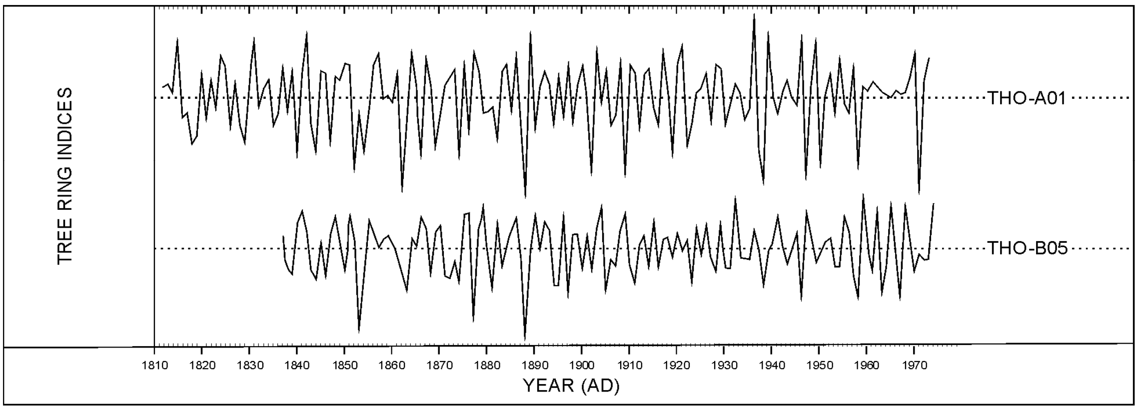


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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.

Figure A7 (b): The Baillie-Pilcher indices of the above widths

The growth trends have been removed completely.

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