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Tree-Ring Analysis of Timbers from the Nave Roof and Ceiling of the Cathedral Church of St Peter and St Wilfred, Ripon, North Yorkshire

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Tree-Ring Analysis of Timbers from the Nave Roof and Ceiling of the Cathedral Church of St Peter and St Wilfred, Ripon, North Yorkshire

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Summary

A total of 30 core samples was obtained from the principal oak timbers of the roof and the ceiling ribs of the nave of Ripon Cathedral. The analysis of these produced two major site chronologies, one of six samples, 226 rings long, and another of nine samples, 117 rings long. Two other site chronologies with only two samples each were also created.

Despite the number of samples obtained, the length of the site chronologies created, and despite being compared with a very extensive range of reference chronologies, none of the site chronologies, nor any individual samples, could be dated.

It would certainly appear that timbers within groups were felled at the same time as each other, possibly for use as specific elements. However, it is not possible to ascertain whether the groups of timbers, or the ungrouped individual timbers, are either contemporary, or whether they represent different woodland sources.

Keywords

Dendrochronology
Standing Building

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Introduction

The earliest church on the site of Ripon Cathedral (NE 314 711; Fig 1) was originally part of a Scottish monastery. This was reorganised along Benedictine lines by St Wilfred in AD 660. Between then and AD 1050 it was refounded as a College of secular canons under the patronage of the Archbishop of York. It remained as a parish church even after the dissolution of the college in AD 1547. In AD 1604 the college was re-founded under James I, dissolved during the commonwealth, but founded yet again in AD 1660. It was elevated to Cathedral status in AD 1836.

Major rebuilding work was begun under Archbishop Roger, AD 1154 – 81, and completed by Walter Gray, AD 1215 – 55. A library was added in the early-fourteenth century, with further alterations in the fifteenth century. The nave is believed to have undergone substantial alterations in the early-sixteenth century, with aisles being added at this time. In AD 1615 the spire on the crossing tower collapsed and in AD 1664 the spires on the two western towers were taken down. Nineteenth-century repairs were undertaken in AD 1829 – 31 by Edward Blore, and in AD 1843 – 44 by William Railton, with more drastic alterations being made by Gilbert Scott in AD 1862.

Sampling

Sampling and analysis by tree-ring dating of the timbers at Ripon Cathedral were commissioned by English Heritage. Initially this was to include timbers in both the nave and the chancel roofs. However, only the timbers of the nave were accessible. This programme of analysis was requested to inform grant-aided repairs by providing a precise date for the construction of the roof and to date any repairs or alterations. The dates, of various elements of the roof, are unclear. It is uncertain, for example, how much, if any, of the roof comprises sixteenth-century, or indeed earlier, material in its original position or possibly reused. This is particularly so with the timbers of the ceiling vault, some of which retain carpenters' marks in the form of Roman numerals. It is also uncertain as to how much of the roof might represent nineteenth-century repair material. Indeed, at the time the roof was first taken off it appeared as if all the timbers were softwood, with no oak remaining at all. A general plan of the Cathedral, taken from 'The Builder', February 1893, and provided by English Heritage, is given in Figure 2.

The nave roof consists of 15 'truncated' trusses, consisting alternately of single larger principal rafters, (trusses 1, 3, 5 etc, numbering from west to east) or of two very slightly smaller principal rafters in close-set pairs (trusses 2, 4, 6, etc). All such principal rafters are of oak. Apart from slight differences in dimension, there appear to be other very slight variations between the timbers of the two types of truss. The larger single rafters appear to be more squarely cut, and have more regular saw-marks on their faces. The smaller 'double' rafters are less well worked, being less well trimmed, and appear slightly more uneven in their sawing. It thus appears as if there are two sets of timbers within the principal trusses.

The apex of each truss appears to have been cut off (if indeed the original ever went to the ridge), and replaced in softwood. In addition the apex sections, the collars, purlins, and all other roof timbers are of softwood. These softwood timbers have the appearance, judging by the carpentry, of being nineteenth-century pieces.

From these principal roof timbers a total of 15 core samples was obtained. Each sample was given the code RIP-C (for Ripon Cathedral) and numbered 01 – 15. An attempt was made to obtain samples from what were thought to be the two possible sets of timbers here, the single principal rafters, and the 'double' principals.

Set to the underside of the principal roof timbers are the beams of the ceiling vault. These consist of ridge and vault ribs, from which spring diagonal and intermediate ribs. All these timbers are of oak. From these beams a further 15 core samples were obtained, RIP-C16 – 30. Because of safety concerns, there being no support or platform beneath the ceiling, it was only possible to sample the ceiling beams at each end of the nave roof, where boarding could be safely laid from above. There is a substantial quantity of other oak timber which could be sampled with the aid of a harness, though preventing public access to the area below might also be necessary.

The positions of these 30 samples are shown on drawings provided by EH, reproduced here as Figure 3. Details of the samples are given in Table 1. In this report the trusses and bays have been numbered from west to east, with the 'double' principals being further designated 'A' or 'B', the west and east of the pair respectively. Individual timbers are described on a north-south basis as appropriate.

The Laboratory would like to take this opportunity to thank Jane McComish and Mark Johnson of York Archaeological Trust for their help in arranging site access, as well as the staff of Joseph Hardgrave, Roofers, Ltd, York, who were most helpful during sampling. We would also like to thank Cathy Groves of the University of Sheffield Dendrochronology Laboratory and our other, international, colleagues who all attempted to find a cross-match and date for the samples.

Analysis

Each of the 30 samples was prepared by sanding and polishing and their annual growth-ring widths measured. The data of these measurements are given at the end of the report. These data were then compared with each other by the Litton/Zainodin grouping procedure (see appendix) and at a minimum value of t=4.5 four satisfactory site chronologies could be formed:

Site chronology	Number of samples	Sequence length	Bar diagram Figure
RIPCSQ01	6	226	4
RIPCSQ02	9	117	5
RIPCSQ03	2	130	6
RIPCSQ04	2	127	7

Each site chronology thus created was compared with an extensive range of British and European site chronologies, including those held by the Nottingham Laboratory and others, the Sheffield Dendrochronology Laboratory for example. Despite this extensive comparison, and despite the length of the site chronologies, there was no satisfactory cross-matching against any available reference chronologies.

Interpretation

Of the 30 samples obtained, 19 have been formed into one of four site chronologies. Although none of these site chronologies, or any of the remaining individual samples, can be dated, it is possible to say something about the relative felling dates of the timbers concerned.

Firstly it is certain that some timbers represent a single phase of felling. For example, five samples, RIP-C02, C03, C08, C10, and C11, in site chronology RIPCSQ01, retain complete sapwood. This means that they each have the last ring produced by the tree represented before it was felled. In each case the last sapwood ring is at the same relative position indicating that the timbers were all cut at the same time. It is highly likely that the timber represented by sample RIP-C09 was felled at the same time as well. It also appears possible that these timbers are used for specific beams. All the samples in site chronology RIPCSQ01 are from the single principal rafter trusses.

A single phase of felling is also represented by a number of samples in site chronology RIPCSQ02. Samples RIP-C05, C13, C14, C15, C20, C29, and C30 retain complete sapwood, the last sapwood ring being at the same relative position in each case. It is probable that the other timbers represented in this site chronology were felled at the same time. There again may be some specific use for the timber represented, many of the samples in this second site chronology, RIP-C05, C07, C13, C14, and C15, being from the 'double' rafter trusses. This site chronology does, however, contain some samples from the ribs of the ceiling.

A single phase of felling is represented by samples RIP-C21 and C27 in site chronology RIPCSQ03, the last complete sapwood rings on these two being in the same relative positions. It is possible, though not certain, that samples RIP-C23 and C24 in site sequence RIPCSQ04, represent a single phase of felling also.

Conclusion

Analysis by dendrochronology has in this instance not been able to provide a date for a single sample. It can show, however, that some specific beams, those of the single principal rafters, are representative of a single phase of felling, as are those of the 'double' principal rafters, and some of the ribs of the ceiling. Other samples also represent single phases of felling.

What it has not been possible to show is the relationship between these felling phases. It is possible that all the groups of timbers were felled at different times, there being no cross-matching between them because they have no temporal overlap with each other. It is also possible that they were all felled at the same time, but there is no cross-matching between them because they are from different sources. Whatever the relative felling of the groups, the original woodland source, or sources, is not represented in any available reference chronology. It is possible that some combination of these two factors is represented by the timbers.

It is unusual to have so many highly suitable samples left undated. Were the timbers felled at different times, it would perhaps be unlikely that every group formed would be unrepresented in the gamut of reference material. Some, at least, of the site chronologies, or some of the remaining individual samples, might be dated. But this is not the case in this instance.

The fact that none of the samples are dated is perhaps most easily explained by the timber being felled at the same time from different sources, which would help account for the site chronologies not cross-matching with each other, and also by the timber being nineteenth century. There are very few reference chronologies available for Yorkshire or the northeast for this time period. Such difficulties might be compounded if, perhaps, the woodland sources were all foreign. This is possibly due to the development in the eighteenth, and especially the nineteenth century, of timber-yards, or timber merchants, along the lines that we know of today. Ripon Cathedral may not have obtained the timbers sampled direct from a single, known, woodland source, as is more often the case in the medieval period, but from a supplier who has obtained material from an extensive range of sources, including, perhaps in this case, from abroad.

Two other features of the samples are noteworthy. Firstly it will be seen from Table 1 that some of them have in excess of 200 rings, and several are in excess of 150 rings long. While this is not unusual it is not common in material of possible nineteenth century or very late-medieval date. The second feature the samples display is the low number of sapwood rings found on the samples. The 95% confidence limit for the amount of sapwood rings on mature oaks in England is usually in the range 15 – 40 rings. In a group of 30 samples it might be expected that one or maybe two samples might have more of less sapwood rings than this. It will again be seen from Table 1 that only a few samples analysed here sapwood rings within the 95% limit, all the others have less, the lowest number of sapwood rings on any sample where it is complete is 9. Such low numbers of sapwood rings are more common in timbers from the east of England and continental Europe.

Table 1: Details of samples from the nave roof and ceiling, Ripon Cathedral

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Principal roof timbers					
RIP-C01	South principal rafter, truss 1	159	17C	------	------	------
RIP-C02	South principal rafter, truss 3	226	16C	------	------	------
RIP-C03	South principal rafter, truss 5	218	14C	------	------	------
RIP-C04	South principal rafter, truss 7	86	14C	------	------	------
RIP-C05	South double rafter, truss 2A	61	13C	------	------	------
RIP-C06	South double rafter, truss 4B	112	no h/s	------	------	------
RIP-C07	South double rafter, truss 6B	81	h/s	------	------	------
RIP-C08	North principal rafter, truss 3	206	17C	------	------	------
RIP-C09	North principal rafter, truss 5	108	no h/s	------	------	------
RIP-C10	North principal rafter, truss 9	212	14C	------	------	------
RIP-C11	North principal rafter, truss 11	212	17C	------	------	------
RIP-C12	North double rafter, truss 2B	75	9C	------	------	------
RIP-C13	North double rafter, truss 6A	91	12C	------	------	------
RIP-C14	North double rafter, truss 6B	104	12C	------	------	------
RIP-C15	North double rafter, truss 10B	83	18C	------	------	------

Table 1: continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Ceiling, bay 1, west end					
RIP-C16	Ceiling rib	79	14C	------	------	------
RIP-C17	Ceiling rib	120	no h/s	------	------	------
RIP-C18	Ceiling rib	66	12C	------	------	------
RIP-C19	Ceiling rib	89	2	------	------	------
RIP-C20	Ceiling rib	82	12C	------	------	------
RIP-C21	Ceiling rib	82	10C	------	------	------
RIP-C22	Ceiling rib	79	no h/s	------	------	------
RIP-C23	Ceiling rib	125	16	------	------	------
RIP-C24	Ceiling rib	120	18C	------	------	------
RIP-C25	Ceiling rib	92	5	------	------	------
	Ceiling, bays 11 & 12					
RIP-C26	Ceiling rib	56	13C	------	------	------
RIP-C27	Ceiling rib	130	13C	------	------	------
RIP-C28	Ceiling rib	69	no h/s	------	------	------
RIP-C29	Ceiling rib	117	11C	------	------	------
RIP-C30	Ceiling rib	110	10C	------	------	------

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

Figure 1: Map to show general location of Ripon Cathedral

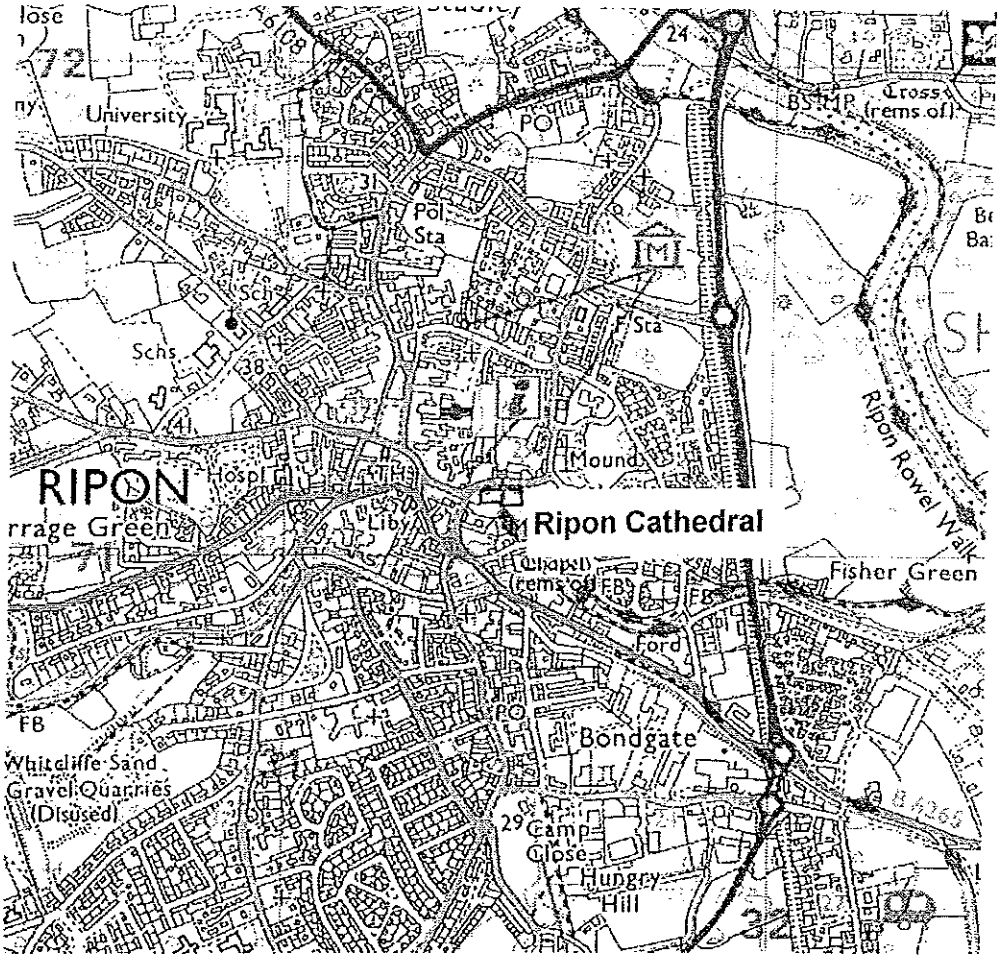


Figure 2: General plan of Ripon Cathedral © NMR 93/7827

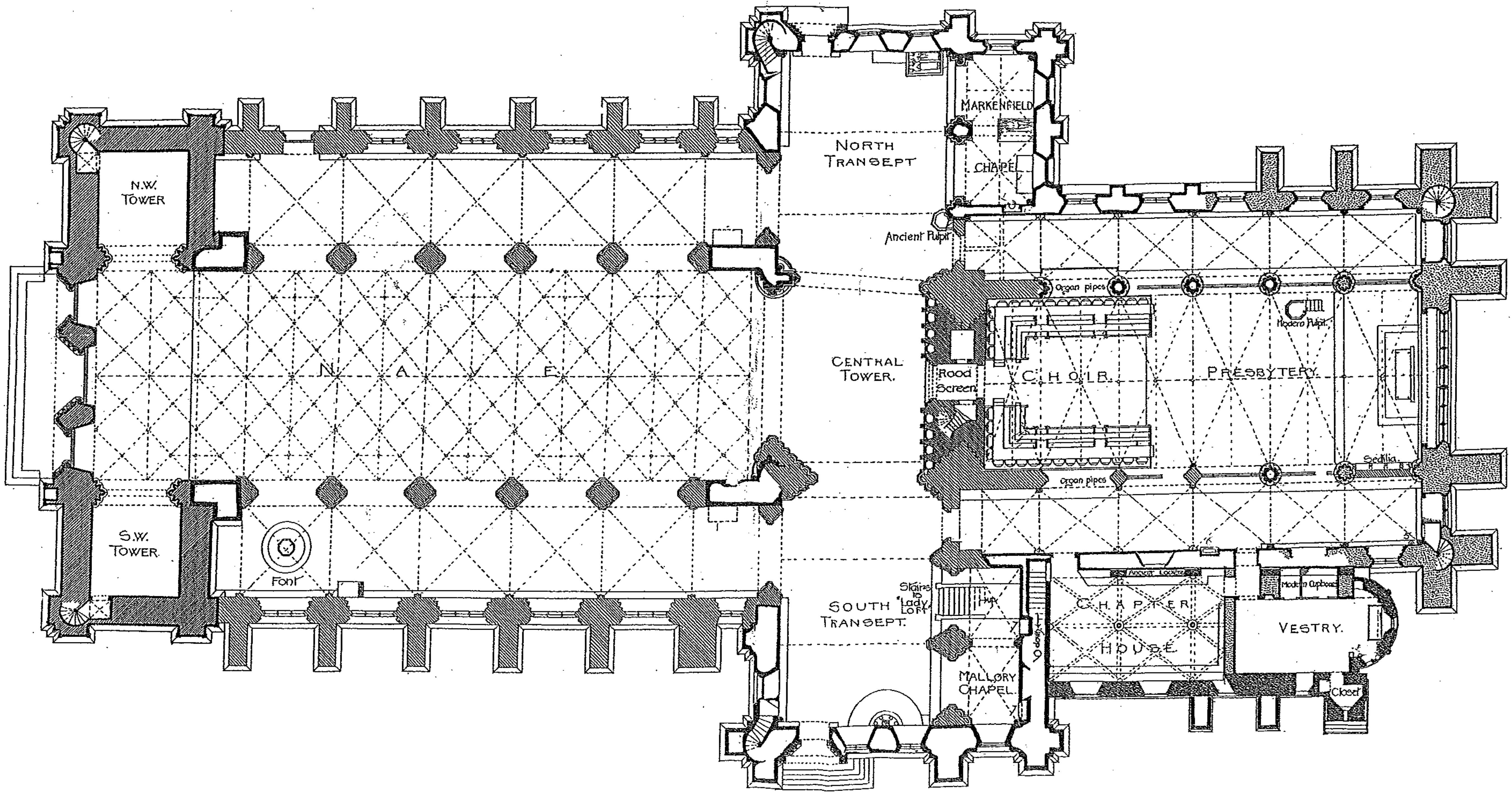


Figure 3: Plan to show position of sampled timbers from the nave roof of Ripon Cathedral © NMR 93/7827

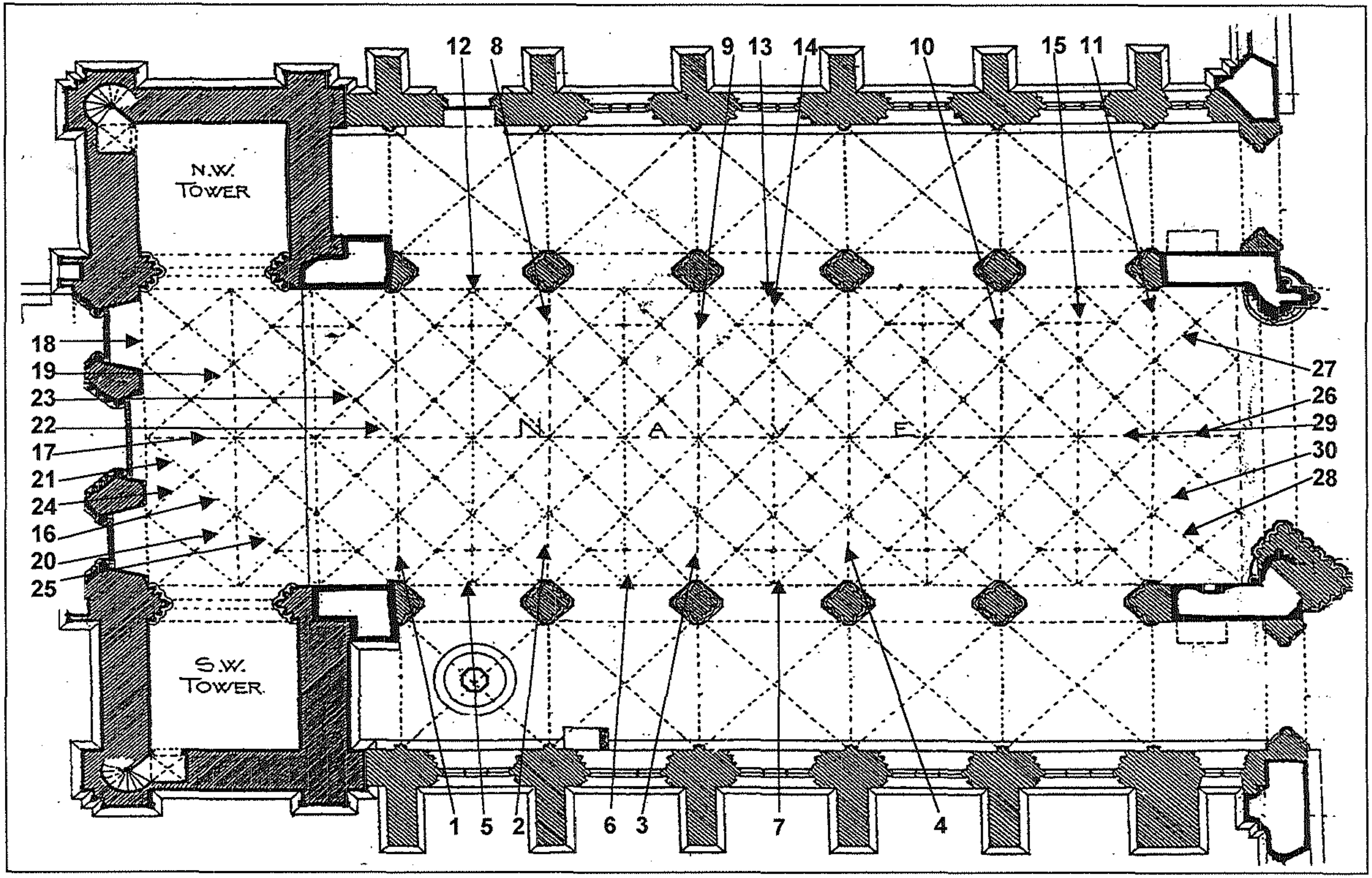
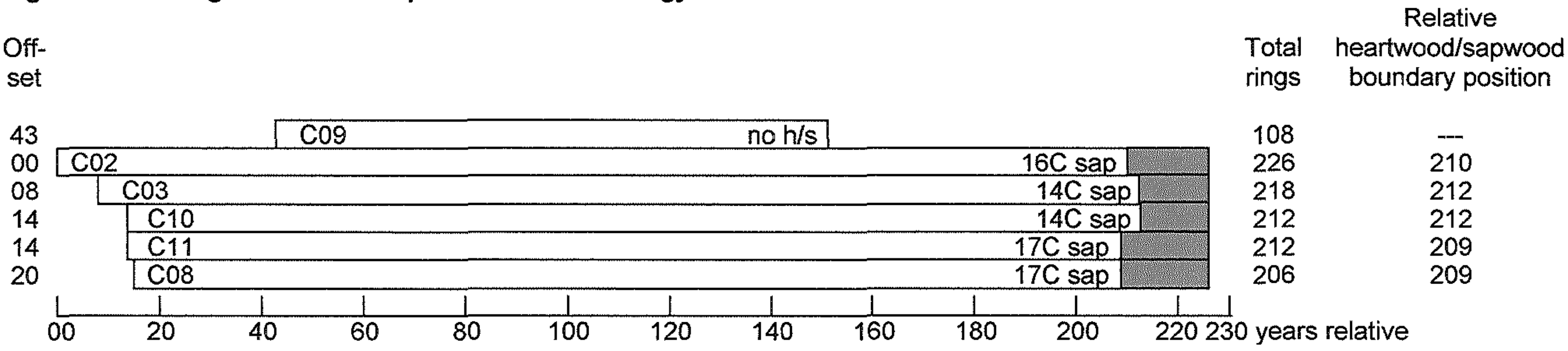
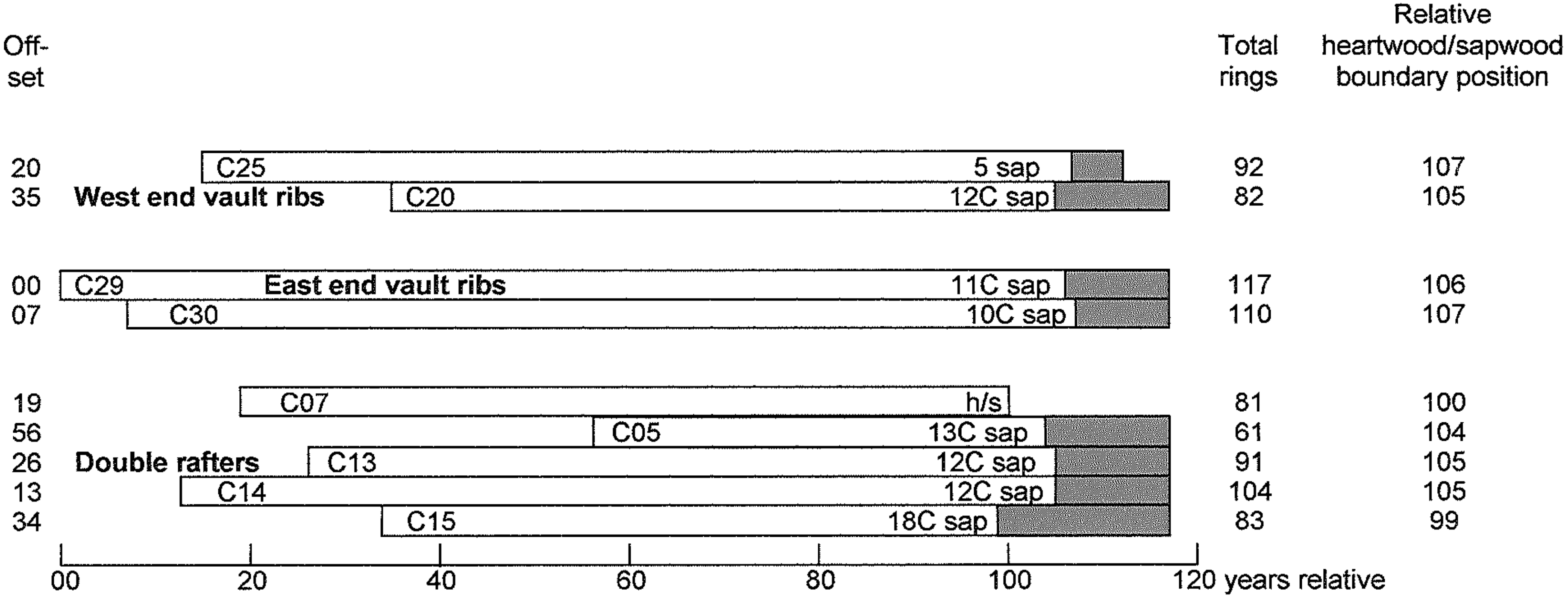


Figure 4: Bar diagram of the samples in site chronology RIPCSQ01



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

Figure 5: Bar diagram of the samples in site chronology RIPCSQ02



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

Figure 6: Bar diagram of the samples in site chronology RIPCSQ03

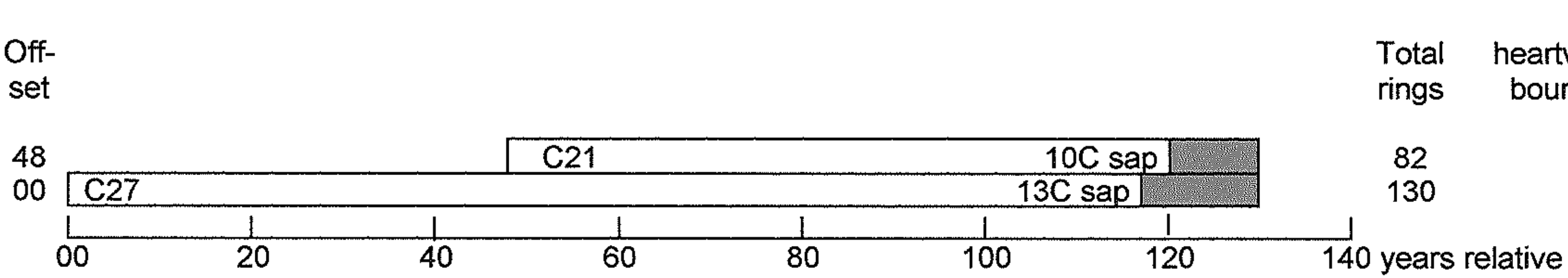
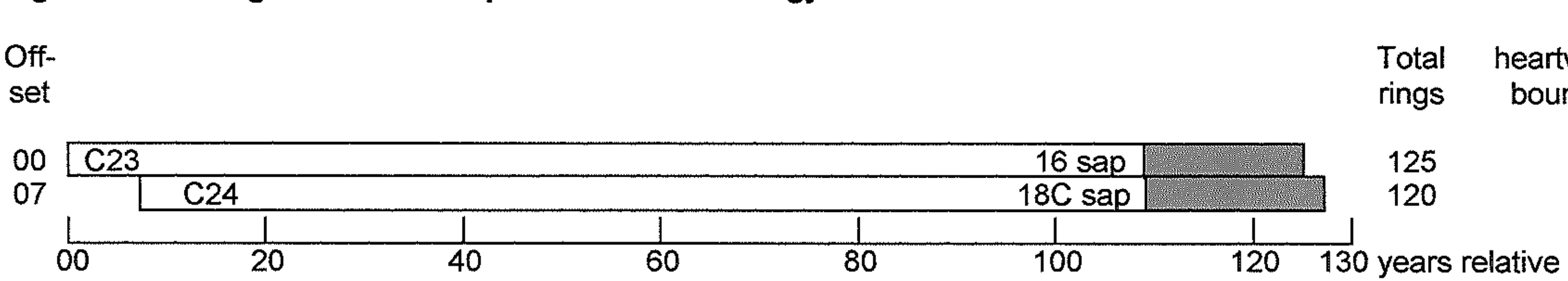


Figure 7: Bar diagram of the samples in site chronology RIPCSQ04



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

Data of measured samples – measurements in 0.01 mm units

RIP-C01A 159
131 141 187 161 233 198 144 149 177 188 155 132 139 145 154 142 156 128 164 147
136 149 138 172 197 156 149 102 111 102 94 103 119 134 159 181 76 79 64 57
39 47 41 49 56 64 64 59 58 75 77 66 65 77 64 68 101 69 62 81
94 80 91 101 94 76 77 82 59 68 51 58 65 70 96 66 90 76 69 83
79 68 77 112 58 89 69 87 80 62 130 110 72 115 80 77 125 130 120 120
93 134 175 183 188 188 186 124 118 130 165 148 151 137 125 101 85 94 111 150
113 79 84 84 72 68 102 78 94 76 109 111 101 151 136 159 122 138 136 185
135 138 171 208 225 144 119 75 120 116 153 112 112 85 63 109 89 107 100
RIP-C01B 159
150 132 186 160 241 189 140 149 194 180 172 126 143 142 158 141 150 120 178 144
141 153 143 172 186 168 138 111 100 99 98 96 112 139 158 174 70 87 70 54
47 37 46 53 55 69 60 46 65 75 79 64 81 60 80 58 109 58 58 92
78 91 85 101 91 77 77 81 62 72 44 58 66 72 92 71 88 73 78 75
81 65 75 111 55 89 72 85 85 56 129 111 78 118 77 79 118 138 116 122
91 134 172 182 193 185 188 127 110 136 170 136 171 138 120 90 85 99 111 142
121 66 90 75 76 65 116 69 96 75 119 119 103 132 150 184 108 144 138 168
131 139 171 210 215 141 120 75 119 119 151 118 103 89 73 93 99 127 110
RIP-C02A 226
290 437 474 428 226 521 422 357 516 474 249 274 302 253 196 133 153 178 209 286
196 172 124 126 103 73 75 71 55 47 70 64 122 91 114 106 156 184 116 100
113 107 74 131 136 127 123 84 88 112 118 161 97 82 72 74 60 49 55 61
56 48 66 67 84 92 99 65 64 73 92 121 123 76 58 61 61 40 54 95
118 105 94 80 73 90 92 64 48 66 96 102 84 62 89 57 68 49 52 52
57 55 109 110 89 87 122 123 129 106 135 58 116 108 74 70 82 80 73 73
76 56 47 46 67 80 66 59 85 76 73 103 91 102 94 83 54 94 81 91
60 60 85 58 78 97 57 81 80 81 55 89 60 91 107 100 88 70 100 90
56 65 84 49 72 50 56 53 50 49 59 65 80 76 69 57 54 47 51 69
62 60 89 64 66 69 89 81 83 74 62 70 83 71 71 58 63 70 52 49
80 56 66 64 61 78 62 62 66 97 87 78 67 71 47 68 68 72 71 83
74 73 92 79 80 81
RIP-C02B 226
357 390 450 388 288 487 388 382 481 470 251 275 285 245 188 126 150 174 196 305
185 185 132 119 90 80 77 56 64 63 62 68 119 101 112 95 137 186 119 93
122 98 81 129 127 116 123 89 102 107 116 143 93 80 69 89 50 55 52 57
71 55 60 73 87 90 101 72 70 57 100 115 119 89 53 56 64 45 45 96
86 118 98 76 75 101 95 63 52 76 93 98 87 79 69 78 70 39 41 54
51 61 112 93 100 96 124 126 135 88 102 89 126 110 68 72 85 84 74 57
88 52 40 61 60 71 80 47 89 82 69 101 89 107 96 73 63 92 90 83
60 49 86 78 79 92 67 70 88 71 65 86 63 99 109 95 90 66 100 86
67 60 68 55 76 53 55 45 44 56 66 56 81 79 71 64 41 53 61 58
57 71 89 68 58 81 70 82 83 66 64 72 78 81 62 58 68 70 50 50
69 74 48 72 68 68 65 75 67 94 89 84 59 82 43 68 72 59 88 65
90 79 85 77 79 80

RIP-C03A 218
218 337 218 262 211 159 175 130 177 289 254 308 221 146 134 91 102 97 75 69
88 91 101 119 108 76 61 57 78 75 71 47 75 58 43 77 95 86 92 70
74 68 98 76 85 53 52 80 50 51 64 47 48 43 47 40 49 59 70 64
64 47 57 60 65 59 63 55 56 60 55 48 87 68 92 72 64 62 87 84
53 63 77 172 147 99 126 159 129 84 91 79 80 66 57 88 117 135 170 142
157 104 74 96 128 123 96 91 78 132 96 77 133 113 102 111 140 144 99 97
123 92 97 136 149 127 124 110 94 117 112 84 77 81 125 117 138 169 182 118
146 120 117 121 103 163 190 138 97 74 90 65 101 114 99 93 103 103 79 65
63 86 107 102 117 125 131 116 65 77 130 97 112 126 147 95 132 177 158 146
111 123 150 165 151 115 96 83 122 109 80 124 159 134 127 117 118 165 143 155
126 172 146 141 122 106 100 125 127 111 131 152 137 128 103 174 138 140
RIP-C03B 218
222 327 228 260 224 154 176 133 179 285 245 306 228 156 121 94 107 86 82 79
94 97 102 115 113 73 58 63 75 74 64 50 75 62 45 80 94 77 88 83
77 67 94 80 85 55 57 69 49 66 57 41 53 43 48 42 51 58 66 68
56 48 60 62 60 56 64 61 60 54 51 52 85 72 90 71 64 57 89 86
41 81 68 163 145 104 127 151 113 82 95 84 68 71 54 98 106 148 166 134
159 106 70 95 128 126 88 91 79 130 100 71 140 105 97 123 140 137 102 102
119 99 91 142 148 132 127 103 85 125 111 79 90 78 122 115 148 167 185 113
146 129 106 114 100 162 185 139 97 72 101 65 106 108 99 92 110 107 78 65
64 85 104 105 116 128 133 110 72 74 125 93 105 138 148 95 131 179 155 161
109 115 148 171 140 114 102 84 126 101 74 131 153 143 123 120 107 170 155 160
140 166 142 144 122 116 100 137 115 89 151 146 139 113 115 172 136 138
RIP-C04A 86
176 119 191 106 205 323 192 101 111 139 134 109 106 74 92 133 89 83 106 81
107 76 89 147 120 138 122 103 114 207 156 108 119 87 143 265 250 228 265 220
93 119 160 97 174 192 142 156 137 105 157 251 260 314 273 282 285 191 200 257
240 327 263 175 283 270 245 175 129 111 142 186 160 183 164 200 180 239 96 153
122 141 133 147 151 155
RIP-C04B 86
131 119 175 113 204 319 184 110 121 126 131 122 117 69 114 115 105 81 100 86
119 90 72 156 120 125 126 98 116 203 154 114 118 99 153 247 262 226 244 204
84 127 166 90 155 194 142 159 139 115 156 260 256 311 265 287 277 186 200 258
231 323 262 167 282 257 238 165 145 122 139 178 170 179 178 219 180 230 98 156
139 150 127 141 142 172
RIP-C05A 61
273 185 166 130 205 274 344 205 273 247 192 136 152 157 184 148 182 195 204 168
266 228 219 142 144 149 143 151 143 194 206 231 201 238 196 155 172 187 210 132
111 167 168 184 131 135 118 180 177 225 181 178 195 232 186 183 169 234 204 200
205
RIP-C05B 61
223 175 176 137 217 276 330 214 275 250 175 126 149 151 193 153 192 184 213 177
252 226 217 164 124 144 158 145 146 195 199 231 196 244 202 147 178 184 199 139
100 173 170 168 145 118 123 170 197 208 189 170 197 237 185 176 177 214 192 208
202
RIP-C06A 112
305 271 238 184 146 270 195 174 65 109 73 123 132 156 106 66 86 95 96 115
136 103 73 117 137 111 96 121 104 125 122 161 151 165 136 113 128 132 158 123
116 161 156 116 130 174 270 189 197 241 156 117 188 297 426 185 168 223 165 125
103 98 147 114 117 111 115 117 145 137 151 142 146 153 101 82 96 92 129 154
217 188 269 182 260 189 176 100 85 126 154 109 116 189 137 187 192 182 199 136
160 200 168 123 98 149 143 145 135 114 135 160

RIP-C06B 112
265 259 240 179 131 281 195 174 60 113 79 122 130 161 104 73 70 101 74 112
137 101 85 99 138 118 92 137 105 121 131 156 148 152 144 113 135 129 164 120
119 161 140 119 131 174 278 192 199 218 168 127 202 285 457 205 160 227 164 125
105 96 145 117 121 107 111 119 143 133 146 162 148 153 99 73 96 97 115 142
221 186 273 182 266 185 168 104 96 123 151 114 119 188 149 173 193 185 203 134
162 204 161 127 102 141 146 145 140 110 142 148
RIP-C07A 81
262 390 351 417 233 172 405 211 157 129 171 178 301 224 183 183 247 231 317 314
342 248 235 200 239 249 130 168 235 166 320 248 221 216 186 155 159 102 84 119
85 120 170 139 91 155 145 135 110 109 138 164 159 157 138 136 159 193 208 156
130 117 129 160 124 168 205 162 194 180 155 158 113 127 133 164 108 87 103 147
180
RIP-C07B 81
327 391 322 395 204 190 410 211 154 136 179 190 319 261 217 181 237 252 331 310
363 246 232 204 239 249 143 165 221 169 300 249 223 203 198 155 147 101 97 106
85 129 178 135 108 137 147 123 105 120 140 157 164 160 128 145 158 201 202 154
135 115 130 160 135 163 195 159 199 175 172 154 110 128 141 149 123 82 99 154
169
RIP-C08A 206
328 237 234 111 110 125 107 89 143 117 179 139 119 87 69 46 55 37 52 42
66 84 69 78 81 78 80 72 51 27 36 65 73 49 54 76 48 84 51 70
52 41 58 54 65 66 88 73 67 83 128 68 83 75 72 65 68 74 66 101
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117 109 115 135 123 136
RIP-C08B 206
423 243 228 118 116 125 111 82 140 132 180 142 113 88 71 49 50 39 46 52
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121 106 118 138 124 132
RIP-C09A 108
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112 110 97 119 84 97 97 105

RIP-C09B 108
109 158 126 142 121 122 55 118 105 120 77 85 145 84 66 60 57 49 50 58
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98 108 111 109 86 90 101 142
RIP-C10A 212
93 134 113 226 160 305 235 111 135 100 77 86 57 53 44 66 39 101 161 95
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101 76 106 86 66 81 96 105 95 115 84 103 82 121 114 100 124 87 74 79
80 85 98 79 98 107 113 99 96 125 133 103
RIP-C10B 212
135 116 124 231 148 298 262 111 143 89 70 87 55 50 55 57 46 113 144 93
116 85 96 94 62 77 87 81 68 111 99 104 119 85 79 64 147 96 72 85
60 125 60 66 57 45 53 48 42 44 63 61 68 83 48 91 105 99 143 98
48 61 63 45 54 84 101 81 100 83 77 80 98 63 57 71 88 97 64 70
77 73 72 52 53 52 51 58 87 91 93 89 144 107 149 71 80 86 120 119
62 58 91 67 79 66 103 70 67 83 99 104 102 72 85 141 111 129 104 137
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159 118 88 73 128 116 95 79 72 69 77 65 78 61 83 91 100 87 135 126
95 113 79 76 94 89 104 110 125 94 86 105 131 169 118 128 88 89 84 94
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67 91 92 78 99 103 117 99 88 119 137 124
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70 63 50 49 39 98 96 101 64 78 154 134 164 104 79 122 222 239 218 111
184 227 149 120 95 98 89 141 199 178 138 200 368 270 150 235 329 229 330 230
163 171 166 162 154 194 253 255 292 246 160 124 270 164 134 153 179 97 102 80
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167 229 145 128 104 81 111 125 205 174 136 204 375 252 157 234 331 225 328 237
168 165 135 157 141 198 258 270 277 249 151 130 294 164 120 147 186 108 99 85
104 94 112 73 68 68 66 88 65 131 102 139 131 136 123 107 91 110 176 205
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166 160 157 130 171 150 196 164 167 174 217 223

RIP-C12A 75
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176 198 200 194 189 199 153 163 165 132 170 147 153 177 127 162 176 156 150 166
116 141 142 137 103 122 144 167 170 159 156 137 118 189 200
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RIP-C13A 91
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173 190 167 162 182 254 180 170 179 171 182 171 176 92 100 157 145 110 114 198
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RIP-C13B 91
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178 168 165 136 204 264 185 166 172 177 164 197 165 100 111 134 147 117 108 232
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RIP-C15B 83
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RIP-C16B 79
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199 202 192 172 221 243
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267 204 177 174 216 256
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RIP-C29A 117
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192 180 139 160 199 146 170 162 131 215 166 167 154 135 189 172 138 101 118 116
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137 124 165 121 168 150 135 154 174 162 172 124 139 119 130 103 91 176 181 199
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RIP-C29B 117
299 413 365 361 441 413 384 328 322 235 185 182 100 160 243 365 256 176 217 247
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RIP-C30B 110
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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.

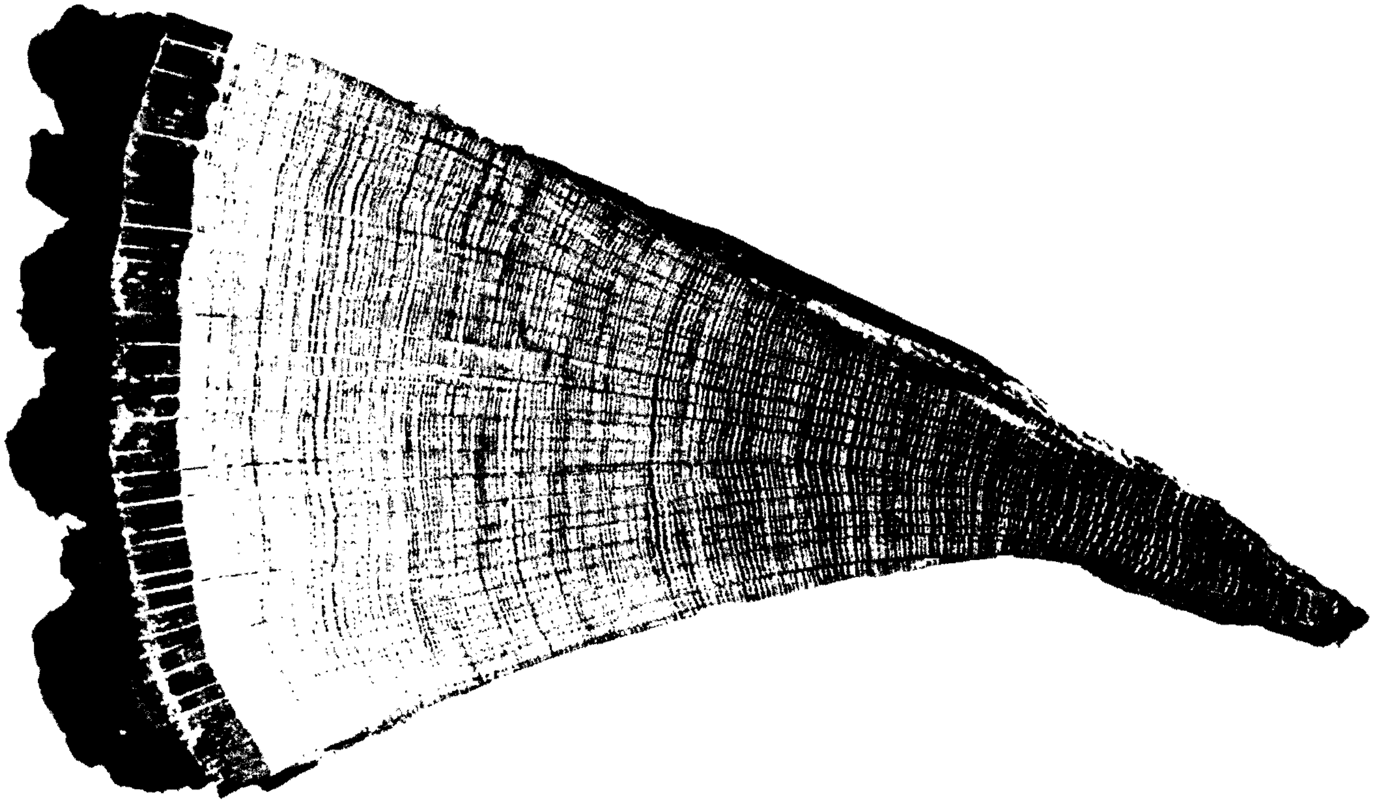


Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can determined by counting back from the outside ring, which grew in 1976.

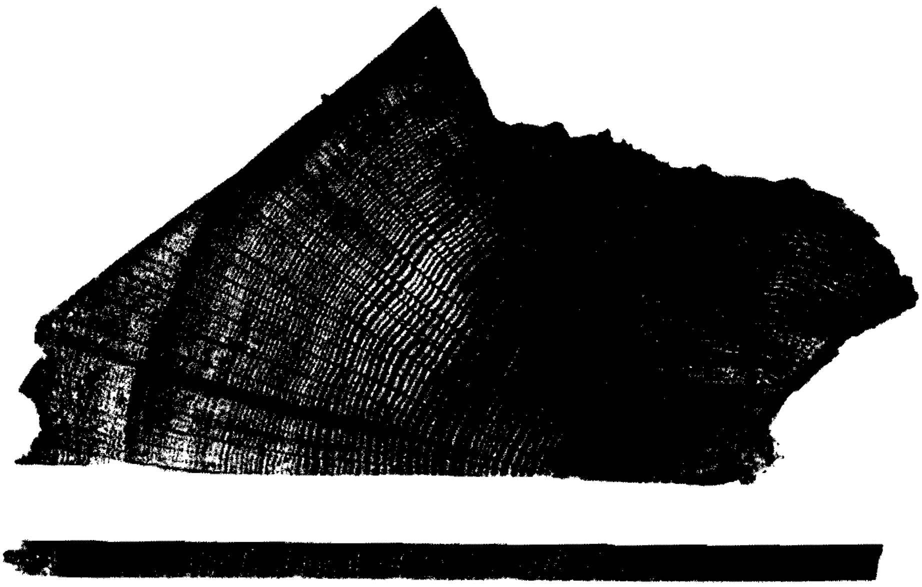


Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the left hand corner, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

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.

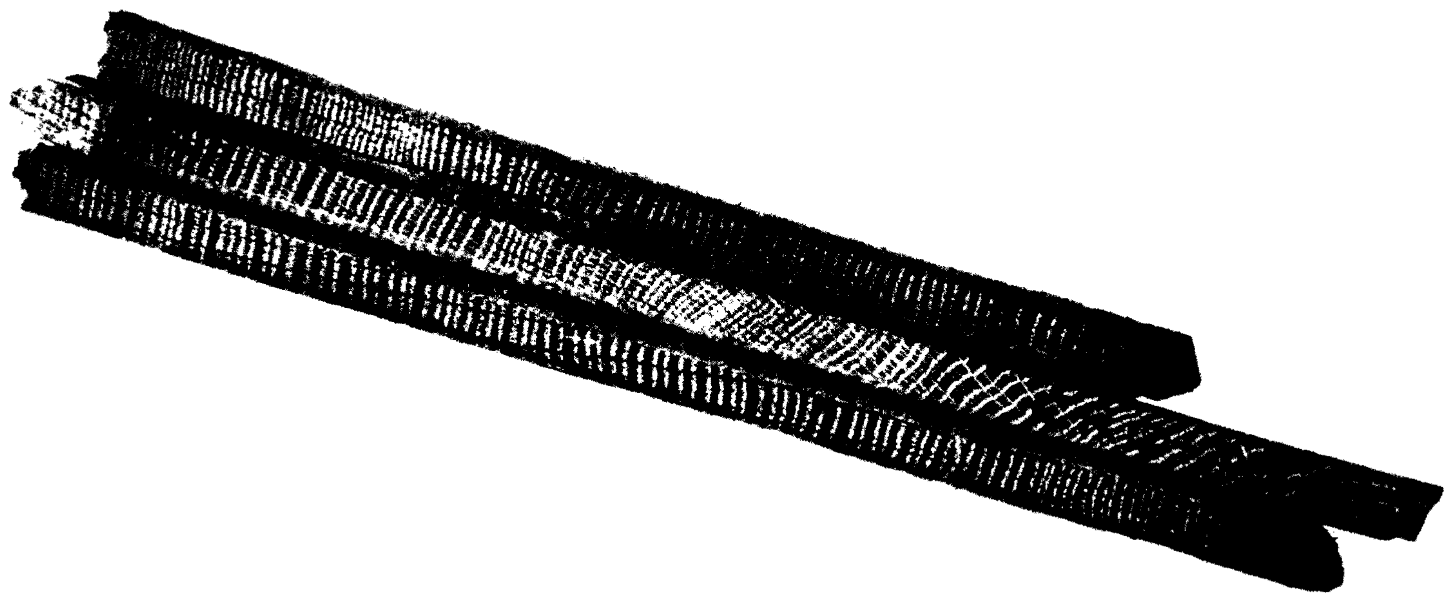


Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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

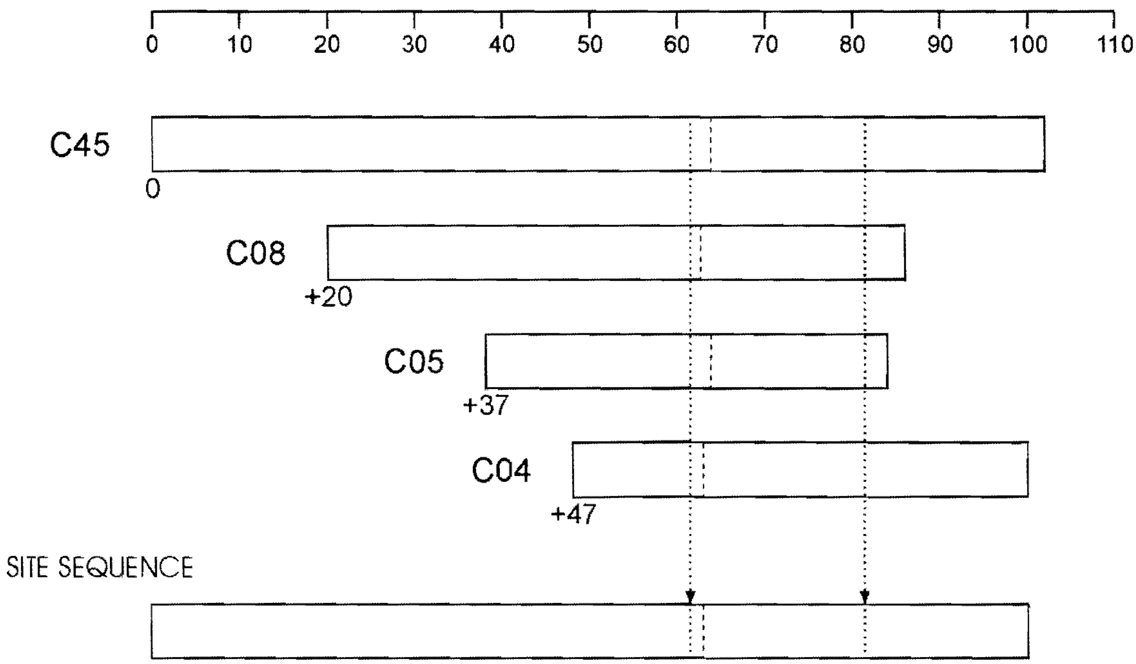


Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

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.

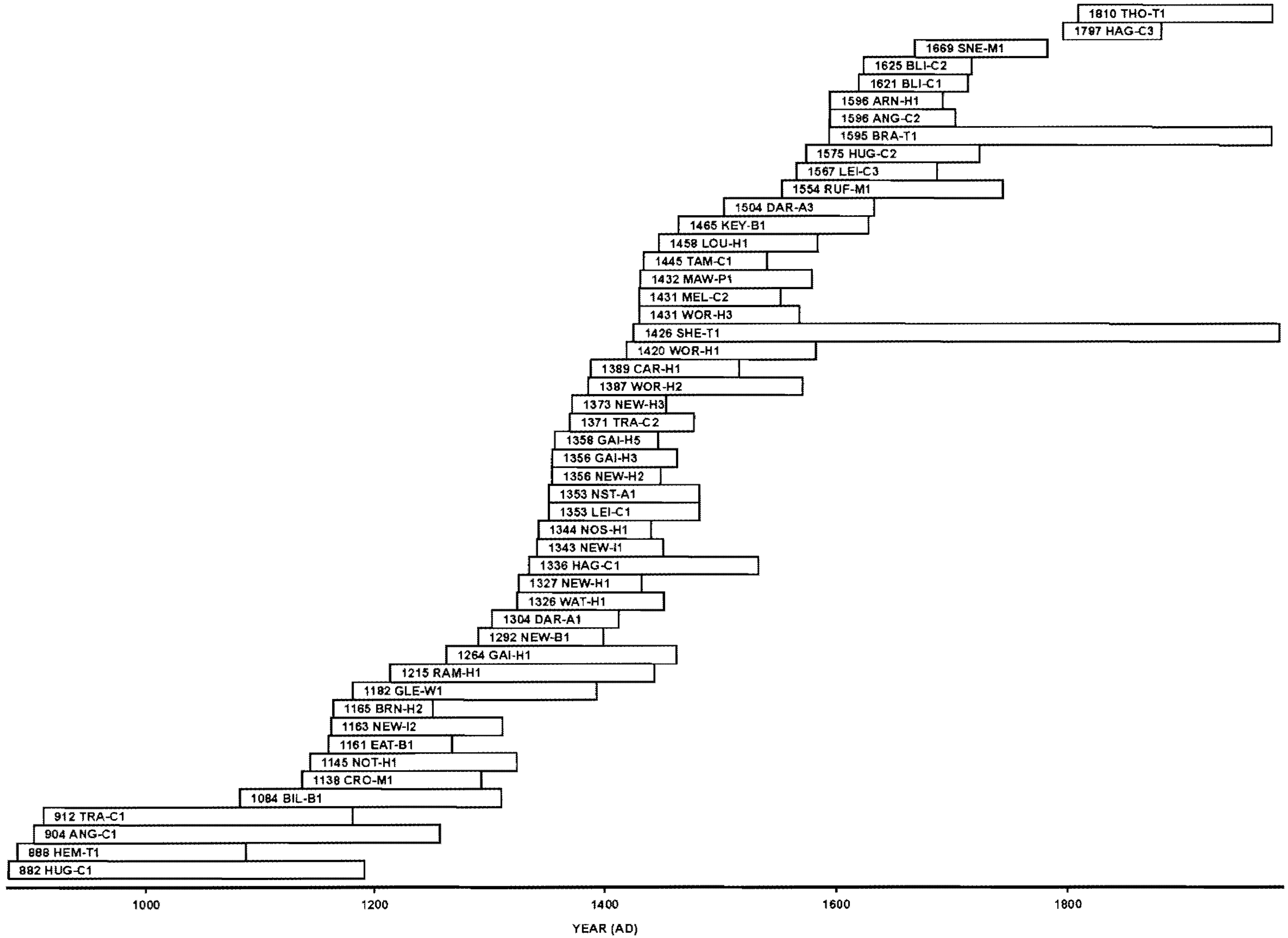
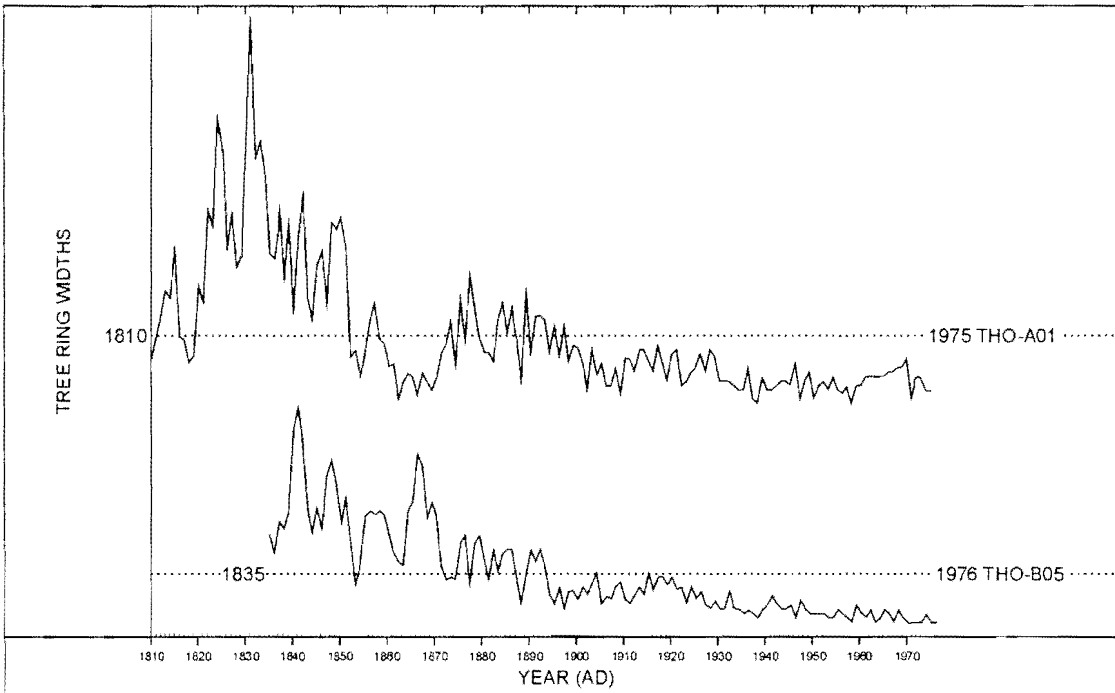


Fig. 6 Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

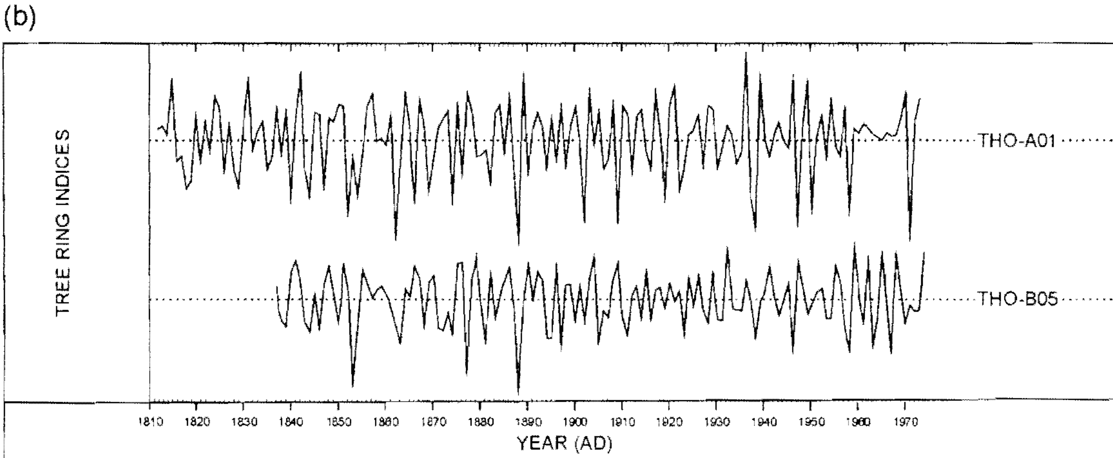


Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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