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Tree-Ring Analysis of Timbers from the Main Guard, Pontefract Castle, Pontefract, West Yorkshire

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Summary

Core samples were obtained from 32 different oak timbers in a wide range of locations throughout the Main Guard of Pontefract Castle. The analysis of these produced a single site chronology, PFCASQ01, comprising 25 samples, and having a combined overall length of 150 rings. The site chronology was dated as spanning the years AD 1507 to AD 1656.

Interpretation of the sapwood would indicate that all the dated timbers, from the basement, ground, and first-floors, and from the roof, were cut in a single phase of felling in AD 1656. Such a date would indicate that while the stone element of the Main Guard may date to the fifteenth century, a considerable amount of work was undertaken at this site shortly after the Civil War. No earlier or later material is detected amongst the sampled timbers.

Keywords

Dendrochronology
Standing Building

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Introduction

The remains of Pontefract Castle barbican, standing above and to the north of the town (SE 460 222, Figs 1 and 2), consist of a medieval polygonal bastion on the approach to the former west gate. The bastion is surmounted by a building which runs parallel with the castle approach. This is collectively known as the 'Main Guard' and comprises a principal structure with a smaller section at one end sometimes referred to as the 'West Cottage'. A photograph of the building is shown in Figure 3. The Castle itself was demolished after the English Civil war, with the Main Guard supposedly suffering some destruction as well. The building now appears to be largely of sixteenth or seventeenth century date, with evidence of further alterations undertaken in the nineteenth and twentieth centuries. Despite these changes it is believed that the fabric may retain elements of its medieval origin.

Sampling

Sampling and analysis by tree-ring dating of the timbers within the Main Guard (including the West Cottage) were commissioned by English Heritage. The purpose of this was to establish the felling date not only of the timbers found within the roof, but also those found at first, ground, and basement floor level. The objective of dating was to establish if the building dates to before the castle's demolition after the Civil War, or post-dates this period, and whether or not it retains elements from the medieval period or indeed later repairs. The analysis was undertaken to inform a listed building consent application, and to assist with recording being undertaken by Field Archaeology Specialists, York.

After an examination of the building with Field Archaeology Specialists staff, and in conjunction with the sampling brief, 32 different oak timbers were cored, with a range of timber types and locations being selected to obtain a representative collection of material. Each sample was given the code PFC-A (for Pontefract, site "A") and numbered 01 – 32. Whilst the roof and many of the basement timbers sampled appeared to be integral with each other, being jointed and pegged, there was less certainty about the bridging beams, these simply being set between walls, and thus possibly of different dates. The positions of these samples are marked on plans made and provided by Field Archaeology Specialists, these being reproduced here as Figures 4a – d. Details of the samples are given in Table 1. In this Table, all trusses are numbered following the form of the drawings provided with individual timbers being identified on a north - south or east - west basis as appropriate.

The Laboratory would like to take this opportunity to thank the owner of the Main Guard, Mrs Love, not only for her enthusiasm and help during this programme of tree-ring sampling, but also for her generous hospitality, with tea and biscuits being constantly available. The Laboratory would also like to take this opportunity to thank Dr Jonathan Clark and Dr Rochelle Remey, of Field Archaeology Specialists Ltd, for their discussions about the roof and for the provision of the text used in the introduction above and the drawings used elsewhere in this report.

Analysis

Each of the 32 samples obtained was prepared by sanding and polishing and its annual growth-ring widths were measured. The growth-ring widths of all 32 samples were compared with each other by the Litton/Zainodin grouping procedure (see appendix). At a minimum value of *t*=4.5 a single group of 25 samples was formed cross-matching with each other as shown in the bar diagram Figure 5.

The samples were combined at these off-set positions to form PFCASQ01, a site chronology of 150 rings. Site chronology PFCASQ01 was then satisfactorily dated by comparison to a number of relevant oak reference chronologies as spanning the years AD 1507 to AD 1656. The evidence for this dating is given in the *t*-values of Table 2.

Site chronology PFCASQ01 was then compared to the seven remaining ungrouped samples but there was no further satisfactory cross-matching. Each of the ungrouped samples was than compared individually to the full range of reference chronologies. There was, again, no reliable cross-matching and these seven samples must remain undated.

Interpretation and conclusion

Analysis by dendrochronology has produced a single site chronology, PFCASQ01, comprising 25 samples, its 150 rings dated as spanning the years AD 1507 to AD 1656. Ten of the 25 samples in this site chronology, PFC-A02, A06, A16, A17, A18 A21, A23, A25, A27, and A31, retain complete sapwood. This means that each has the last ring produced before the tree it represents was felled. In each case the last measured ring date is the same, AD 1656, this thus being the felling date of the timbers.

As can be seen from the bar diagram Figure 6, where the samples are sorted by location, timbers with complete sapwood, and thus a felling date of AD 1656, are found in all areas of the Main Guard. Furthermore, the relative position of the heartwood/sapwood boundary on the other 16 dated samples which do not have complete sapwood is consistent with the timbers these represent being felled in AD 1656 as well. There is no indication of any earlier, or indeed later, material being represented. Such a felling date would indicate that whilst the stone elements of the Main Guard may date to the fifteenth century, the roof and interior of the building were the subject of major works in the mid-seventeenth century, immediately following the Civil War.

During the analysis it was seen that some pairs of samples cross-matched with *t*-values high enough to suggest that the beams represented may have been derived from the same tree, though this is not certain. Samples PFC-A08 and A10, for example, cross-match with a value of *t*=12.8, and samples PFC-A23 and A27 cross-match with a value of *t*=11.2.

The cross-matching between some of the other samples gave *t*-values high enough to suggest the possibility that the trees they represent grew in the same copse or stand of woodland. For example, some of the roof timbers may have been derived from the same copse, whereas some of the bridging beams used in the ground and first-floor ceilings appear to represent another stand of woodland.

Seven samples, PFC-A01, A03 and A07, A19, A20, A22, and A28 remain ungrouped and undated. Some samples, PFC-A01 and A07, for example, show very slightly complacent annual ring growth. Sample PFC-A03 shows a band of compacted rings. Some of the other ungrouped and undated samples have lower numbers of rings, although sufficient for analysis. It is possible that these factors make the samples more difficult to successfully cross-match and date.

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Table 1: Details of samples from the Main Guard, Pontefract Castle, Pontefract, West Yorkshire

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Roof timbers					
PFC-A01	North principal rafter, truss 1 (east)	59	h/s	------	------	------
PFC-A02	South principal rafter, truss 1	90	28C	AD 1567	AD 1628	AD 1656
PFC-A03	Collar, truss 1	60	8	------	------	------
PFC-A04	South upper purlin, truss 1 - 2	61	9	AD 1585	AD 1636	AD 1645
PFC-A05	North principal rafter, truss 2	80	h/s	AD 1552	AD 1631	AD 1631
PFC-A06	South principal rafter, truss 2	98	30C	AD 1559	AD 1626	AD 1656
PFC-A07	Collar, truss 2	81	25C	------	------	------
PFC-A08	South lower purlin, truss 2 - 3	63	h/s	AD 1572	AD 1634	AD 1634
PFC-A09	North lower purlin, truss 2 - 3	69	h/s	AD 1561	AD 1629	AD 1629
PFC-A10	South upper purlin, truss 2 - 3	71	h/s	AD 1564	AD 1634	AD 1634
PFC-A11	North principal rafter, truss 3	70	8	AD 1570	AD 1631	AD 1639
PFC-A12	South principal rafter, truss 3	84	17	AD 1564	AD 1630	AD 1647
PFC-A13	Collar, truss 3	75	19	AD 1574	AD 1629	AD 1648
PFC-A14	South lower purlin, truss 2 - 3	56	no h/s	AD 1553	------	AD 1608
	Ceiling beams					
PFC-A15	First-floor, east ceiling beam	132	17	AD 1507	AD 1621	AD 1638
PFC-A16	First-floor, middle ceiling beam	126	27C	AD 1531	AD 1629	AD 1656
PFC-A17	First-floor, west ceiling beam	136	30C	AD 1521	AD 1626	AD 1656

Table 1: Continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Ceiling beams continued					
PFC-A18	Ground floor, east longitudinal beam	103	32C	AD 1554	AD 1624	AD 1656
PFC-A19	Ground floor, west longitudinal beam	107	21	------	------	------
PFC-A20	Basement, middle bridging beam	57	h/s	------	------	------
PFC-A21	Basement, west bridging beam	86	19C	AD 1571	AD 1637	AD 1656
PFC-A22	Kitchen, east bridging beam	60	h/s	------	------	------
	West cottage timbers					
PFC-A23	Cellar, main bridging beam	120	34C	AD 1537	AD 1622	AD 1656
PFC-A24	Cellar, ceiling joist	78	3	AD 1555	AD 1629	AD 1632
PFC-A25	Cellar, ceiling joist	105	28C	AD 1552	AD 1628	AD 1656
PFC-A26	Cellar, ceiling joist	123	9	AD 1517	AD 1630	AD 1639
PFC-A27	Cellar, ceiling joist	105	31C	AD 1552	AD 1625	AD 1656
PFC-A28	Cellar, ceiling joist	68	h/s	------	------	------
PFC-A29	Cellar, ceiling joist	72	no h/s	AD 1535	------	AD 1606
PFC-A30	Cellar, inner lintel to window	82	h/s	AD 1547	AD 1628	AD 1628
PFC-A31	Ground-floor ceiling beam	148	26C	AD 1509	AD 1630	AD 1656
PFC-A32	First-floor ceiling beam	70	20	AD 1580	AD 1629	AD 1649

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

C = complete sapwood is retained on the sample; the last measured ring date is the felling date of the timber

Table 2: Results of the cross-matching of site chronology PFCASQ01 and relevant reference chronologies when first ring date is AD 1507 and last ring date is AD 1656

Reference chronology	Span of chronology	*t*-value	
East Midlands	AD 882 – 1981	9.5	(Laxton and Litton 1988)
Nun Appleton, Tadcaster, W Yorks	AD 1478 – 1657	9.2	(Howard *et al* 1995a unpubl)
England	AD 401 – 1981	8.7	(Baillie and Pilcher 1982 unpubl)
1 Soar Lane, Sutton Bonnigton, Notts	AD 1552 – 1651	8.3	(Howard *et al* 1993)
Bolsover Little Castle, Bolsover, Derbys	AD 1532 – 1749	8.0	(Arnold *et al* 2003)
Sutton Scarsdale Manor, Derbys	AD 1513 – 1644	7.7	(Howard *et al* 1995b unpubl)
Sutton Scarsdale Manor barn, Derbys	AD 1520 – 1632	7.5	(Howard *et al* 1997)
Fair Flats Farm, Bradfield, S Yorks	AD 1492 – 1633	6.5	(Howard *et al* 1994)

Figure 1: Map to show general location of Pontefract and the Castle

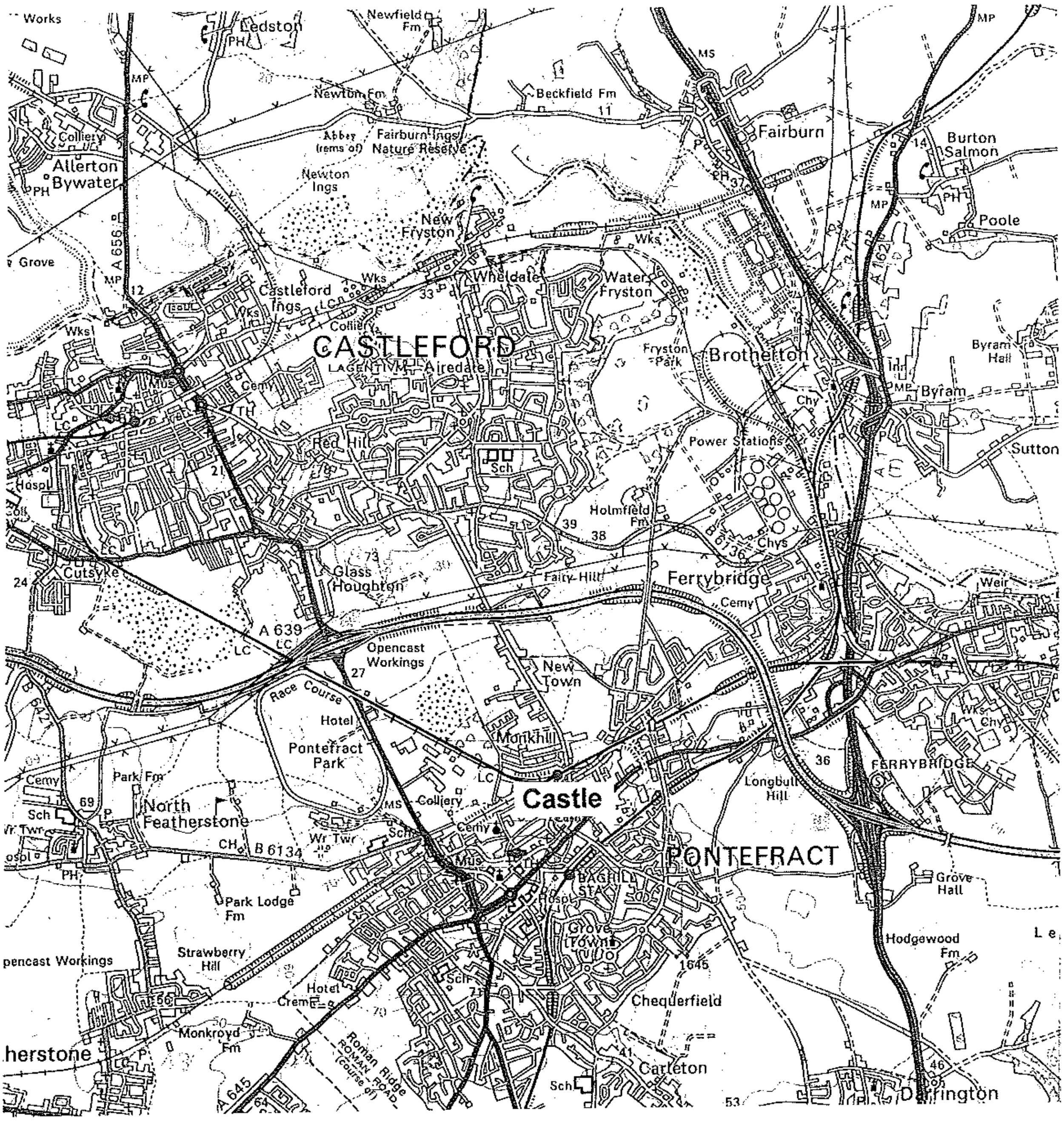


Figure 2: Plan to show location of the Main Guard (outlined in red)
(after Field Archaeology Specialists Ltd, York)

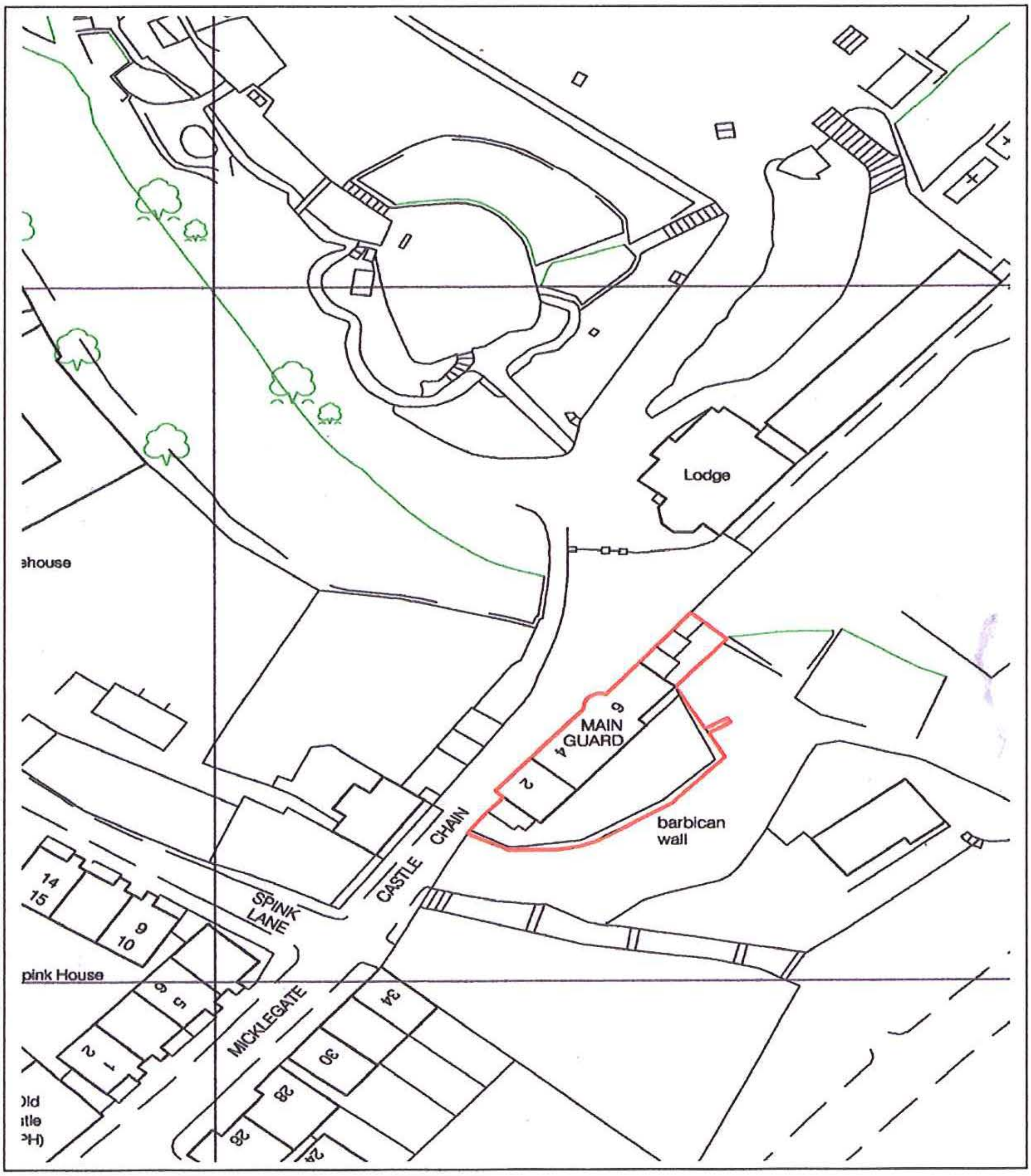


Figure 3: View of the Main Guard from the front or north-east

Figure 4a: Roof trusses showing sample locations (after Field Archaeology Specialists Ltd, York) (viewed from the east looking west)

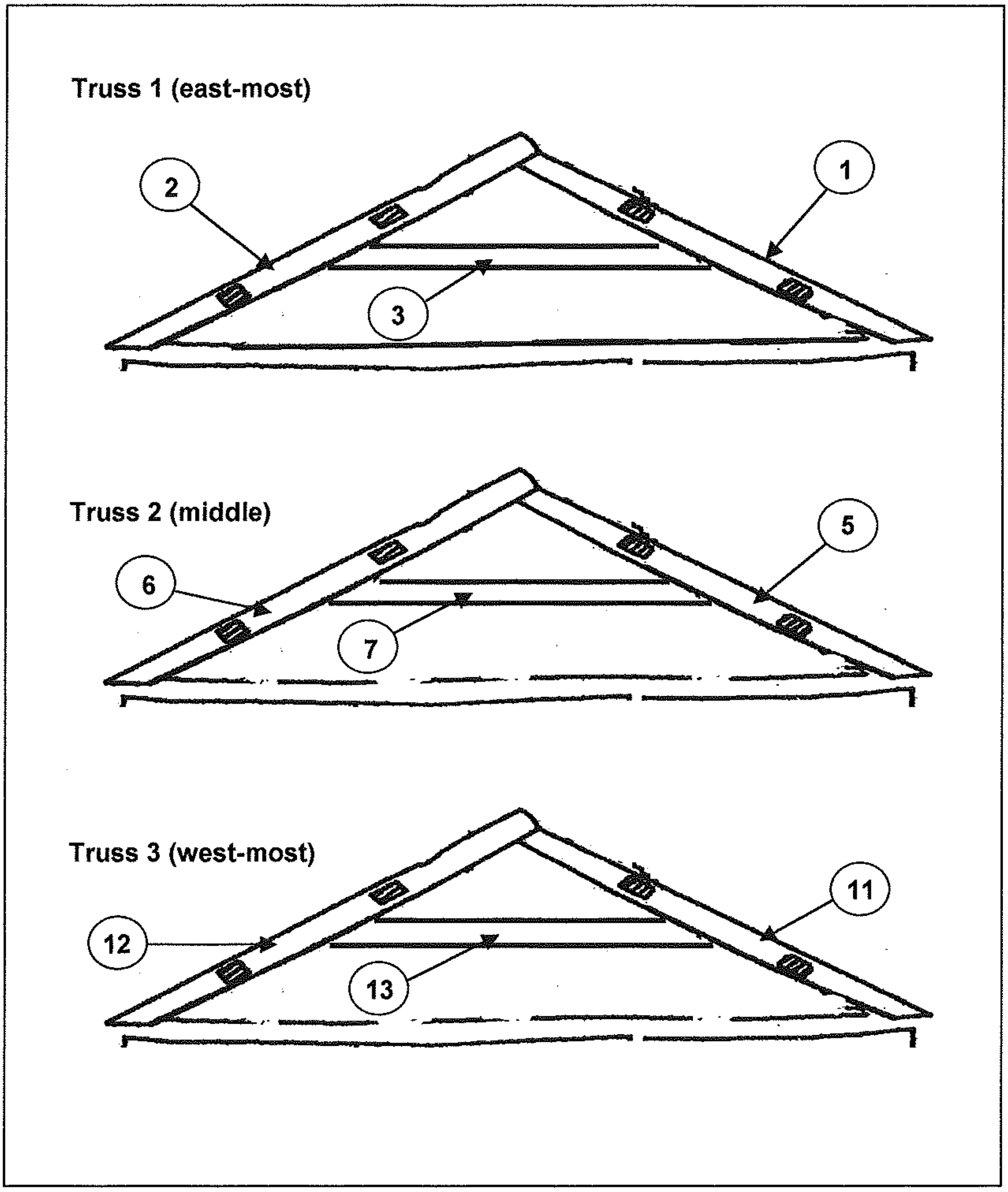


Figure 4b: Plan of the attic showing roof timbers sampled
(after Field Archaeology Specialists Ltd, York)

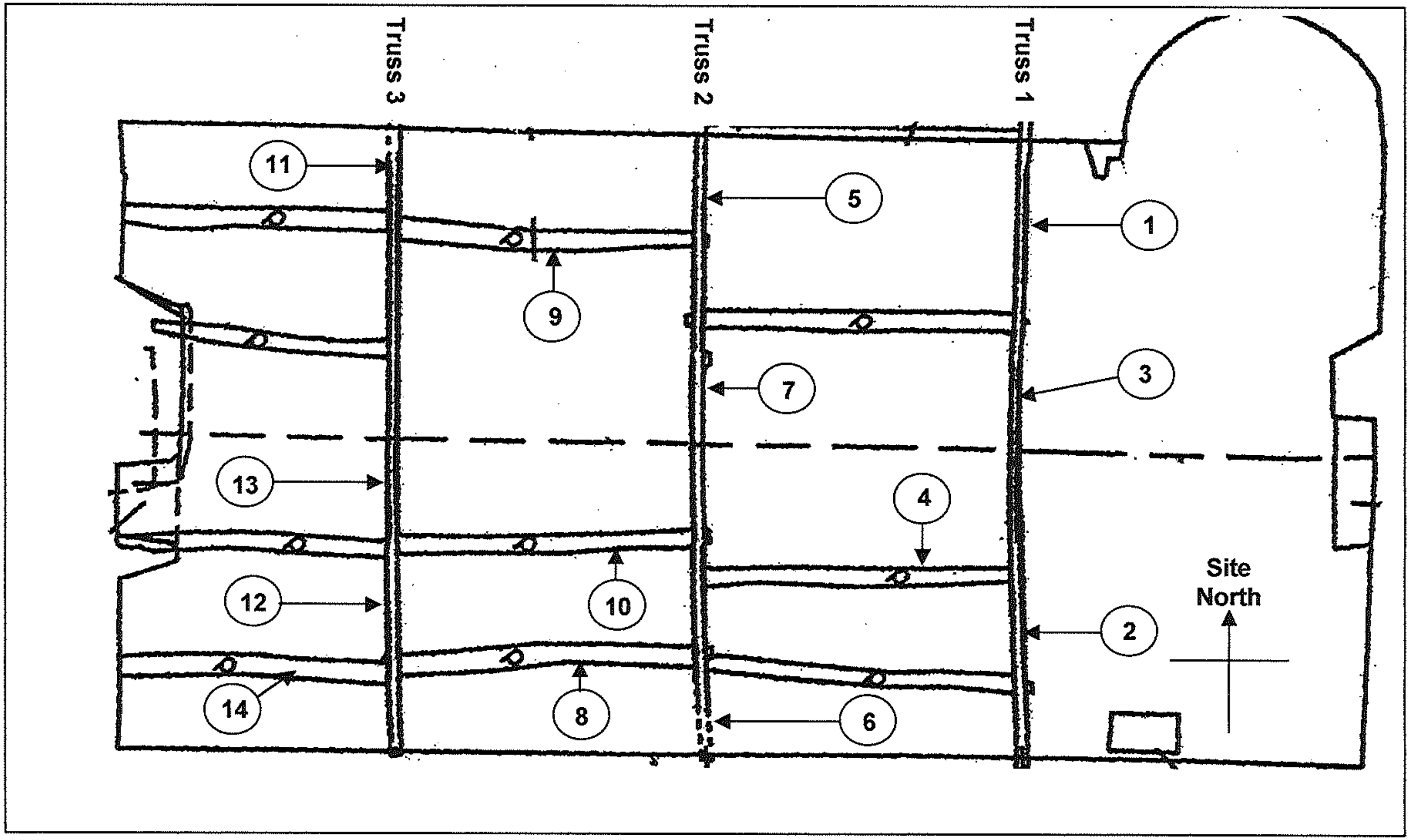


Figure 4c: Plan of the first-floor showing timbers sampled (after Field Archaeology Specialists Ltd, York)

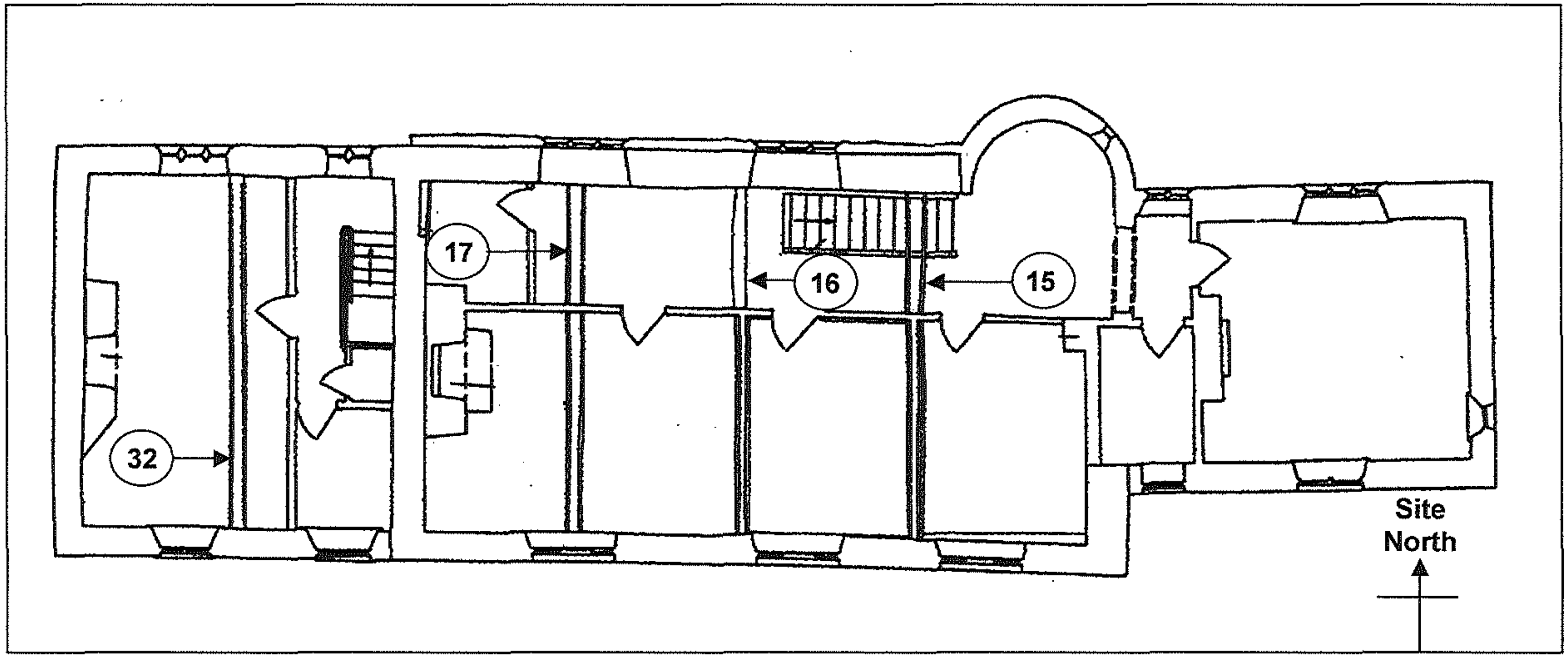


Figure 4d: Plan of the basement (bottom) and ground floor (above) showing timbers sampled (after Field Archaeology Specialists Ltd, York)

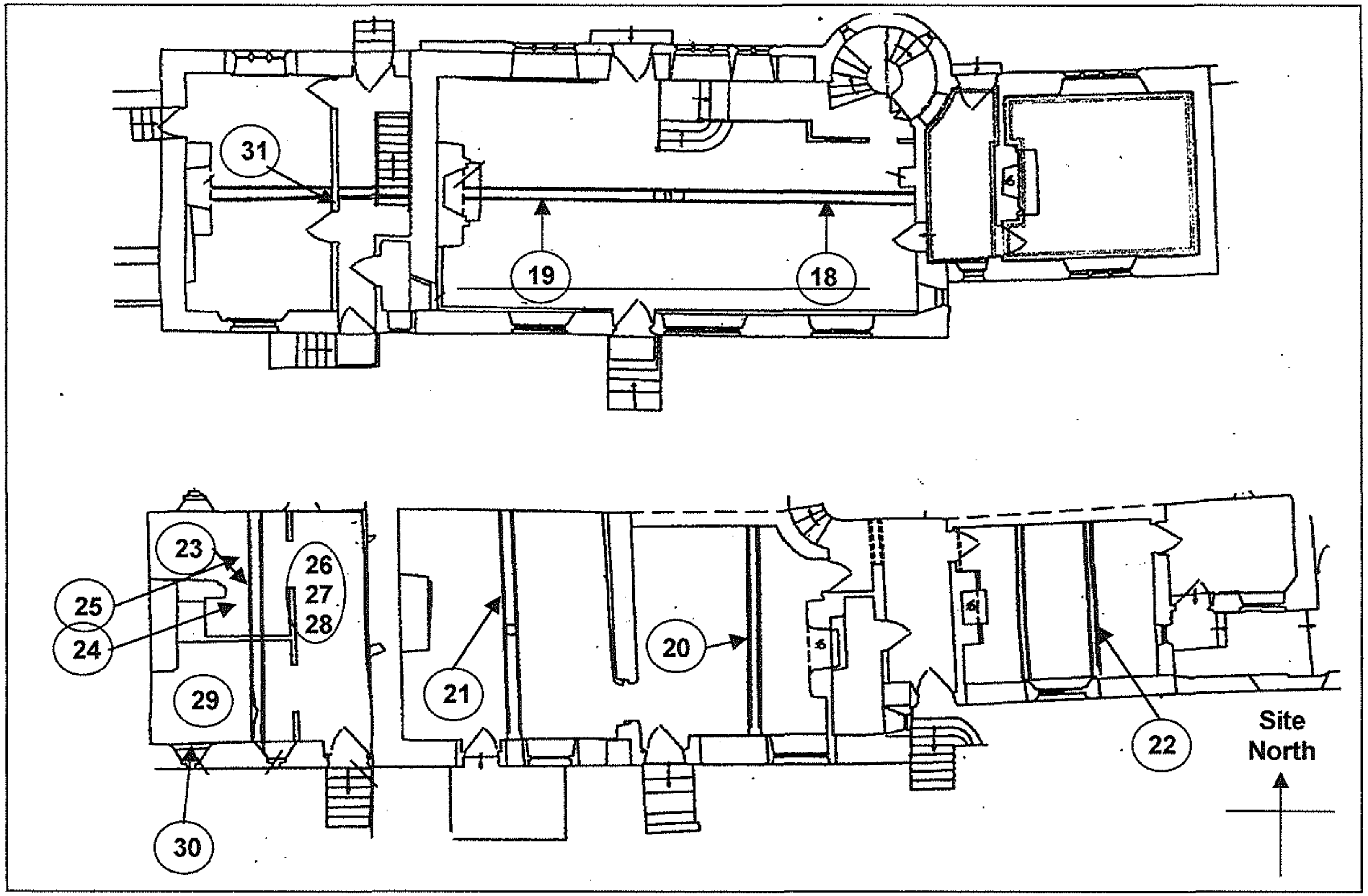
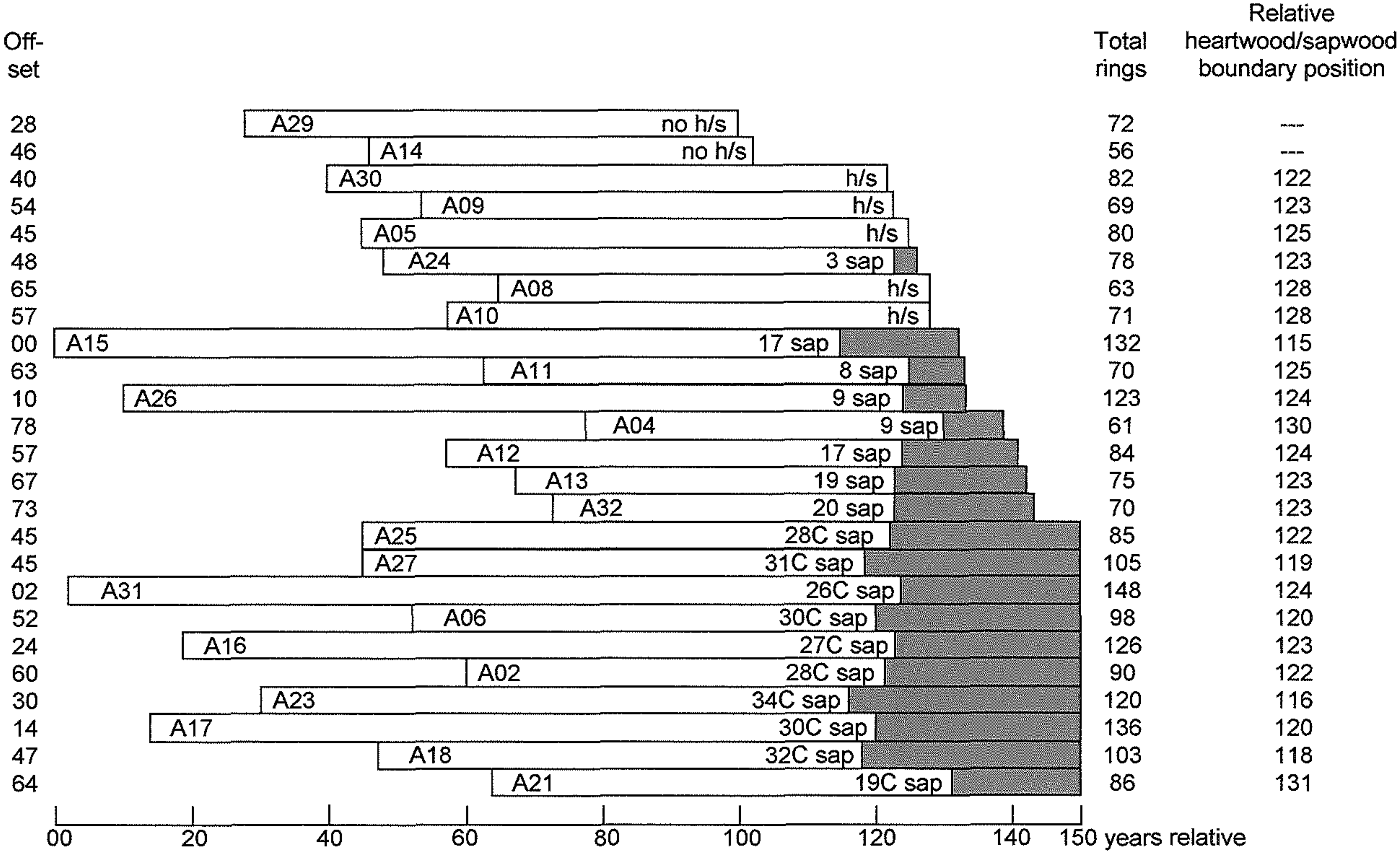
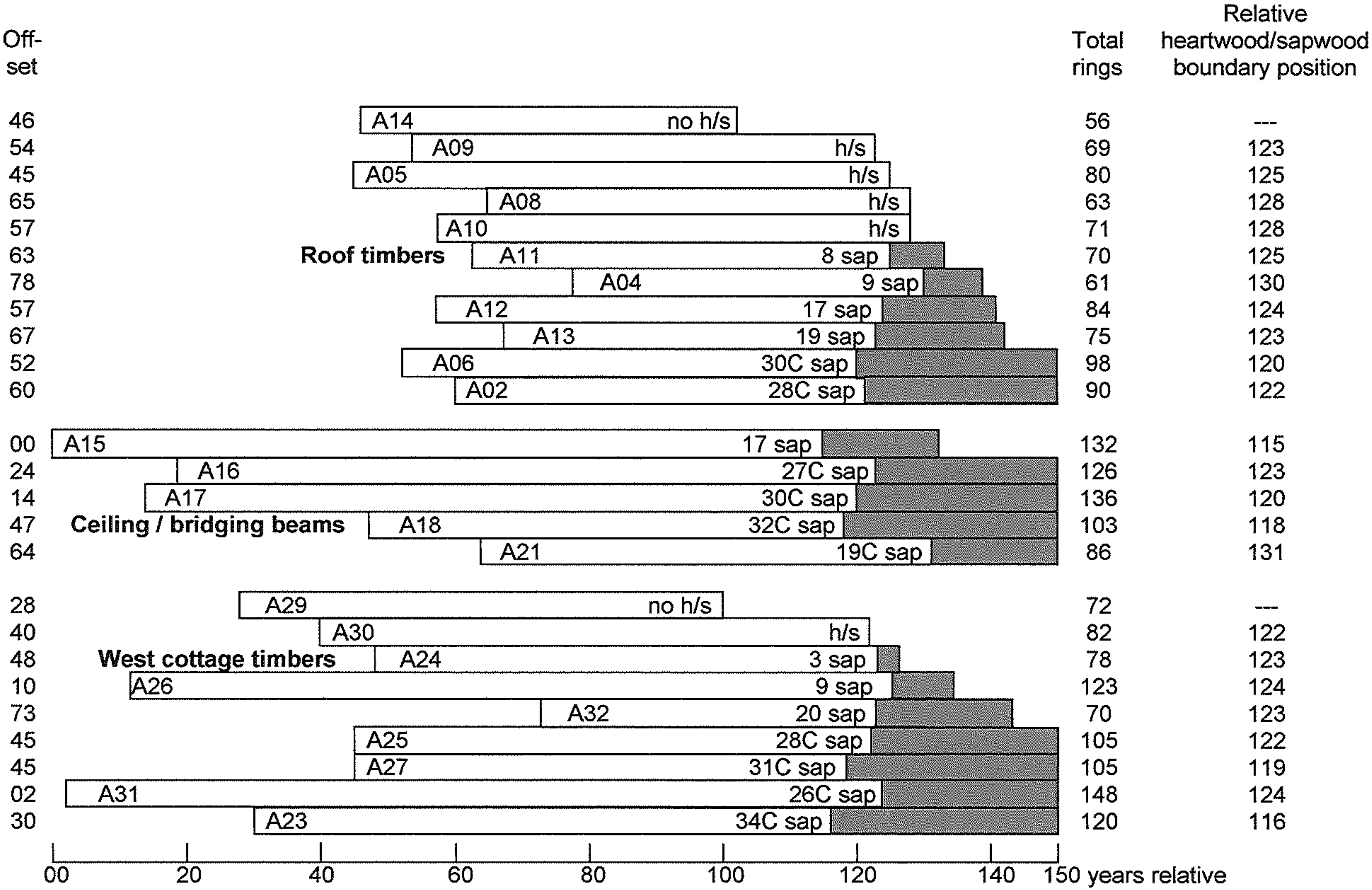


Figure 5: Bar diagram of the samples in site chronology PFCASQ01



White bars = heartwood rings, shaded area = sapwood rings. h/s = the heartwood/sapwood boundary is the last ring on the sample
C = complete sapwood retained on the sample; last measured ring date is the felling date of the timber

Figure 6: Bar diagram of the samples in site chronology PFCASQ01 sorted by sample location



White bars = heartwood rings, shaded area = sapwood rings. h/s = the heartwood/sapwood boundary is the last ring on the sample
C = complete sapwood retained on the sample; last measured ring date is the felling date of the timber

Data of measured samples – measurements in 0.01 mm units

PFC-A01A 59
156 157 273 350 474 389 462 380 494 483 422 326 477 518 401 328 269 255 208 253
278 318 305 306 255 193 212 258 286 357 265 203 222 227 226 194 171 170 177 170
140 166 165 189 240 272 226 191 149 122 131 168 163 202 137 216 259 284 232
PFC-A01B 59
183 161 247 351 458 433 494 391 450 485 416 315 480 545 403 344 261 255 214 232
302 302 312 305 245 209 199 267 263 353 313 207 232 211 230 161 191 167 169 168
138 197 156 170 255 265 235 177 147 117 142 141 171 180 152 242 263 282 226
PFC-A02A 82
210 321 399 492 559 365 447 338 257 288 254 238 281 304 285 255 207 288 322 363
358 317 219 204 182 202 266 213 208 196 254 224 221 234 236 224 211 183 138 176
213 199 193 210 234 252 262 189 171 163 180 175 198 176 121 120 155 72 90 102
114 118 111 97 94 119 86 77 69 67 74 116 107 120 164 102 108 104 120 146
134 156
PFC-A02B 85
365 352 255 235 281 201 205 192 265 237 241 229 260 294 395 285 255 237 202 179
243 320 278 328 276 328 309 269 295 270 218 229 203 176 181 208 221 191 201 220
276 260 171 172 163 163 166 168 205 113 115 135 85 67 111 121 113 112 85 95
117 88 72 71 56 85 104 97 114 160 99 89 97 117 135 138 149 119 70 113
80 91 101 130 137
PFC-A03A 60
134 197 243 190 137 252 354 270 228 80 64 55 76 105 152 168 161 146 172 129
244 181 118 61 57 179 182 230 212 222 121 181 97 120 38 45 42 53 40 62
69 165 155 188 159 93 80 68 187 204 189 103 78 65 75 63 43 45 73 147
PFC-A03B 60
112 207 249 199 122 220 357 275 222 88 59 56 70 106 141 166 164 152 168 131
211 169 123 56 80 154 215 262 183 223 137 188 92 101 39 42 40 58 38 54
68 121 150 178 150 94 86 63 200 206 184 132 75 45 87 46 54 57 78 146
PFC-A04A 61
258 296 300 278 290 269 160 211 229 344 329 404 463 283 236 280 331 285 353 324
153 217 269 241 182 232 255 201 241 125 79 62 60 95 105 137 165 179 164 85
59 111 141 133 155 111 163 177 165 108 165 105 125 170 132 150 73 108 127 119
136
PFC-A04B 61
283 296 295 276 293 264 169 207 236 341 305 403 463 261 242 278 326 287 354 328
151 214 249 247 171 220 248 194 234 111 79 60 61 88 116 136 154 176 164 81
61 115 142 125 154 114 155 179 148 124 141 109 128 165 127 140 86 109 128 114
135
PFC-A05A 80
368 539 416 418 440 323 402 361 342 317 337 353 377 277 228 220 195 208 252 144
137 200 160 163 111 154 162 173 172 152 159 134 140 165 179 162 142 142 114 89
103 126 155 108 127 160 138 113 141 111 101 176 131 107 96 136 103 126 113 106
109 156 126 130 111 111 155 145 131 122 99 113 72 106 129 119 134 145 99 113
PFC-A05B 80
254 520 379 472 393 274 440 348 278 296 341 350 393 309 231 220 192 194 228 159
155 183 163 159 126 132 170 171 161 159 154 145 145 161 183 151 138 149 110 106
87 144 142 108 126 163 158 106 139 120 108 149 140 101 100 135 104 108 131 109
108 152 125 124 101 106 149 147 133 131 95 109 74 104 125 116 139 141 99 112

PFC-A06A 98
325 352 280 214 263 265 269 230 215 308 325 415 345 225 253 211 211 162 147 189
215 179 171 175 168 195 159 182 152 141 141 134 118 148 178 183 140 136 150 159
135 132 121 115 105 121 105 127 143 137 123 144 152 142 184 170 158 148 127 166
129 169 127 145 143 84 115 119 131 121 102 93 114 136 118 98 74 52 104 163
137 140 147 107 112 111 117 156 119 121 116 79 85 103 107 142 103 108
PFC-A06B 98
330 339 269 215 246 288 258 224 225 295 328 400 323 266 209 215 214 158 147 185
219 172 167 170 168 196 168 176 148 128 144 131 114 152 180 178 140 142 144 176
131 115 125 111 118 119 110 121 128 129 129 152 142 151 181 166 161 146 143 154
152 164 129 140 152 74 105 115 129 144 107 92 110 126 126 93 69 46 109 148
125 142 145 114 102 103 110 162 117 133 112 94 99 101 108 149 108 112
PFC-A07A 81
422 366 415 388 419 382 342 329 271 335 352 335 232 272 264 251 218 190 195 200
176 125 152 123 148 148 109 177 169 144 161 146 171 198 209 170 193 178 151 136
136 145 181 213 196 296 215 218 171 161 204 150 149 198 153 151 174 161 116 103
91 106 120 139 134 104 91 100 154 115 129 140 136 122 87 99 98 94 104 111
133
PFC-A07B 81
429 336 406 378 451 458 346 315 262 310 336 318 227 295 277 255 203 188 192 206
175 128 165 125 144 150 107 168 161 146 157 145 169 184 205 177 190 177 152 130
139 147 179 212 199 267 214 215 179 164 207 148 143 196 148 151 181 175 114 103
89 108 126 145 134 103 96 102 148 118 129 136 137 123 78 100 97 96 101 109
134
PFC-A08A 63
254 264 330 214 200 138 120 73 96 137 139 177 126 245 233 238 240 208 159 120
118 187 256 193 289 274 200 160 188 244 187 202 188 102 150 173 167 139 178 162
149 159 72 62 53 43 100 93 136 117 108 94 52 41 64 62 78 88 65 75
90 83 116
PFC-A08B 63
234 245 321 230 186 127 124 80 89 145 140 172 131 229 233 247 240 199 154 124
117 173 260 204 283 279 193 156 181 244 199 198 181 87 151 177 152 143 183 169
151 144 75 55 58 43 96 94 127 120 113 88 55 47 52 71 69 98 55 68
84 75 116
PFC-A09A 69
228 322 326 315 221 131 164 194 237 242 310 318 328 475 292 214 301 250 208 262
205 150 128 136 202 218 191 108 95 79 76 90 107 153 177 144 92 82 41 89
86 72 96 97 70 67 82 63 110 92 74 74 103 52 37 47 75 75 93 83
86 70 67 54 43 49 69 77 100
PFC-A09B 69
223 315 310 324 241 121 165 182 228 247 295 314 317 421 266 213 344 247 213 250
199 147 142 142 194 224 177 124 106 84 79 93 110 144 164 145 103 73 53 83
84 76 91 87 57 75 82 60 100 99 73 86 93 59 37 41 70 83 73 103
79 70 69 52 49 40 49 74 106
PFC-A10A 71
260 272 218 199 234 178 212 189 211 250 228 230 247 165 129 65 57 92 118 157
128 220 280 228 218 232 168 119 150 248 281 242 251 298 249 137 149 192 149 183
153 70 114 159 119 106 175 199 182 213 84 65 70 40 142 159 174 181 192 191
92 78 73 131 152 189 106 173 163 209 112
PFC-A10B 71
239 288 222 214 154 189 224 190 194 237 239 220 242 179 149 69 69 69 119 145
122 234 278 237 213 224 156 130 142 235 286 247 258 280 252 150 143 190 140 185
153 62 126 149 123 113 175 212 177 207 77 77 54 46 131 152 173 176 185 186
79 84 83 127 152 184 108 168 157 223 122

PFC-A11A 70
339 362 222 195 200 164 153 134 146 143 136 133 167 118 149 148 188 146 133 127
99 74 116 155 121 117 125 168 180 149 158 192 147 169 120 120 136 139 122 126
142 108 141 160 144 136 129 148 177 159 184 169 187 194 113 132 147 187 133 133
112 107 139 109 77 93 97 96 90 118
PFC-A11B 70
277 350 196 212 183 162 153 138 136 144 139 136 155 120 145 151 144 161 133 114
88 78 119 150 80 115 131 170 186 144 161 186 153 167 143 110 133 142 125 127
132 118 136 155 136 126 133 155 161 175 183 180 181 198 125 122 151 183 132 144
120 83 154 107 81 90 85 118 94 132
PFC-A12A 84
353 282 214 233 209 265 265 209 191 289 195 188 127 152 145 182 204 184 181 180
209 237 213 175 166 152 113 130 137 164 151 85 140 218 182 157 198 168 130 189
163 139 107 152 132 170 158 135 159 182 169 182 166 155 182 256 151 95 102 135
81 101 133 132 161 174 145 147 155 134 96 95 67 86 111 133 119 125 92 99
80 74 93 100
PFC-A12B 84
343 283 221 219 223 264 259 193 199 292 198 178 121 160 140 192 199 185 179 183
207 232 201 189 158 148 100 128 137 159 160 84 138 207 175 183 177 174 132 186
161 133 96 159 142 165 155 135 164 181 179 187 173 151 179 260 160 88 107 128
83 104 134 133 154 176 142 139 172 135 106 96 64 82 105 135 135 103 54 61
76 71 92 100
PFC-A13A 75
182 206 203 239 314 258 280 311 221 192 196 238 227 258 225 257 308 224 240 304
274 252 198 154 140 112 122 126 103 113 85 76 115 129 131 113 129 122 121 169
111 115 82 142 139 159 170 145 160 165 69 91 121 133 115 109 98 137 182 129
120 112 77 127 135 149 164 148 91 97 119 171 204 168 172
PFC-A13B 75
139 201 215 235 297 237 270 313 239 183 182 245 233 242 220 250 293 228 227 292
276 237 197 165 149 113 115 147 101 104 95 83 103 115 137 117 131 108 135 160
120 106 90 127 142 160 172 153 166 165 69 92 130 119 122 111 96 133 183 125
103 128 65 114 158 150 158 151 80 109 108 153 190 154 175
PFC-A14A 56
516 506 377 426 262 334 307 349 397 407 401 430 351 315 245 223 252 252 198 186
241 204 178 174 162 167 181 151 130 160 138 159 162 193 194 169 145 108 81 106
169 125 108 128 137 139 95 113 118 121 165 134 122 112 163 149
PFC-A14B 56
349 508 391 403 266 325 314 343 388 423 388 422 357 271 239 222 255 256 197 166
242 206 174 170 162 159 180 153 136 167 131 169 149 193 183 170 123 102 91 97
161 143 115 108 155 154 103 101 107 129 168 135 129 115 154 153
PFC-A15A 132
223 218 236 206 147 138 172 159 149 127 117 172 170 155 167 167 99 126 109 154
151 120 151 87 87 132 98 95 125 135 117 134 112 138 195 177 141 179 118 130
102 113 162 209 338 264 233 256 273 212 143 141 314 344 335 399 355 378 272 189
197 180 262 253 243 220 175 138 124 112 158 154 194 221 155 124 128 189 223 211
155 121 129 91 109 106 118 142 159 189 216 193 172 185 160 150 224 206 140 146
140 156 114 152 174 145 155 135 84 103 112 155 151 158 227 213 198 137 114 132
174 137 162 129 138 158 161 94 132 86 96 136

PFC-A15B 132
341 226 186 137 123 139 183 157 141 123 135 171 159 150 151 160 95 140 99 144
161 119 150 67 115 106 81 99 116 143 117 137 106 152 176 170 157 179 100 133
106 108 163 204 326 263 237 258 276 209 143 147 307 341 323 393 343 378 284 180
185 181 252 245 260 203 180 150 120 119 165 158 204 218 176 148 121 187 222 196
151 110 126 95 101 91 109 134 157 199 210 178 172 175 174 150 219 213 125 154
143 143 116 140 171 154 155 121 87 100 102 152 162 161 206 220 198 145 94 126
174 142 133 120 130 180 101 112 102 85 101 144
PFC-A16A 126
47 49 43 30 46 33 47 30 42 44 67 74 64 68 71 57 66 94 102 178
246 197 146 159 177 107 107 120 216 285 225 243 207 297 231 232 207 181 180 186
178 106 149 162 115 99 100 128 158 137 116 120 74 88 104 137 126 123 136 111
100 111 145 147 111 137 120 140 99 86 99 122 133 118 98 131 122 130 128 125
106 150 165 97 83 103 117 185 163 173 151 165 172 116 92 156 160 159 138 129
134 178 141 107 96 145 123 148 139 142 109 78 101 120 152 149 146 132 111 106
78 98 161 199 244 250
PFC-A16B 126
37 47 45 28 51 37 46 29 41 50 55 73 76 65 67 61 53 107 72 150
226 196 146 129 200 123 96 99 199 302 217 245 219 290 240 245 199 165 184 187
168 115 141 160 106 106 94 115 147 141 144 95 72 72 87 133 129 120 117 111
89 106 158 130 109 135 130 137 91 109 94 120 130 126 87 116 142 131 118 115
103 149 145 108 67 100 118 164 157 183 143 157 166 120 72 190 152 161 128 136
134 163 133 118 90 133 141 148 116 158 103 105 99 102 156 136 152 136 112 85
88 101 159 193 243 250
PFC-A17A 136
248 176 321 443 297 445 420 330 212 298 228 204 197 138 228 146 158 133 160 172
173 132 133 149 155 126 111 128 161 174 159 141 111 161 232 130 75 101 167 180
129 117 95 108 82 84 94 97 108 157 103 114 115 122 117 82 65 78 57 93
105 78 83 90 104 136 95 72 62 68 55 64 75 113 125 104 84 61 60 77
86 88 106 107 85 107 141 125 134 132 125 154 170 87 70 85 90 113 113 148
139 149 115 91 73 121 126 94 94 86 115 156 122 69 62 66 109 169 104 119
134 83 111 114 113 139 150 148 133 112 74 85 87 97 101 104
PFC-A17B 136
126 165 334 428 312 440 434 325 226 268 263 207 195 131 238 160 168 148 141 134
187 134 120 155 168 113 114 124 154 180 149 138 114 163 220 128 80 101 158 181
135 114 86 112 77 90 86 102 107 157 122 104 113 127 113 80 69 71 59 100
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142 148 118 81 73 114 132 88 92 103 95 158 122 91 64 68 94 150 123 119
127 82 120 104 112 140 145 140 127 113 83 85 89 97 103 105
PFC-A18A 103
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193 217 198 166 210 259 357 258 203 188 205 170 183 167 128 136 107 95 79 105
124 141 138 151 134 132 117 128 160 201 182 116 140 172 178 175 154 178 176 178
123 118 104 91 138 152 175 149 176 185 149 112 114 162 182 201 147 163 158 204
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183 204 202 168 185 275 328 261 210 185 184 186 185 166 153 139 103 86 96 103
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119 118 100 95 129 149 161 162 171 189 140 117 118 165 163 216 148 159 171 195
138 144 90 104 176 126 112 109 92 80 100 90 157 112 104 100 77 75 73 90
83 110 119

PFC-A19A 107
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PFC-A19B 107
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155 117 104 152 102 89 118 121 153 147 169 145 156 65 86 69 98 92 73 72
77 64 63 77 97 114 108 120 97 88 78 89 88 103 135 132 98 83 77 86
106 110 78 106 113 82 122 80 98 128 99 136 92 110 78 67 92 99 96 103
149 107 86 108 97 101 91 82 111 143 109 145 159 118 132 143 110 129 93 123
121 95 99 110 120 177 171
PFC-A20A 57
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222 114 79 58 32 40 51 48 89 84 232 260 224 265 252 198 239 141 241 270
30 63 54 115 124 157 195 120 111 87 56 94 105 197 183 171 178
PFC-A20B 57
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234 121 59 75 38 37 55 48 92 86 231 250 234 260 252 207 224 139 236 212
30 59 52 114 128 160 182 129 106 84 68 95 109 196 179 172 170
PFC-A21A 86
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127 131 167 114 113 121 153 153 181 164 156 171 171 140 141 186 157 212 212 178
162 179 174 121 126 160 155 164 210 178 180 150 146 116 125 108 127 133 105 120
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PFC-A21B 86
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PFC-A22A 60
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PFC-A23A 120
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PFC-A23B 120
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PFC-A25A 105
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112 148 140 173 152 152 154 93 131 141 135 157 154 129 123 155 149 140 178 196
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PFC-A25B 85
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37 32 52 94 87 94 70 80 52 44 27 40 70 64 82 65 63 55 56 56
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PFC-A26B 123
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PFC-A27A 105
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PFC-A27B 105
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349 264 177 190 246 232 303 324
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PFC-A31B 148
108 103 103 104 176 188 207 135 134 117 93 106 151 196 144 171 171 156 137 142
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PFC-A32A 70
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PFC-A32B 70
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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.

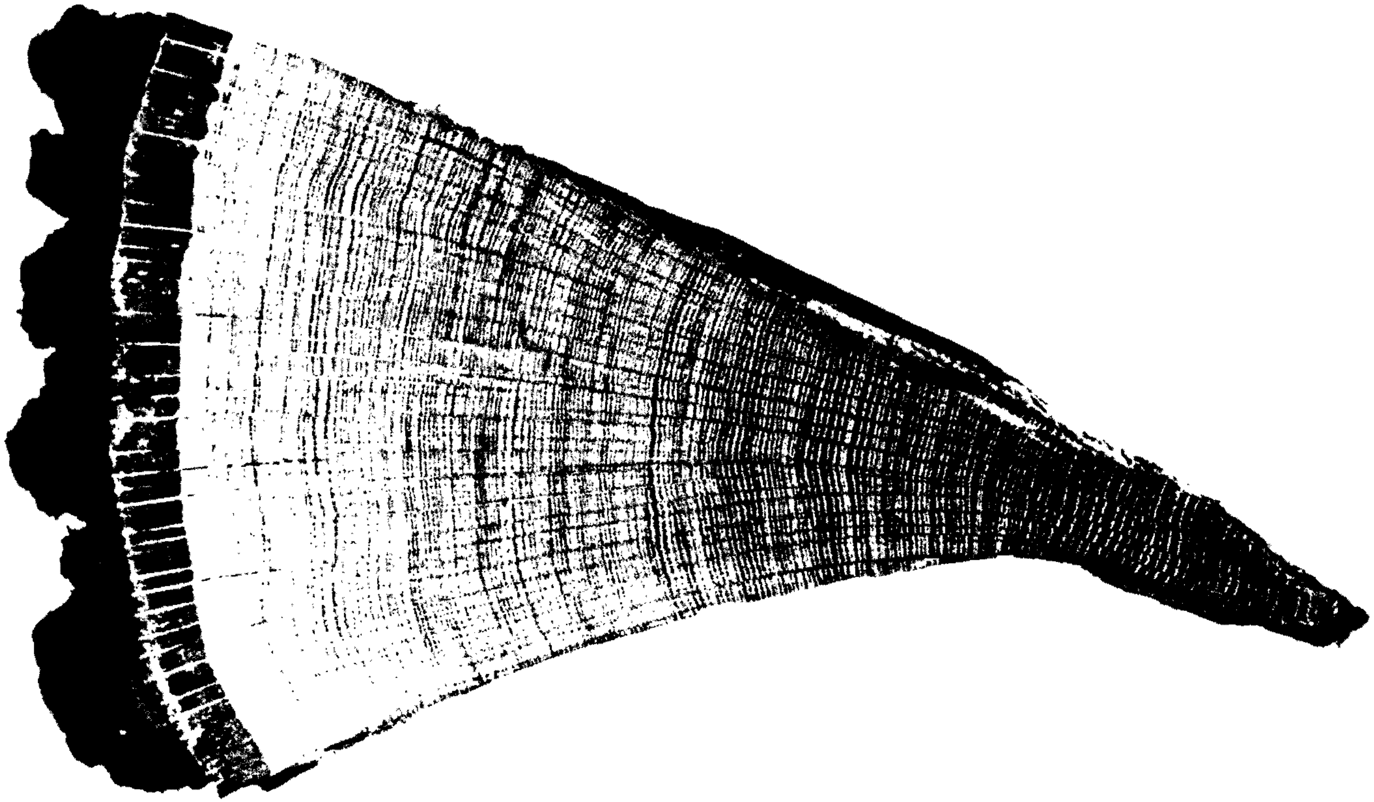

Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can determined by counting back from the outside ring, which grew in 1976.

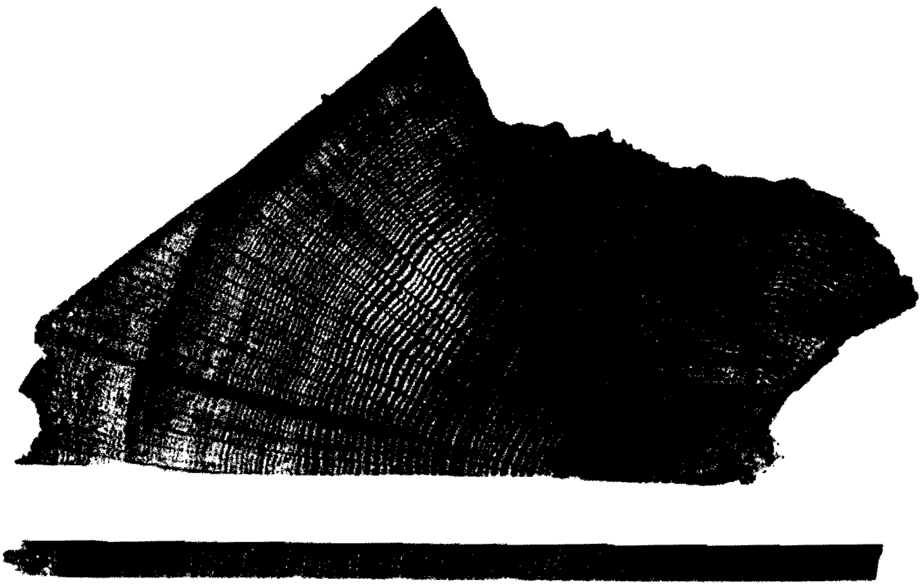

Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the left hand corner, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

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.

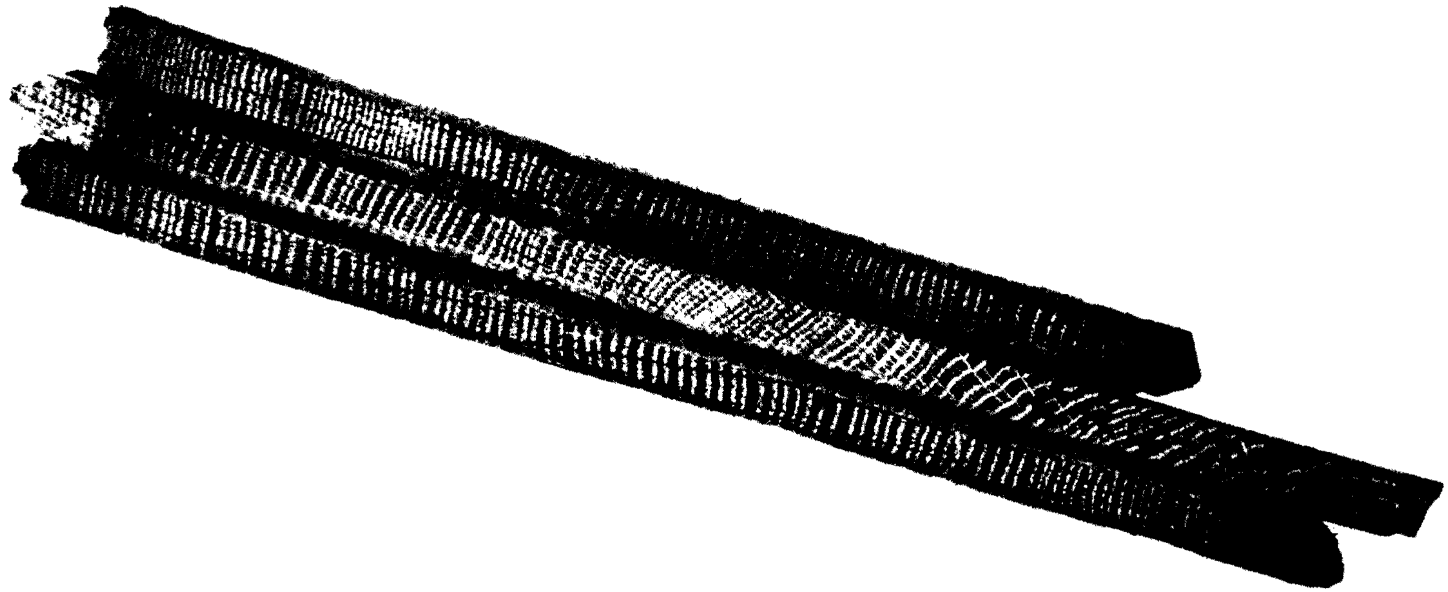

Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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