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# Tree-Ring Analysis of Timbers from the Church of All Saints, Main Street, Fenton, South Kesteven, Lincolnshire

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# Tree-Ring Analysis of Timbers from the Church of All Saints, Main Street, Fenton, South Kesteven, Lincolnshire

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## Summary

Tree-ring analysis was undertaken on 24 core samples obtained from different timbers in the nave and south aisle roofs of the Church of All Saints, Fenton, in Lincolnshire. A further six sliced samples were obtained from oak boards covering the nave roof.

The analysis of these 30 samples produced a single site chronology, FENASQ02, comprising 4 samples (all from the oak boards), with a combined overall length of 184 rings. This site chronology was dated as spanning the years AD 1434 to AD 1617.

Unfortunately, given the nature of these dated samples, there is no sapwood, or heartwood/sapwood boundary, on any of them. It is thus not possible to reliably calculate an estimated felling date range for them. It is unlikely, however, that they were felled before AD 1632.

None of the samples from the structural timbers could be dated.

## Keywords

Dendrochronology
Standing Building

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## Introduction

The Church of All Saints stands, in traditional style, adjacent to the Manor House and village green near the centre of the village of Fenton, in the district of South Kesteven, Lincolnshire (SK 878 506, Fig 1). It is built from a variety of materials including coursed ironstone rubble, Ancaster stone ashlar, and red brick, and contains remains from several periods. The interior includes two bays of a Norman arcade to the north side, the pillars having scalloped capitals, whilst the north aisle is pierced by a doorway of the Transitional period (ie late-twelfth century). The south arcade, with octagonal pillars, is probably of late-thirteenth century date. To the west end there is a tower of three stages with clasping buttress, belonging to the Perpendicular period (probably of fifteenth century date), as does, it is believed, the nave roof. The roof of the south aisle on the other hand is dated by an inscription to AD 1652. The chancel was rebuilt in AD 1838 and further restoration work, particularly to the north aisle roof, was undertaken in AD 1875.

## Sampling

Sampling and analysis by tree-ring dating of the timbers of the nave, chancel, and aisle roofs were commissioned by English Heritage. The purpose of this was to establish the date of these roofs with greater certainty to inform a programme of repairs and renovation which is being currently being grant-aided by English Heritage. Sampling was undertaken at a time when the roof was being repaired, the removal of the lead and the boards beneath, and the provision of scaffold platform throughout giving a unique opportunity to access all the timbers at this time.

The roof of the nave and chancel consists of six bays formed by seven cambered tiebeams, the tiebeams supporting a ridge beam. There are single purlins to each pitch. Within each bay there are five common rafters. Whilst the majority of these timbers are of oak, and appear to be integral with each other and original, a small number of beams are of softwood, the ridge beam between truss 2 – 3 and between 3 – 4 for example. The tiebeam at the east gable end is also of softwood. Two views of the roof are given in Figure 2a/b.

The roof of the south aisle comprises four bays formed by five principal rafters, with common rafters of only slightly smaller scantling being found in between. In this instance more than half the timbers have been replaced with modern, probably nineteenth century, softwood beams. One of the principal rafters in this roof has been inscribed with the date '1652' and may represent a mid-seventeenth century repair phase. The north aisle roof is composed of simple small common rafters, these all being some form of modern softwood.

From these roof timbers a total of 24 core samples were obtained. Each sample was given the code FEN-A (for Fenton, site "A") and numbered 01 – 24. Sixteen samples, FEN-A01 – A16, were obtained from the nave and chancel roofs, with a further 8 samples, FEN-A17 – A24, being obtained from the timbers of the south aisle roof. The positions of these samples are marked on plans provided by English Heritage, these being reproduced here as Figure 3.

At the time of sampling it was noted that while most of the boards removed from the roof were of softwood, perhaps having been laid down in one of the nineteenth century repairs phases, a small number of them were of oak. Although slightly broken and split, it was possible to obtain a further six samples, FEN-A25 – 30, as sliced samples. Although it is known that the boards are from the nave roof, their exact original locations are not known and their positions are not shown on the location plans.

Details of the samples are given in Table 1. In this Table, all frames and timbers are numbered from west to east, following that of the plans provided, and identified on a north - south basis as appropriate.

The Laboratory would like to take this opportunity to thank Alex McIntyre for his help in providing details on the site and in arranging access during repair work. We would also like to thank the staff of John Coxon, Roofing Ltd, for their help and assistance during sampling and for their interest and enthusiasm for the project.

## Analysis

Each of the 30 samples obtained was prepared by sanding and polishing and their annual growth-ring widths were measured. The growth-ring widths of all 30 samples were compared with each other by the Litton/Zainodin grouping procedure (see appendix). At a minimum value of $t$=4.4, very slightly lower than the usual minimum figure of $t$=4.5, a single group comprising 3 samples, FEN-A26, A27, and A30, could be formed

The three cross-matching samples were combined at their indicated off-set positions to form FENASQ01, a site chronology of 166 rings. This site chronology was then satisfactorily dated by comparison to a number of relevant reference chronologies for oak as spanning the years AD 1452 to AD 1617.

Site chronology FENASQ01 was then compared to all the remaining ungrouped samples. With the majority of samples there was no further satisfactory cross-matching. There was, however, a match between FENASQ01 and sample FEN-A25, with a low, though maximum, value of $t$=4.1. This is found when the first ring of FEN-A25 is at minus 18 rings relative to the first ring of site chronology FENASQ01, the first ring date of which is AD 1452.

To check this cross-match, sample FEN-A25 was compared individually to a full range of reference chronologies. This indicated a series of satisfactory cross-matches with a number of these reference chronologies giving the sample a first ring date of AD 1434 and a last measured ring date of AD 1529. Such a date is consistent with this sample's cross-match with site chronology FENASQ01.

Because of this the three samples of the site chronology and sample FEN-A25 were combined to make a new site chronology, FENASQ02, with a combined overall length of 184 rings. The relative positions of these four samples are shown in the bar diagram, Figure 4. Site chronology FENASQ02 was then dated by comparison to a number of reference chronologies as spanning the years AD 1434 to AD 1617. Evidence for this cross-matching is given in the *t*-values of Table 2.

All the remaining ungrouped samples were than compared individually to a full range of reference chronologies, but there was no further satisfactory cross-matching.

## Interpretation and conclusion

Analysis by dendrochronology has produced a single site chronology, FENASQ02 comprising 4 samples, its 184 rings dated as spanning the years AD 1434 to AD 1617. Unfortunately, given that the samples are from boards which have been heavily trimmed to fit close together, there is no sapwood or even heartwood/sapwood boundary on any of the dated samples. It is thus not possible to calculate a felling date range for the timbers represented. It is unlikely, however, that the timbers were felled before AD 1632, this date being based on a 95% probability of a minimum of 15 sapwood rings. Given the last measured ring date, however, the next possible historical context into which the boarding might fit is the mid-seventeenth century work on the south aisle roof denoted by one of the main rafters here inscribed with the date '1652'.

A large number of samples, 26 in total, remain undated. Although all of them have sufficient rings for dating, the numbers of rings on them are generally low, with most of them having only 55 - 65 rings. Some of the samples also show slightly complacent rings which can also make cross-matching and dating difficult. These factors, along with some possible reuse of older material, and substantial replacement by later inserts making many of the timbers in effect singletons, might account for the lack of cross-matching between samples and the dating of the samples individually.

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Table 1: Details of samples from All Saints Church, Fenton, Lincolnshire

| Sample number | Sample location | Total rings | *Sapwood rings | First measured ring date | Last heartwood ring date | Last measured ring date |
|---|---|---|---|---|---|---|
| | Nave and chancel roof timbers | | | | | |
| FEN-A01 | Tiebeam 1 (west most) | 57 | c | ------ | ------ | ------ |
| FEN-A02 | Tiebeam 6 | 55 | c | ------ | ------ | ------ |
| FEN-A03 | Tiebeam 5 | 56 | h/s | ------ | ------ | ------ |
| FEN-A04 | Tiebeam 4 | 61 | h/s | ------ | ------ | ------ |
| FEN-A05 | Tiebeam 3 | 73 | h/s | ------ | ------ | ------ |
| FEN-A06 | Tiebeam 2 | 59 | h/s | ------ | ------ | ------ |
| FEN-A07 | Ridge beam, truss 1 - 2 | 71 | h/s | ------ | ------ | ------ |
| FEN-A08 | Ridge beam, truss 2 - 3 | 57 | c | ------ | ------ | ------ |
| FEN-A09 | Ridge beam, truss 3 - 4 | 71 | h/s | | ------ | ------ |
| FEN-A10 | North purlin, truss 4 - 5 | 66 | c | ------ | ------ | ------ |
| FEN-A11 | South purlin, truss 5 - 6 | 60 | c | ------ | ------ | ------ |
| FEN-A12 | Ridge beam, truss 6 - 7 | 61 | h/s | ------ | ------ | ------ |
| FEN-A13 | North purlin, truss 5 - 6 | 65 | h/s | ------ | ------ | ------ |
| FEN-A14 | South purlin, truss 4 - 5 | 54 | h/s | ------ | ------ | ------ |
| FEN-A15 | South purlin, truss 3 - 4 | 62 | h/s | ------ | ------ | ------ |
| | South aisle timbers | | | | | |
| FEN-A16 | Rafter 20 | 54 | h/s | ------ | ------ | ------ |
| FEN-A17 | Rafter 17 | 60 | h/s | ------ | ------ | ------ |
| FEN-A18 | Rafter 15 | 58 | h/s | ------ | ------ | ------ |

Table 1: continued

| Sample number | Sample location | Total rings | *Sapwood rings | First measured ring date | Last heartwood ring date | Last measured ring date |
|---|---|---|---|---|---|---|
| | South aisle timbers continued | | | | | |
| FEN-A19 | Rafter 13 | 56 | h/s | ------ | ------ | ------ |
| FEN-A20 | Rafter 12 | 55 | h/s | ------ | ------ | ------ |
| FEN-A21 | Rafter 11 | 56 | h/s | ------ | ------ | ------ |
| FEN-A22 | Rafter 6 | 72 | h/s | ------ | ------ | ------ |
| FEN-A23 | Rafter 5 | 58 | h/s | ------ | ------ | ------ |
| FEN-A24 | Rafter 3 | 63 | h/s | ------ | ------ | ------ |
| | Loose oak roof boards | | | | | |
| FEN-A25 | Oak board, exact location unknown | 96 | no h/s | AD 1434 | ------ | AD 1529 |
| FEN-A26 | Oak board, exact location unknown | 166 | no h/s | AD 1452 | ------ | AD 1617 |
| FEN-A27 | Oak board, exact location unknown | 146 | no h/s | AD 1471 | ------ | AD 1616 |
| FEN-A28 | Oak board, exact location unknown | 114 | no h/s | ------ | ------ | ------ |
| FEN-A29 | Oak board, exact location unknown | 101 | no h/s | ------ | ------ | ------ |
| FEN-A30 | Oak board, exact location unknown | 62 | no h/s | AD 1531 | ------ | AD 1590 |

*h/s = the heartwood/sapwood boundary is the last ring on the sample
c = complete sapwood on timber, all or part lost during sampling

Table 2: Results of the cross-matching of site chronology FENASQ02 and relevant reference chronologies when first ring date is AD 1434 and last ring date is AD 1617

| Reference chronology | Span of chronology | *t*-value | |
|---|---|---|---|
| Manor House, Sutton in Ashfield, Notts | AD 1441 – 1656 | 9.8 | ( Howard *et al* 1996 ) |
| Mansfield Woodhouse Priory, Notts | AD 1432 – 1579 | 9.2 | ( Howard *et al* 1987 ) |
| East Midlands | AD 882 – 1981 | 9.1 | ( Laxton and Litton 1988 ) |
| England | AD 401 – 1981 | 8.2 | ( Baillie and Pilcher 1982 ) |
| Lowdham Old Hall, Lowdham, Notts | AD 1422 – 1527 | 7.9 | ( Howard *et al* 1997 ) |
| 21 Church St, Mansfield, Notts | AD 1439 – 1584 | 7.6 | ( Howard *et al* 1994 ) |
| 15/19 Station St, Mansfield Woodhouse, Notts | AD 1431 – 1538 | 7.4 | ( Howard *et al* 1997 ) |
| London England | AD 413 – 1728 | 6.0 | ( Tyers and Groves 1999 ) |

**Figure 1: Map to show general location of Fenton**

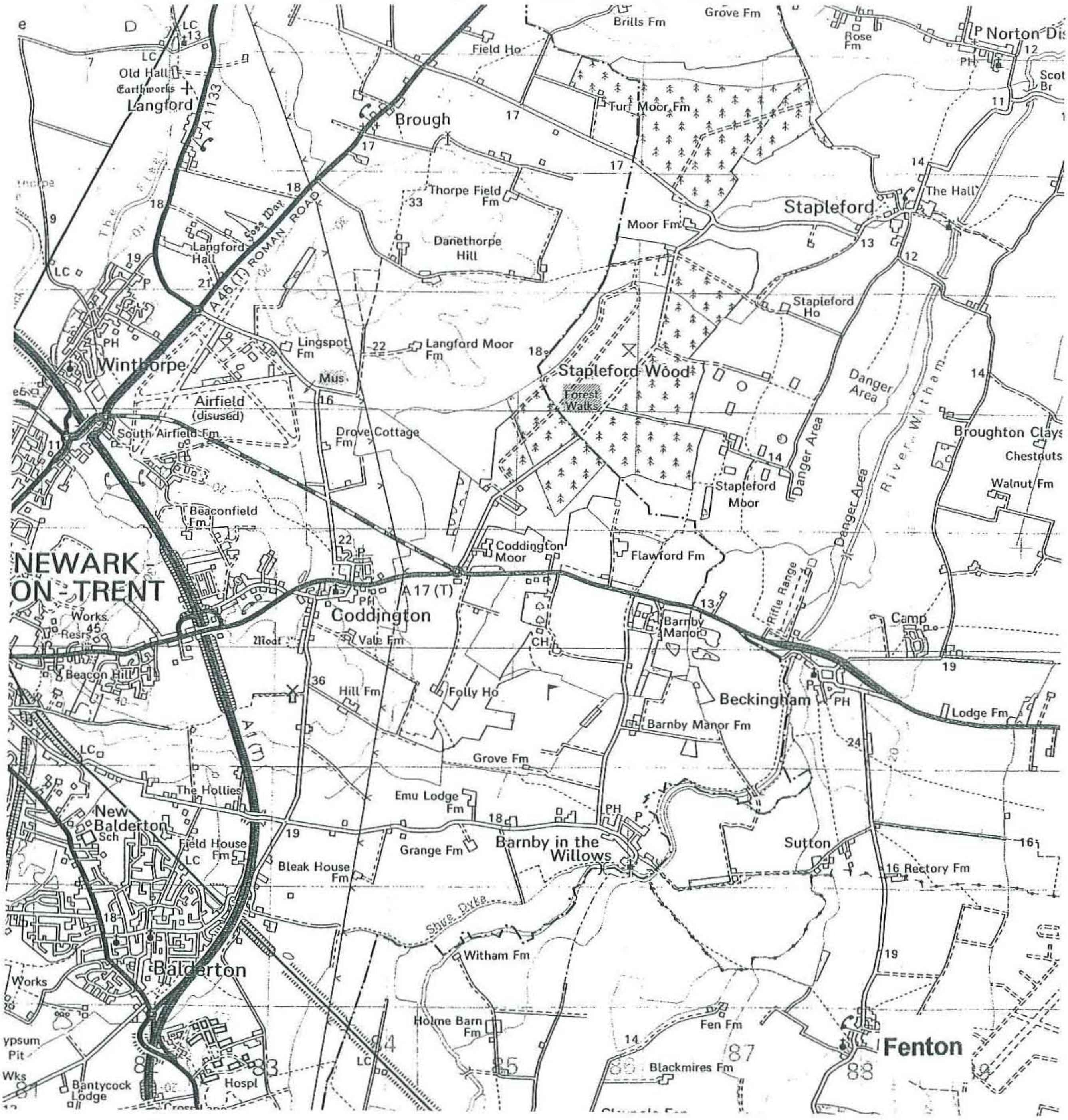


Figure 2a: View of the nave roof looking from east to west

Figure 2b: View of the south aisle roof looking from east to west

**Figure 3: Plan of the roof to show timbers sampled (after Peter McFarlane, architect)**

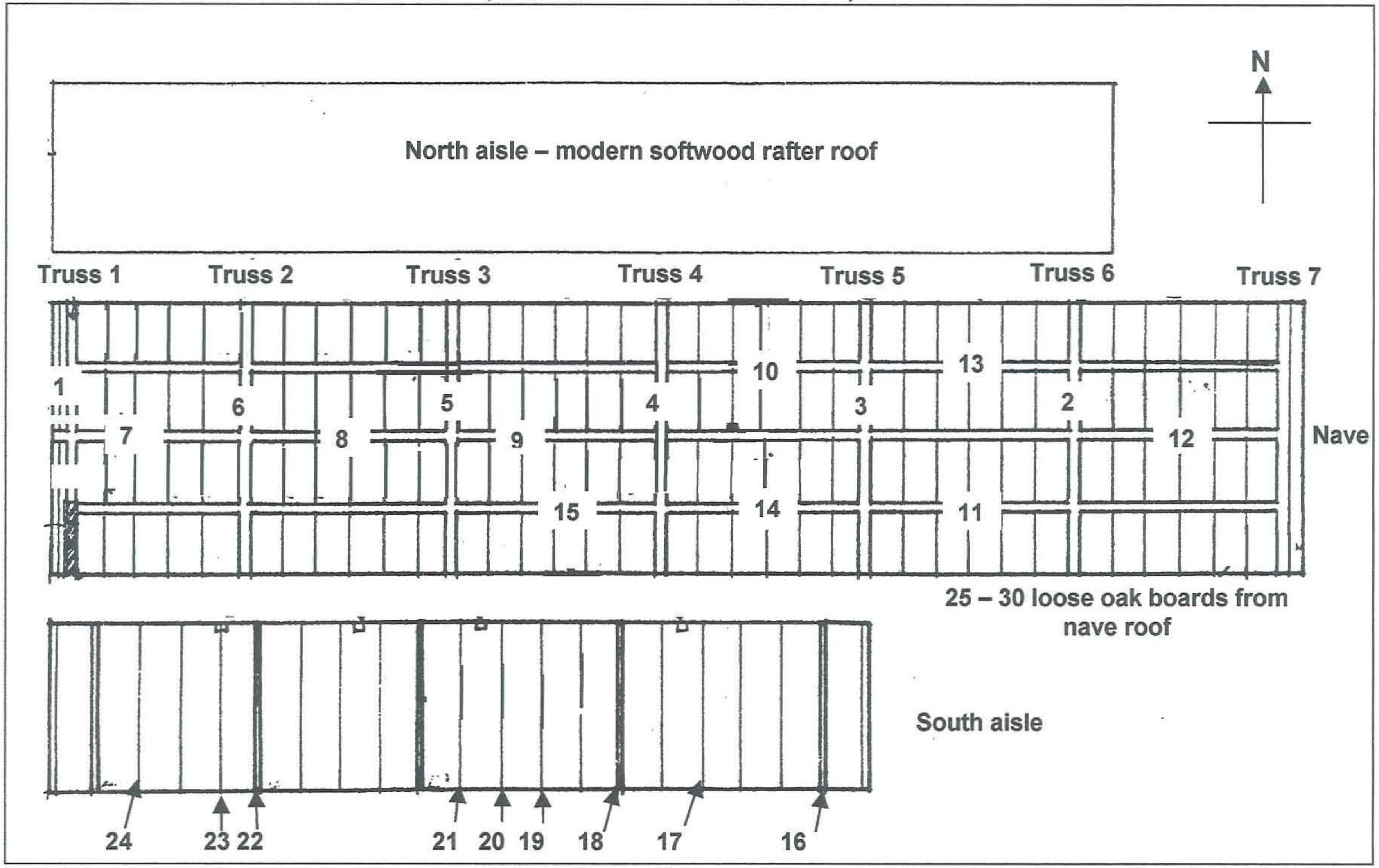
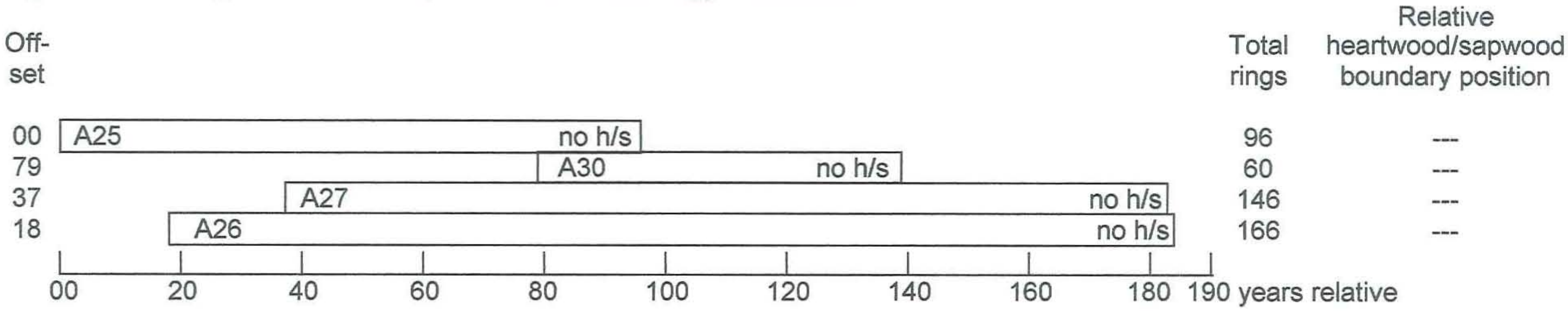


**Figure 4: Bar diagram of the samples in site chronology FENASQ02**




white bars = heartwood rings
no h/s = there is no heartwood/sapwood boundary on the sample

Data of measured samples – measutrments in 0.01 mm units

FEN-A01A 57
110 147 132 99 78 52 61 52 61 77 88 65 75 71 60 70 67 83 94 82
73 61 60 61 69 68 75 92 63 67 81 81 76 87 82 67 73 71 65 73
81 116 69 79 86 60 56 44 53 70 76 83 81 62 81 65 73
FEN-A01B 57
106 139 133 96 70 56 62 56 66 84 80 60 71 62 58 74 67 85 96 78
80 54 64 63 72 69 82 88 56 67 85 73 75 83 83 64 71 68 63 80
84 105 71 84 78 58 53 60 71 77 71 91 80 58 83 68 68
FEN-A02A 55
174 165 271 266 212 214 154 138 124 190 155 135 130 110 121 199 236 156 120 140
246 298 271 169 260 227 103 118 173 135 176 195 213 157 174 153 149 238 227 230
196 144 87 57 43 42 44 68 80 88 100 95 104 118 103
FEN-A02B 55
171 163 280 268 225 202 160 134 120 191 150 134 129 110 127 204 232 149 121 144
253 300 271 176 258 233 110 116 175 134 182 191 218 147 176 179 143 222 228 227
185 145 80 61 41 41 47 69 80 90 100 90 107 119 101
FEN-A03A 56
105 153 184 167 110 174 192 139 159 174 144 122 163 125 150 151 71 54 67 48
72 73 38 37 44 71 76 83 81 62 81 65 73 87 82 67 73 71 65 73
81 116 69 79 86 60 56 44 53 70 81 100 113 123 145 150
FEN-A03B 56
103 160 177 165 121 175 206 162 167 183 160 144 154 132 131 154 74 43 62 51
70 79 43 35 42 72 71 91 80 58 83 68 68 83 83 64 71 68 63 80
84 105 71 84 78 58 53 60 71 77 85 102 114 120 139 153
FEN-A04A 61
116 148 117 81 159 83 101 126 141 132 114 137 160 131 161 122 164 126 139 163
162 103 122 164 137 116 194 172 120 223 116 162 132 134 104 197 104 129 121 192
125 124 129 101 118 119 283 191 194 136 92 125 109 101 108 115 99 107 91 107
88
FEN-A04B 61
143 128 116 84 143 79 97 128 135 127 100 150 155 135 153 129 162 118 147 170
140 120 104 153 133 121 201 146 156 209 126 148 133 142 117 137 114 135 138 187
125 125 139 107 111 113 216 173 229 127 92 129 108 104 105 119 99 106 91 100
81
FEN-A05A 73
100 155 199 145 147 204 241 143 52 50 47 65 67 115 108 212 228 314 277 210
220 252 321 390 347 417 350 284 397 502 435 401 569 496 673 586 765 181 95 72
88 106 103 90 103 122 126 125 134 149 134 151 160 163 64 52 63 47 76 80
111 127 129 138 151 152 194 156 147 140 93 110 105
FEN-A05B 73
126 146 159 157 156 199 233 143 52 71 33 49 77 100 120 202 244 310 291 201
213 257 328 395 363 391 349 292 394 505 435 405 555 500 683 589 809 197 81 76
94 102 100 95 124 105 127 118 131 138 139 149 152 174 90 63 62 48 72 86
104 133 126 140 146 158 188 149 150 136 98 107 96
FEN-A06A 59
300 250 239 264 271 304 159 127 223 150 206 238 194 175 173 146 200 123 165 194
504 100 297 313 292 352 392 186 188 174 121 199 147 249 199 282 209 152 174 175
145 98 111 116 113 145 149 141 115 136 144 110 158 149 136 125 122 185 152

FEN-A06B 59
303 239 242 277 304 337 153 152 210 138 167 230 186 149 160 150 198 116 165 198
462 117 340 299 300 342 375 187 179 179 104 192 146 231 204 276 218 148 179 165
143 100 114 109 125 143 152 139 109 126 130 107 154 148 138 128 112 184 159
FEN-A07A 71
141 123 152 201 198 147 192 159 168 247 235 174 123 131 147 111 140 135 159 132
127 156 115 110 96 116 137 98 128 114 123 122 118 131 91 131 129 119 118 102
133 119 126 128 161 89 123 150 172 130 121 102 137 179 139 136 92 125 109 101
99 107 91 107 88 102 98 82 120 104 101
FEN-A07B 71
175 129 148 194 188 154 180 155 170 247 225 181 146 121 150 124 140 134 157 146
112 159 121 112 99 84 141 107 116 111 127 118 116 126 101 115 122 128 117 96
139 108 130 144 135 102 101 167 152 134 135 106 139 172 140 127 92 129 108 104
99 106 91 100 81 104 93 89 105 113 120
FEN-A08A 57
60 92 133 121 169 130 129 154 132 99 58 67 79 98 134 123 137 121 102 174
158 230 234 142 91 56 52 68 67 59 78 70 56 48 47 66 76 51 44 44
43 88 89 66 71 75 41 49 29 41 43 52 58 43 55 49 68
FEN-A08B 57
57 83 134 129 162 132 134 155 132 101 64 74 82 100 127 124 149 118 102 153
162 231 230 130 80 54 45 59 79 53 69 63 52 51 51 58 69 53 45 39
42 78 79 62 77 76 45 54 25 45 49 56 59 45 58 46 78
FEN-A09A 71
363 326 370 362 292 288 409 521 125 63 51 92 175 181 216 351 378 169 146 323
235 227 339 310 349 83 112 98 109 159 183 157 132 273 265 245 106 85 60 108
89 92 90 115 253 50 69 51 71 134 133 55 59 62 54 56 73 61 101 93
194 191 168 169 141 174 204 231 266 191 182
FEN-A09B 71
383 309 373 367 301 306 404 514 129 60 55 102 168 180 210 383 374 167 132 306
238 223 337 343 351 88 101 113 110 132 189 158 124 260 275 228 110 78 72 99
88 85 85 123 246 50 63 53 74 128 134 46 61 66 51 71 100 66 95 104
205 196 160 175 147 171 219 238 262 193 181
FEN-A10A 66
271 437 400 422 410 345 362 464 610 162 81 53 109 149 168 211 226 216 231 293
348 259 263 232 116 83 64 89 96 139 105 114 172 184 168 122 75 56 60 71
42 69 64 82 114 121 66 69 46 66 75 70 108 97 96 197 138 157 140 163
148 150 166 188 266 196
FEN-A10B 66
234 423 420 401 399 338 379 436 598 171 74 58 105 153 177 206 233 221 229 276
335 259 260 234 125 74 71 85 96 140 104 125 155 191 155 135 84 56 53 50
56 75 60 86 123 105 72 65 38 73 85 74 109 106 88 217 154 138 140 153
160 150 175 194 264 206
FEN-A11A 60
188 244 206 177 151 147 113 141 107 149 132 156 90 147 162 103 125 110 142 134
79 125 114 110 146 149 155 126 173 187 178 156 163 138 124 244 251 208 155 201
182 164 117 157 177 209 145 115 114 129 98 122 122 144 91 109 107 113 99 130
FEN-A11B 60
169 239 205 174 149 156 106 145 112 152 123 157 112 144 159 101 121 92 153 126
92 118 124 101 146 155 152 135 181 180 189 151 172 145 114 248 237 219 157 203
166 163 122 160 176 222 153 120 106 125 100 118 135 142 95 107 108 120 103 123
FEN-A12A 61
157 141 133 135 147 119 135 126 188 183 155 196 128 193 196 223 218 209 200 161
168 179 188 124 157 120 135 116 103 97 130 154 141 168 154 121 190 155 165 156
82 101 100 104 80 152 140 72 83 115 154 156 164 153 96 124 92 105 104 95
95

FEN-A12B 61
159 149 141 130 139 129 141 128 178 179 159 190 134 199 190 229 211 201 201 169
178 175 178 135 156 118 131 125 107 94 124 153 145 139 144 123 177 157 162 130
85 108 104 109 98 156 141 79 75 126 156 154 162 147 96 126 103 91 110 100
89
FEN-A13A 65
129 111 100 103 152 137 122 96 84 127 121 104 117 122 83 121 111 111 87 114
97 96 109 126 148 166 185 112 173 245 150 179 177 169 153 47 32 41 51 52
98 54 44 75 71 70 73 84 85 92 73 64 73 57 65 74 77 69 64 64
77 70 75 78 71
FEN-A13B 65
119 105 96 110 157 131 121 92 86 127 129 104 126 166 83 124 121 119 75 112
96 103 107 119 152 165 179 120 176 237 142 180 176 162 161 72 45 49 56 52
95 66 41 74 68 87 79 91 74 65 69 62 71 60 70 74 73 66 67 77
77 70 72 74 55
FEN-A14A 54
138 187 210 179 193 197 183 158 164 120 178 132 140 232 176 155 94 95 164 243
134 155 169 119 156 151 176 158 163 98 160 111 105 120 163 166 126 143 89 121
82 66 66 56 69 87 320 232 220 223 242 159 214 199
FEN-A14B 54
148 200 199 185 197 210 185 161 168 125 181 149 157 200 177 150 94 123 147 235
142 137 178 130 154 152 170 160 163 101 165 127 108 117 187 148 98 148 104 126
92 65 61 71 85 72 315 223 242 246 254 183 210 192
FEN-A15A 62
89 120 97 88 73 73 69 92 141 125 161 91 88 92 98 97 66 76 85 64
226 245 240 248 232 147 167 164 137 130 129 118 120 92 74 62 90 92 80 89
105 90 109 125 128 114 126 118 90 142 112 165 143 104 78 81 49 48 106 94
75 72
FEN-A15B 62
95 120 99 99 60 76 74 89 146 116 154 96 84 94 84 92 68 77 78 69
287 251 237 273 257 136 168 188 155 114 124 112 128 83 88 59 82 95 77 94
98 89 112 113 123 133 118 123 84 138 111 168 144 112 83 82 45 44 95 95
66 79
FEN-A16A 54
211 331 347 354 265 206 248 178 250 220 181 223 199 242 159 214 202 199 320 232
343 278 268 306 173 183 128 126 126 173 147 171 153 130 159 206 173 110 136 104
109 108 150 144 140 201 148 205 205 74 87 145 170 150
FEN-A16B 54
266 335 341 343 248 189 212 194 226 242 158 246 198 254 183 210 186 192 315 223
342 302 263 290 186 164 97 136 135 179 134 186 151 137 144 205 177 111 142 88
103 109 149 172 124 213 153 191 198 71 79 144 180 158
FEN-A17B 60
210 182 165 182 173 188 177 150 143 140 215 232 261 359 182 312 192 236 242 255
272 244 220 235 262 296 305 299 269 261 202 407 290 260 393 246 225 146 218 312
146 118 142 145 94 107 95 115 86 122 204 154 167 176 179 179 164 157 125 156
FEN-A17A 60
194 187 174 179 170 193 172 154 141 153 214 234 259 336 189 293 204 229 228 261
276 210 166 230 306 324 325 309 255 286 238 415 279 264 398 253 237 146 228 309
153 129 126 145 95 111 99 108 94 109 209 151 174 166 202 175 147 151 140 160
FEN-A18A 58
192 287 212 192 189 176 244 243 198 237 246 198 223 206 197 140 103 113 185 209
153 146 163 169 154 168 153 136 172 115 191 189 166 199 154 183 156 186 181 163
163 168 207 181 161 156 130 156 153 140 154 186 122 150 159 138 142 127

FEN-A18B 58
192 283 221 191 193 171 236 244 207 227 249 203 222 197 207 151 115 118 194 205
165 152 160 178 150 165 155 129 177 112 187 190 167 182 155 192 156 181 186 159
167 174 223 172 164 159 135 156 157 133 140 184 119 147 157 135 150 117
FEN-A19A 56
111 134 157 79 127 126 122 79 98 100 113 115 131 143 172 203 177 115 118 84
346 289 251 247 246 195 172 105 122 157 136 135 163 176 180 127 121 154 109 203
187 199 215 174 155 148 165 262 150 177 219 185 238 225 145 172
FEN-A19B 56
120 140 161 78 123 112 124 86 98 100 113 118 132 150 179 214 179 97 119 80
334 291 259 234 262 181 168 111 134 152 134 138 179 161 176 127 116 145 137 201
170 189 216 179 145 119 171 257 150 177 219 189 245 227 129 185
FEN-A20A 55
114 123 175 184 150 156 123 164 266 206 157 172 151 144 173 151 112 148 143 107
120 202 170 182 219 320 252 201 263 249 230 329 209 260 179 204 190 176 140 164
156 96 140 206 452 161 179 158 125 132 111 152 229 179 135
FEN-A20B 55
160 124 173 176 140 173 123 179 267 228 148 182 146 143 177 151 104 144 138 117
117 216 152 180 224 318 250 204 263 250 226 331 197 256 180 207 179 163 157 189
131 120 142 206 443 142 170 171 119 117 131 160 239 174 149
FEN-A21A 56
166 193 153 202 137 145 153 179 169 225 186 182 202 163 235 253 242 253 292 255
168 99 76 57 88 102 122 107 122 102 83 144 119 149 129 160 143 175 163 187
141 81 99 102 97 95 110 150 149 107 72 92 142 122 112 112
FEN-A21B 56
147 173 176 183 142 151 156 189 166 232 186 194 214 153 230 247 215 252 317 253
167 102 76 58 90 102 123 112 123 90 88 135 138 144 125 158 138 184 154 185
148 81 103 94 103 84 115 135 164 121 81 91 137 150 115 103
FEN-A22A 72
146 101 123 78 163 212 228 113 148 133 119 95 89 120 151 116 145 161 180 143
152 163 158 133 99 103 114 118 162 138 111 86 77 137 167 127 159 94 187 130
136 119 109 112 116 82 93 87 97 92 95 127 106 107 137 144 126 142 168 142
57 68 49 89 78 88 86 70 64 71 73 82
FEN-A22B 72
137 98 125 75 182 218 216 109 149 128 109 90 86 116 147 117 136 152 176 128
145 172 161 129 99 104 118 119 169 145 110 78 71 141 157 137 149 99 191 128
130 111 106 119 124 85 96 81 99 91 95 121 109 104 141 148 123 136 152 138
57 66 41 69 76 88 90 68 54 75 78 88
FEN-A23A 58
187 119 113 136 147 125 178 195 201 211 190 203 178 107 137 105 93 176 265 215
182 191 243 111 114 121 152 210 184 143 102 137 87 145 189 189 145 196 202 198
187 178 174 193 177 138 130 146 118 129 92 137 178 169 143 104 77 77
FEN-A23B 58
178 120 110 136 139 125 183 187 207 218 187 203 169 127 136 97 93 175 260 163
151 205 245 139 116 126 158 208 180 146 104 143 82 142 189 209 115 170 205 202
180 177 173 187 183 140 137 149 115 138 86 150 173 165 164 110 78 75
FEN-A24A 59
232 360 281 236 242 181 283 294 326 282 166 154 131 92 81 94 68 124 199 196
208 157 102 101 83 66 82 119 87 97 124 118 101 104 116 118 91 103 75 72
109 177 129 146 118 181 132 103 104 113 140 155 149 115 128 112 91 120 150
FEN-A24B 60
168 194 123 214 190 227 204 141 116 106 65 52 70 53 103 165 180 139 114 70
85 61 41 80 105 64 78 85 85 75 102 114 85 73 110 62 78 128 127 84
103 78 140 112 103 82 119 114 123 123 100 123 88 92 95 111 85 111 118 83

FEN-A25A 96
127 180 137 133 51 55 126 140 148 189 147 142 83 125 107 151 86 65 62 84
137 156 188 120 83 52 97 124 151 172 172 125 169 218 146 170 179 183 179 178
183 285 109 130 124 196 172 175 159 178 167 157 185 226 90 77 76 61 76 110
138 155 132 142 129 149 135 118 130 108 92 131 143 104 101 101 108 101 95 96
92 87 107 91 155 150 150 186 170 135 138 111 168 123 123 136
FEN-A25B 96
127 178 142 132 61 61 105 151 161 179 174 150 76 134 104 167 77 64 82 82
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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.

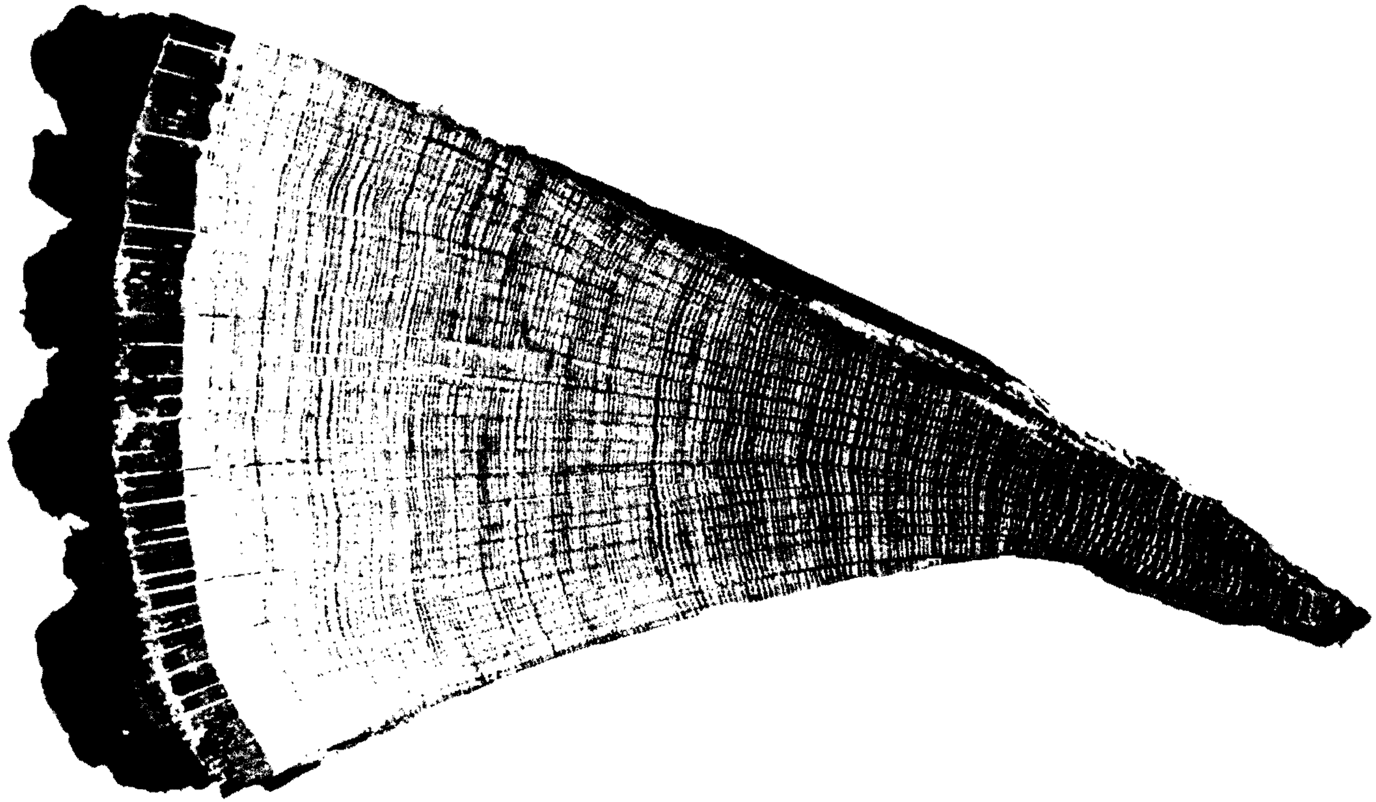


Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can determined by counting back from the outside ring, which grew in 1976.

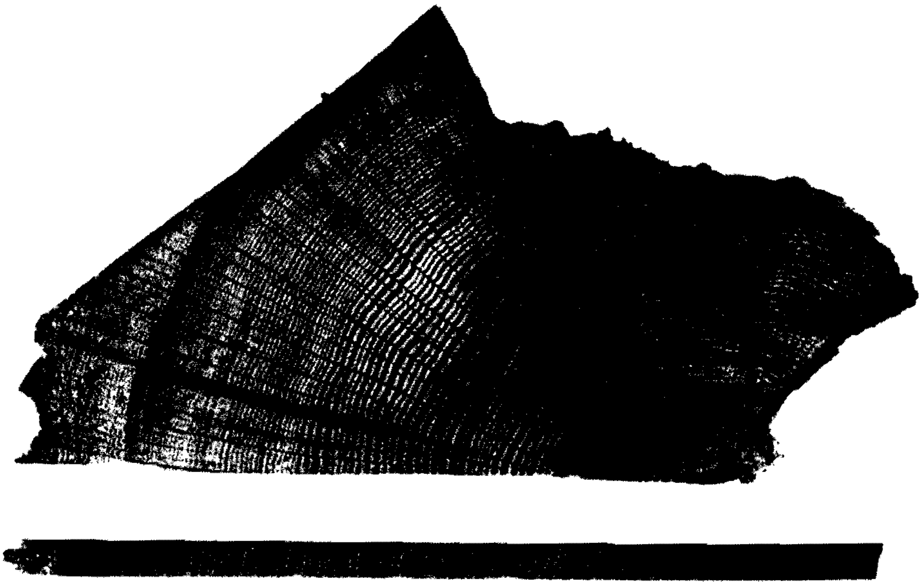


Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the left hand corner, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

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.

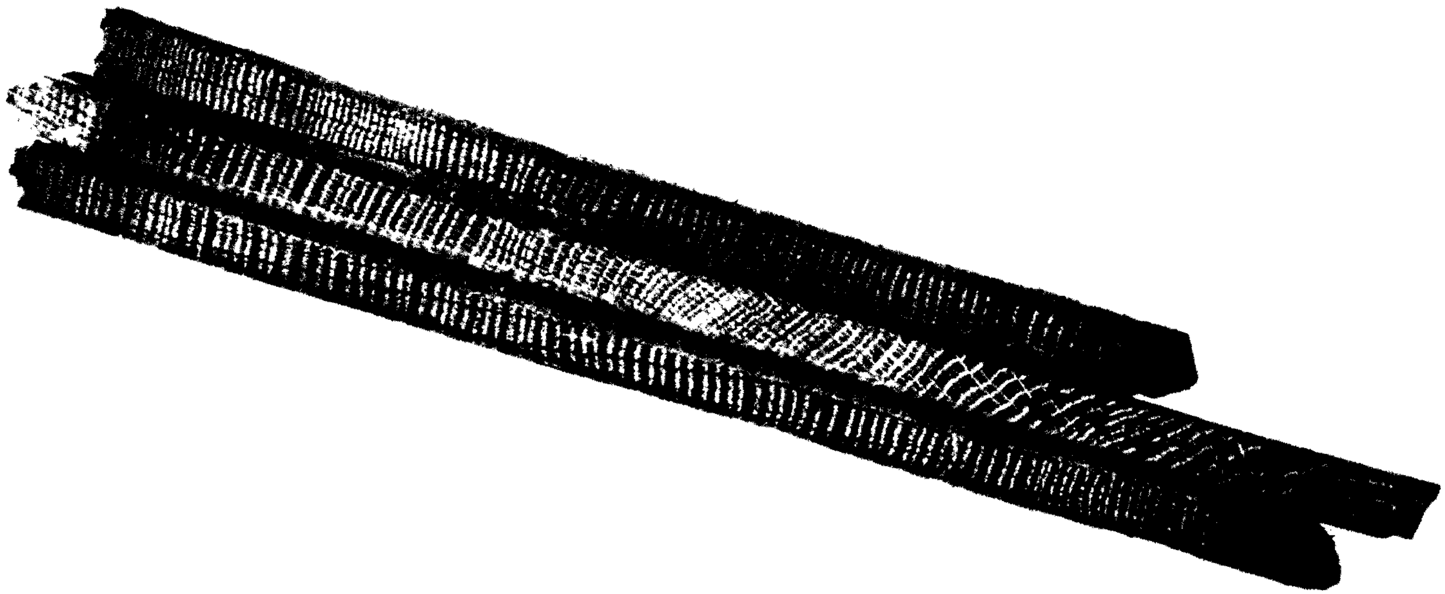


Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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

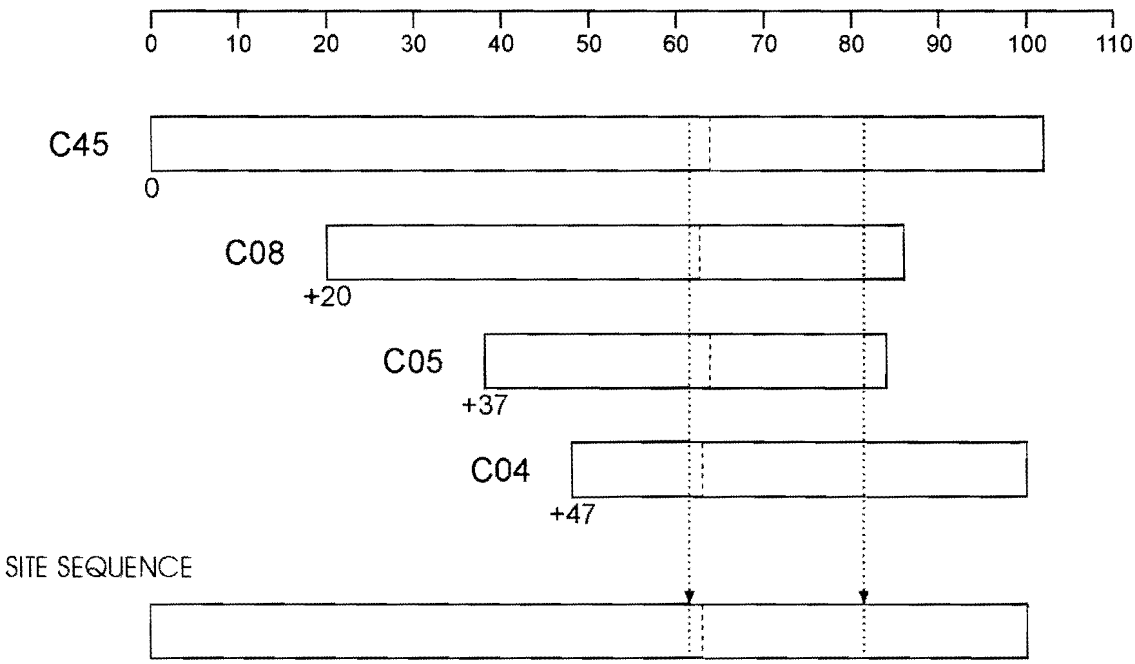



Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

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.

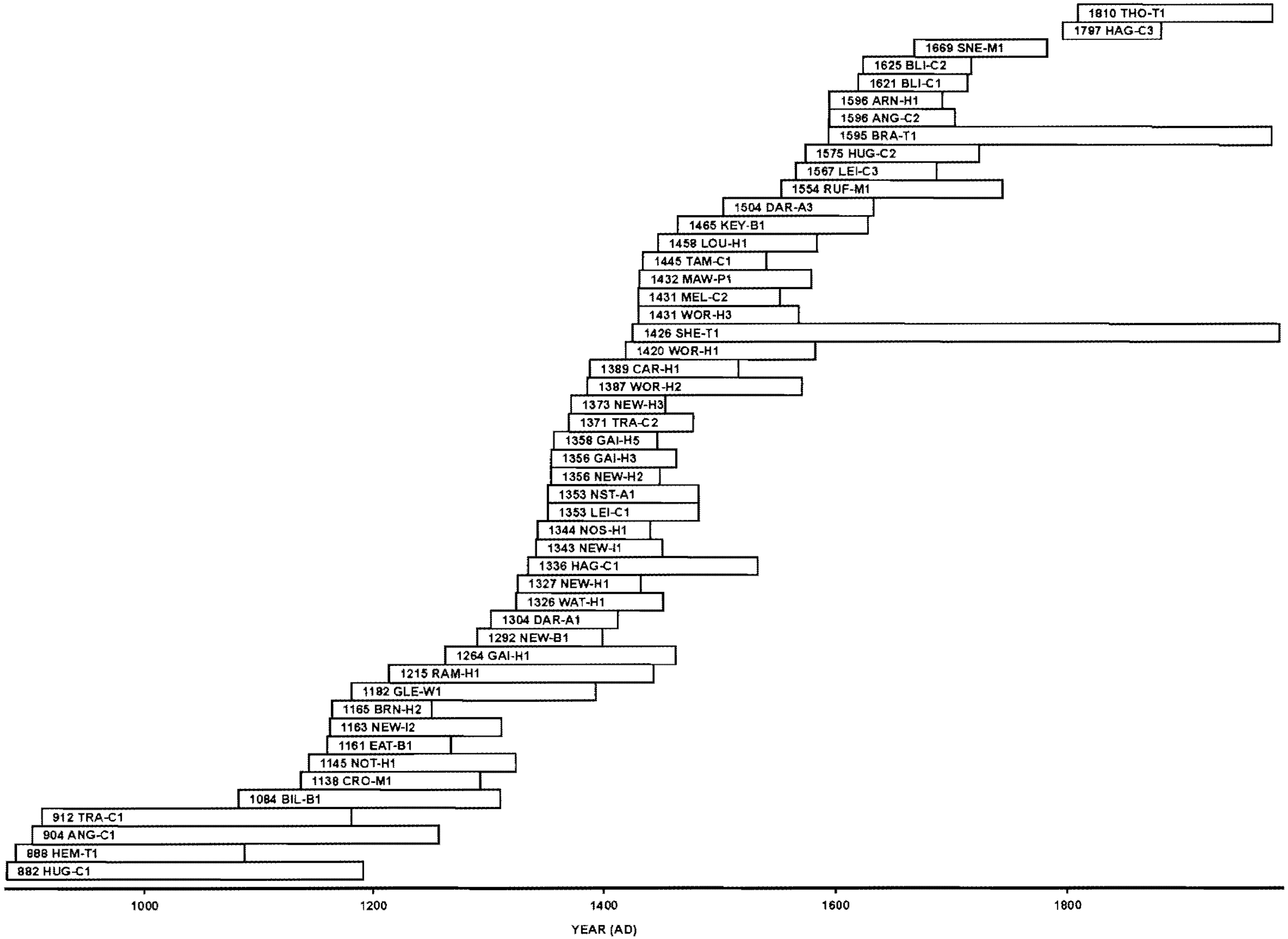
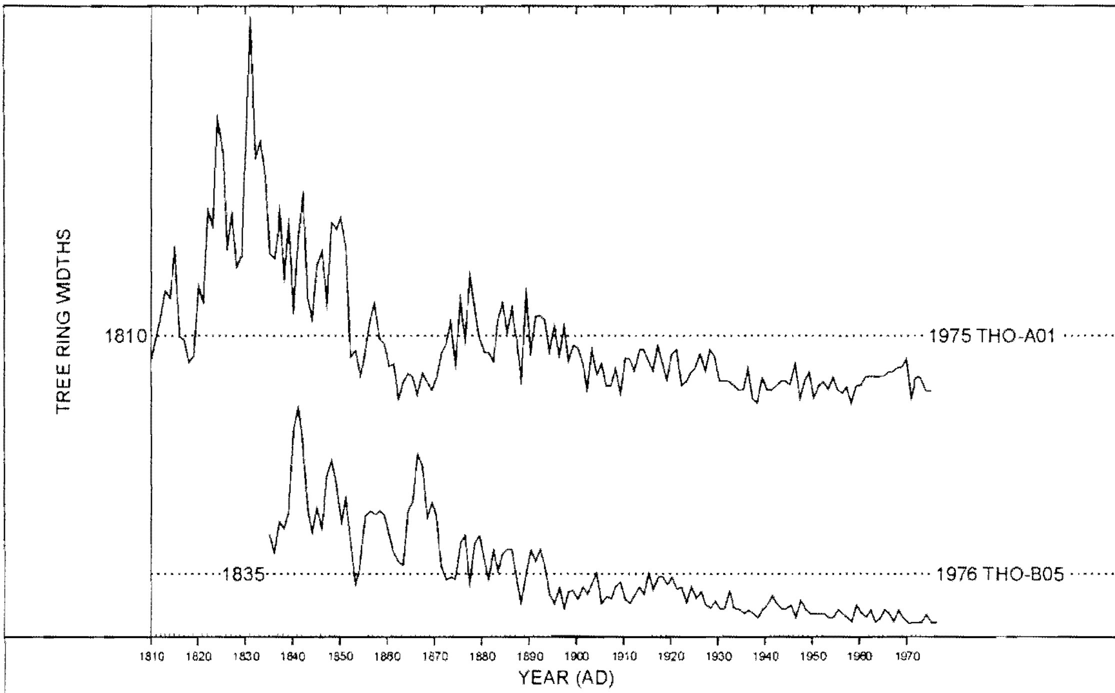



Fig. 6 Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)




(b)

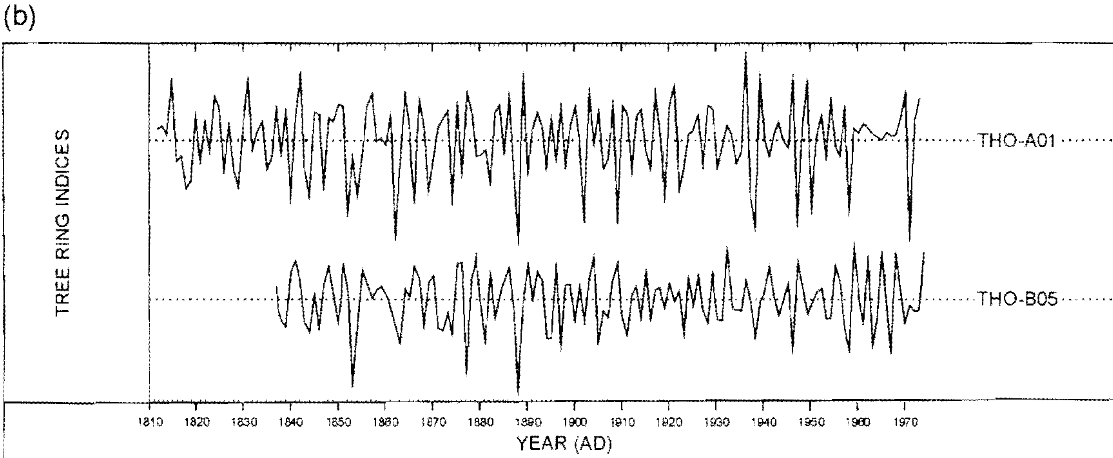



Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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