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Tree-Ring Analysis of Timbers from Manor Farm Barn, Frindsbury, Kent

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Summary

Analysis was undertaken of ten samples from oak timbers of the barn at Manor Farm, Frindsbury; a further three samples were not analysed due to their short ring-width sequences. The analysis of these samples resulted in the production of two site chronologies.

The first site chronology, FRDBSQ01, consists of six samples, and 150 rings, spanning the period AD 1254-AD 1403. Contained within this site chronology is sample FRD-B01, which has complete sapwood and a last-ring date of AD 1403, this being the felling date of the timber represented. The average heartwood/sapwood boundary dates of the other timbers points towards a felling date for these within the range AD 1392-AD 1412, consistent with a felling date of AD 1403 as well.

The second site chronology, FRDBSQ02, consists of two samples, and 100 rings. Unfortunately, this site chronology could not be matched and these samples remain undated.

Attempts to date the remaining two samples individually proved unsuccessful and these also remain undated.

Dendrochronological analysis has shown that six of the timbers, all arcade posts, used in the construction of this barn were from trees felled in the period *c* AD 1392-AD 1412 and probably in *c* AD 1403, suggesting it to be later than originally believed.

Keywords

Dendrochronology
Standing Building

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TREE-RING ANALYSIS OF TIMBERS FROM MANOR FARM BARN, FRINDSBURY, KENT

Introduction

The barn at Manor Farm (TQ 747700; Fig 1), located to the south-west of the Manor house has been described as 'the queen of Kentish barns' (Rigold 1966, 10). Built on a high flint plinth, it comprises fourteen bays, which are aisled on both sides and at the ends. The arcade posts are on cills at a lower level than the wall cills. Long curved shores are lapped over the aisle ties to the arcade posts. Long curved braces run from the arcade posts to the arcade plate and tie-beams; there are also vertical and horizontal blocking pieces (Fig 2). The roof is of plain crown-post type with collar-purlins and two long curved downward braces and two upward braces each. The collars are morticed and tenoned and it is weather boarded. This barn falls into Rigold's "Class 1" type (barns with passing shores and crown-post roofs), construction of which he suggests began well before AD 1300 until their obsolescence after *c* AD 1500. Due to a number of archaic features used in the Frindsbury barn construction, such as splayed scarfs with 'keys', extra stiffening in the spandrels of the arch-braces, and 'reversed assembly' in the aisles, stylistically Rigold dated it from *c* AD 1300 (Rigold 1966, 9). However, work carried out since Rigold wrote his paper in 1966 has led to a development of stylistic/typlogical information and David Martin assigns a construction date of *c* AD 1400 to the barn (*pers comm*).

Sampling and analysis by tree-ring dating was commissioned and funded by English Heritage. It was hoped that tree-ring analysis could provide a precise date for the construction of this acknowledged very important barn, renewing interest in the barn with the ultimate aim of finding a long-term solution to its survival, suffering as it does periodically from vandalism.

The Laboratory would like to take this opportunity to thank the tenant farmer Mr Castle, for his assistance and co-operation with the sampling of the barn.

Sampling

Thirteen oak timbers from the barn were sampled, from arcade posts, wall posts, an aisle tie, and a passing shore. These samples were given the code FRD-B (for Frindsbury) and numbered 01-13. The position of the samples were noted at the time of sampling and marked on available drawings (Fig 2). Further details relating to these samples are to be found in Table 1. Sampling was restricted to those timbers which could be reached safely from a ladder. Work on the upper part of the roof would have required the erection of scaffolding and as the structure is believed to be of one phase only this was not thought necessary.

Analysis and dating

All thirteen samples were prepared by sanding and polishing; at this stage three of the samples, FRD-B02, FRD-B03, and FRD-B04 were discarded, due to their short ring-width sequences making secure dating impossible. The ring widths of the remaining ten samples were then measured, the data of the measurements of the samples being given at the end of the report. The samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix). At a value of t=4.5 two groups of samples were formed.

Six samples matched each other, at the relative positions shown in Figure 3. The growth-ring widths of these six samples were combined at these relative offset positions to form FRDBSQ01, a site chronology of 150 rings. This site sequence was cross-matched against the relevant reference chronologies for oak and was found to match at a first-ring date of AD 1254 and a last-ring date of AD 1403. Evidence for this dating is given in the t-values of Table 2.

The second site sequence was made up of two samples, which matched each other at the relative positions shown in Figure 4. The growth-ring widths of these two samples were combined at these relative offset positions to form FRDBSQ02, a site sequence of 100 rings. This site sequence was again cross-matched against the reference chronologies but no secure match was found. Therefore, these samples, and the timbers they represent are undated.

Attempts were then made to date the remaining two samples by individually comparing them with the reference chronologies. However, this proved unsuccessful and these are all still undated.

Interpretation

The analysis of samples from this barn produced one dated site chronology, FRDBSQ01, of six samples. This was found to span the period AD 1254-AD1403. One of these, FRD-B01, retains complete sapwood, and has a last-ring date of AD 1403, this being the felling date for the timber represented. The average heartwood/sapwood boundary ring date for the other five samples in this site chronology is AD 1377, which allows an estimated felling date for these timbers to be calculated to within the range AD 1392-AD 1412, therefore, also consistent with a felling date of *c* AD 1403. The estimated felling date range has been based on the estimate that mature oaks growing in this area have between 15-35 sapwood rings.

Discussion

Following analysis by tree-ring dating it has been possible to obtain dates for six of the timbers from a number of different trusses from this barn; from truss 1 at one end to truss 14 at the other. One of these is now known to have been felled in AD 1403, with the other five timbers also quite likely to have this felling date. These results suggest construction of the barn at or soon after the felling of these trees in AD 1403, therefore, at the very beginning of the fifteenth century. This is very close to the construction date of *c* AD 1400, suggested by David Martin (*pers comm*). All of the dated samples are from arcade posts when ideally we would prefer to have dated a range of timbers. However, the arcade posts are considered integral to the original structure and, therefore, there is no reason to doubt that the dates gained cannot be assigned to the building as a whole.

As noted above, the date previously assigned to the barn on the basis of Rigold's typology was *c* AD 1300, some one hundred years earlier. Two other barns of Rigold's "Class 1" type are the minor and major barns at Faversham. The minor he placed in the "Mature type" category which he suggests runs from AD 1350 to AD 1450, whilst those with "later characteristics", including the major barn, he provisionally assigned to the later fifteenth and early sixteenth centuries. Tree-ring analysis has since shown the minor barn to be built from timbers felled in AD 1426 and the major barn from timbers felled in AD 1475 (Howard 1998a). It can be seen that here we have three "Class 1" barns, with early, mature, or late characteristics, all probably being built in the fifteenth century. This has clear implications for the typology put forward by Rigold, perhaps indicating the need for reassessment in view of the development of stylistic/typological information built up by work carried out since 1966.

Unfortunately, including the three discarded prior to analysis, seven samples could not be dated. In the case of FRD-B12 this was probably due to a number of very narrow rings, spanning about 30 years. This severe growth suppression could point towards non-climatic growth conditions/stresses unique to that tree.

Figure 1: Map showing the location of Manor Farm Barn, Frindsbury, Kent

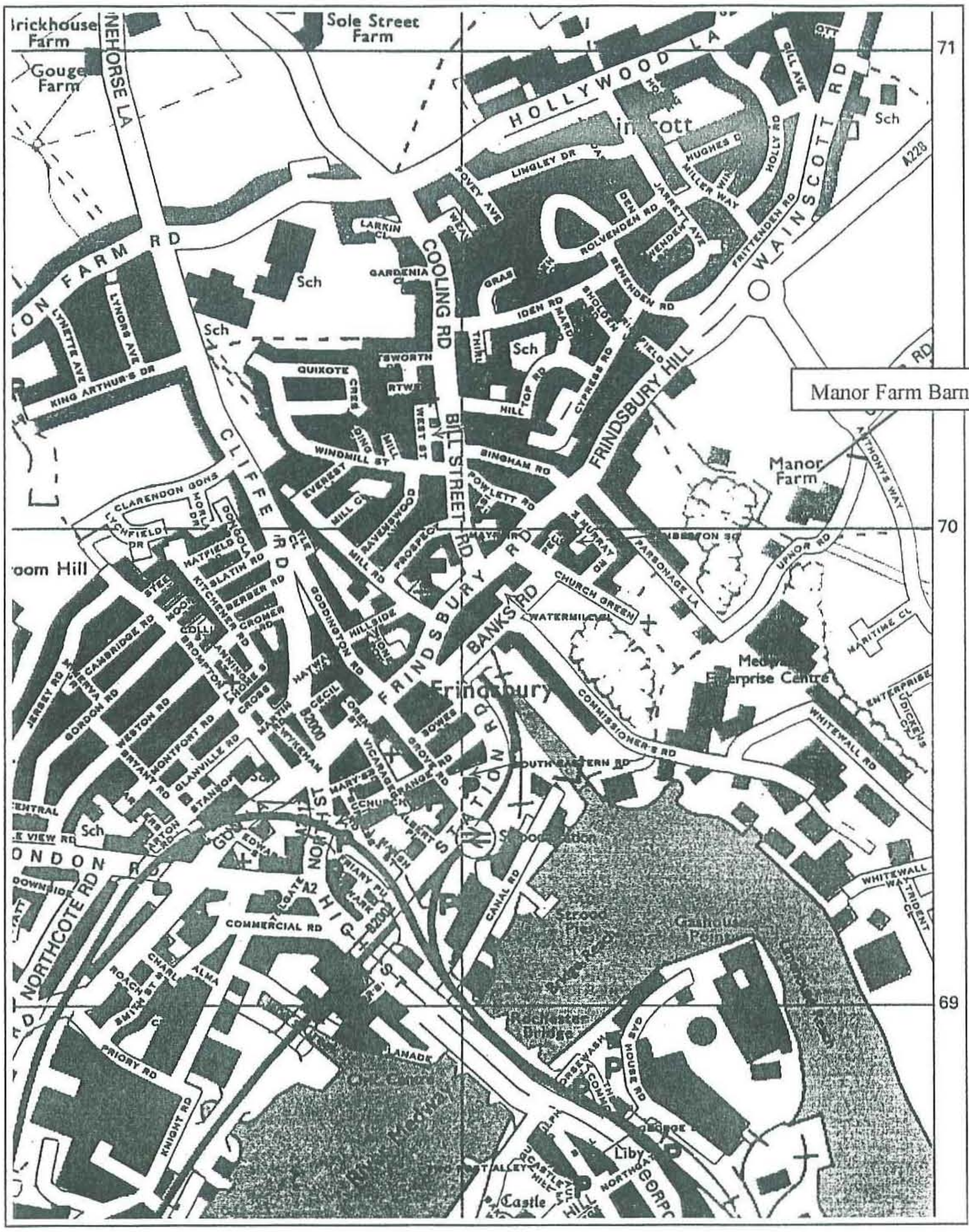


Figure 2: Plan of the barn at Manor Farm, Frindsbury, Kent and Trusses 1, 2, 6, 7, 9 and 14 showing the location of samples (based on Rigold 1966)

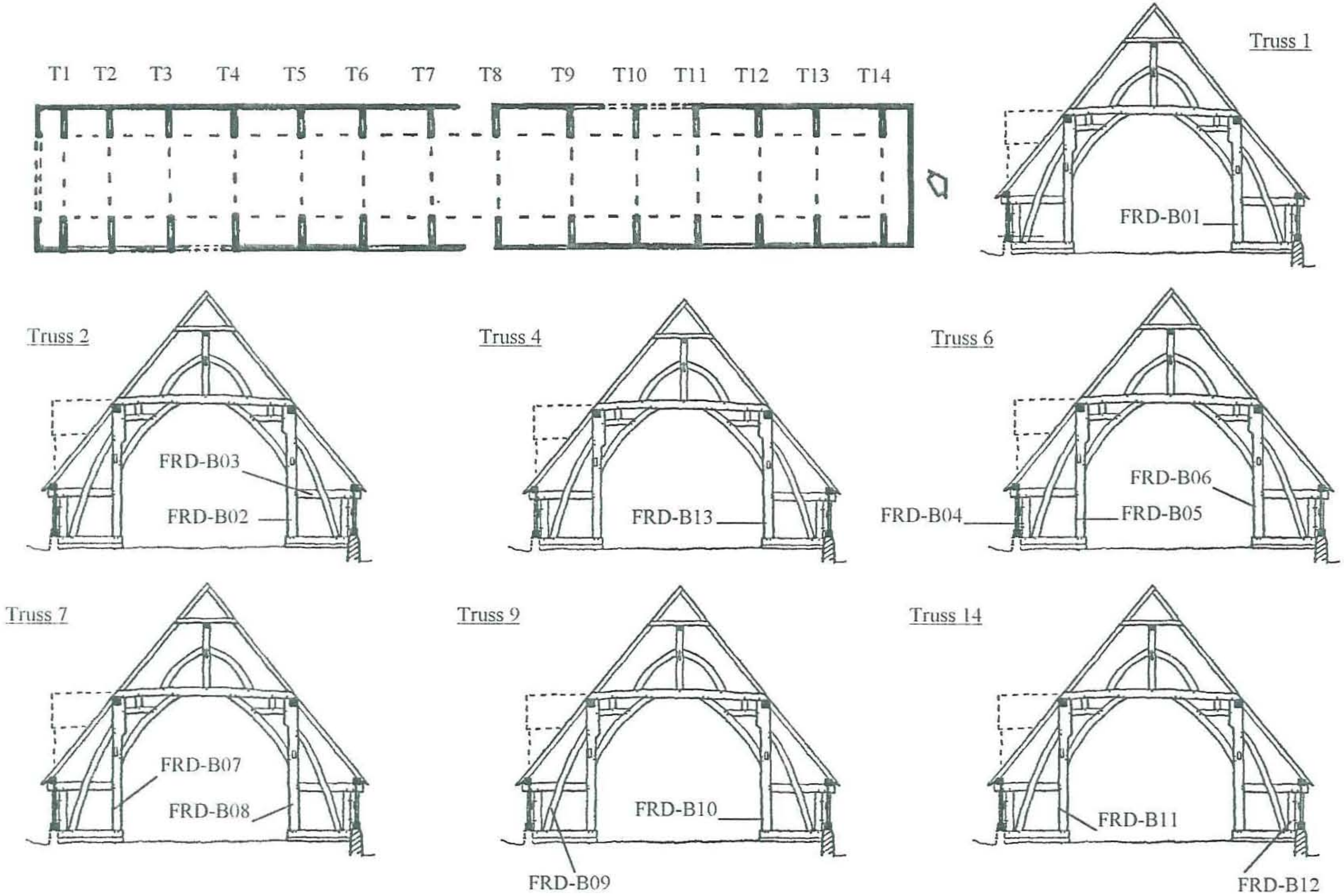
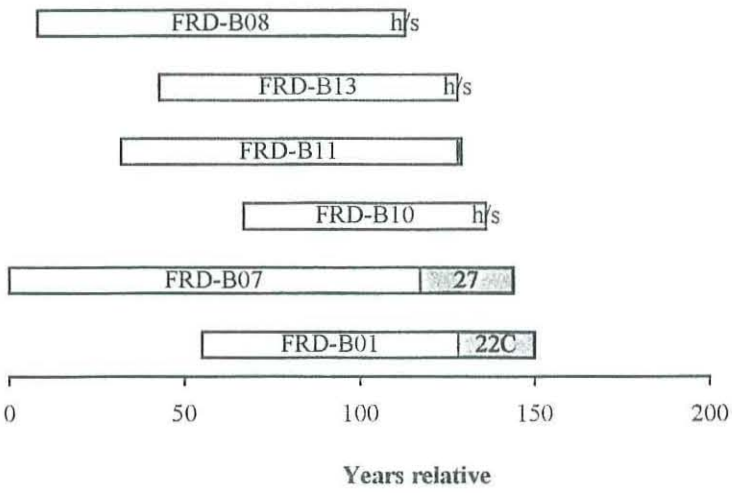


Figure 3: Bar diagram of samples in site sequence FRDBSQ01



Offset		Total rings	Relative last heartwood ring position
8	FRD-B08	105	113
43	FRD-B13	85	128
32	FRD-B11	97	128
67	FRD-B10	69	136
0	FRD-B07	144	117
55	FRD-B01	95	128

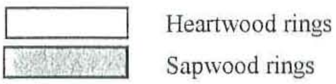


Figure 4: Bar diagram of samples in site sequence FRDBSQ02

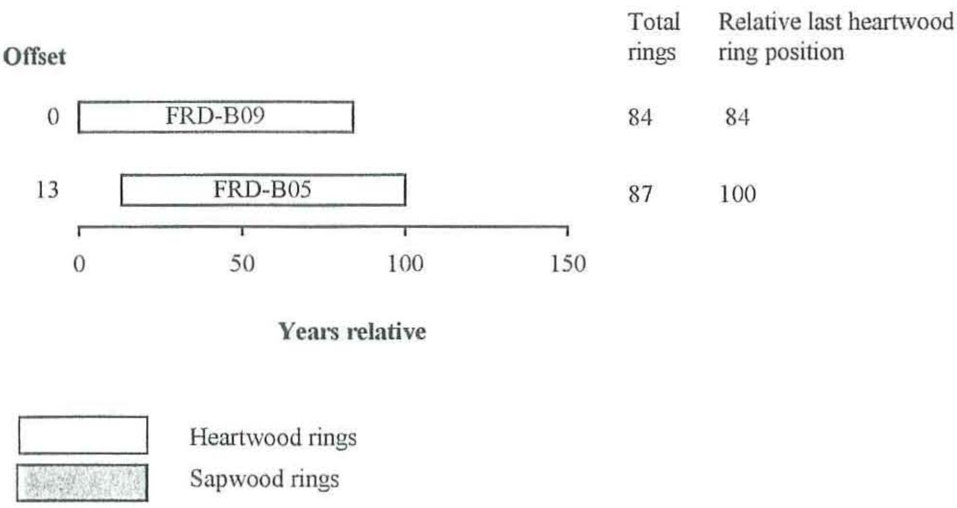


Table 1: Details of tree-ring samples from Manor Farm Barn, Frindsbury, Kent

Sample no.	Sample location	Total rings	Sapwood rings*	First measured ring date	Last heartwood ring date	Last measured ring date
FRD-B01	Arcade post, west, truss 1	95	22C	AD 1309	AD 1381	AD 1403
FRD-B02	Arcade post, west, truss 2	NM	--	------	------	------
FRD-B03	Aisle tie, west, truss 2	NM	--	------	------	------
FRD-B04	Wall Post, east, truss 6	NM	--	------	------	------
FRD-B05	Arcade post, east, truss 6	87	h/s	------	------	------
FRD-B06	Arcade post, west, truss 6	76	16c(+10-15 lost)	------	------	------
FRD-B07	Arcade post, east, truss 7	144	27	AD 1254	AD 1370	AD 1397
FRD-B08	Arcade post, west, truss 7	105	h/s	AD 1262	AD 1366	AD 1366
FRD-B09	Passing shore, east, truss 9	84	h/s	------	------	------
FRD-B10	Arcade post, west, truss 9	69	h/s	AD 1321	AD 1389	AD 1389
FRD-B11	Arcade post, east, truss 14	97	01	AD 1286	AD 1381	AD 1382
FRD-B12	Post, west, truss 14	103	h/s	------	------	------
FRD-B13	Arcade post, west, truss 4	85	h/s	AD 1297	AD 1381	AD 1381

*h/s = the heartwood/sapwood boundary is the last ring on sample
C = complete sapwood retained on sample
c(+x-y lost) = complete sapwood on timber, some lost in sampling (estimated number of sapwood rings lost)

Table 2: Results of the cross-matching of site chronology FRDBSQ01 and relevant reference chronologies when first ring date is AD 1254 and last measured ring date is AD 1403

Reference chronology	Span of chronology	*t*-value	
England London	AD 413-1728	7.2	Tyers and Groves 1998 unpubl
England	AD 401-1981	5.1	Baillie and Pilcher 1982 unpubl
East Midlands	AD 882-1981	4.9	Laxton and Litton 1988
Kent	AD 1158-1540	4.8	Laxton and Litton 1989
Chicksands Priory, Bedfordshire	AD 1200-1541	6.8	Howard *et al* 1998b
Queens Head, Crowmarsh, Gifford, Oxon	AD 1203-1341	6.6	Haddon-Reece *et al* 1990
Readinga	AD 1160-1407	6.5	Groves *et al* 1985
Thame Park House, nr Thame, Oxon	AD 1234-1319	6.2	Howard *et al* 1993
Ramsey, Great Whyte, Cambs	AD 1215-1443	5.7	Laxton and Litton 1988
Stowmarket Church (tower), Suffolk	AD 1251-1363	5.6	Howard *et al* 1994
Walnut Tree, East Sutton, Kent	AD 1219-1393	5.3	Laxton and Litton 1989

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Data of measured samples – measurements in 0.01mm units

FRD-B01A 95
186 235 179 337 300 331 340 401 304 303 270 258 348 273 276 260 272 225 286 275
321 309 361 186 217 231 268 234 177 204 218 196 156 149 105 108 126 160 108 136
146 134 149 160 157 124 113 110 118 73 104 114 112 110 130 139 113 100 111 123
147 181 132 136 137 129 128 153 149 141 130 144 149 116 86 97 106 114 102 98
107 93 78 86 96 83 88 110 127 106 123 154 133 151 114
FRD-B01B 95
204 239 182 331 305 349 366 380 295 299 284 267 349 294 276 266 279 240 276 272
339 299 344 177 222 227 276 232 184 203 219 199 157 143 102 110 133 134 135 131
144 133 129 166 156 143 109 113 113 74 118 106 117 96 129 135 125 93 114 132
142 182 132 131 140 130 131 151 147 144 125 145 146 121 117 91 98 122 106 101
100 88 85 107 86 92 93 105 117 127 134 135 114 150 115
FRD-B05A 87
482 388 374 314 308 277 258 201 165 200 207 230 249 217 164 216 266 213 217 199
146 194 212 248 238 231 188 170 192 249 200 192 150 234 179 134 144 151 162 182
163 132 128 170 131 111 127 77 73 117 111 86 131 100 117 114 112 135 145 107
136 141 66 93 90 150 154 191 217 190 142 76 96 186 233 189 200 187 259 350
311 313 322 226 274 278 206
FRD-B05B 87
473 389 365 331 302 280 239 193 163 193 201 220 246 228 151 213 266 215 214 197
146 198 215 236 238 237 184 171 189 255 200 194 152 228 182 120 143 148 172 169
161 126 125 179 118 118 132 73 77 108 108 97 122 113 110 99 97 149 112 114
126 128 85 96 84 159 151 203 212 211 147 75 100 195 208 200 197 187 246 342
305 321 329 231 269 275 204
FRD-B06A 76
179 292 287 284 315 268 297 316 184 162 186 186 126 121 131 146 188 170 197 252
141 183 213 220 150 184 141 114 151 176 151 170 225 158 182 151 138 161 113 210
169 160 174 134 128 107 162 244 194 139 111 164 199 248 178 201 201 182 201 273
129 144 174 140 109 119 123 96 102 176 102 99 91 99 78 80
FRD-B06B 76
137 300 271 271 313 269 322 308 184 158 174 202 115 126 124 158 186 190 221 209
150 190 233 223 156 186 131 113 156 176 148 173 220 150 179 147 162 123 202 177
182 152 165 122 116 144 156 245 194 126 121 157 198 245 174 206 192 190 184 251
135 153 164 139 130 98 117 97 98 163 101 95 89 76 103 73
FRD-B07A 72
273 283 287 356 269 270 263 215 222 125 159 194 145 103 204 300 245 254 253 302
96 60 50 75 84 99 110 199 148 165 139 114 181 105 79 146 154 156 155 190
175 154 151 149 80 82 115 105 111 61 73 74 83 67 73 72 62 74 75 79
96 126 131 67 79 57 61 75 86 77 61 76
FRD-B07B 128
192 235 228 244 92 50 42 76 70 121 117 211 172 176 141 111 177 117 92 144
143 164 135 179 170 146 160 146 67 98 115 117 121 61 88 63 77 73 81 72
65 79 77 77 104 126 129 88 82 59 53 78 82 75 68 72 45 62 86 80
57 65 60 55 69 46 46 60 58 90 73 87 67 71 56 70 80 69 82 98
110 85 62 47 61 51 67 69 75 105 96 75 75 117 81 100 98 99 111 115
143 95 112 76 96 70 72 88 81 79 68 86 82 72 54 80 86 81 77 80
52 56 50 61 56 70 48 64

FRD-B08A 105
227 161 260 288 326 145 207 374 284 284 217 370 326 226 289 406 143 208 189 212
177 139 203 123 176 133 201 268 270 309 312 323 300 239 233 177 82 96 116 158
155 97 101 118 105 74 106 127 110 96 96 97 146 147 163 97 100 79 114 133
137 154 102 81 59 61 59 73 86 94 56 70 80 79 112 70 74 102 98 93
109 88 69 103 77 87 96 73 55 45 41 54 54 48 50 88 55 60 58 44
37 50 45 46 53
FRD-B08B 105
222 155 266 282 316 148 225 372 276 277 225 367 325 215 296 399 151 207 193 213
174 137 204 125 180 123 199 272 266 314 309 326 297 241 238 166 82 104 109 158
167 86 104 121 98 79 102 120 105 96 96 95 148 148 165 96 96 78 114 138
136 151 102 81 61 57 65 71 85 97 56 69 79 78 112 70 71 105 98 92
106 85 72 104 80 84 99 71 59 52 36 54 45 53 60 71 61 61 49 51
47 55 40 61 55
FRD-B09A 84
207 297 361 303 247 211 268 234 255 171 134 78 86 116 116 94 75 91 132 159
127 183 130 146 187 197 175 145 155 150 109 115 88 85 107 128 171 165 136 110
104 106 82 104 109 79 131 99 80 72 100 126 134 125 120 113 104 107 96 95
56 54 86 72 67 73 98 105 106 101 91 81 75 91 57 44 36 51 67 53
54 55 54 74
FRD-B09B 84
217 300 332 311 260 219 249 249 275 163 129 87 98 114 127 92 80 83 127 158
127 175 144 146 191 206 175 145 153 151 119 114 87 93 95 128 159 164 136 99
112 97 88 102 95 101 129 94 82 78 83 129 124 121 116 125 122 87 94 91
58 58 89 69 65 73 97 104 116 91 97 88 71 103 51 36 55 47 62 49
54 54 48 62
FRD-B10A 69
285 301 181 266 288 171 254 291 257 240 210 220 178 230 321 248 126 122 188 198
285 370 265 222 221 300 287 247 277 237 259 162 225 183 160 156 157 157 207 189
107 108 176 114 187 174 183 214 261 241 142 182 117 161 124 89 101 109 97 76
96 67 93 65 73 131 104 168 97
FRD-B10B 69
278 306 186 263 289 174 256 285 263 238 217 222 182 231 317 250 126 119 193 197
279 375 272 225 214 297 286 251 268 235 264 161 224 186 153 151 157 147 201 199
107 107 178 113 187 186 179 214 260 237 156 176 122 183 121 102 92 114 86 83
83 74 84 66 80 119 105 157 106
FRD-B11A 97
86 115 119 144 158 161 180 125 143 164 169 124 107 136 113 95 178 61 146 78
97 93 109 98 126 63 72 86 122 155 175 155 74 136 91 125 102 70 102 68
72 99 107 184 114 71 73 57 93 93 108 73 94 120 98 79 73 58 54 120
122 107 88 85 67 104 78 120 114 91 76 103 89 116 99 74 76 107 89 69
74 71 75 115 116 80 72 85 142 110 90 94 100 99 116 60 57
FRD-B11B 97
89 112 118 145 153 153 186 130 145 134 166 124 100 139 123 109 127 72 151 74
88 88 103 99 129 60 71 77 135 154 187 149 79 142 86 112 96 81 100 69
61 95 105 184 120 82 78 60 104 95 111 83 84 121 94 78 76 52 65 107
124 124 90 93 64 114 78 131 114 87 76 102 89 116 91 79 70 106 87 71
76 61 81 115 113 81 78 85 143 111 88 98 92 111 110 53 59
FRD-B12A 103
215 319 158 176 199 183 244 175 222 234 174 128 220 230 223 254 204 185 153 285
242 323 236 245 208 188 161 172 265 228 82 62 78 89 78 73 87 160 152 158
147 162 122 117 84 90 70 72 95 119 143 109 118 110 73 80 97 99 51 49
93 127 179 179 250 183 54 59 27 36 27 20 36 67 22 20 27 19 34 36
47 39 36 25 36 24 30 29 28 45 66 52 58 66 46 64 39 60 44 36
56 61 46

FRD-B12B 102
232 304 189 182 196 185 249 173 228 234 175 129 241 241 236 263 212 185 149 286
244 327 232 250 207 196 162 172 268 229 82 65 74 83 74 85 86 148 150 155
152 160 121 115 86 93 73 72 87 121 134 109 110 106 81 82 98 100 55 47
96 139 179 193 257 179 67 43 49 33 28 36 20 41 32 31 33 23 22 61
27 29 38 29 61 49 39 76 59 69 53 68 44 58 56 46 44 42 37 47
47 45
FRD-B13A 85
241 270 289 236 307 248 249 372 398 299 334 265 222 100 149 149 174 176 135 163
142 114 127 159 213 196 177 154 122 87 133 136 166 172 122 98 150 195 163 112
102 116 119 118 115 122 90 100 138 113 112 157 167 180 171 147 216 197 161 147
152 104 166 138 138 90 192 157 121 84 91 102 136 162 126 161 173 152 137 176
186 250 188 262 196
FRD-B13B 85
242 274 292 283 295 250 274 397 421 306 326 279 215 103 161 134 162 184 131 160
123 142 140 165 200 195 188 146 108 92 124 132 155 181 126 79 166 192 163 106
93 127 113 117 118 129 86 91 125 120 119 150 173 177 166 148 216 203 143 164
147 119 152 141 127 82 186 154 113 88 80 101 158 138 135 183 153 150 159 170
193 236 210 253 196
FRD-B14A 66
215 319 158 176 199 183 244 175 222 234 174 128 220 230 223 254 204 185 153 285
242 323 236 245 208 188 161 172 265 228 82 62 78 89 78 73 87 160 152 158
147 162 122 117 84 90 70 72 95 119 143 109 118 110 73 80 97 99 51 49
93 127 179 179 250 183
FRD-B14B 66
232 304 189 182 196 185 249 173 228 234 175 129 241 241 236 263 212 185 149 286
244 327 232 250 207 196 162 172 268 229 82 65 74 83 74 85 86 148 150 155
152 160 121 115 86 93 73 72 87 121 134 109 110 106 81 82 98 100 55 47
96 139 179 193 257 179

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 Buildings*' (Laxton and Litton 1988b) and, for example, in *Tree-Ring Dating and Archaeology* (Baillie 1982) or *A Slice Through Time* (Baillie 1995). 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 Figure1 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, 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 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. 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 we inspect the timbers in a building 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. Similarly the core has just over 100 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.

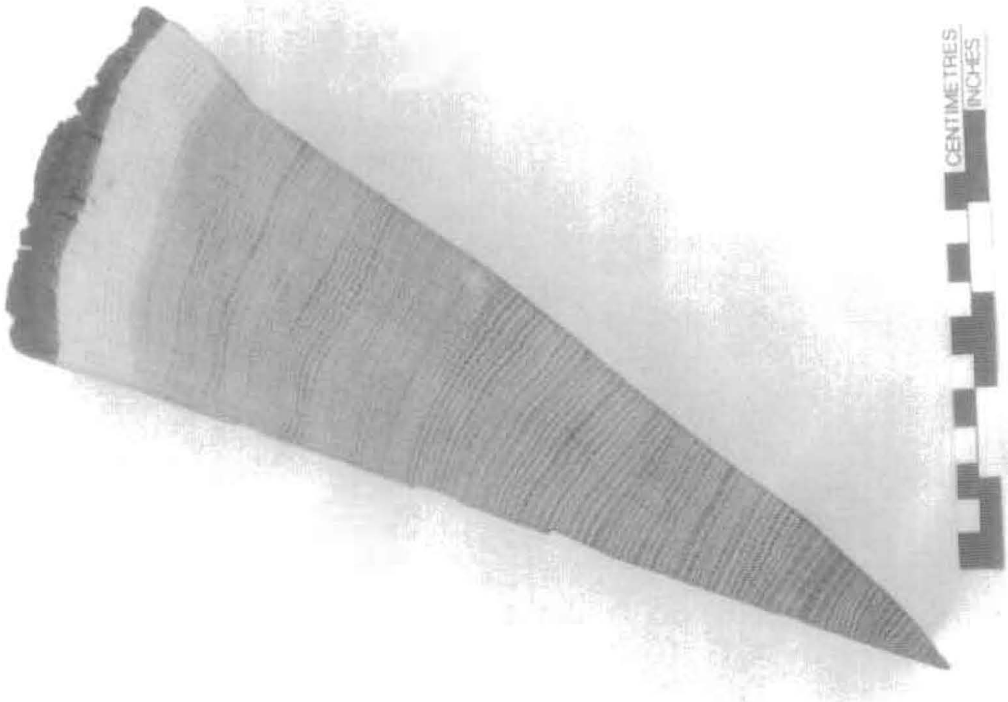

Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners, 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 measured twice to ensure that an error has not been made. This type of apparatus is needed to process a large number of samples on a regular basis.

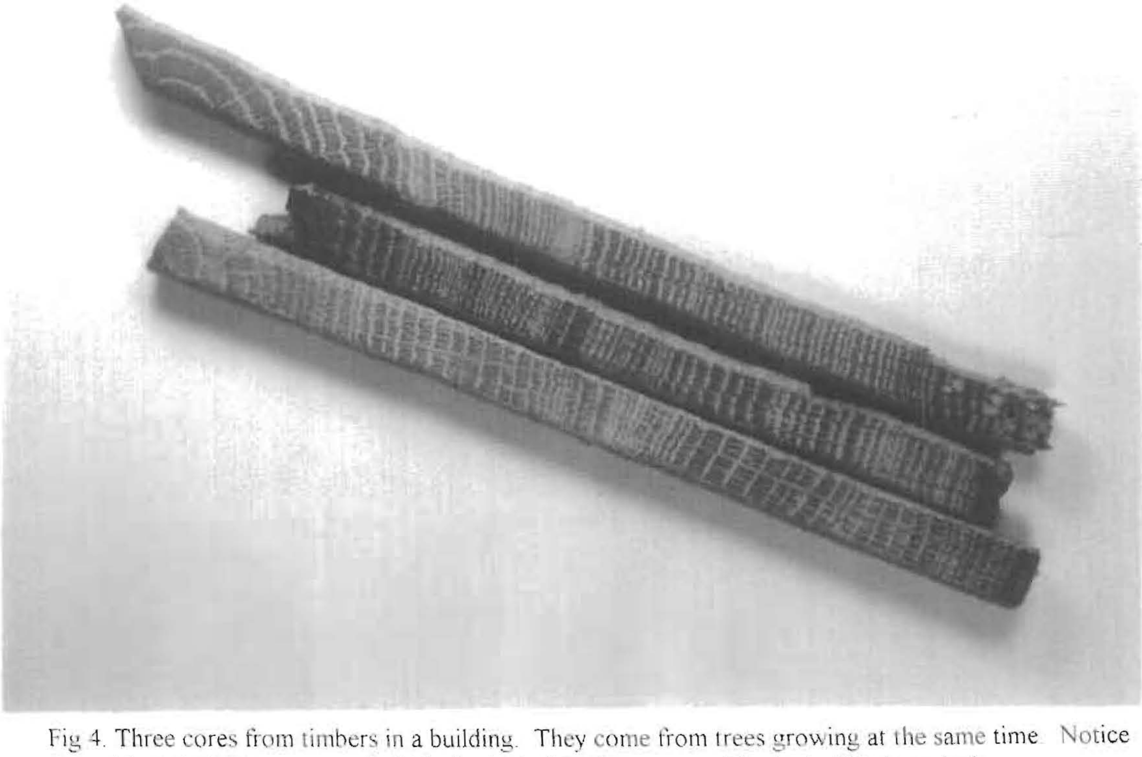

Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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 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 inspecton 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 is insured with the CBA.

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 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton *et al* 1988a,b; 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. C08 matches C45 best when it is at a position starting 20 rings after the first ring of 45. 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 between these two whatever the position of one sequence relative to the other.

   It is standard practice in our Laboratory first to cross-match as many as possible of the 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 from 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. 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.

average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

This 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'. This was developed and tested in the Laboratory and has been published (Litton and Zainodin 1991; Laxton *et al* 1988a). To illustrate the difference between the two approaches with the above example, consider sequences C08 and C05. They are the most similar pair with a t-value of 10.4. Therefore, these two are first averaged with the first ring of C05 at +17 rings relative to C08 (the offset at which they match each other). This average sequence is then used in place of the individual sequences C08 and C05. The cross-matching continues in this way gradually building up averages at each stage eventually to form the site sequence.

4. ***Estimating the Felling Date.*** 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, they can be seen in two upper corners of the rafter and at the outer end of the core in Figure 2. 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 for 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. Thus in these circumstances the date of the present last ring is at least close to the date of the original last ring on the tree, and so to the date of felling.

Various estimates have been made for the average number of sapwood rings in a mature oak. One estimate is 30 rings, based on data from living oaks. So, in the case of the core in Figure 2 where 9 sapwood rings remain, this would give an estimate for the felling date of 21 (= 30 - 9) years later than of the date of the last ring on the core. Actually, it is better in these situations to give an estimated range for the felling date. Another estimate is that in 95% of mature oaks there are between 15 and 50 sapwood rings. So in this example this would mean that the felling took place between 6 (= 15 - 9) and 41 (= 50 - 9) years after the date of the last ring on the core and is expected to be right in at least 95% of the cases (Hughes *et al* 1981; see also Hillam *et al* 1987).

Data from the Laboratory has shown that when sequences are considered together in groups, rather than separately, the estimates for the number of sapwood can be put at between 15 and 40 rings in 95% of the cases with the expected number being 25 rings. We would use these estimates, for example, in calculating the range for the common felling date of the four sequences from Lincoln Cathedral using the average position of the heartwood/sapwood boundary (Fig 5). These new estimates are now used by us in all our publications except for timbers from Kent and Nottinghamshire where 25 and between 15 to 35 sapwood rings, respectively, is used instead (Pearson 1995).

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. Sapwood rings were only lost in coring, because of their softness. By measuring in the timber the depth of sapwood lost, say 2 cm., a reasonable estimate can be made of the number of sapwood rings missing from the core, 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 40 years later we would have estimated without this observation.

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

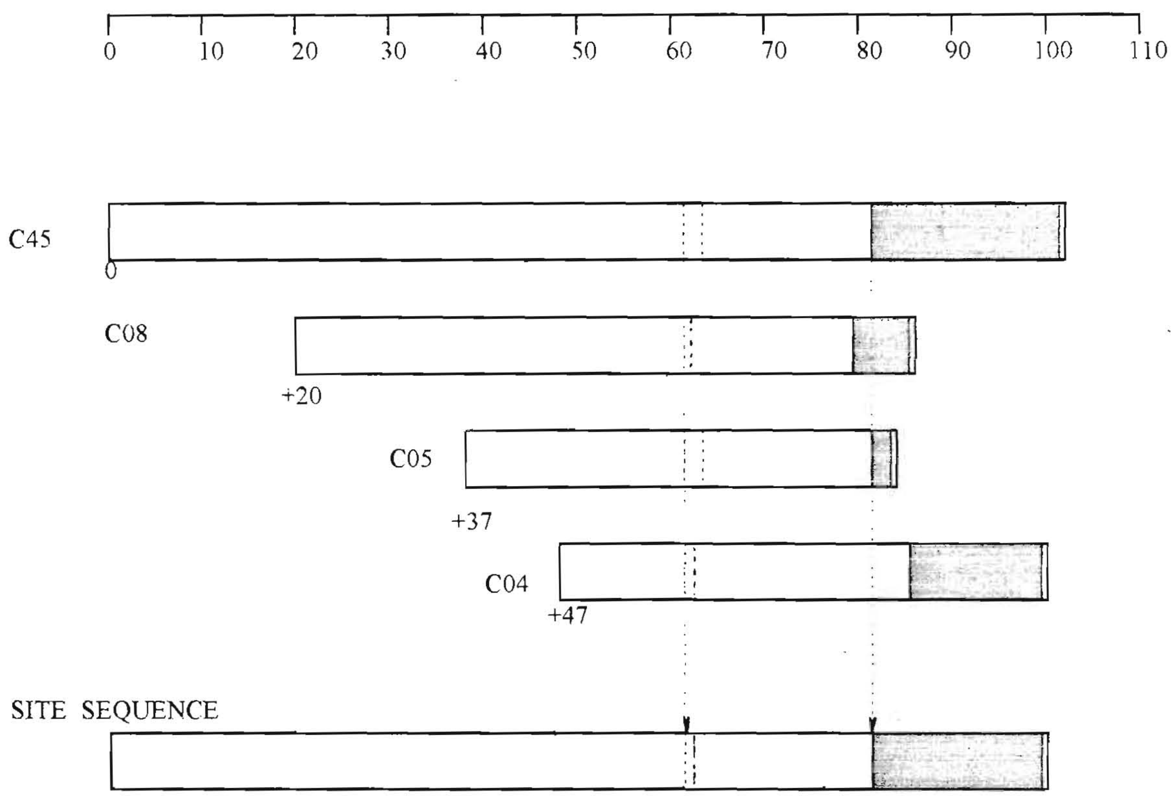

Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.
The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set 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.

Even if all the sapwood rings are missing on all the timbers sampled, an estimate of the felling date is still possible in certain cases. For provided the original last heartwood ring of the tree, called the heartwood/sapwood boundary (H/S), is still on some of the samples, an estimate for the felling date of the group of trees can be obtained by adding on the full 25 years, or 15 to 40 for the range of felling dates.

If none of the timbers have their heartwood/sapwood boundaries, then only a *post quem* date for felling is possible.

5. ***Estimating the Date of Construction.*** There is a considerable body of evidence in the data collected by the Laboratory that the oak timbers used in vernacular buildings, at least, were used 'green' (see also Rackham (1976)). Hence provided the samples are taken *in situ,* and several dated with the same estimated common felling date, then this felling date will give an estimated date for the construction of the building, or for the phase of construction. If for some reason or other we are rather restricted in what samples we can take, then an estimated common felling date may not be such a precise estimate of the date of construction. More sampling may be needed 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 1988b, 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* 1988a). 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 (1988b) 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 (a), the generally large early growth after 1810 is very apparent as is the smaller generally later growth from about 1900 onwards. A similar difference can be observed in the lower sequence 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, hopefully corresponding to good and poor growing seasons, respectively. The two corresponding sequences of Baillie-Pilcher indices are plotted in (b) where the differences in the early and late growths have been removed and only the rapidly changing peaks and troughs remain only associated with the common climatic signal and so make cross-matching easier.

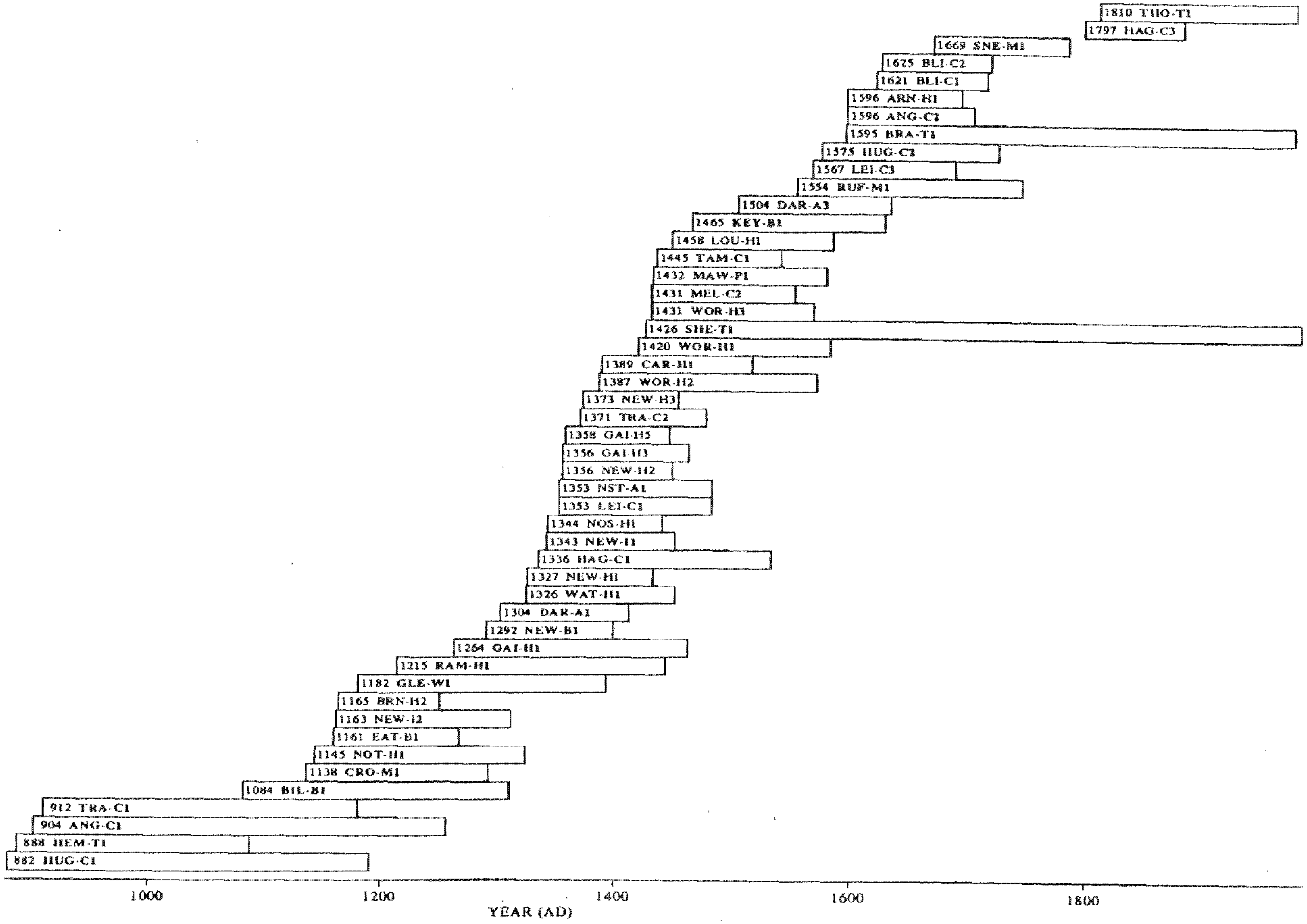

Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

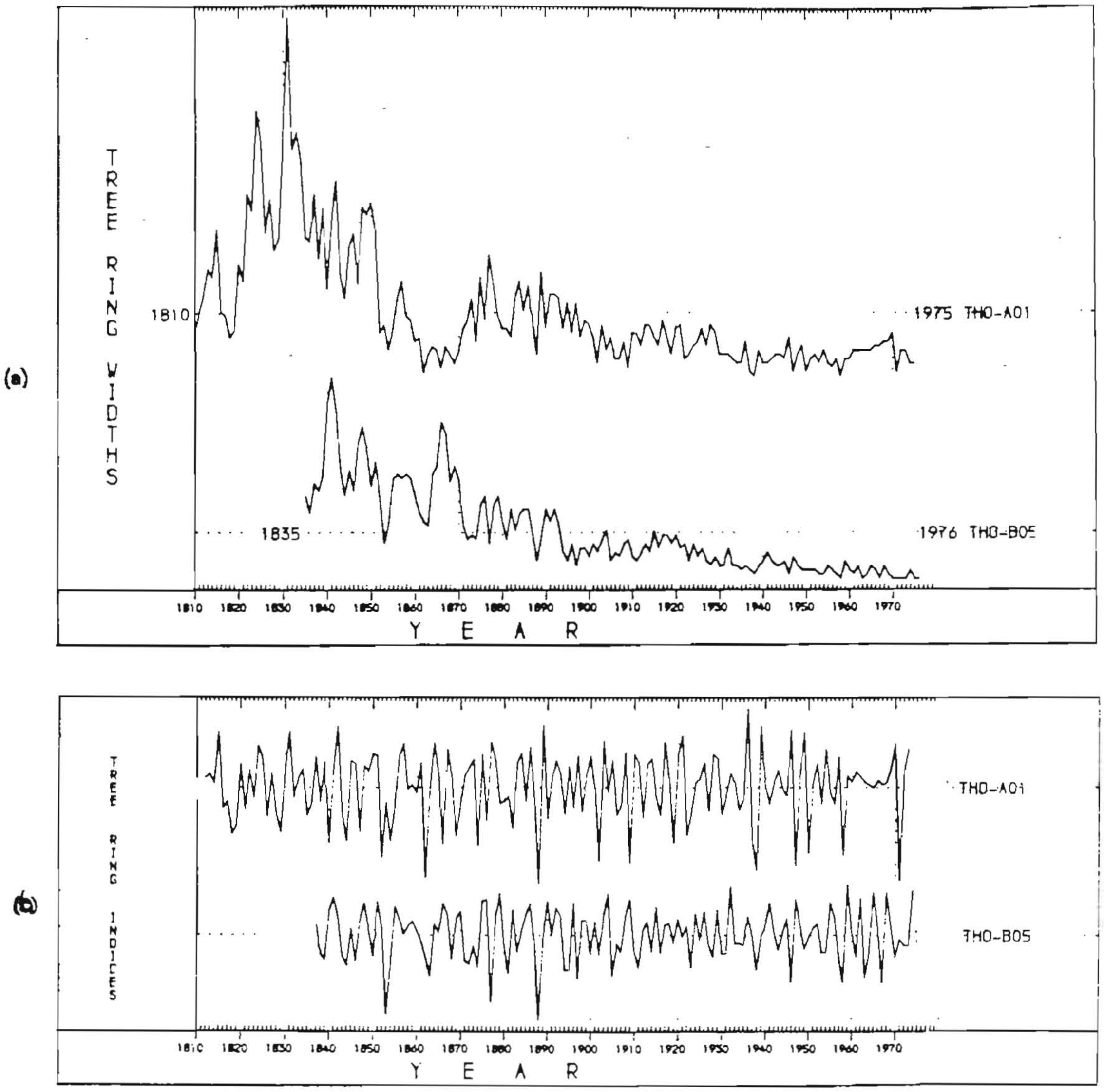

Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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

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

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