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Tree-Ring Analysis of Timbers from 39 Strand Street, Sandwich, Kent

A J Arnold[1], R E Howard[1], Dr R R Laxton[2] & Dr C D Litton[2]

Summary

Ten Samples were taken from oak timbers at these premises for dendrochronological analysis. Two of these were later rejected; SND-B08 and SND-B10 have very short ring-width sequences, which would have made successful dating unlikely.

This analysis resulted in the construction of two site sequences. The first SNDBSQ02, has 134 rings, and was successfully matched at a first ring date of AD 1201 and a last-ring date of AD 1334. Three of the samples contained within this site sequence, SND-B06, SND-B07 and SND-B09 have complete sapwood and last-ring dates of AD 1334, this being the felling date for the three timbers represented. The heartwood/sapwood boundary ring date for the fourth sample in the site sequence, SND-B05, is also consistent with a felling date of AD 1334.

The second site sequence, SNDBSQ03, has 94 rings and was successfully matched at a first ring date of AD 1241 and a last-ring date of AD 1334. One of the two samples which go to make up this site sequence, SND-B04 has complete sapwood and a last-ring date of AD 1334, this being the felling date of the timber represented. The heartwood/sapwood boundary ring date for the second sample in the site sequence, SND-B03, is again consistent with a felling date of AD 1334.

The analysis has resulted dating of six timbers, three joists and three internal timbers, four to AD 1334, with the other two having felling date ranges, entirely consistent with this date. This suggests a construction date at or soon after this time.

The remaining samples could not be dated.

Keywords

Dendrochronology
Standing Building

Author's address

[1]Department of Archaeology, University of Nottingham, University Park, Nottingham, NG7 2RD
[2] Department of Mathematics, University of Nottingham, University Park, Nottingham, NG7 2RD

Introduction

Number 39 Strand Street lies on the south side of Strand Street, near the junction with the Butchery and Harnet Street (TR 33065833; Fig 1). A three-storey timber-framed range fronts onto Strand Street with a tall open hall behind, lying along one side of a small courtyard. The south, or rear, of the property contains a semi-sunken stone undercroft, with a three-storey stone and timber-framed range above. The hall and front range are structurally separate from the rear range, which is likely to have been built shortly before these. Alterations and improvements took place during the sixteenth, seventeenth, and eighteenth centuries, and parts of the roof were rebuilt in the late eighteenth or nineteenth centuries.

Sampling and analysis by tree-ring dating was commissioned and funded by English Heritage, as part of their training programme in dendrochronology. Additionally, this building is believed to be one of the earliest of Sandwich's medieval buildings and so if it could be successfully dated it would provide a *terminus post quem* for timber-framed construction in the town.

The Laboratory would like to thank the owners of the property, Mr and Mrs D Novakovic, and Finns Estate Agents for allowing us access to the premises for inspection and to undertake the sampling. We also thank Sarah Pearson for all her assistance in locating the property and arranging access, and for the building description above, taken from her report into the building (Pearson 1999), and the drawings, which are reproduced with her kind permission (Figs 2-4).

Sampling

A total of ten samples were taken from oak timbers at these premises, by means of coring. These samples were from rails, posts, and joists. They were given the code SND-B (for Sandwich, site "B") and numbered 01-10. The position of all the samples was noted at the time of sampling and has been marked on Figures 2-4. Further details relating to the samples are recorded in Table 1. Two samples, SND-B08 and SND-B10 were later found to contain too few rings, less than 50, to make analysis worthwhile and so were rejected prior to this. Sampling was restricted to the front range as the timbers in the other phase were considered unsuitable for successful tree-ring analysis, being especially wide-ringed, therefore, suggesting there would be insufficient rings on the samples. Additionally, the roof timbers of the front range and hall are modern.

Analysis and Results

Each sample was prepared by sanding and polishing and the growth-ring widths of the remaining eight samples were measured; the data of these measurements are given at the end of the report. The growth-ring widths of the samples were compared with each other by the Litton/Zainodin grouping procedure (see appendix). At a least value of t=4.5 three of the samples matched and site sequence SNDBSQ01 of 134 rings, was constructed containing these samples at the offsets shown in the bar diagram (Fig 5). This site sequence was successfully matched against the relevant reference chronologies for oak at a first-ring date of AD 1201 and a last-ring date of AD 1334. The evidence for this dating is given by the *t*-values in Table 2.

It was then noticed that sample SND-B09 matched site sequence SNDBSQ01 at a value of *t*=4.4 at the offset +53. Before a second site sequence containing all four samples was constructed sample SND-B09 was individually compared with the reference chronologies for oak. It was found to match at a first-ring date of AD 1254 and a last-ring date of AD 1334, dating consistent with an offset position of +53 in site sequence SNDBSQ01. At this point a second site sequence, SNDBSQ02, of 134 rings, was constructed containing the three samples making up SNDBSQ01 and sample SND-B09 at the offsets shown in Figure 6. This site sequence was successfully matched against the relevant reference chronologies for oak, again at a first-ring date of AD 1201 and a last-ring date of AD 1334. The evidence for this dating is given by the *t*-values in Tables 3 and 4.

Samples SND-B03 and SND-B04 match each other at the value of *t*=4.2. As this is lower than the usual value of *t*=4.5 used by this laboratory when cross-matching, although not as low as the statistically accepted reliable minimum of *t*=3.5. Attempts were first made to individually date these samples before combining them to form a site sequence. This resulted in sample SND-B03 being matched at a first-ring date of AD 1277 and a last-ring date of AD 1330 and sample SND-B04 being matched at a first-ring date of AD 1241 and a last-ring date of AD 1334. These are the relative dates suggested by the grouping and so a third site sequence, SNDBSQ03 of 94 rings, containing these two samples were constructed by combining their ring width sequences at the offsets shown in Figure 7. This site sequence was successfully matched against the reference chronologies and was found to match at a first-ring date of AD 1241 and a last-ring date of AD 1334. The evidence for this dating is given by the *t*-values in Tables 5-7.

The remaining samples could not be matched and are undated.

Interpretation

Analysis of samples from 39 Strand Street resulted in two site chronologies. Site chronology, SNDBSQ02, contained four samples and spanned the period AD 1201-AD 1334. One of the samples (SND-B05) is from a main post and the other three (SND-B06, SND-B07, and SND-B09) are from joists. Samples SND-B06, SND-B07, and SND-B09 all have complete sapwood and last-ring dates of AD 1334, this being the felling date for the three timbers represented. The heartwood/sapwood boundary ring date for the other sample in this site chronology, SND-B05, is AD 1296 which, using the estimate that 95% of mature oaks growing in this area have 15-35 sapwood rings (Pearson 1994, 150), would normally calculate to an estimated felling date range of AD 1311-31 for the timber represented. However, there is no sign of this timber having been reused and it is quite likely that it was also felled in AD 1334, giving the timber 38 sapwood rings, slightly more than the usual 35 but only one more than sample SND-B06 which has 37 sapwood rings.

Site chronology SNDBSQ03 contains two samples, one from a cross-rail (SND-B03) and the second from a main post (SND-B04), and was found to span the period AD 1241-AD 1334. Sample SND-B04 has complete sapwood and a last-ring date of AD 1334, this being the felling date for the timber represented. The heartwood/sapwood boundary date for sample SND-B03 is AD 1314, giving the timber it represents an estimated felling date within the range AD 1331-49, therefore, consistent with the felling date of AD 1334.

Discussion

Following analysis by tree-ring dating it has been possible to obtain dates for six of the timbers in this building. Four of these have complete sapwood and last-ring dates of AD 1334, with a fifth having a felling date range, consistent with this felling date also. The sixth dated sample, SND-B05, has a felling date range, AD 1311-31, slightly earlier, however, as outlined above it is perfectly feasible, on the evidence of sample SND-B06, that the sample may have slightly more sapwood rings than the usual 15-35. This allows the possibility that the timber represented by sample SND-B05 was also felled in AD 1334. Three of the dated timbers are joists in the front range, but since three of the timbers, SND-B03, SND-B04, and SND-B05, are structural timbers common to the hall and front range, it is clear that both parts of the building were constructed in or soon after AD 1334.

Dendrochronological analysis has confirmed the early-fourteenth century date expected for the construction of this building, making it one of the earliest medieval buildings in the town.

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Figure 1: Street plan of Sandwich to show the location of 39 Strand Street

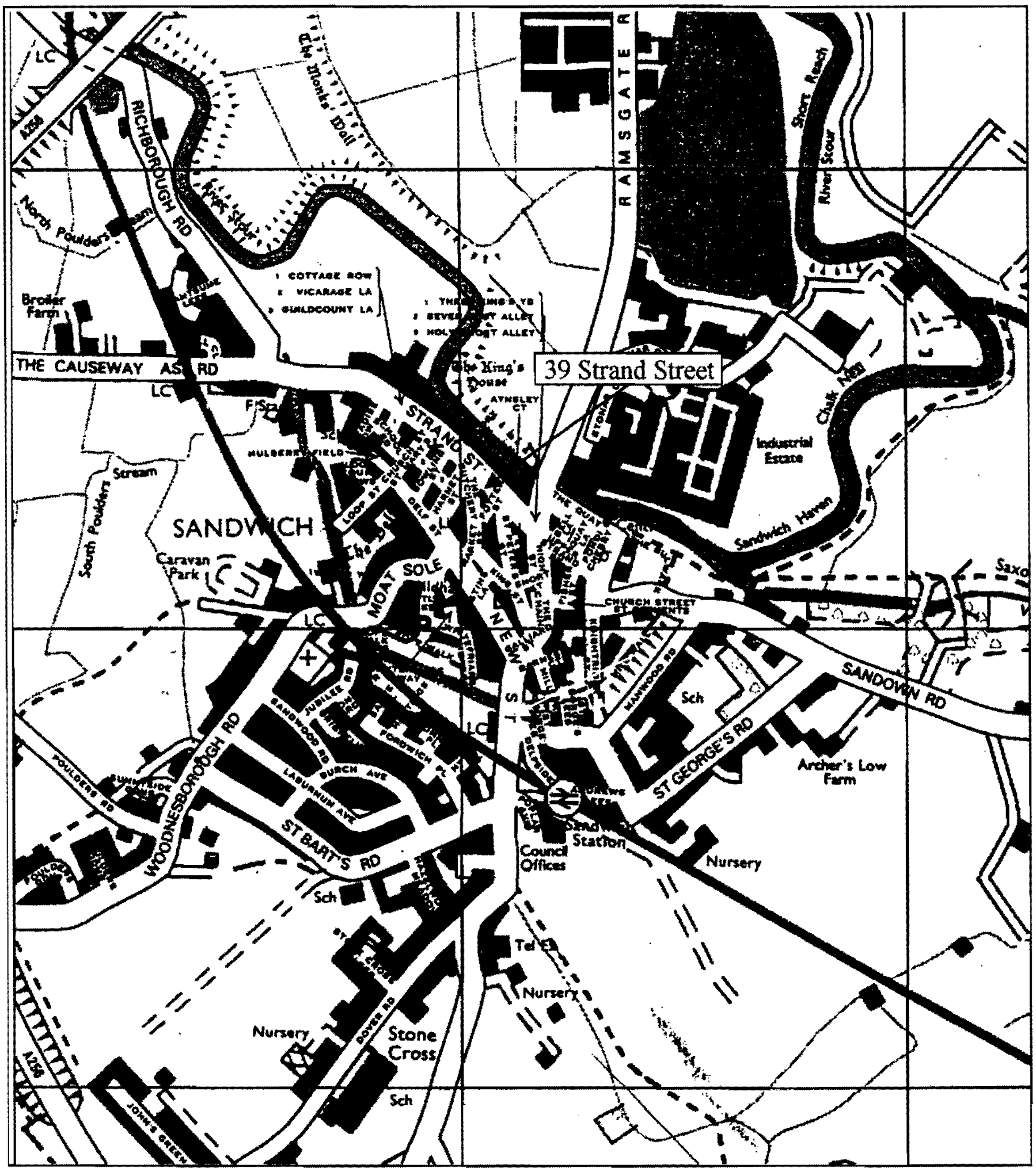

Figure 2: Ground-floor plan of 39 Strand Street, Sandwich, showing the location of samples SND-B06-10, drawn by Allan T Adams

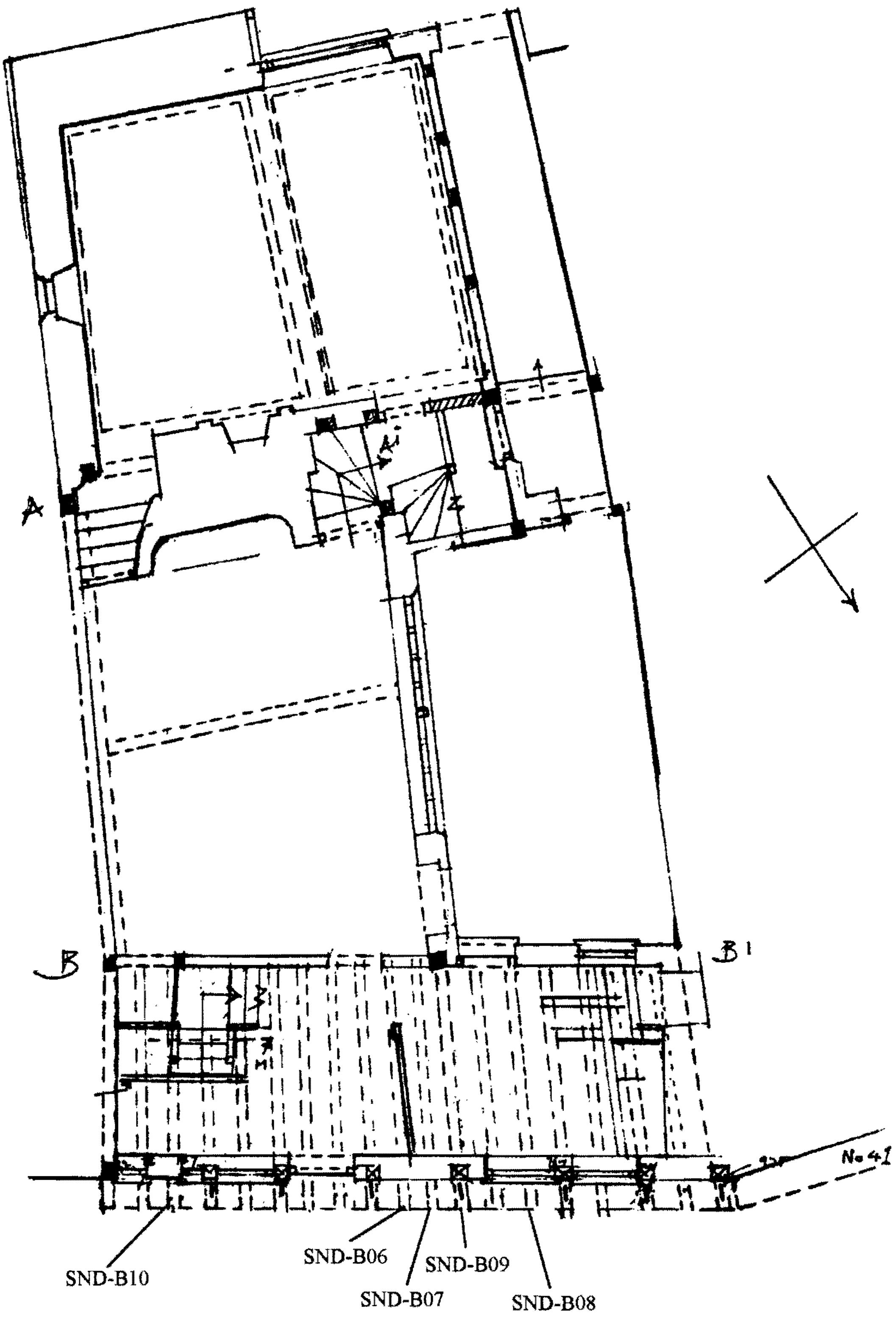

Figure 3: First-floor plan of 39 Strand Street, Sandwich, showing the location of samples SND-B02-05, drawn by Allan T Adams

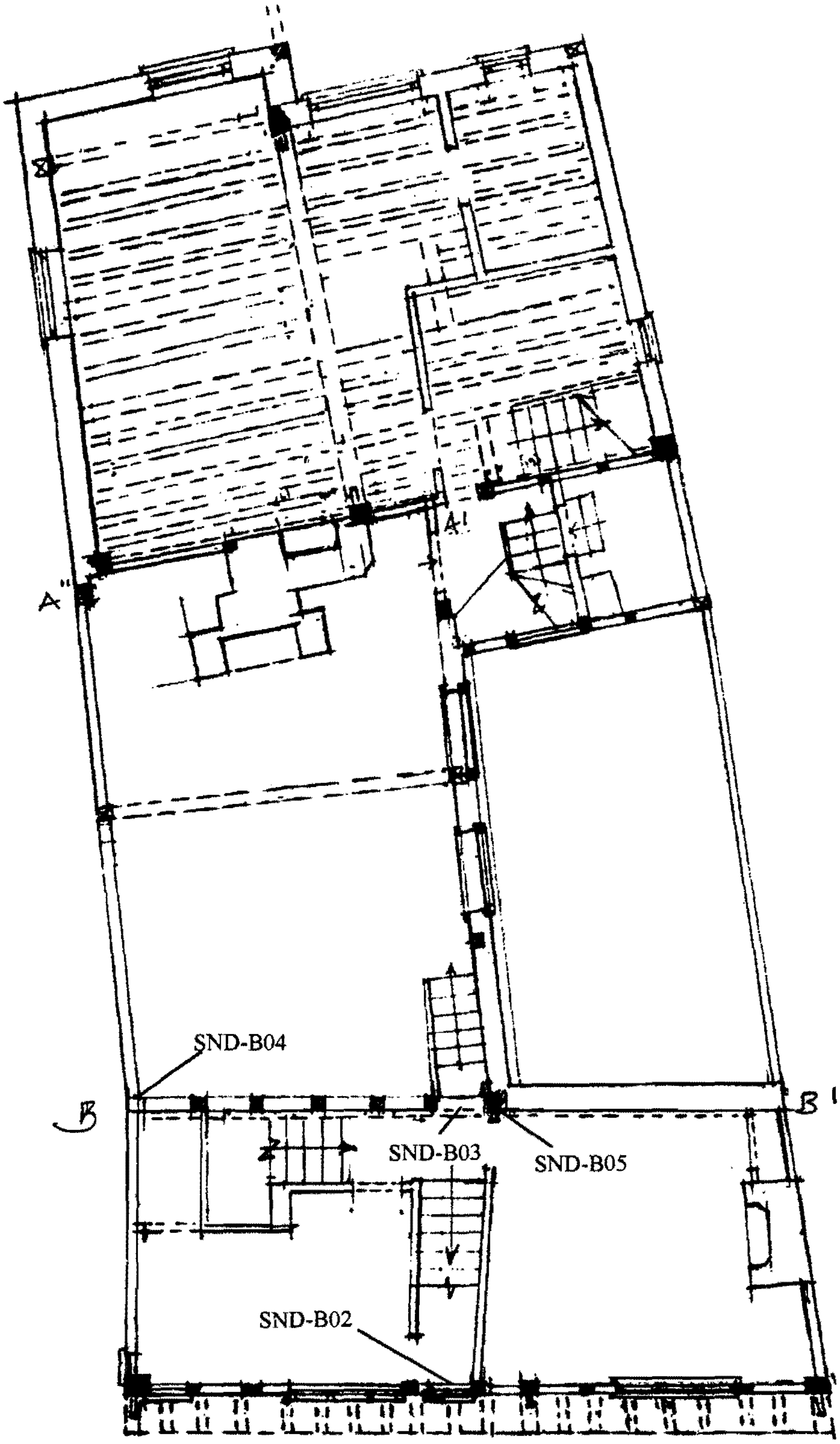

Figure 4: Sections through 39 Strand Street, Sandwich, Kent, showing the location of sample SND-B01, (after RCHME 1994)

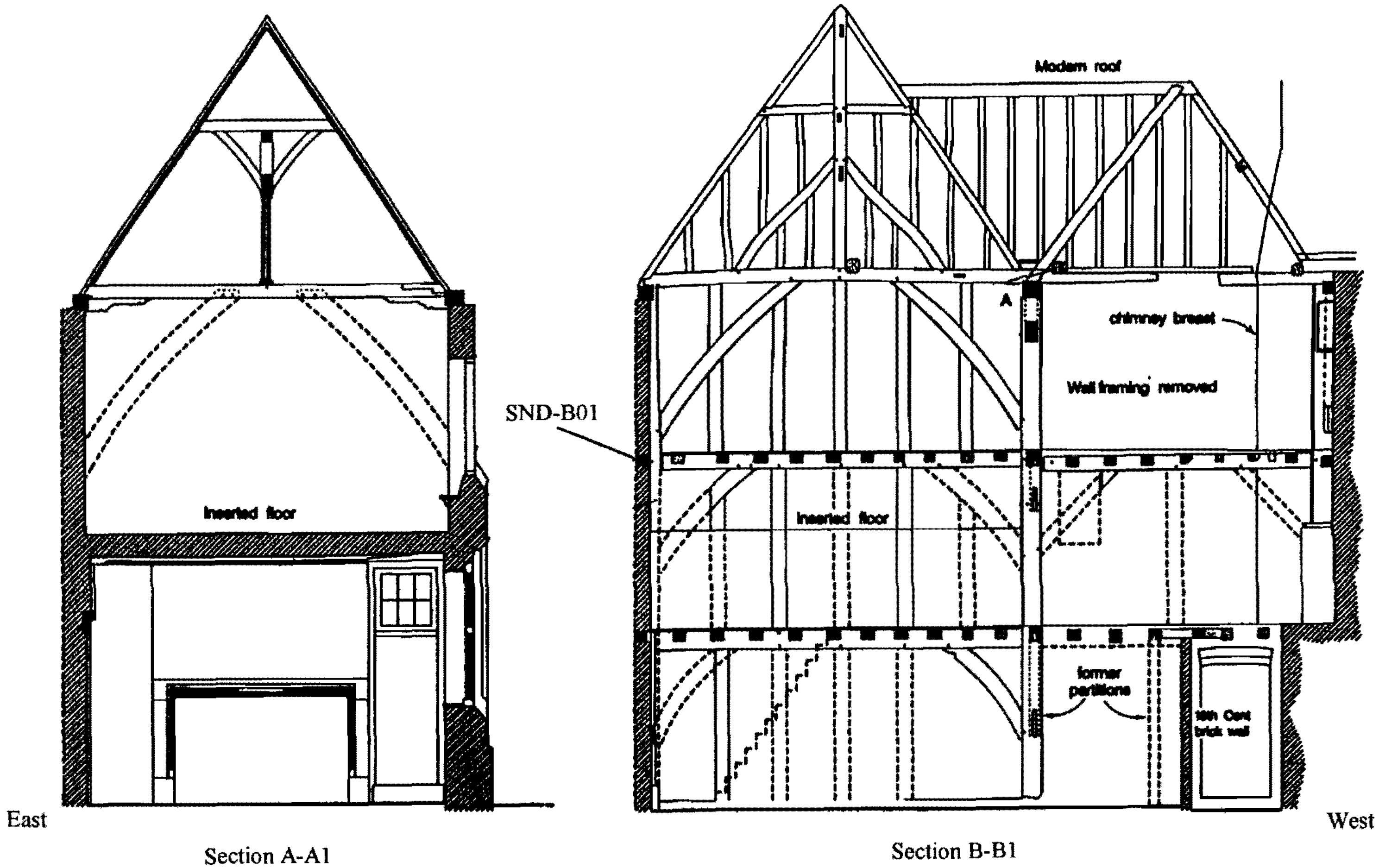

Figure 5: Bar diagram of samples in site sequence SNDBSQ01

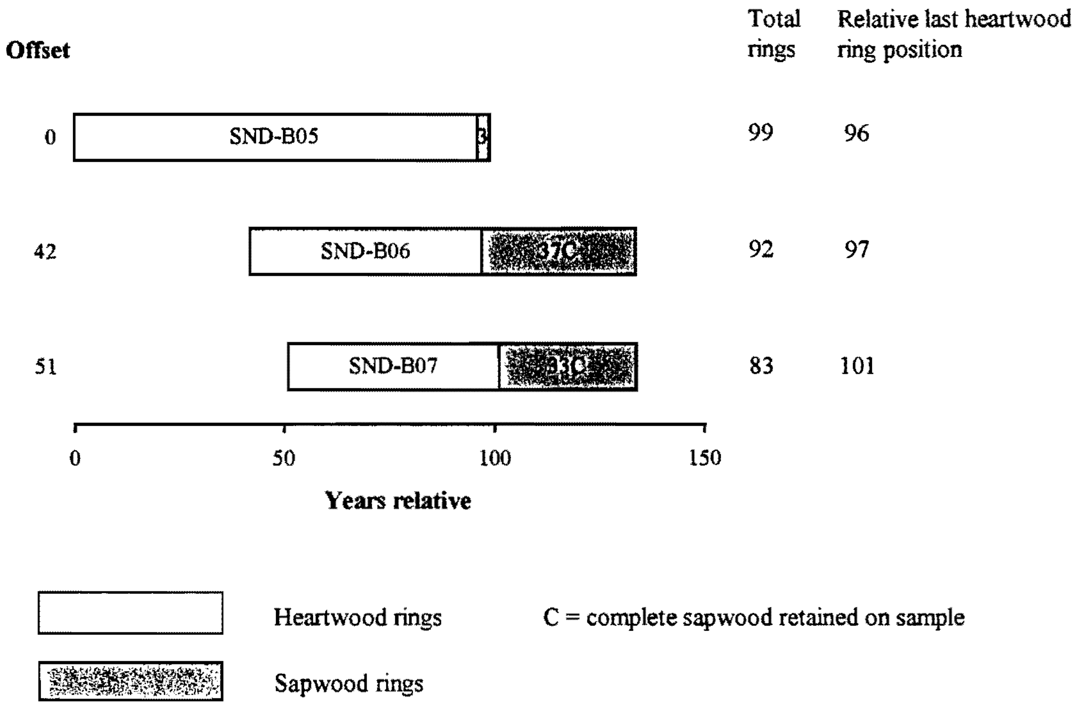

Figure 6: Bar diagram of samples in site sequence SNDBSQ02

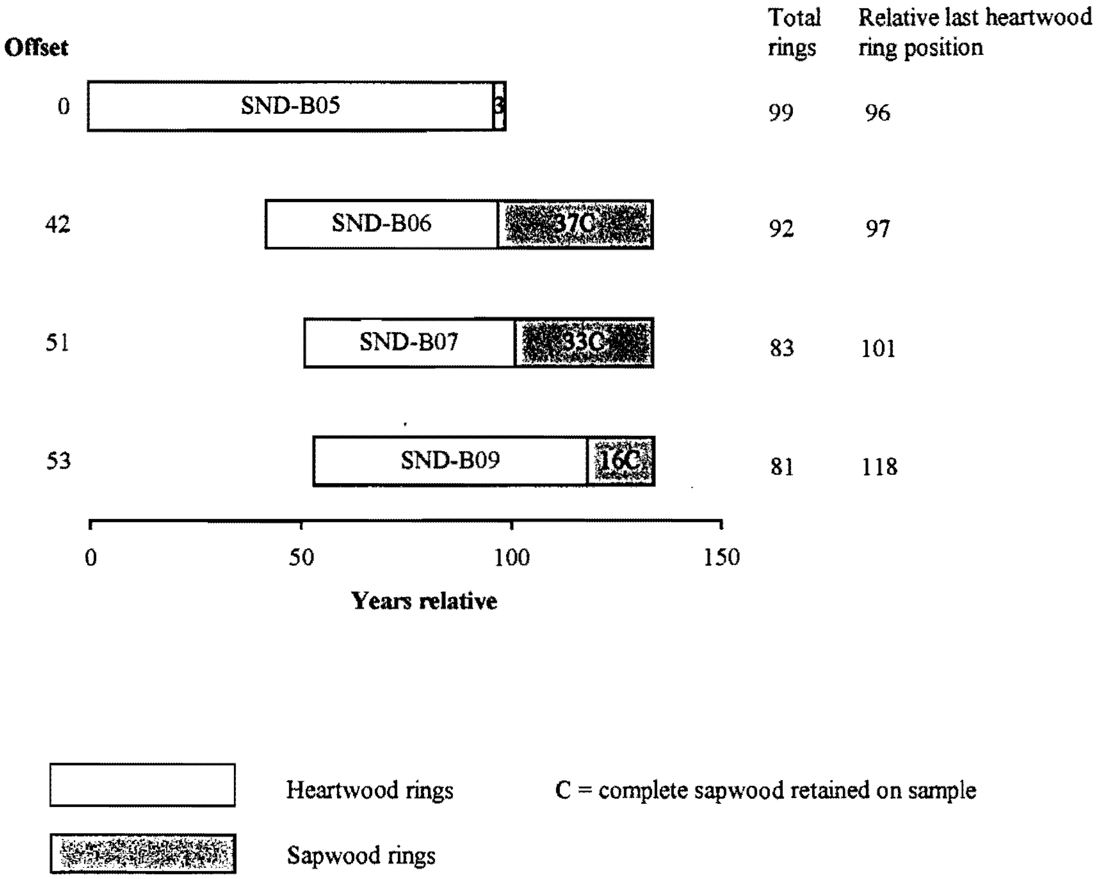

Figure 7: Bar diagram of samples in site sequence SNDBSQ03

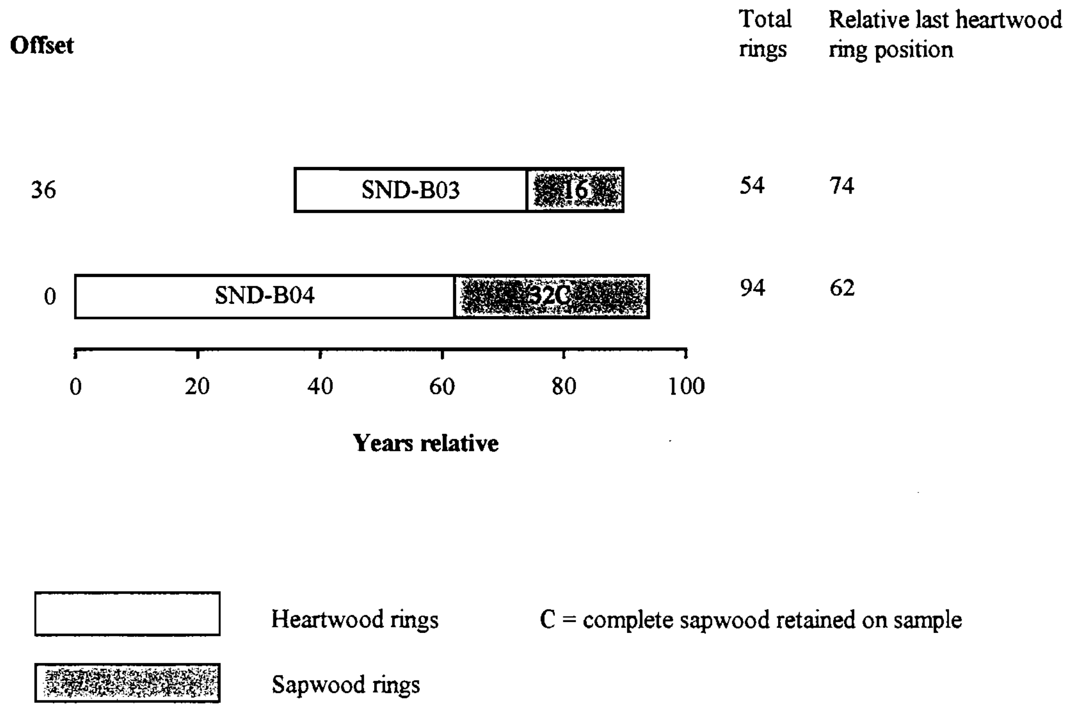

Table 1: Details of tree-ring samples from 39 Strand Street, Sandwich, Kent

Sample number	Sample location	Total rings	Sapwood rings*	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
SND-B01	First-floor cross rail, east wall	104	--	----	----	----
SND-B02	First-floor rail below jetty	79	--	----	----	----
SND-B03	First-floor cross rail of truss B-B'	54	16	1277	1314	1330
SND-B04	Main post B, east side of B-B'	94	32C	1241	1302	1334
SND-B05	Main post, west side of hall, truss B-B'	99	03	1201	1296	1299
SND-B06	Tenth joist from east end	92	37C	1243	1297	1334
SND-B07	Eleventh joist from east end	83	33C	1252	1301	1334
SND-B08	Fourteenth joist from east end	NM	--	----	----	----
SND-B09	Twelfth joist from east end	81	16C	1254	1318	1334
SND-B10	Third joist from east end	NM	--	----	----	----

*h/s = the heartwood/sapwood boundary is the last ring on sample
C = complete sapwood retained on sample, last measured ring date is felling date
NM = not measured as too few rings

Table 2: Results of the cross-matching of site sequence SNDBSQ01 and relevant reference chronologies when the first-ring date is AD 1201 and the last-ring date is AD 1334

Reference chronology	*t*-value	Span of chronology	Reference
Kent	10.3	AD 1158-1540	Laxton and Litton 1989
London	6.4	AD 413-1728	Tyers and Groves 1998 unpubl
Ightham Mote (Hall), Kent	9.8	AD 1177-1327	Howard *et al* 1988
Ightham Mote (Solar), Kent	8.9	AD 1158-1312	Howard *et al* 1988
Ightham Mote (New Chapel), Kent	7.5	AD 1394-1465	Howard *et al* 1994
Ightham Mote (East Range), Kent	7.0	AD 1276-1402	Howard *et al* 1996
Ightham Mote (West gate tower), Kent	6.7	AD 1161-1308	Howard *et al* 1994
Lower Newlands, Teynham, Kent	6.6	AD 1278-1366	Laxton and Litton 1989

Table 3: Results of the cross-matching of sample SND-B09 and relevant reference chronologies when the first-ring date is AD 1254 and the last-ring date is AD 1334

Reference chronology	*t*-value	Span of chronology	Reference
East Midlands	5.5	AD 882-1981	Laxton and Litton 1988
Kent	5.3	AD 1158-1540	Laxton and Litton 1989
London	4.7	AD 413-1728	Tyers and Groves 1998 unpubl
Reading Abbey	5.6	AD 1160-1407	Groves *et al* 1985
Queens Head, Crowmarsh, Gifford, Oxon	5.0	AD 1203-1341	Haddon-Reece *et al* 1990
Thame Park House, nr Thame, Oxon	4.7	AD 1234-1319	Howard *et al* 1993
Ightham Mote, (East Range), Kent	4.5	AD 1276-1402	Howard *et al* 1996
Chicksands Priory, Bedfordshire	4.4	AD 1200-1541	Howard *et al* 1998

Table 4: Results of the cross-matching of site sequence SNDBSQ02 and relevant reference chronologies when the first-ring date is AD 1201 and the last-ring date is AD 1334

Reference chronology	*t*-value	Span of chronology	Reference
Kent	10.5	AD 1158-1540	Laxton and Litton 1989
London	6.7	AD 413-1728	Tyers and Groves 1998 unpubl
Ightham Mote (Hall), Kent	9.4	AD 1177-1327	Howard *et al* 1988
Ightham Mote (Solar), Kent	9.0	AD 1158-1312	Howard *et al* 1988
Ightham Mote (New Chapel), Kent	7.5	AD 1394-1465	Howard *et al* 1994
Ightham Mote (East Range), Kent	7.2	AD 1276-1402	Howard *et al* 1996
Ightham Mote (West gate tower), Kent	6.7	AD 1161-1308	Howard *et al* 1994
Lower Newlands, Teynham, Kent	6.4	AD 1278-1366	Laxton and Litton 1989

Table 5: Results of the cross-matching of sample SND-B03 and relevant reference chronologies when the first-ring date is AD 1277 and the last-ring date is AD 1330

Reference chronology	*t*-value	Span of chronology	Reference
England	4.3	AD 404-1981	Baillie and Pilcher 1982 unpubl
Green Farm, Bradgate Road, Ansty, Leics	5.3	AD 1254-1449	Alcock *et al* 1990
Walnut Tree, East Sutton, Kent	5.0	AD 1219-1393	Laxton and Litton 1989
Chicksands Priory, Bedfordshire	4.6	AD 1200-1541	Howard *et al* 1998
Ramsey, Gt Wythe	4.3	AD 1215-1443	Laxton and Litton 1988
Merchant Adventurers Hall, York	4.3	AD 1241-1357	Howard *et al* 1992

Table 6: Results of the cross-matching of sample SND-B04 and relevant reference chronologies when the first-ring date is AD 1241 and the last-ring date is AD 1334

Reference chronology	*t*-value	Span of chronology	Reference
England	3.5	AD 404-1981	Baillie and Pilcher 1982
Chicksands Priory, Bedfordshire	5.1	AD 1200-1541	Howard *et al* 1998
Stowmarket Church (tower), Suffolk	4.5	AD 1251-1363	Howard *et al* 1994
Queens Head, Crowmarsh, Gifford, Oxon	4.0	AD 1203-1341	Haddon-Reece *et al* 1990
Walnut Tree, East Sutton, Kent	3.7	AD 1219-1393	Laxton and Litton 1989
Quaintree House Braunston, Leics	3.6	AD 1165-1305	Alcock *et al* 1991
51-2 High Street, Burton on Trent, Staffs	3.6	AD 1156-1387	Howard *et al* 1997
The Old Manor House, Cubbington, Warwicks	3.5	AD 1170-1312	Howard *et al* 1988

Table 7: Results of the cross-matching of site sequence SNDBSQ03 and relevant reference chronologies when the first-ring date is AD 1241 and the last-ring date is AD 1334

Reference chronology	*t*-value	Span of chronology	Reference
Chicksands Priory, Bedfordshire	6.4	AD 1200-1541	Howard *et al* 1998
Stowmarket Church (tower), Suffolk	5.5	AD 1251-1363	Howard *et al* 1994
Walnut Tree, East Sutton, Kent	5.0	AD 1219-1393	Laxton and Litton 1989
Headstone Manor, Headstone, Middlesex	4.9	AD 1234-1305	Howard *et al* 1996
Queens Head, Crowmarsh, Gifford, Oxon	4.6	AD 1203-1341	Haddon-Reece *et al* 1990
The Old Manor House, Cubbington, Warwicks	4.5	AD 1170-1312	Howard *et al* 1988
Quaintree House, Braunston, Leics	4.2	AD 1165-1305	Alock *et al* 1991
51-2 High Street, Burton on Trent, Staffs	4.1	AD 1156-1387	Howard *et al* 1997

Data of measured samples – measurements in 0.01mm units

SND-B01A 104
171 80 158 397 379 379 276 208 206 217 324 546 282 240 347 390 274 251 267 266
268 189 222 243 301 262 267 158 151 206 173 171 182 205 174 106 127 186 127 138
82 115 123 91 105 118 145 115 144 80 125 116 135 112 127 142 112 109 88 117
127 111 106 137 142 153 172 137 117 148 191 105 71 76 135 99 117 93 161 152
94 67 44 92 87 78 70 76 58 86 120 141 93 94 69 63 92 90 59 67
69 98 73 76
SND-B01B 104
149 70 166 401 398 373 279 210 215 228 339 543 277 235 370 395 279 258 257 266
263 188 212 252 299 263 276 159 147 212 191 154 183 200 190 109 127 186 143 116
88 130 104 110 101 137 136 112 124 89 118 122 127 121 133 142 108 103 91 130
111 116 108 135 140 162 171 127 122 156 187 103 70 75 146 94 105 101 153 157
93 70 43 83 92 76 80 58 63 82 117 139 95 81 78 75 85 81 55 59
78 99 59 74
SND-B02A 79
105 196 140 115 145 143 99 130 122 166 119 72 82 59 69 80 79 55 48 45
44 40 50 47 56 123 178 186 248 269 393 452 433 325 460 467 423 331 233 181
176 99 122 120 135 104 137 131 113 102 176 309 304 326 355 353 290 286 232 218
296 255 244 269 257 249 238 192 225 273 214 244 174 118 111 218 181 174 261
SND-B02B 79
205 224 130 110 139 149 109 133 129 165 118 66 79 75 90 66 76 50 55 45
37 50 54 46 60 123 178 180 225 273 401 456 470 338 452 480 429 340 250 194
178 106 117 134 131 109 114 145 110 99 179 310 346 338 343 354 294 282 221 232
276 243 221 215 253 256 220 193 225 267 208 246 192 105 111 213 186 180 255
SND-B03A 54
202 178 203 274 291 254 258 270 279 199 130 193 368 317 194 233 203 261 252 273
273 188 259 176 205 234 101 135 128 158 89 113 131 148 103 73 130 167 155 164
126 137 140 160 244 233 228 105 159 88 160 118 114 143
SND-B03B 54
238 184 201 221 309 247 258 226 246 226 121 186 329 266 174 229 190 248 266 261
266 191 245 196 194 226 92 146 114 165 103 104 133 138 109 61 111 161 149 172
116 135 139 160 232 260 194 86 145 106 140 137 108 127
SND-B04A 94
63 69 131 91 107 155 134 130 267 262 307 307 253 286 299 374 469 270 292 353
211 261 211 260 234 172 154 181 165 221 193 158 159 107 96 93 240 175 186 231
231 182 111 163 91 131 177 160 273 203 160 172 137 172 114 134 175 106 141 78
107 141 79 90 89 147 87 77 76 87 83 78 141 106 100 129 69 64 66 110
89 102 62 58 87 64 64 48 53 39 29 31 49 80
SND-B04B 94
63 68 136 99 104 156 138 138 249 269 310 328 239 294 292 368 492 271 288 343
210 261 218 262 224 174 157 178 160 224 201 151 179 108 94 95 243 178 195 243
235 173 118 163 90 131 178 155 275 208 154 178 131 180 109 139 168 108 128 89
96 136 80 92 94 144 78 77 73 94 86 80 130 115 99 120 69 61 62 97
98 94 72 66 83 55 66 50 60 34 39 27 45 85
SND-B05A 99
200 300 295 299 289 216 185 241 223 269 227 243 314 162 208 228 173 154 159 137

121 118 141 231 197 193 131 194 231 113 97 99 120 71 112 103 89 97 116 120
122 100 100 87 61 101 115 85 91 111 101 100 102 103 92 118 84 77 118 133
110 114 81 76 103 81 68 75 67 68 102 71 52 59 51 43 50 48 62 86
56 53 57 58 88 79 69 46 69 61 52 59 68 70 49 70 48 60 60
SND-B05B 99
233 271 296 296 292 233 180 236 215 266 225 235 302 185 194 239 171 154 171 131
120 91 145 233 201 183 127 206 217 116 93 96 118 86 100 103 81 120 102 123
119 102 101 89 70 93 120 76 94 108 96 104 88 110 97 100 89 73 98 131
114 108 77 67 93 83 61 82 59 74 98 73 55 62 56 48 39 58 57 75
69 46 52 49 82 80 61 63 63 73 47 56 57 73 68 60 49 58 57
SND-B06A 92
169 304 250 333 278 206 163 196 211 214 226 231 197 202 194 192 148 226 153 200
131 159 145 128 132 154 156 162 157 116 107 169 151 118 102 95 142 149 134 100
132 117 144 140 144 152 151 171 134 130 143 170 106 128 115 110 144 134 98 95
101 132 121 106 145 92 110 123 92 172 133 133 157 103 81 46 69 63 73 70
79 83 67 62 65 63 66 46 43 36 58 84
SND-B06B 92
166 297 254 343 281 217 165 192 218 206 248 236 187 214 196 178 159 228 159 191
130 153 147 121 125 167 148 165 162 122 101 166 138 113 102 92 137 154 127 99
132 124 145 152 137 146 153 174 128 132 146 170 105 134 100 121 140 139 93 99
102 137 120 118 148 84 96 118 97 165 145 122 172 103 74 51 73 59 81 76
71 77 56 81 58 65 77 73 44 39 66 70
SND-B07A 83
199 298 336 217 269 290 234 230 170 290 261 198 211 208 194 190 202 168 174 178
151 155 196 175 130 119 122 163 172 149 124 150 125 148 146 107 103 135 135 147
124 160 143 100 111 105 138 123 120 89 89 98 127 122 122 145 115 102 96 106
126 124 158 169 117 86 90 111 92 84 106 106 121 71 88 131 104 105 85 63
77 115 120
SND-B07B 83
186 304 332 216 270 291 235 224 192 287 250 203 208 221 218 170 219 165 182 182
154 148 201 170 128 104 119 169 184 153 119 155 141 125 155 106 100 129 147 148
150 166 117 95 109 108 129 120 131 93 81 95 128 124 130 150 111 113 88 109
144 109 150 147 108 102 76 116 92 103 87 116 115 68 84 141 97 109 83 71
79 119 129
SND-B09A 81
345 324 355 416 447 328 370 315 365 288 287 279 245 149 169 141 204 168 161 135
130 91 95 122 94 90 154 147 112 95 101 119 152 87 81 155 159 171 154 146
116 91 104 87 131 109 153 132 94 84 74 77 111 117 106 117 119 90 112 123
132 156 111 63 82 128 108 126 113 90 104 93 65 77 84 85 79 55 59 65
79
SND-B09B 81
345 325 358 408 443 329 373 333 351 275 299 292 253 144 162 160 200 162 149 138
134 94 93 119 87 103 142 135 135 94 107 112 151 93 80 155 154 170 157 146
137 77 96 86 112 126 150 129 102 71 86 77 108 121 105 118 112 101 116 108
131 148 109 58 81 134 109 128 107 93 101 99 92 74 83 83 85 57 54 63
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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 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.

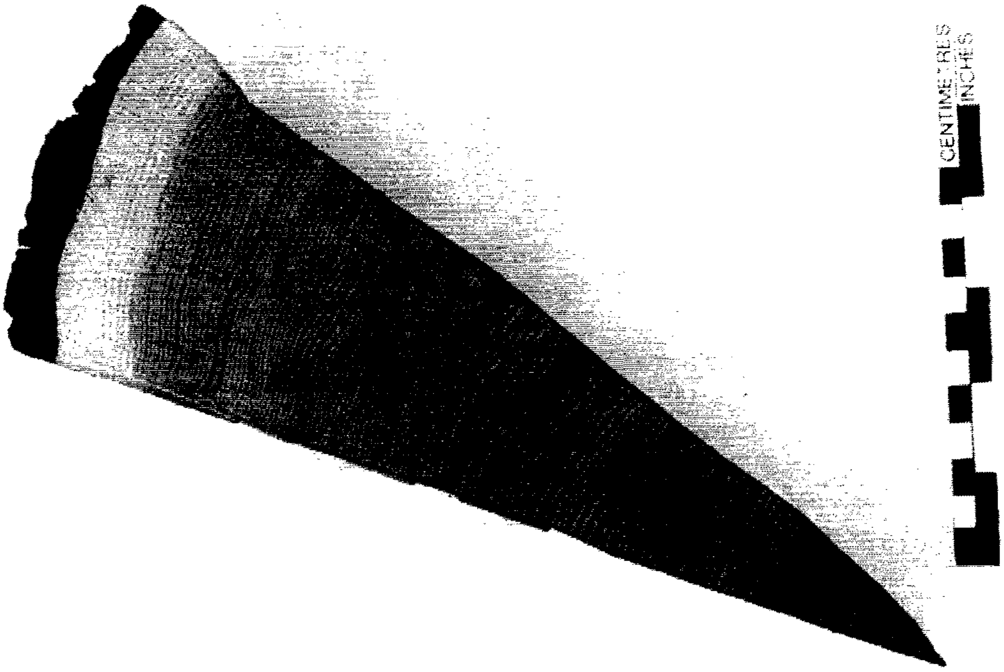

Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

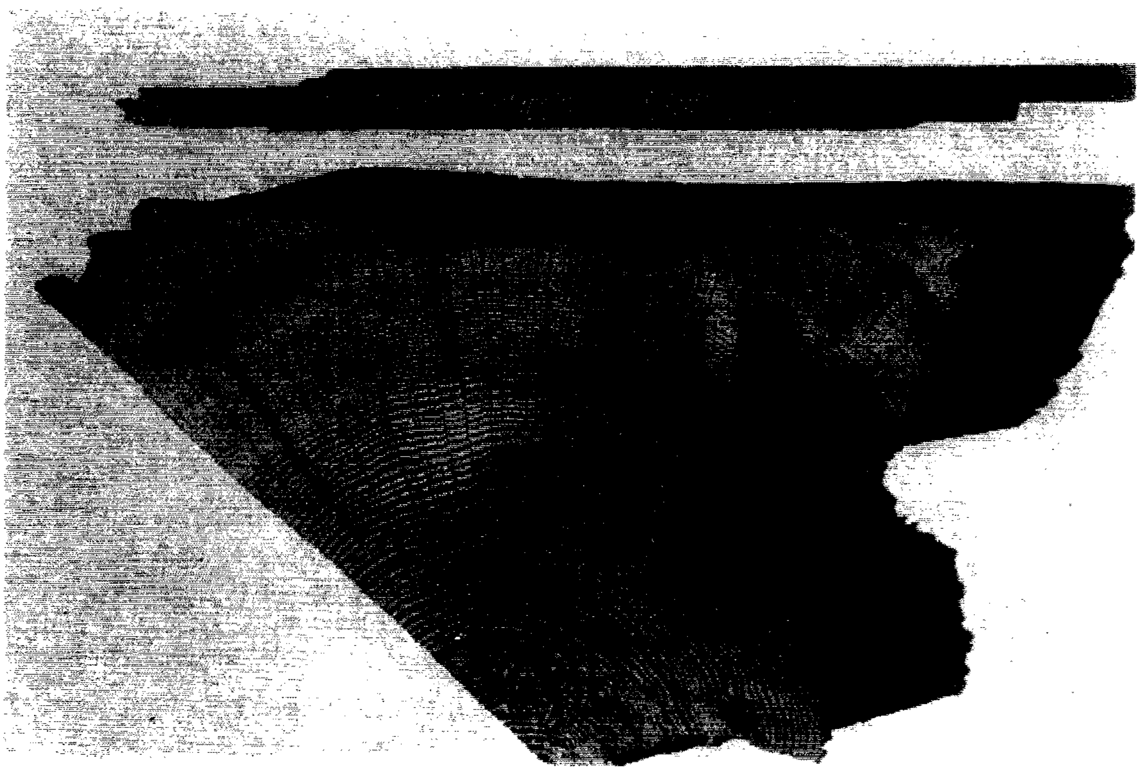

Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners; the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

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.

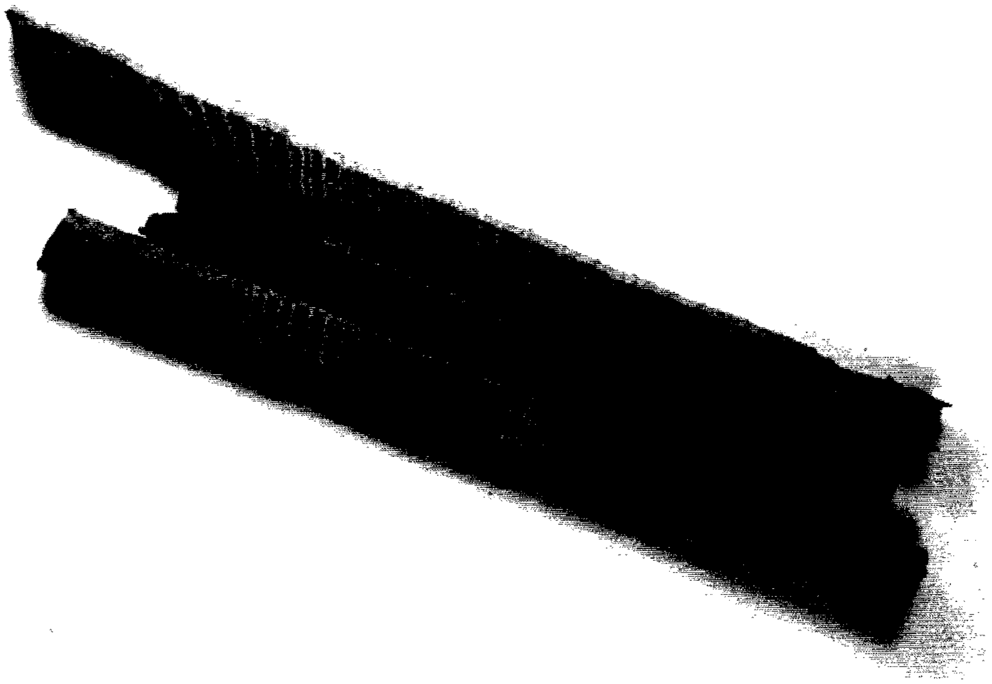

Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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.

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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

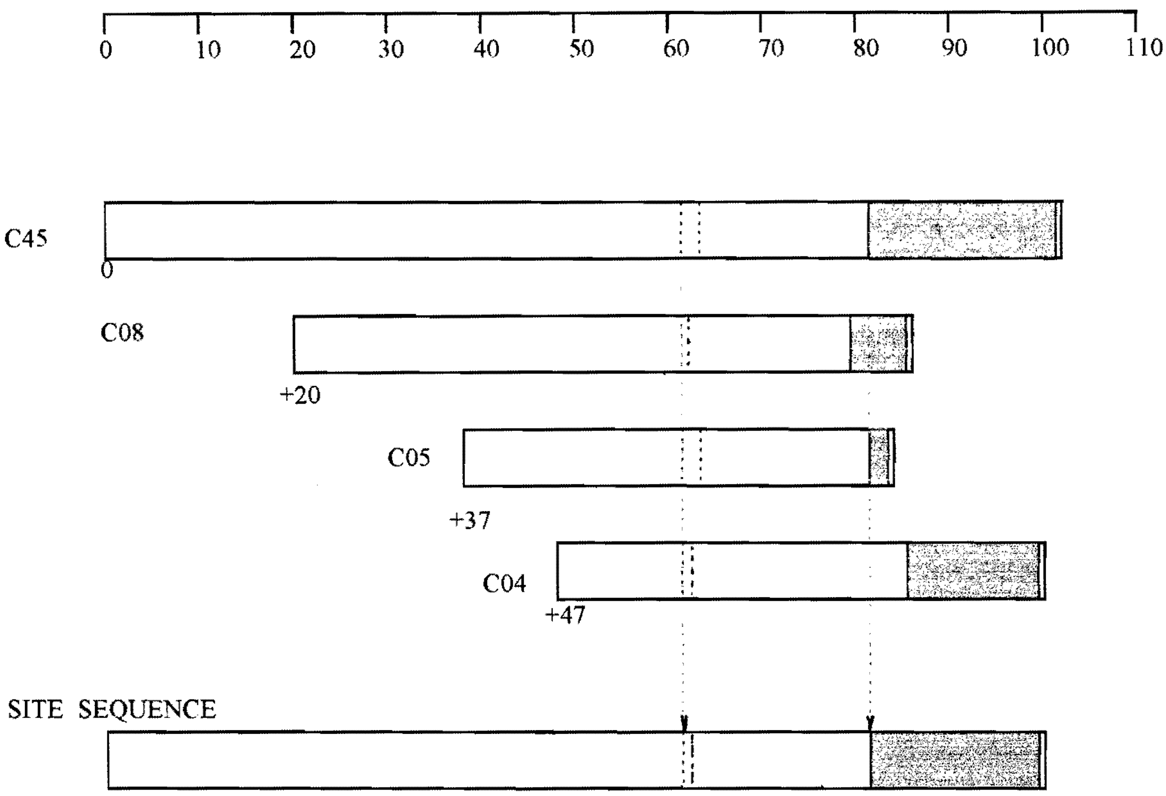

Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.
The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set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

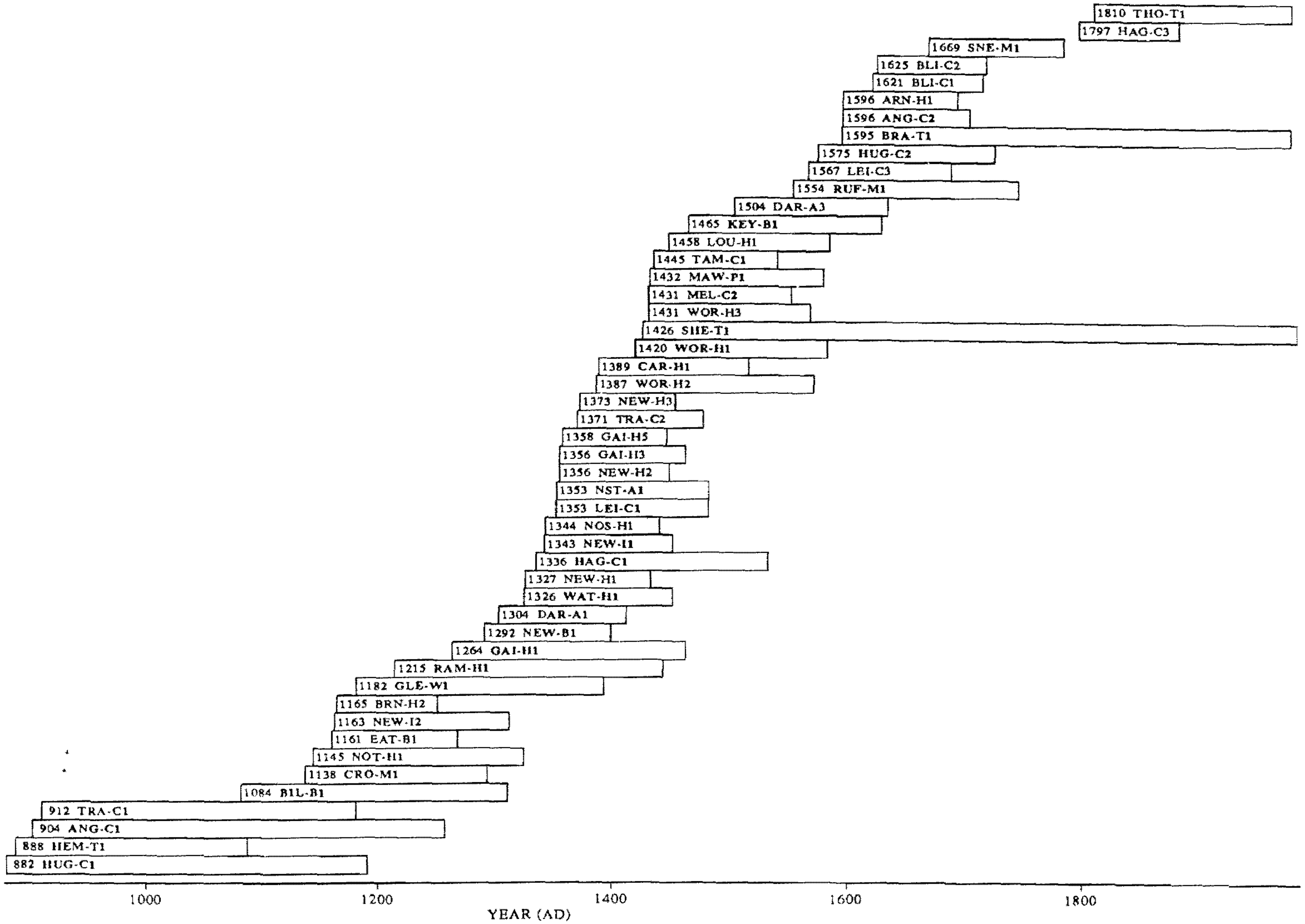

Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

(a)

(b)

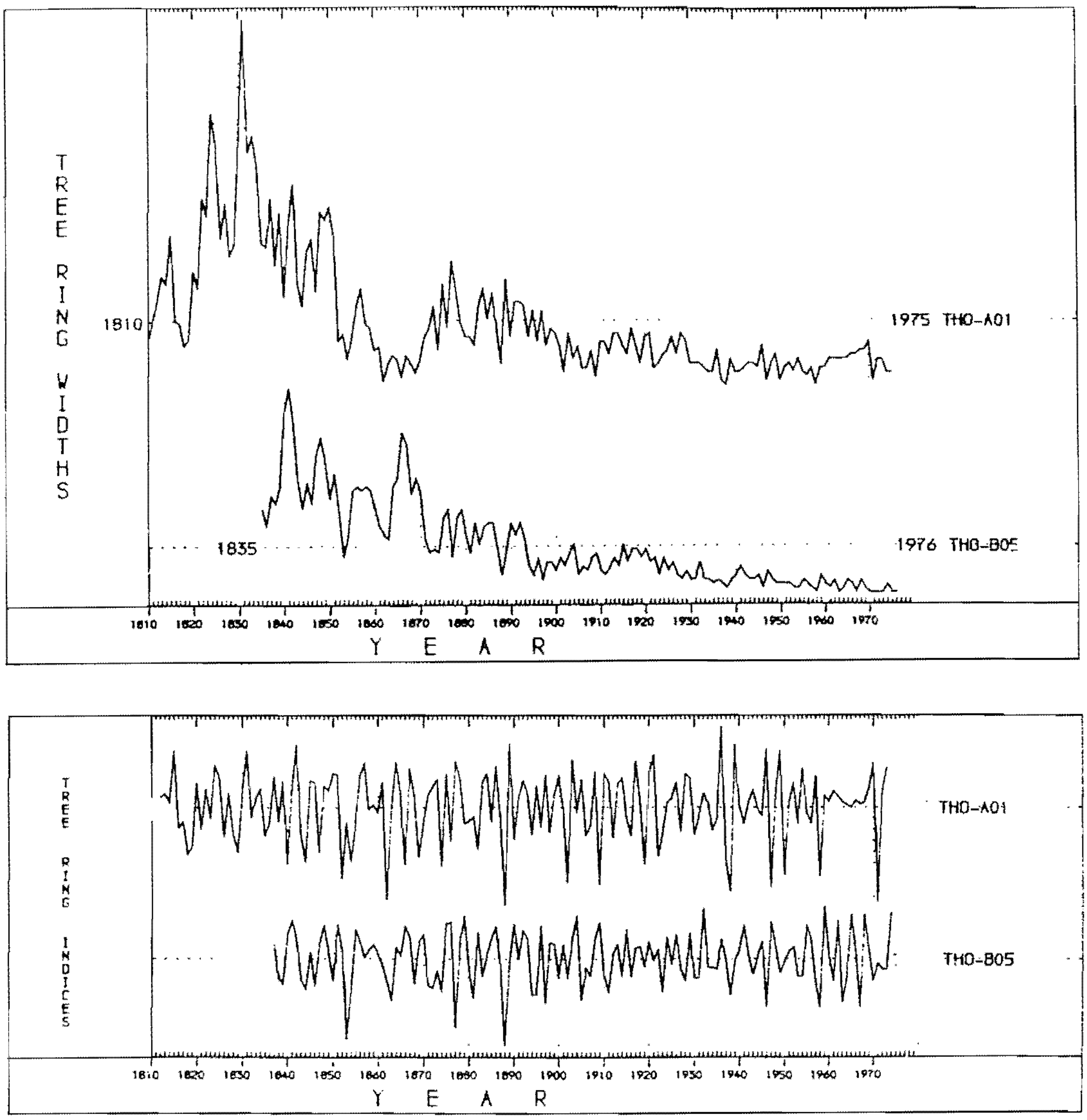

Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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

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

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