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St Peter's Church, West Molesey, Elmbridge, Surrey
Tree-Ring Analysis of Timbers

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Summary

Tree-ring analysis undertaken on timbers of the tower roof and bell-chamber floor at this church has resulted in the successful dating of three site sequences and one individual sample.

Seven of the floor timbers have been dated to a felling within the range AD 1504–22.

Ten roof timbers have also been dated. One of these is now known to have been felled in AD 1518 and nine others to a felling within the range AD 1515–40, consistent with an AD 1518 felling.

The tower itself has been dated on stylistic grounds to the fifteenth century. It is now known that the bell-tower floor and extant roof contain timbers of the early-sixteenth century. If the fifteenth-century date attributed to the tower is correct, the tree-ring results demonstrate that neither the floor nor the roof can be original.

Keywords

Dendrochronology
Standing Building

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Introduction

The Grade-II listed parish church of St Peter (Figs 1 and 2; TQ13376838) in West Molesey, Surrey was rebuilt in AD 1843 but incorporates an earlier three-stage, battlemented tower. The stone and flint tower is Perpendicular in style and believed to have been erected in about AD 1420. The present church replaced an earlier one thought to date to the end of the twelfth century, which consisted simply of a nave and chancel, and had a small porch on the south side.

The extant tower roof is of three trusses, with each truss consisting of king post and principal rafters. There is a ridge beam, common rafters, and a single purlin on each side (Fig 3). The bell-tower floor consists of eight heavy joists running east-west and three supporting beams running north-south (Fig 4).

Objectives

Sampling and analysis by tree-ring dating was commissioned and funded by English Heritage to inform grant-aided repairs. The two particular areas of interest identified were the tower roof and the bell-chamber floor. Presently, it is unclear as to whether either of these structures are original to the tower or represent later work. For this reason gaining felling dates for the timbers used in their construction would be extremely useful. The identification of any fifteenth-century timbers would also provide support for the stylistic date attributed to the tower itself.

Acknowledgements

The Laboratory would like to thank Nye Saunders, the project architects, for assisting with access and their help on site. Figures 5–9 were kindly provided by the structural engineers, Hockley and Dawson. Thanks are also given to Cathy Tyers of the Dendrochronology Laboratory at Sheffield University for her advice and assistance with this site, especially in providing further reference chronologies against which to date the site sequences.

Sampling

A total of 22 samples was obtained from timbers of the roof and bell-tower floor. Each sample was given the code MOL-A (for Molesey, site 'A') and numbered 01–22. Twelve of these samples were from the roof timbers (MOL-A01–12) and ten from the floor beams (MOL-A13–22). The position of samples was noted at the time of sampling and has been marked on Figures 5–9. Further details relating to the samples can be found in Table 1. The roof trusses were identified as north, mid, and south truss, and the floor beams numbered north to south.

Within the roof are two beams which had been particularly highlighted as of interest, one adjacent to the north parapet and a second at the southern end of the roof. Unfortunately, neither of these beams was suitable for analysis. The northern timber had too few rings for secure dating and the southern beam was softwood. Therefore, neither was sampled.

Analysis and Results

At this stage it was noticed that three of the floor samples (MOL-A13, MOL-A14, and MOL-A22) had too few rings to make secure dating a possibility and these samples was rejected prior to measurement. The remaining 19 samples were prepared by sanding and polishing and their growth-ring widths measured; the data of these measurements are given at the end of the report. All 19 samples were compared with each other by the Litton/Zainodin grouping procedure (see appendix).

At a least value of *t*=4.5, 16 samples had formed three groups. Firstly, seven samples matched and were combined at the relevant offset positions to form MOLASQ01, a site sequence of 140 rings (Fig 10). This site sequence was then compared with a large number of relevant reference chronologies for oak indicating a consistent match when the date of its first ring is AD 1364 and of its last measured ring is AD 1503. The evidence for this dating is given by the *t*-values in Table 2.

Five samples matched and were combined at the relevant offset positions to form MOLASQ02, a site sequence of 121 rings (Fig 10). This site sequence was then compared against the reference chronologies where it was found to match consistently at a first-ring date of AD 1382 and a last-ring date of AD 1502. The evidence for this dating is given by the *t*-values in Table 3.

Finally, four samples matched and were again combined at the relevant offset position to form MOLASQ03, a site sequence of 109 rings. This site sequence was found to span the period AD 1410–1518. The evidence for this dating is given by the *t*-values in Table 4.

Attempts were then made to date the remaining three ungrouped samples by individually comparing them with the reference material. This resulted in sample MOL-A11 being found to span the period AD 1440–1512. The evidence for this is given by the *t*-values in Table 5. The remaining two samples could not be matched and are undated.

Interpretation

Analysis of 19 samples taken from timbers of the roof and floor of the bell tower of this church has resulted in the construction and dating of three site sequences and the individual dating of one sample.

Site sequence MOLASQ01 contains seven samples, all from the bell-tower floor, and spans the period AD 1364–1503. All seven samples have the heartwood/sapwood boundary ring, the dates of which are similar and, therefore, consistent with a single felling. The average of these is AD 1482, allowing an estimated felling date to be calculated for the seven timbers represented to within the range AD 1504–22 (this allows for sample MOL-A17 having a last measured ring date of AD 1503 with incomplete sapwood.)

Ten of the roof timbers have been successfully dated within site sequences MOLASQ02 and MOLASQ03, or individually (MOL-A11). One of these samples, MOL-A04, has complete sapwood and the last measured ring date of AD 1518, the felling date of the timber represented. Seven of the other dated roof samples have the heartwood/sapwood boundary ring, the dates of which are broadly contemporary and, therefore, again suggestive of a single felling. The average of these dates is AD 1500, allowing an estimated felling date to be calculated for the seven timbers represented to within the range AD 1515–40, a felling date range consistent with an AD 1518 felling. Two other samples dated within site sequence MOLASQ02 do not have the heartwood/sapwood boundary ring date and so an estimated felling date cannot be calculated for these. However, with last measured ring dates of AD 1481 (MOL-A07) and AD 1490 (MOL-A09) it is also possible that these were felled in the early-sixteenth century.

That these two samples are contemporary with the rest of the roof timbers is supported by the high values at which they match other samples within MOLASQ02. Sample MOL-A07 matches MOL-A08 at *t*=11.9 and MOL-A12 at *t*=11.0, whilst sample MOL-A09 matches MOL-

A08 at *t*=16.01 and MOL-A12 at *t*=13.7. At the very least these high values point towards a group of trees grown very closely together being utilised for these beams, and perhaps may even suggest that two or more of them are from the same tree.

All felling date ranges have been calculated using the estimate that 95% of mature oak trees from this area have 15–40 sapwood rings.

Discussion

Prior to dendrochronological analysis being undertaken at this church, the tower itself had been dated stylistically to the fifteenth century, although whether the roof and/or bell-chamber floor were original was unclear.

Tree-ring analysis has successfully dated ten of the roof timbers. One of these is known to have been felled in AD 1518, with the felling date range calculated for another seven of the beams being consistent with these timbers having also been felled at this time.

Seven of the timbers from the bell-chamber floor have also been dated, to a felling within the range AD 1504–22.

The felling date range calculated for the timbers of the bell-chamber floor encompasses AD 1518. This may mean that the timbers used in the roof and in the floor were felled at the same time. However, when the dated samples are ordered by heartwood/sapwood boundary ring date (Fig 11) it can be seen that those of the floor timbers are consistently slightly earlier than those of the roof timbers. This might suggest that the timbers used in the construction of the floor were actually felled slightly before those used in the roof. Alternatively, it may simply be that the trees used in the floor structure had slightly more sapwood rings than those of the roof.

The analysis has shown that the timber of the roof and the bell-chamber floor falls into four distinct groups (as demonstrated by the three site sequences and single sample) rather than being a single coherent group. This is particularly of interest if the two structures are in fact contemporary as it perhaps suggests several sources of timber being used.

When tree-ring analysis was requested at this church it was hoped that by gaining a date for the roof and the bell-chamber floor it might be possible to establish whether these structures are contemporary with the tower itself. If the fifteenth-century date attributed to the tower is correct then it is clear that neither the roof nor the bell-chamber floor can be original to it, as they are constructed from timbers which were still growing at the end of the fifteenth century. Rather than belonging to the fifteenth century, the results suggest both the floor and the roof date to the first quarter of the sixteenth century.

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Table 1: Details of tree-ring samples from St Peter's Church, West Molesey, Elmbridge, Surrey. Timbers numbered from north to south.

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Roof						
MOL-A01	Tiebeam, north truss	69	h/s	1434	1502	1502
MOL-A02	King post, north truss	81	h/s	1424	1504	1504
MOL-A03	Tiebeam, mid truss	64	h/s	----	----	----
MOL-A04	West principal rafter, mid truss	109	14C	1410	1504	1518
MOL-A05	King post, mid truss	76	h/s	1426	1501	1501
MOL-A06	King post, south truss	99	03	1410	1505	1508
MOL-A07	North east purlin	100	--	1382	----	1481
MOL-A08	North west purlin	103	h/s	1392	1494	1494
MOL-A09	South west purlin	92	--	1399	----	1490
MOL-A10	East common rafter 2, bay 1	85	h/s	----	----	----
MOL-A11	West common rafter 2, bay 2	73	15	1440	1497	1512
MOL-A12	East common rafter 4, bay 2	75	01	1422	1495	1496
Floor						
MOL-A13	Mid supporting beam	NM	--	----	----	----
MOL-A14	West supporting beam	NM	--	----	----	----
MOL-A15	Beam 1	76	h/s	1411	1486	1486
MOL-A16	Beam 2	101	h/s	1385	1485	1485
MOL-A17	Beam 3	137	17	1367	1486	1503
MOL-A18	Beam 4	96	h/s	1383	1478	1478
MOL-A19	Beam 5	108	h/s	1375	1482	1482
MOL-A20	Beam 6	89	h/s	1390	1478	1478
MOL-A21	Beam 7	118	h/s	1364	1481	1481
MOL-A22	Beam 8	NM	--	----	----	----

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

Table 2: Results of the cross-matching of site sequence MOLASQ01 and relevant reference chronologies when the first-ring date is AD 1364 and the last-ring date is AD 1503

Reference chronology	*t*-value	Span of chronology	Reference
England, London	5.6	AD 413–1728	Tyers and Groves 1999 unpubl
Kent	5.3	AD 1158–1540	Laxton and Litton 1989
Hays Wharf, Southwark, London	6.2	AD 1248–1647	Tyers 1996
Walmer Castle, Kent	5.9	AD 1396–1523	Howard *et al* 1997a
Headstone Manor Barn, Harrow, London	5.6	AD 1374–1505	Howard *et al* 2000
Old Palace Lane, Richmond, London	5.6	AD 1358–1584	Hillam 1997
Windsor Castle Kitchen, Berkshire	5.3	AD 1331–1573	Tyers *et al* 1997
Langmans, Woking, Surrey	5.1	AD 1437–1536	Miles and Worthington 2000

Table 3: Results of the cross-matching of site sequence MOLASQ02 and relevant reference chronologies when the first-ring date is AD 1382 and the last-ring date is AD 1502

Reference chronology	*t*-value	Span of chronology	Reference
England, London	9.7	AD 413–1728	Tyers and Groves 1999 unpubl
Kent	6.7	AD 1158–1540	Laxton and Litton 1989
Hampshire	9.9	AD 443–1972	Miles 2003
St Andrews Church, Ford, West Sussex	10.7	AD 1286–1511	Bridge 2000
Hays Wharf, Southwark, London	9.0	AD 1248–1647	Tyers 1996
Abbey Gatehouse roof, Bristol Cathedral	8.0	AD 1306–1494	Arnold *et al* 2003a
Headstone Manor Barn, Harrow, London	7.5	AD 1374–1505	Howard *et al* 2000
Stonepits Manor, Seal, Kent	7.4	AD 1389–1497	Arnold *et al* 2003b

Table 4: Results of the cross-matching of site sequence MOLASQ03 and relevant reference chronologies when the first-ring date is AD 1410 and the last-ring date is AD 1518

Reference chronology	*t*-value	Span of chronology	Reference
England, London	4.2	AD 413–1728	Tyers and Groves 1999 unpubl
Hampshire	4.5	AD 443–1972	Miles 2003
Cowfold Barn at Singleton, West Sussex	6.0	AD 1377–1535	Tyers 1990
Westenhanger Castle Barn, Kent	6.1	AD 1433–1578	Howard *et al* 2002
Ightham Mote, NW Range	5.6	AD 1465–1586	Howard *et al* 1997b
Victoria Wharf, Tower Hamlets, London	5.5	AD 1410–1585	Tyers and Hall 1997
Rookwood Hall Barn, Abbess Roding, Essex	5.5	AD 1416–1537	Tyers and Hibberd 1993
Chiddingly Place, East Sussex	5.4	AD 1324–1576	Arnold and Litton 2003

Table 5: Results of the cross-matching of sample MOL-A11 and relevant reference chronologies when the first-ring date is AD 1440 and the last-ring date is AD 1512

Reference chronology	*t*-value	Span of chronology	Reference
England, London	6.2	AD 413–1728	Tyers and Groves 1999 unpubl
Hampshire	5.7	AD 443–1972	Miles 2003
Ightham Mote, Cottage/Dovecote	7.3	AD 1392–1463	Howard *et al* 1994
Ightham Mote, East Range	7.1	AD 1405–1521	Howard *et al* 1996a
Abbey Road, Barking, London	6.3	AD 1314–1599	Tyers 2001
Hays Wharf, Southwark, London	6.0	AD 1248–1647	Tyers 1996
Reigate Priory School, Reigate, Surrey	5.7	AD 1384–1545	Bridge 2003
Mercer’s Hall, Glos	5.4	AD 1289–1541	Howard *et al* 1996b

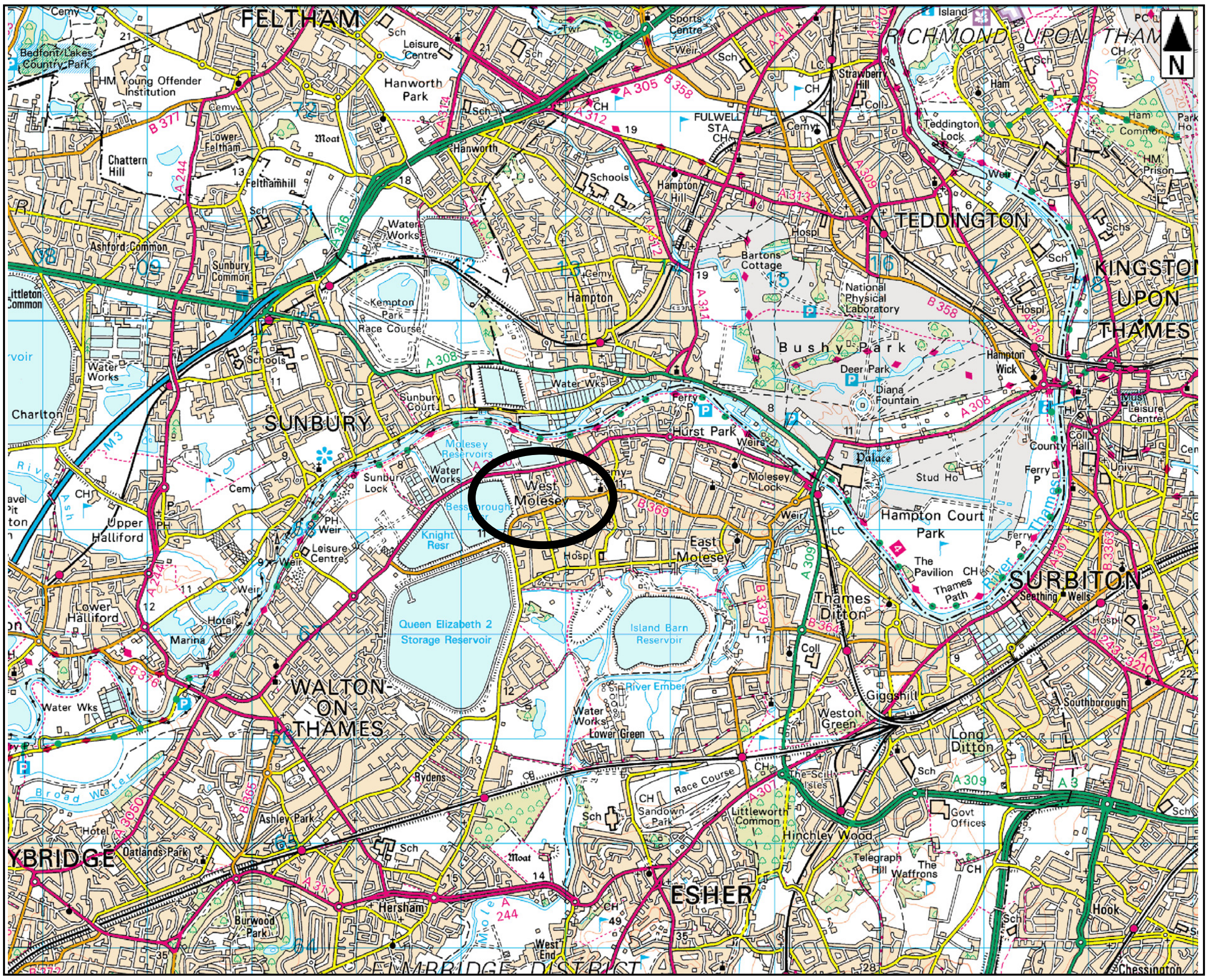


Figure 1: Map to show the location of West Molesey, Surrey

Figure 2: Map to show the location of St Peter's Church, West Molesey

Figure 3: St Peter’s Church, tower roof (north truss)

Figure 4: St Peter's Church, bell-tower floor (looking north-west)

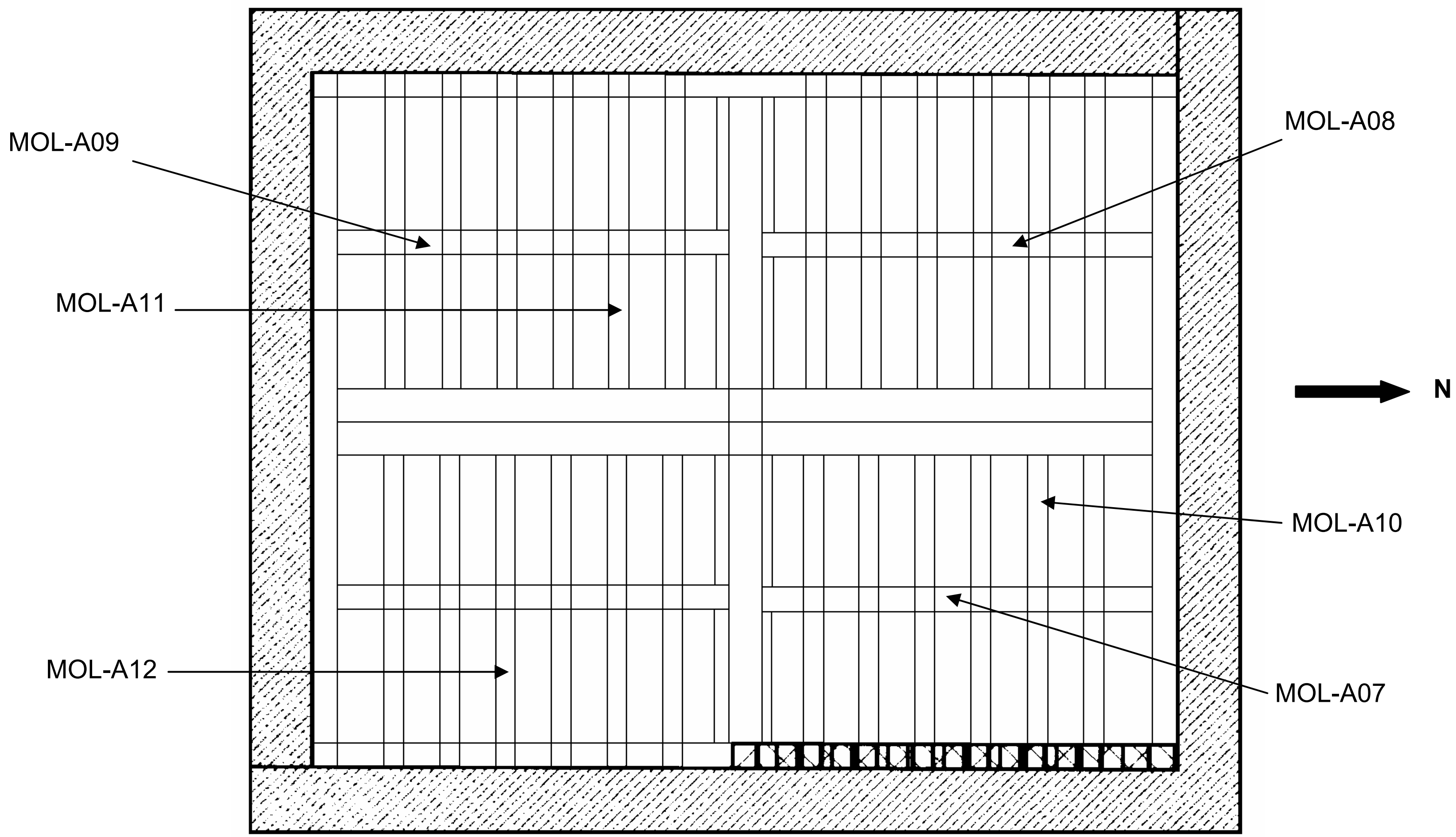


Figure 5: Plan of roof structure, showing the location of samples MOL-A07–12 (Hockley and Dawson)

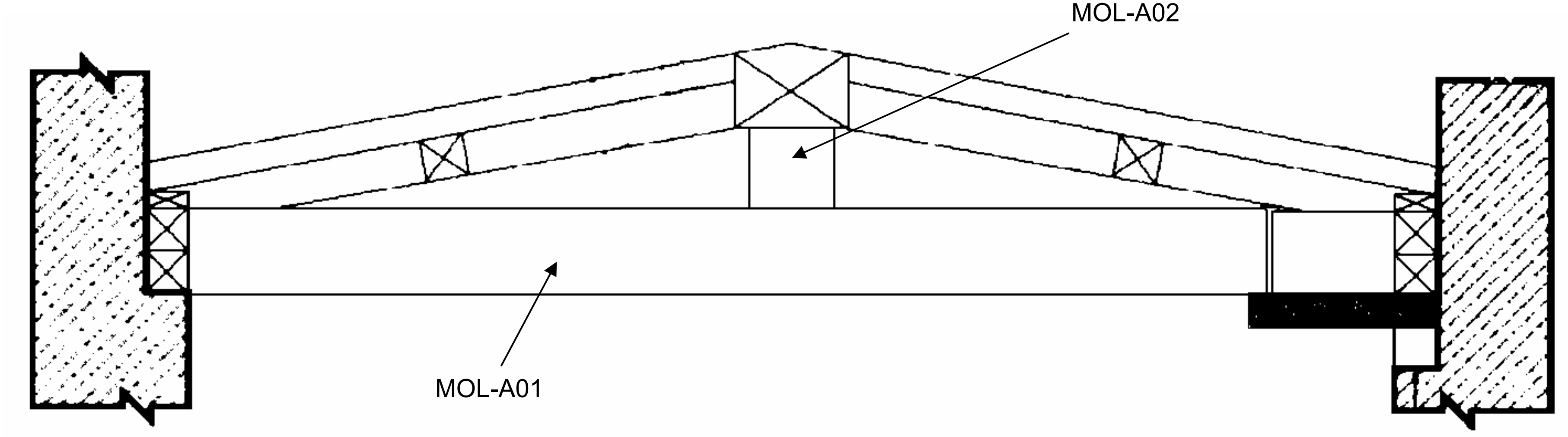


Figure 6: Roof truss, north truss, showing the location of samples MOL-A01 and MOL-A02 (Hockley and Dawson)

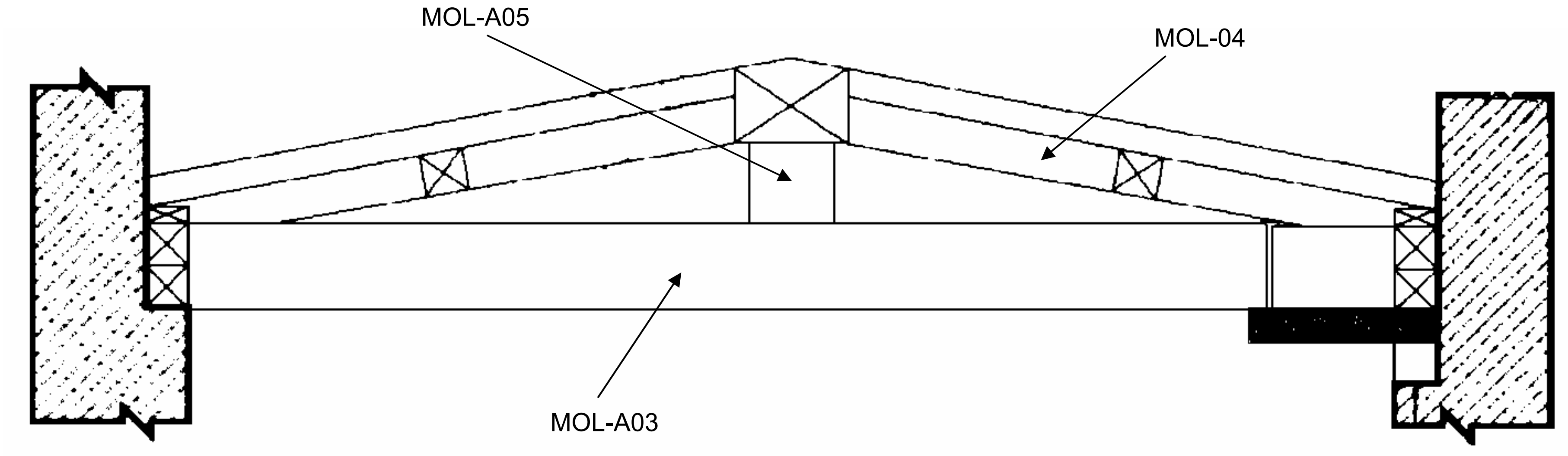


Figure 7: Roof truss, mid truss, showing the location of samples MOL-A03–5 (Hockley and Dawson)

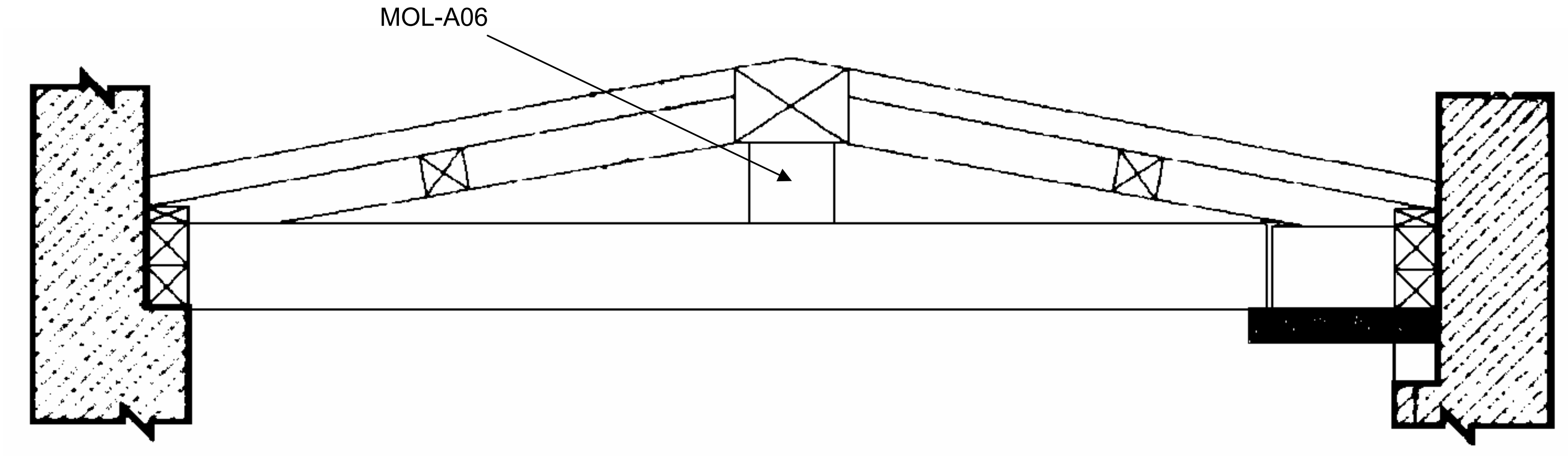


Figure 8: Roof truss, south truss, showing the location of samples MOL-A06 (Hockley and Dawson)

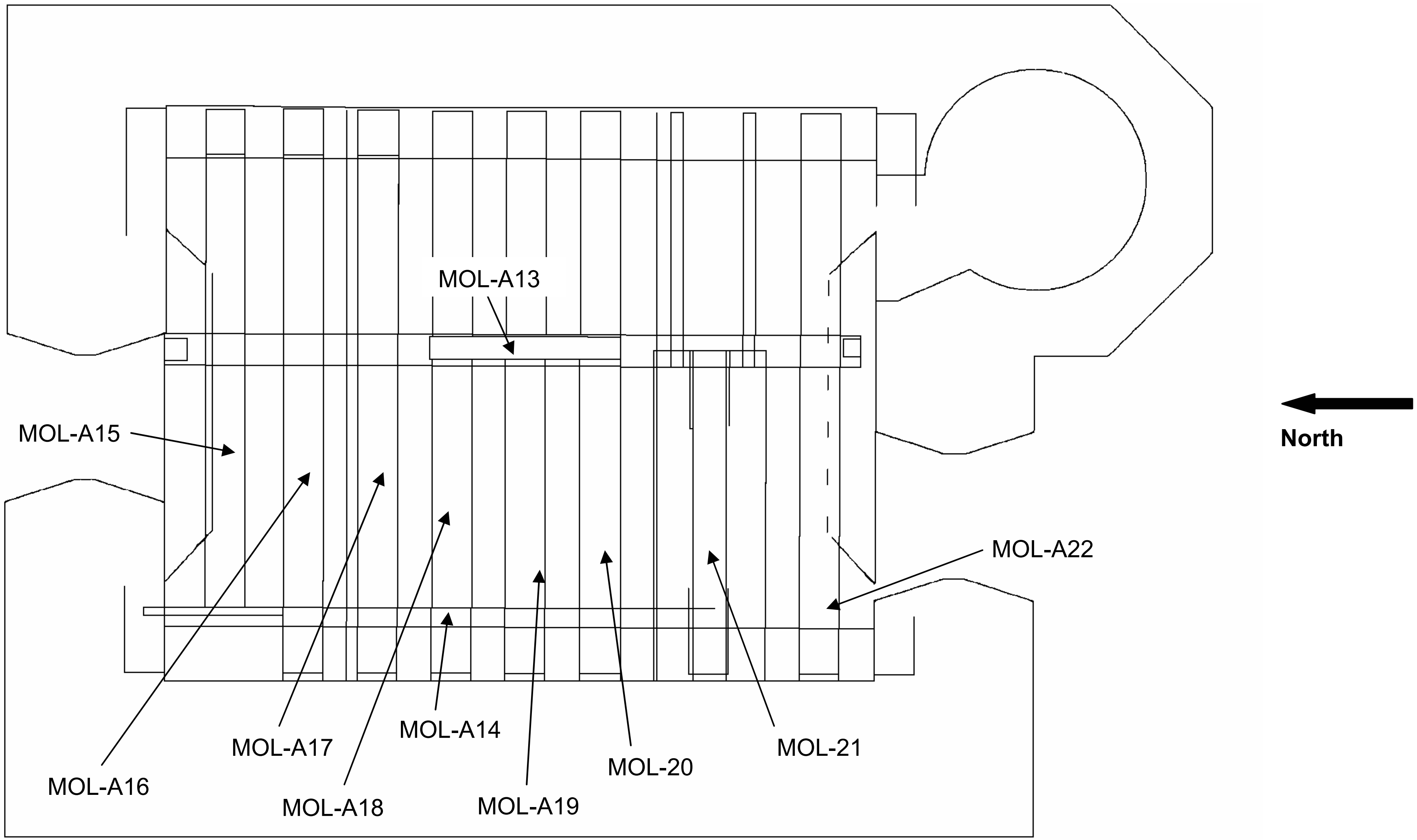
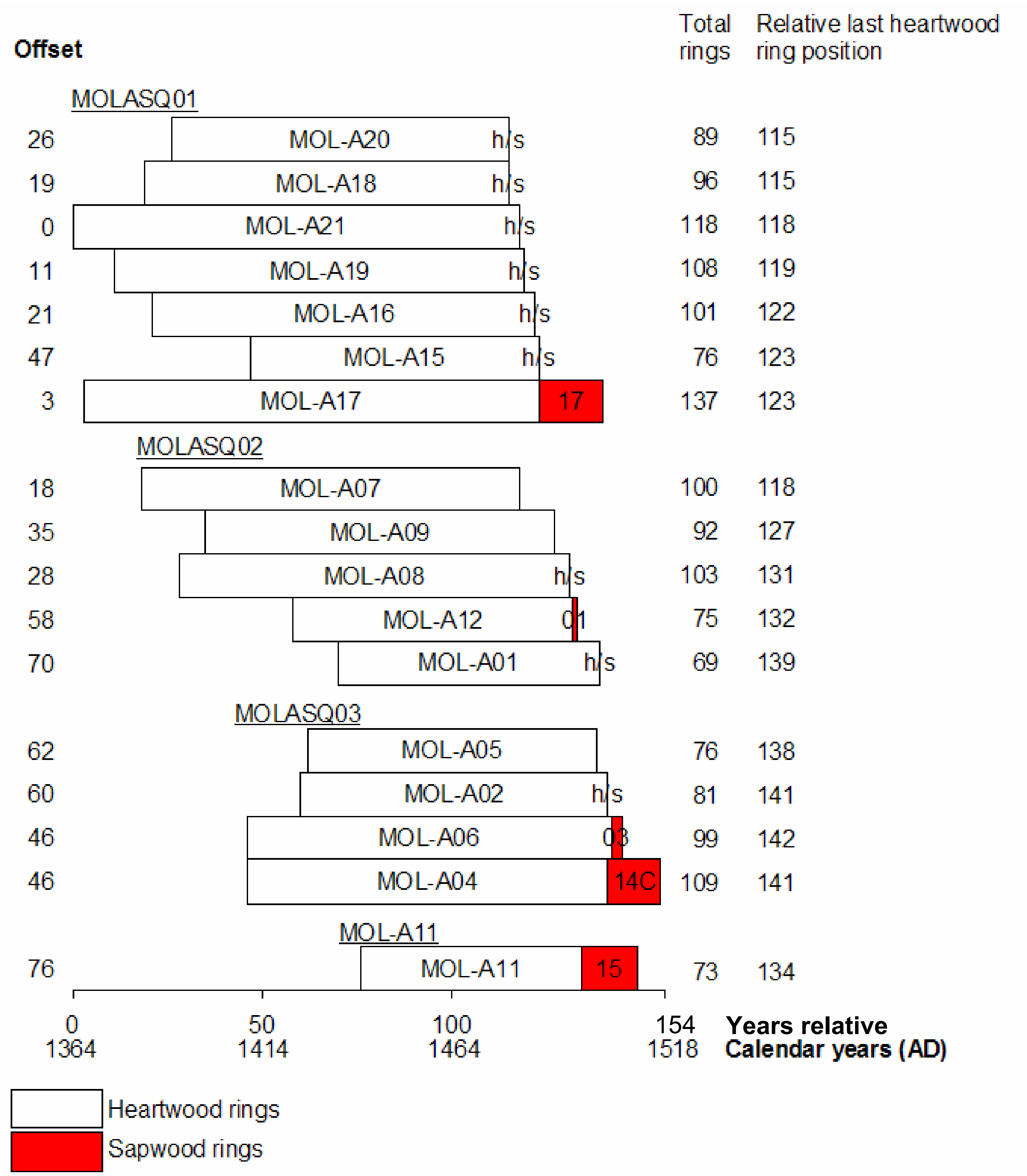


Figure 9: Plan of floor, showing the location of samples MOL-A13–22 (Hockley and Dawson)



h/s = the heartwood/sapwood boundary ring is the last ring on the sample
C = complete sapwood retained on sample, last measured ring is the felling date

Figure 10: Bar diagram of dated samples

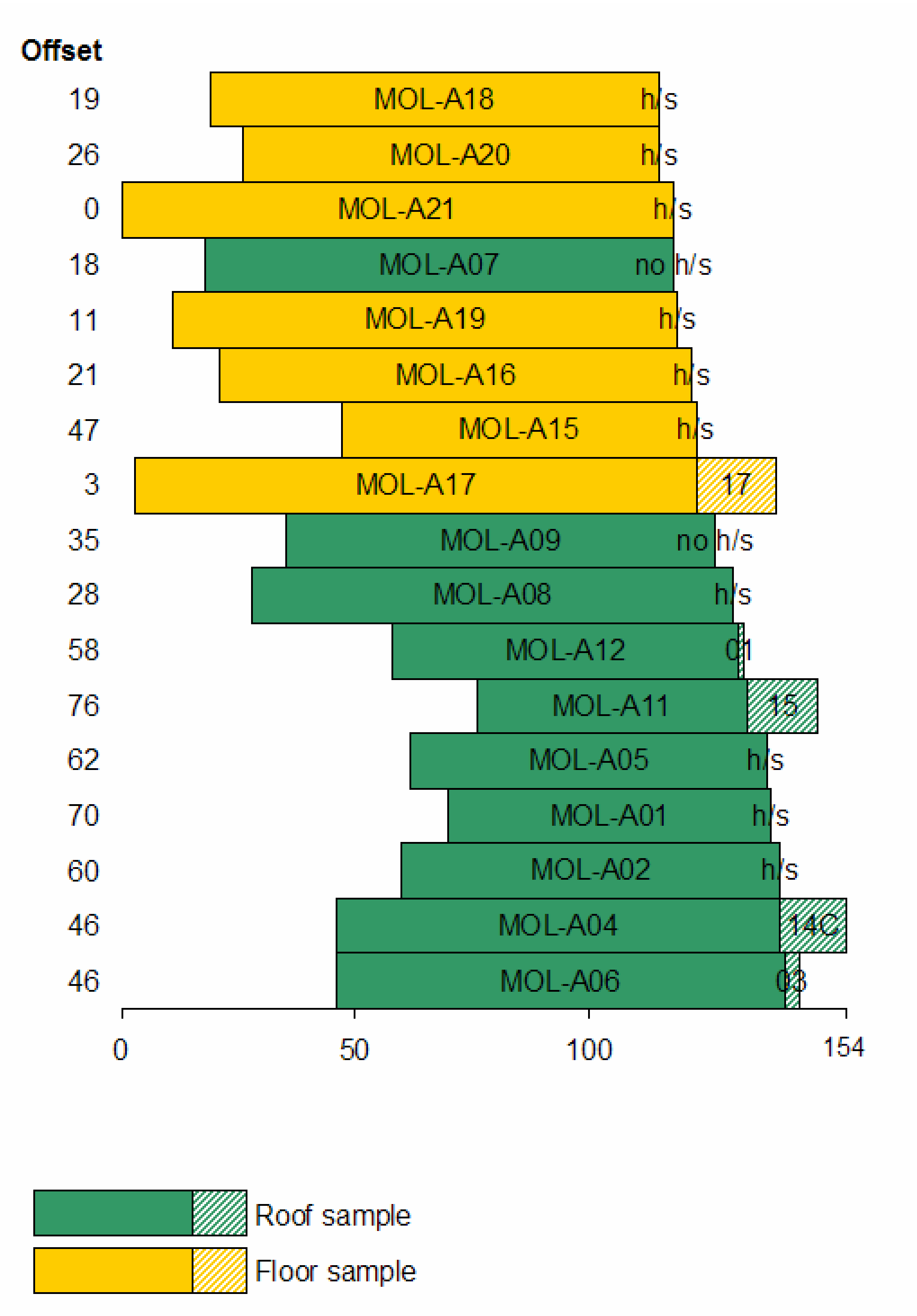


Figure 11: Bar diagram of samples in last heartwood ring date order

Data of measured samples – measurements in 0.01mm units

MOL-A00A 79
351 384 312 362 308 324 413 373 508 384 396 354 356 335 299 276 289 339 303 238
209 202 238 210 208 226 156 191 176 172 122 108 122 145 252 195 185 155 97 173
136 142 180 159 145 163 161 136 73 106 141 116 136 136 140 149 153 136 132 144
153 130 131 101 94 140 140 156 121 161 151 87 145 131 189 179 149 151 127
MOL-A01A 69
131 134 173 164 147 178 153 214 208 160 172 156 148 187 92 162 169 234 168 168
282 274 354 356 263 295 190 125 196 253 179 151 243 174 252 181 158 134 115 140
177 236 171 108 133 148 118 183 99 106 81 85 117 122 169 181 252 157 171 171
190 223 209 241 150 136 100 103 91
MOL-A01B 69
131 135 173 162 152 177 156 209 198 168 196 140 160 186 94 165 175 240 168 167
282 276 349 353 263 288 192 136 209 263 182 152 234 176 249 182 158 129 123 128
170 231 173 102 133 146 123 182 94 93 96 88 114 122 163 183 259 158 169 171
187 221 212 243 147 127 88 105 115
MOL-A02A 81
154 183 216 179 208 184 176 229 175 234 184 107 84 133 110 142 186 177 137 166
125 148 101 183 145 174 144 137 167 150 194 162 173 142 109 91 110 67 106 160
123 148 172 149 149 97 140 77 122 116 125 191 133 97 87 81 141 129 156 134
115 149 195 201 148 160 165 113 102 130 129 163 214 169 121 167 92 95 65 120
104
MOL-A02B 81
179 187 215 180 217 186 174 232 179 232 182 118 75 132 91 128 201 157 148 149
120 145 106 181 144 165 133 150 171 150 198 162 173 145 110 89 109 75 105 156
122 147 177 151 146 100 134 82 122 115 124 192 135 92 93 72 148 137 151 133
120 144 200 202 145 162 165 112 104 138 133 154 211 172 113 173 94 88 73 115
93
MOL-A03A 64
350 251 215 215 282 168 255 261 221 301 232 319 300 303 265 271 400 208 272 195
186 218 357 465 259 351 303 325 251 460 334 307 473 310 407 419 416 517 511 600
467 477 469 396 497 563 371 461 455 428 440 290 382 497 367 608 651 543 467 341
315 299 355 226
MOL-A03B 64
351 516 271 263 260 226 290 226 248 333 240 366 308 333 276 275 351 265 254 200
216 275 360 474 236 327 306 349 266 439 341 307 475 317 397 427 423 511 501 580
467 473 488 403 508 576 367 430 461 399 430 303 390 509 386 585 648 535 472 344
298 297 324 237
MOL-A04A 109
189 220 204 317 109 175 169 149 275 187 244 287 204 222 217 231 230 200 233 253
170 210 214 213 181 172 143 192 148 159 143 166 153 131 90 97 76 133 106 108
107 126 109 104 136 109 170 198 135 73 58 39 76 81 59 76 100 96 115 54
98 53 81 97 81 134 133 116 117 106 133 119 79 89 69 65 87 77 77 52
86 80 81 90 57 75 112 81 80 74 55 68 54 85 62 68 125 111 156 120
138 128 105 86 142 106 129 133 124
MOL-A04B 109
197 207 207 308 114 175 181 138 278 181 263 282 216 226 210 214 236 221 219 264
181 228 220 211 185 177 146 195 141 147 148 166 152 105 121 101 70 126 105 119
103 111 121 107 119 120 165 203 136 64 65 42 65 87 62 71 104 96 109 62
92 54 90 86 89 124 134 123 111 101 138 134 81 98 69 66 84 81 82 60
86 75 79 85 61 75 110 73 80 73 58 61 62 79 56 51 123 109 162 129
138 126 100 95 130 112 142 133 116

MOL-A05A 76
140 184 209 294 139 258 276 304 207 168 159 148 129 146 226 220 192 156 107 152
139 178 159 210 224 186 176 171 218 204 211 188 131 90 108 76 157 188 124 202
223 179 184 116 175 145 214 236 215 234 204 123 114 159 202 210 161 176 181 126
221 198 154 165 174 117 121 119 116 163 223 152 152 211 137 157
MOL-A05B 76
154 185 220 294 129 264 267 314 195 175 163 143 134 143 233 223 182 160 110 153
123 184 164 201 229 183 181 172 221 194 216 172 130 97 94 82 152 179 125 190
222 178 185 112 174 139 216 234 207 248 194 124 143 136 195 213 159 176 170 141
204 192 152 163 174 116 121 118 112 159 220 143 160 207 142 141
MOL-A06A 99
246 143 287 156 89 96 102 69 156 152 219 229 207 262 235 171 163 204 216 230
131 232 160 215 194 114 131 125 107 140 189 170 197 177 139 127 138 163 141 215
174 159 166 144 208 173 150 126 103 82 91 65 114 151 132 231 211 165 163 115
181 125 188 190 183 226 166 104 115 108 167 147 143 197 159 147 172 158 109 112
142 111 127 108 92 151 150 133 113 155 112 116 99 132 104 118 164 146 119
MOL-A06B 99
236 144 287 159 87 102 102 68 154 159 216 228 211 257 229 169 168 199 225 225
149 223 163 213 182 127 129 124 112 138 193 161 203 171 126 142 135 163 139 210
176 160 168 148 204 167 150 127 105 83 96 63 99 146 142 222 211 165 150 112
180 122 186 197 181 216 169 101 121 115 166 165 139 202 157 153 176 151 111 105
178 117 128 120 100 146 148 124 138 158 103 119 100 129 109 112 180 153 111
MOL-A07A 100
49 87 85 117 128 96 98 83 67 125 166 114 101 119 168 143 135 234 248 353
192 205 218 159 236 139 208 138 119 133 116 105 131 175 123 142 160 103 166 142
66 124 94 80 65 63 122 82 67 80 150 56 50 69 93 56 74 74 79 109
75 73 86 82 64 62 80 81 96 117 56 58 64 97 142 81 66 57 32 59
64 106 63 105 116 113 172 167 113 86 109 104 168 245 126 78 68 92 139 161
MOL-A07B 100
51 94 77 117 125 97 91 94 56 139 169 117 91 126 164 144 175 257 251 360
177 204 202 160 237 153 213 135 119 133 119 102 129 183 120 143 181 105 154 137
73 114 89 73 72 70 133 67 78 84 137 51 53 67 96 72 70 81 75 109
62 82 90 80 65 53 87 83 84 114 61 55 69 89 133 82 69 57 39 51
66 103 62 99 129 101 190 166 107 90 111 107 170 239 124 79 67 93 137 158
MOL-A08A 103
264 403 316 357 287 255 289 278 252 241 157 212 241 162 237 154 180 169 109 112
152 98 102 129 103 128 182 116 163 138 68 118 75 76 50 61 143 133 103 89
148 56 57 93 108 62 74 76 72 87 60 87 105 96 68 86 82 110 96 144
84 78 45 99 143 99 90 50 29 60 59 103 77 106 138 141 183 178 190 153
126 88 117 218 112 56 81 68 109 128 124 114 112 90 108 90 92 100 70 63
36 53 80
MOL-A08B 103
253 376 301 351 298 247 291 278 274 236 160 212 240 163 237 147 182 167 103 119
145 94 103 129 102 134 170 114 156 138 78 106 88 60 61 56 152 130 91 89
129 56 62 83 120 78 67 85 76 90 62 79 113 91 76 73 100 124 105 146
81 65 59 101 136 97 85 45 27 58 65 103 78 112 131 138 180 199 194 145
121 99 114 216 125 49 90 60 86 146 121 112 109 96 104 84 100 101 71 60
46 54 79
MOL-A09A 92
307 281 329 237 294 228 172 250 194 190 171 103 123 167 126 129 136 116 100 136
99 114 136 84 109 109 88 76 84 209 103 112 108 197 74 62 92 115 70 64
64 62 95 68 81 109 97 62 73 92 118 110 156 92 76 82 110 149 118 82
61 38 68 75 140 81 125 141 142 184 144 150 85 85 84 120 234 130 78 63
67 94 118 106 102 92 84 74 92 60 95 77

MOL-A09B 92
314 252 320 239 287 229 176 245 184 191 170 105 138 164 116 131 139 118 89 147
96 117 139 64 119 114 81 66 100 191 109 99 118 197 78 63 87 111 76 56
54 74 77 72 84 119 87 72 74 86 115 122 151 84 82 79 118 152 108 84
56 44 65 76 139 76 129 142 139 194 146 133 92 99 78 126 233 132 76 66
64 94 118 109 96 103 73 81 78 78 81 74
MOL-A10A 85
469 509 475 320 199 105 77 191 191 374 323 339 217 148 150 140 151 148 114 122
58 70 78 54 61 93 120 123 80 55 53 74 92 59 46 57 49 30 45 47
55 61 70 66 56 49 63 82 39 39 60 58 57 98 92 113 135 109 81 85
49 78 59 86 69 53 64 77 72 133 106 123 128 100 137 127 127 143 113 138
108 128 147 139 112
MOL-A10B 85
482 479 447 283 188 116 101 196 183 367 310 301 206 154 149 146 164 167 123 103
70 82 94 59 65 92 116 123 87 49 50 79 90 66 40 51 53 33 40 47
61 59 64 68 50 51 71 70 48 42 58 57 66 84 109 103 135 103 74 77
42 70 72 81 78 41 69 75 70 129 106 139 125 108 130 133 132 151 99 133
119 120 139 133 104
MOL-A11A 73
287 293 250 263 208 192 122 171 135 173 118 184 133 139 184 155 129 140 134 144
175 116 90 148 94 135 129 145 175 146 149 69 111 106 128 191 148 123 137 188
160 227 151 133 194 157 192 119 154 146 189 145 131 126 217 136 216 127 119 137
120 102 72 78 72 99 129 138 90 118 85 121 105
MOL-A11B 73
272 294 251 258 206 195 121 169 133 175 117 176 139 148 182 148 138 132 130 135
177 112 92 140 97 135 133 152 171 144 134 67 114 109 134 189 147 114 143 181
164 202 156 140 196 161 189 120 151 150 192 143 129 133 207 145 220 118 125 146
95 105 72 86 78 101 113 167 94 115 87 119 108
MOL-A12A 75
82 178 164 106 82 88 200 162 137 123 189 66 50 79 96 42 47 51 51 75
57 85 82 61 62 60 65 79 86 122 56 60 92 107 140 102 54 45 34 40
42 90 68 145 170 182 241 197 175 113 98 110 259 360 178 92 73 76 135 186
172 167 131 103 84 101 111 118 143 126 94 78 120 94 113
MOL-A12B 75
80 176 167 109 81 93 149 160 124 118 186 60 45 82 97 53 36 50 56 74
57 92 70 73 58 54 71 80 87 111 70 54 86 110 139 105 57 31 37 45
41 85 74 131 181 180 239 197 174 114 92 118 235 376 184 103 64 89 140 176
180 170 129 102 97 88 109 136 143 139 99 72 120 94 116
MOL-A15A 76
256 213 248 281 215 186 181 245 154 172 183 139 155 148 126 96 123 153 121 108
122 142 127 115 144 126 134 176 142 149 162 181 135 121 125 127 125 154 135 131
164 143 153 148 176 179 123 153 122 115 153 158 164 119 153 146 86 171 172 174
168 152 208 188 184 153 142 127 155 154 209 173 166 171 132 146
MOL-A15B 76
257 213 259 273 222 189 181 211 159 175 177 157 153 144 118 103 117 153 118 117
112 143 127 120 144 112 147 174 146 152 166 179 127 123 131 125 121 149 149 146
162 138 156 154 189 158 135 152 119 115 149 158 145 124 148 150 101 150 163 173
168 160 200 190 186 160 139 120 167 154 209 167 170 167 137 132
MOL-A16A 101
478 560 540 563 429 471 294 286 339 349 337 363 334 280 358 409 364 390 409 445
317 343 312 311 262 223 235 221 296 294 242 224 218 272 205 239 305 218 247 179
167 157 115 220 211 210 170 191 166 130 161 136 159 189 169 126 146 150 165 117
133 115 126 111 136 124 138 114 127 147 200 186 152 198 141 113 170 158 187 147
167 186 118 121 123 146 173 155 163 94 107 101 90 86 92 106 166 146 149 141
103

MOL-A16B 57
153 138 122 159 202 204 164 183 157 125 168 119 158 170 143 173 166 151 170 141
132 144 146 133 145 125 119 140 145 160 220 190 173 199 146 122 167 175 196 135
165 189 98 124 138 180 192 165 176 90 119 100 82 82 91 100 113
MOL-A17A 137
528 618 656 619 637 634 475 533 498 551 469 636 531 500 401 351 328 352 502 543
438 595 545 541 467 336 373 381 314 375 295 266 254 365 262 225 230 244 220 233
187 221 231 171 199 169 245 219 178 157 178 158 137 145 195 141 139 116 126 101
107 123 120 133 117 117 100 94 127 106 154 83 93 94 117 92 120 97 90 103
91 91 101 89 171 188 199 145 126 121 106 128 107 101 146 182 173 156 211 272
138 162 135 134 118 143 124 84 104 116 98 109 114 119 184 202 184 213 171 127
149 169 168 140 172 160 170 167 124 147 122 118 162 144 124 151 154
MOL-A17B 137
509 642 653 626 619 628 479 544 507 559 466 635 533 505 402 345 320 348 517 538
445 598 559 530 454 337 376 373 324 364 286 249 266 376 254 222 222 254 219 240
187 214 227 165 198 168 247 225 174 163 168 153 126 152 189 145 132 118 117 111
102 127 125 139 112 123 97 85 128 94 141 101 81 102 110 106 120 81 107 86
91 82 114 100 156 190 202 145 132 135 107 123 116 91 138 172 147 134 211 263
143 143 131 122 114 146 119 85 108 115 95 97 119 122 182 206 185 215 169 143
140 163 181 132 173 143 176 171 136 154 122 114 149 150 145 133 145
MOL-A18A 96
230 245 330 363 307 266 182 230 184 298 195 177 268 274 210 242 226 178 159 255
260 343 245 288 255 281 164 150 154 150 259 288 279 162 166 170 186 164 154 100
141 103 104 84 81 100 102 134 148 132 139 86 131 117 127 146 152 129 182 204
158 143 120 141 130 136 169 132 133 176 174 142 161 154 115 118 85 74 88 120
146 104 98 113 62 88 77 100 89 94 97 85 64 77 63 73
MOL-A18B 96
244 249 339 366 319 268 186 239 174 280 200 180 270 294 206 222 210 180 163 270
269 329 256 283 260 279 164 157 150 156 238 275 275 161 165 169 187 162 156 100
143 93 110 84 78 92 113 139 142 122 128 104 111 127 133 149 144 126 172 206
157 145 129 151 121 139 166 129 137 166 180 160 157 146 129 124 78 74 82 120
143 104 106 108 66 83 86 91 94 93 97 80 74 69 70 74
MOL-A19A 108
108 145 128 302 238 253 189 268 147 227 237 245 293 223 207 211 132 194 128 143
155 206 179 156 194 218 162 166 171 195 158 176 184 180 152 103 92 113 138 159
134 111 116 109 138 130 184 129 161 119 129 108 101 122 140 141 125 152 125 96
136 126 132 99 91 96 109 103 104 93 100 116 107 81 91 76 91 116 103 97
104 104 83 92 71 59 101 81 101 80 105 109 77 115 98 118 94 100 99 105
117 89 93 85 109 81 106 77
MOL-A19B 108
123 148 129 299 240 245 195 260 131 241 257 255 315 243 165 191 155 165 164 149
159 207 175 161 185 220 158 163 176 195 154 185 179 177 155 98 106 98 149 157
128 113 117 101 134 133 177 124 158 128 130 100 100 131 128 141 136 153 118 90
143 123 125 122 87 103 108 93 109 92 106 117 101 82 97 82 88 119 106 100
108 96 96 71 65 63 91 103 97 78 93 112 78 96 104 102 103 99 109 102
107 94 87 88 105 87 101 69
MOL-A20A 89
376 441 314 337 289 352 341 309 256 241 339 284 260 284 345 245 260 227 231 236
151 143 145 162 179 151 112 112 121 122 120 155 129 118 118 118 114 92 129 109
102 113 100 97 57 98 73 85 116 127 113 121 122 110 88 121 114 116 124 135
114 120 124 109 118 123 123 98 114 89 86 134 116 115 96 98 102 68 81 105
115 139 102 99 73 67 78 65 92

MOL-A20B 89
329 436 307 338 317 331 325 296 240 245 327 285 261 292 349 243 264 211 249 224
160 143 151 157 173 148 111 112 116 128 122 141 131 118 115 133 109 93 123 111
102 120 99 101 59 100 84 77 111 122 115 120 121 115 85 117 115 115 126 140
114 122 119 111 116 121 127 98 114 83 97 138 103 110 101 104 107 58 94 106
121 146 92 102 79 63 73 72 97

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 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.

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.

Figure 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.

Figure 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.

Figure 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.

Figure 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.

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 Figure 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 Figure 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 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 phenomenon 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.

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

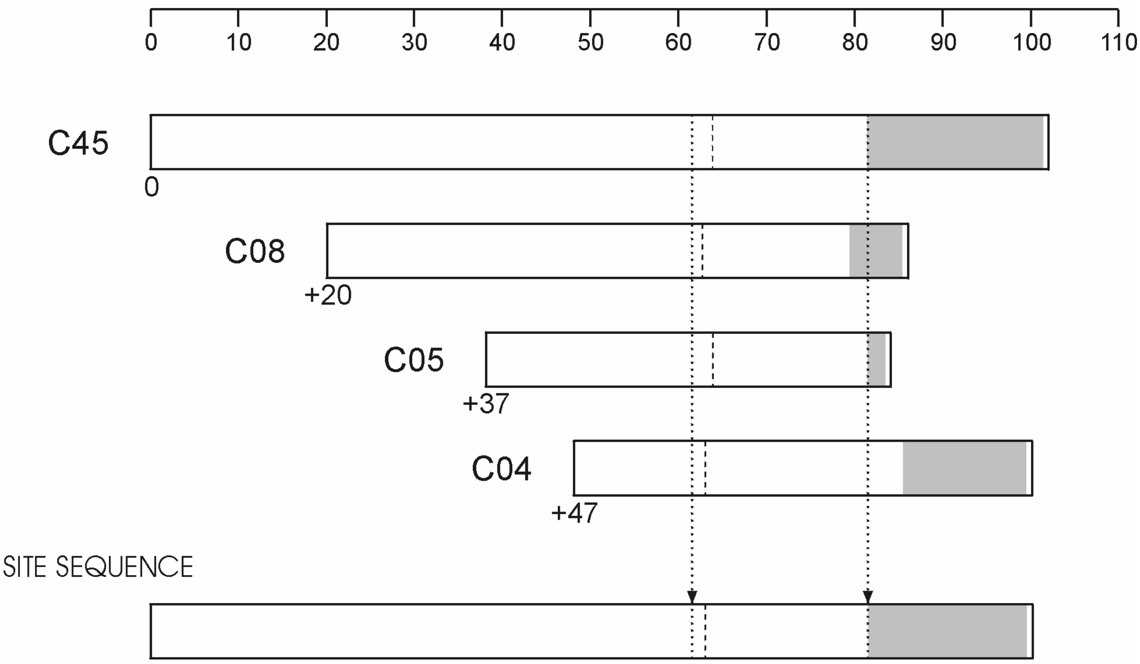


Figure 5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

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.

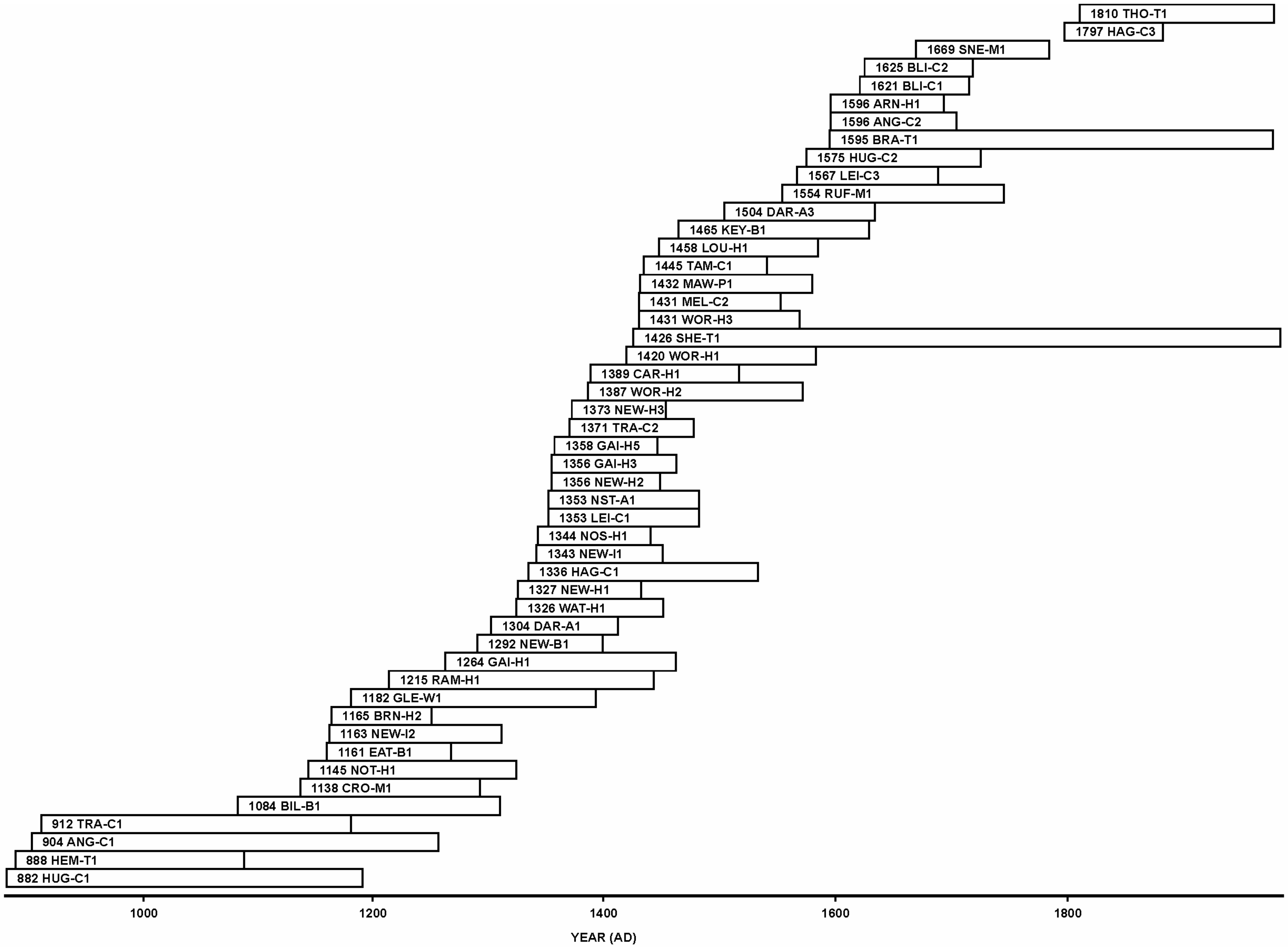
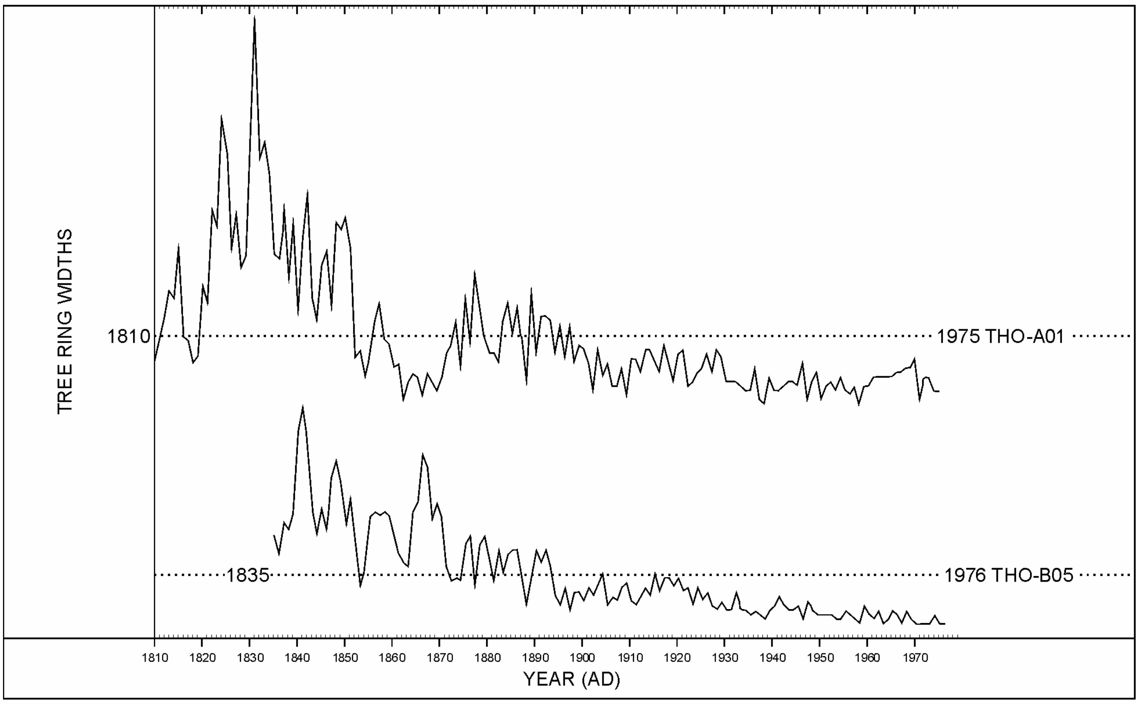


Figure 6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

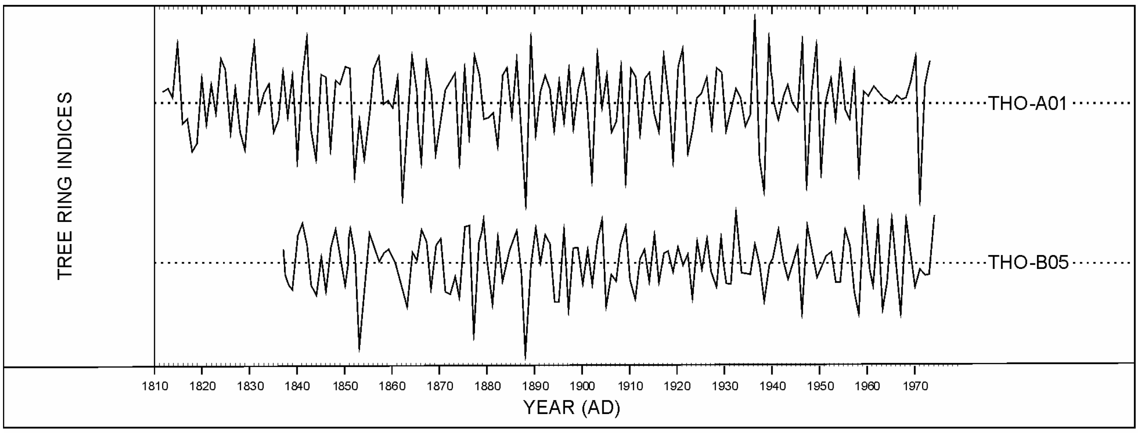


Figure 7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young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

Figure 7 (b): The *Baillie-Pilcher* indices of the above widths. The growth-trends have been removed completely.

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