RESEARCH REPORT SERIES no. 33-2013

MUNIMENT ROOM, MELBOURNE HALL, MELBOURNE, DERBYSHIRE
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

INTERVENTION AND ANALYSIS

ENGLISH HERITAGE

Research Report Series 33-2013

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NGR: SK 39016 25044

ISSN 2046-9799 (Print)
ISSN 2046-9802 (Online)

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SUMMARY

Tree-ring analysis was undertaken on samples taken from the timbers of the roof of this structure resulting in the construction and dating of a single site sequence. Site sequence MELDSQ01 contains all 12 samples and spans the period AD 1601–1708. All timbers represented appear to have been felled in AD 1708 confirming that this roof forms part of the AD 1709 remodelling of the building.

CONTRIBUTORS

Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS

The Laboratory would like to thank Richard Maddison of Maddison James Associates for arranging access and Alan Staley Building Contractors for their assistance during sampling. Thanks are also given to Cathy Tyers and Shahina Farid, English Heritage Scientific Dating Team, for their advice and assistance throughout the production of this report.

ARCHIVE LOCATION

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DATE OF INVESTIGATION

2012/13

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CONTENTS

INTRODUCTION

The grade I listed Muniment Room, located in the grounds of Melbourne Hall, Derbyshire (Figs 1–3) is believed to have originated as a small dovecote or garden pavilion. It is a hexagonal building with a low vaulted cellar and main room above and is constructed of buff-coloured sandstone rubble with well-dressed quoins to the angles and a moulded cornice. The roof is of Westmoreland slates and is bell shaped and domed with lead flashings and a top ball finial. The structure consists of six main ribs and two rows of common ribs, separated by six purlins. The ribs curve down to wall plates and up to a central post which is supported on a cross beam (Figs 4 and 5). The structure is thought to date to the early seventeenth century but is known to have undergone remodelling in AD 1709 as part of the early eighteenth-century work to the gardens.

SAMPLING

Dendrochronological analysis was requested by Nick Hill of English Heritage in conjunction with grant aided repair works. It was hoped that dendrochronological analysis might identify timbers from its primary construction and thereby provide a precise date for its construction and in doing so allow a greater understanding of its origin and function.

A total of 12 timbers was sampled by coring. Each sample was given the code MEL-D (for Melbourne, site 'D') and numbered 01–12. The location of samples was noted at the time of sampling and has been marked on Figure 6. Further details relating to the samples can be found in Table 1.

ANALYSIS AND RESULTS

All samples were prepared by sanding and polishing and their growth-ring widths measured; the data for these measurements are given at the end of the report. These samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), resulting in all samples matching to form a single group.

All samples were then combined at the relevant offset positions to form MELDSQ01, a site sequence of 108 rings (Fig 7). This site sequence was compared against a series of relevant reference chronologies where it was found to match consistently and securely at a first-ring date of AD 1601 and a last-measured ring date of AD 1708. The evidence for this dating is given by the *t*-values in Table 2.

INTERPRETATION

Five of the samples have complete sapwood and the last-measured ring date of AD 1708 is the felling date of the timbers represented. All of the other samples have the heartwood/sapwood boundary ring date. In the case of five of these this heartwood/sapwood ring is broadly contemporary with those samples with complete sapwood, making it likely that these were also felled in AD 1708. Two samples (MEL-D08 and MEL-D10), both from purlins, have substantially earlier heartwood/sapwood boundary rings to the rest of the samples. However, with sample MEL-D08 having incomplete sapwood of 49 rings it is also clear that the tree represented falls into the 5% of oak trees which have a sapwood complement outside the usual 15–40. Thus, although it is possible that this timber (and that represented by MEL-D10) are felled slightly earlier than the rest of the material, it is more likely that these two timbers simply have an abnormally high number of sapwood rings and were also felled in AD 1708; it is extremely unlikely that they would have been felled any later.

DISCUSSION

Prior to tree-ring analysis being undertaken on the timbers of this roof structure the building was thought to date to the early seventeenth century but underwent remodelling in AD 1709.

It is now known that the roof is constructed from timber felled in AD 1708 demonstrating that the roof was part of the early eighteenth-century remodelling. No timbers relating to the primary, early seventeenth-century phase of the building have been identified.

Generally, the intra-site matching seen within the components of site sequence MELDSQ01 is very good, with the majority of samples coming together at a value of *t*=6.0 and above. Indeed, the degree of similarity between some samples is so high as to suggest they might be cut from the same tree; samples MEL-D07 and MEL-D11 match each other at a value of *t*=11.9 and matching between MEL-01, MEL-D03, and MEL-D05 is also of a level to suggest a single tree. The overall similarity between samples suggests trees growing in close proximity to each other and although it cannot be said with complete certainty, looking at Table 2, it is likely that the woodland utilised for these trees is reasonably local.

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TABLES

Table 1: Details of tree-ring samples from the Muniment Room, Melbourne Hall, Derbyshire

Sample number	Sample location	Total rings	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
MEL-D01	North main rib	72	19C	1637	1689	1708
MEL-D02	North-east main rib	76	20C	1633	1688	1708
MEL-D03	South main rib	68	17	1640	1690	1707
MEL-D04	South-west main rib	50	06	1645	1688	1694
MEL-D05	North-west main rib	82	24C	1627	1684	1708
MEL-D06	North-east purlin	81	19C	1628	1689	1708
MEL-D07	East purlin	93	19C	1616	1689	1708
MEL-D08	South-east purlin	90	49	1607	1647	1696
MEL-D09	South-west purlin	56	h/s	1622	1677	1677
MEL-D10	West purlin	70	27	1601	1643	1670
MEL-D11	North-west purlin	69	h/s	1605	1673	1673
MEL-D12	Main cross beam	82	16	1624	1689	1705

**h/s = the heartwood/sapwood boundary is the last measured 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 MELDSQ01 and relevant reference chronologies when the first-ring date is AD 1601 and the last-measured ring date is AD 1708

Reference chronology	*t*-value	Span of chronology	Reference
Middleton Hall, Middleton, Warwickshire	10.3	AD 1593–1718	Arnold *et al* 2006
The Wheatsheaf, Cropwell Bishop, Nottinghamshire	10.1	AD 1604–1703	Arnold *et al* 2008
Bolsover Castle (Riding School), Bolsover, Derbyshire	9.7	AD 1494–1744	Howard *et al* 2005
Bolsover Castle (Little Castle), Bolsover, Derbyshire	9.7	AD 1532–1749	Arnold *et al* 2003
Combermere Abbey, Whitchurch, Cheshire	9.7	AD 1602–1727	Howard *et al* 2003
Church Farm House, Ockbrook, Derbyshire	9.0	AD 1560–1672	Arnold and Howard 2009
Castle House, Melbourne, Derbyshire	8.5	AD 1583–1720	Arnold and Howard 2009 unpubl

FIGURES

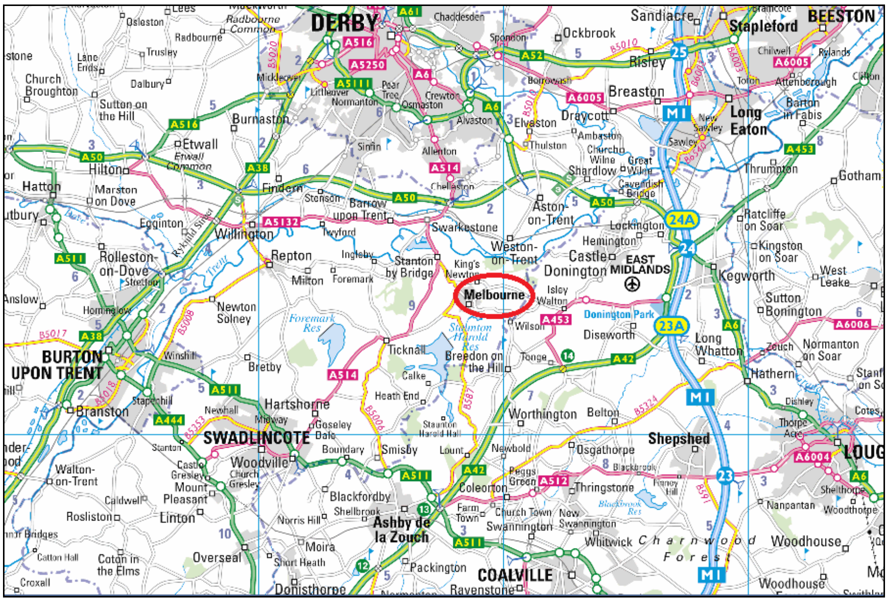


Figure 1: Map to show the location of Melbourne, Derbyshire, circled. © Crown Copyright and database right 2013. All rights reserved. Ordnance Survey Licence number 100024900.

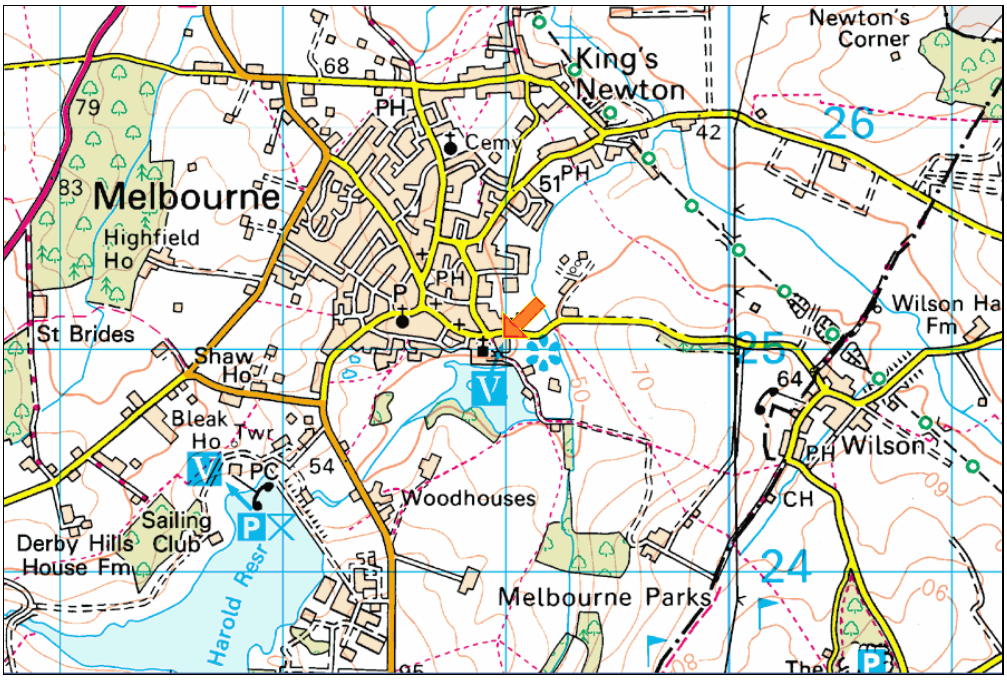


Figure 2: Map to show the general location of Melbourne Hall, arrowed. © Crown Copyright and database right 2013. All rights reserved. Ordnance Survey Licence number 100024900

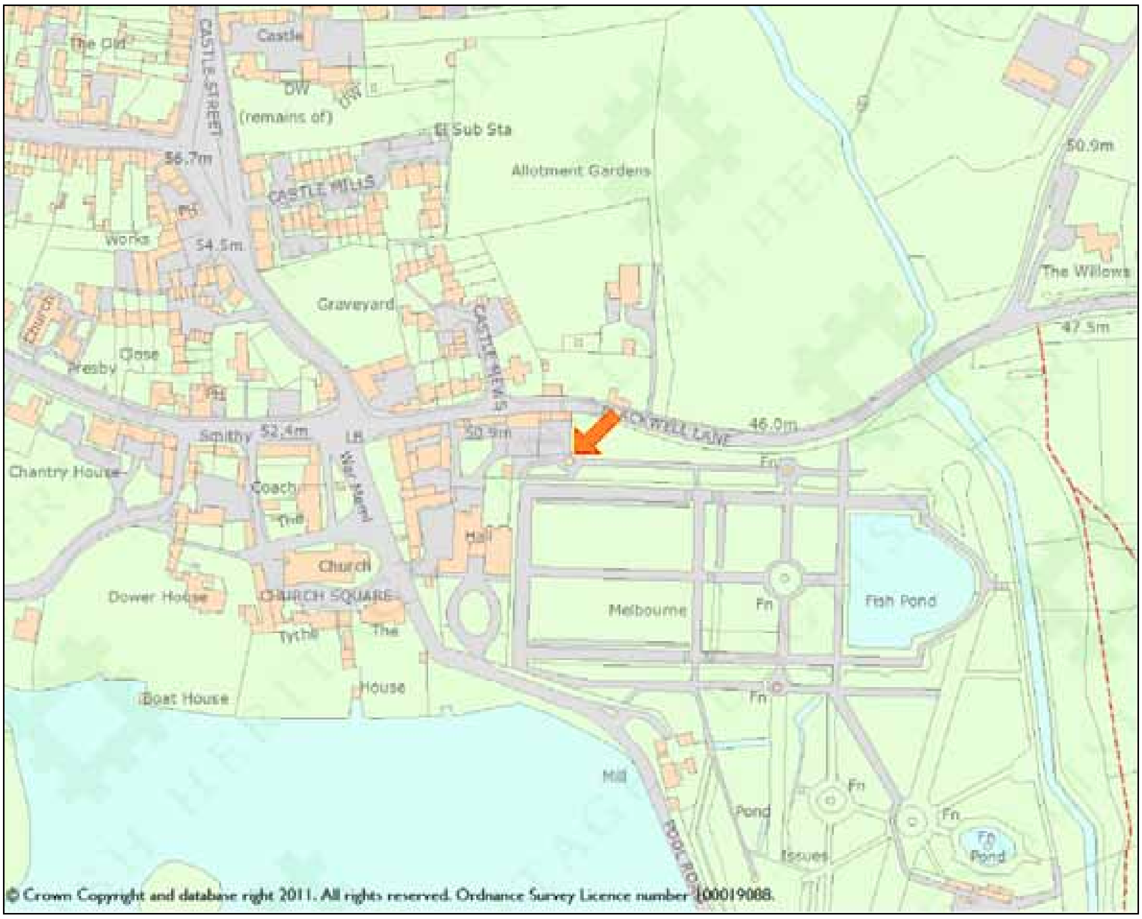


Figure 3: Map to show the location of the Muniment Room, Melbourne Hall, arrowed. © Crown Copyright and database right 2013. All rights reserved. Ordnance Survey Licence number 100024900

Figure 4: Muniment Room roof (photograph Robert Howard)

Figure 5: Muniment Room roof (photograph Robert Howard)

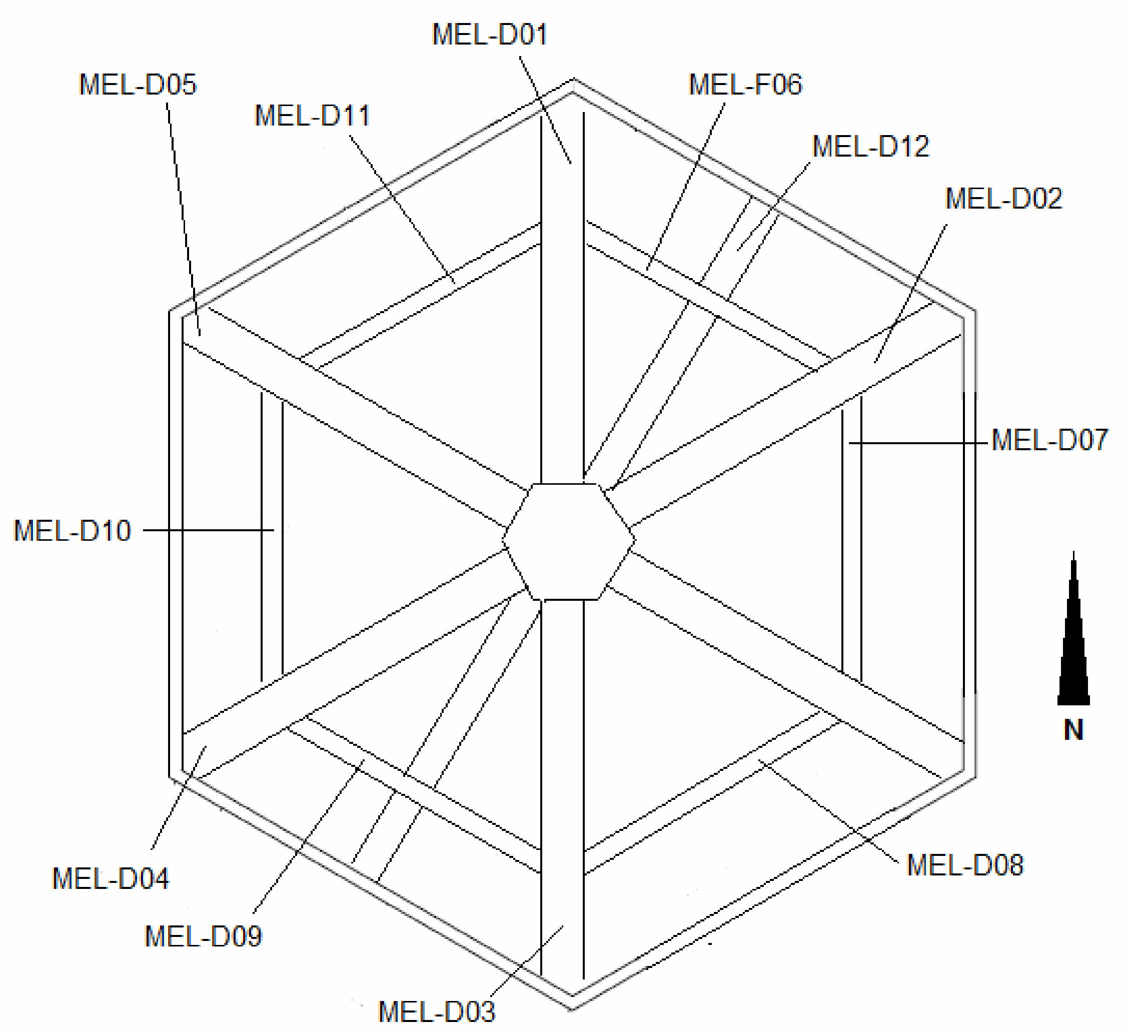


Figure 6: Sketch plan of roof showing the location of samples MEL-D01–12

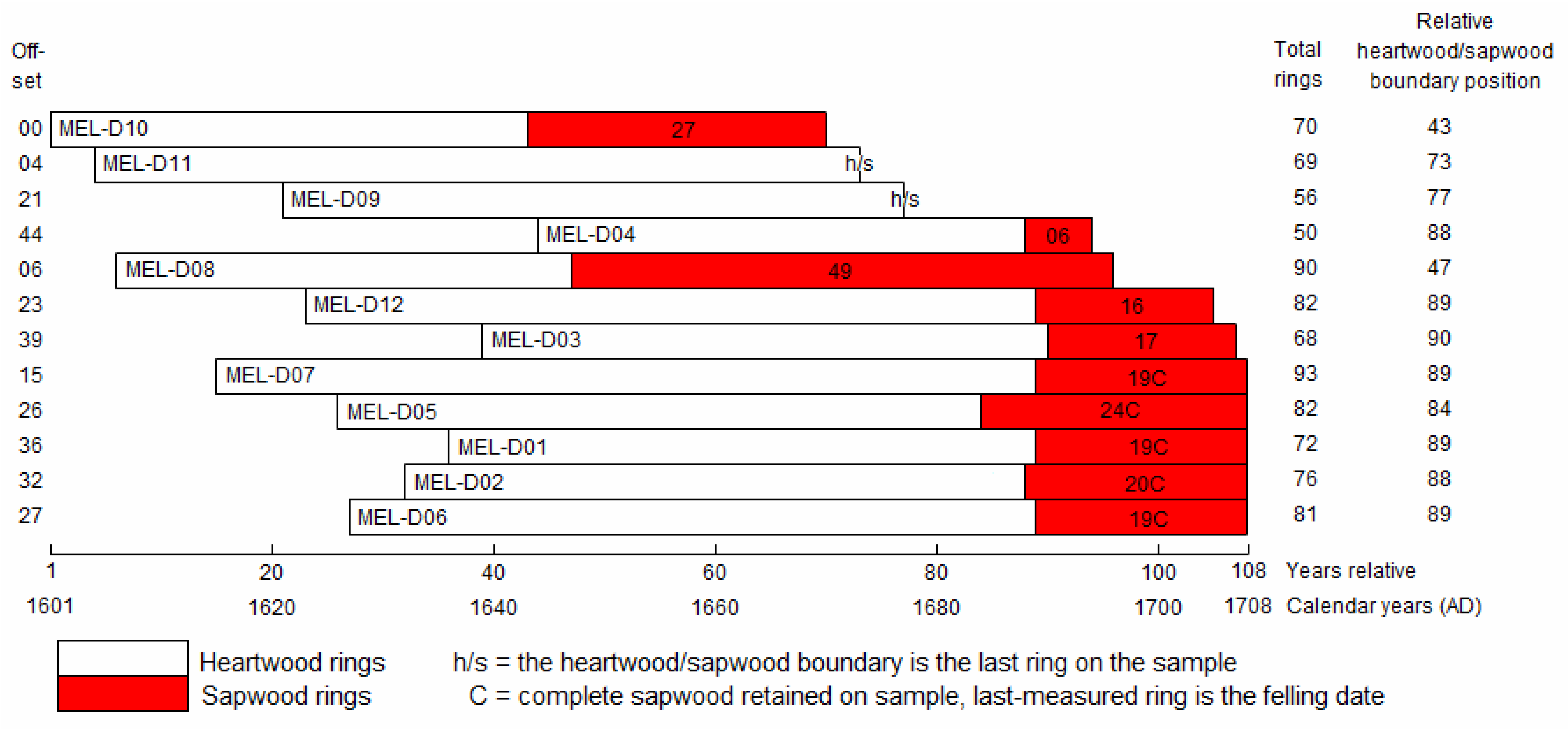


Figure 7: Bar diagram of samples in site sequence MELDSQ01

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

MEL-D01A 72
121 224 359 337 389 163 164 135 212 389 291 403 243 118 133 142 103 224 346 268
291 230 116 131 138 130 133 155 122 249 212 250 216 231 247 231 182 147 148 247
277 240 222 218 182 258 144 113 102 188 252 237 198 114 119 113 215 206 183 187
213 172 146 77 135 173 139 200 74 122 186 110
MEL-D01B 72
124 219 363 364 382 149 176 136 169 374 286 400 262 114 134 140 112 219 340 270
292 232 114 125 127 134 132 163 113 252 197 256 210 240 237 231 176 143 159 243
279 244 227 216 182 249 146 120 107 182 251 235 200 114 112 116 215 203 172 185
222 178 147 82 141 154 137 187 75 126 181 123
MEL-D02A 76
456 252 234 250 202 401 263 235 178 22 28 23 51 138 140 232 180 66 110 89
54 79 210 264 227 231 103 139 168 126 96 86 57 131 127 202 209 362 440 331
204 221 255 352 441 364 327 467 206 299 98 86 82 193 384 350 383 200 139 94
218 171 149 140 144 135 99 121 181 197 181 196 102 69 159 226
MEL-D02B 76
441 255 222 249 207 380 272 229 181 32 26 24 51 119 152 242 182 60 113 96
50 78 210 285 223 258 105 137 160 118 94 90 58 133 123 209 215 316 431 338
209 214 236 355 446 376 327 467 214 304 105 85 81 197 379 342 389 205 131 97
224 161 151 136 155 141 84 118 155 199 166 201 106 64 160 242
MEL-D03A 68
252 419 159 103 80 128 332 244 313 259 106 179 150 84 157 424 329 181 201 158
149 215 196 147 135 125 244 314 452 333 381 348 332 216 234 227 286 366 332 324
292 230 360 199 156 168 362 370 303 248 180 219 142 307 202 233 272 293 275 215
117 272 240 215 270 116 146 229
MEL-D03B 68
229 423 155 99 84 121 334 246 309 265 105 172 141 93 155 374 338 186 201 161
156 215 200 154 146 131 227 325 431 340 382 338 316 230 222 224 276 385 337 320
313 243 376 200 155 136 358 363 314 251 184 220 135 306 210 233 274 290 268 218
115 272 234 216 275 115 145 227
MEL-D04A 50
129 222 183 259 226 104 127 115 107 174 295 168 168 152 94 145 136 85 82 88
66 221 93 198 129 156 186 234 180 100 143 290 337 253 285 289 219 411 184 140
83 241 232 183 228 136 176 101 240 160
MEL-D04B 50
124 228 178 269 218 94 136 129 95 187 283 168 158 141 78 140 132 82 83 90
65 209 105 208 127 117 175 254 196 95 141 295 337 251 287 288 220 410 197 139
97 233 231 177 227 137 176 110 228 169
MEL-D05A 82
284 558 514 326 313 410 454 233 210 163 238 350 351 379 411 178 210 118 219 437
185 221 223 94 110 93 79 122 301 172 103 106 74 89 86 89 83 64 57 109
136 209 159 174 180 191 134 101 107 189 227 139 171 132 123 202 82 73 46 80
99 89 99 84 73 45 54 60 68 70 92 75 71 47 75 72 68 70 35 40
60 51
MEL-D05B 82
326 564 496 332 305 409 455 233 212 165 230 345 372 370 443 195 203 110 213 407
203 271 222 94 113 92 78 119 304 167 99 105 73 89 86 86 83 58 61 115
113 216 150 171 170 186 136 110 108 185 220 130 163 135 115 207 81 76 43 83

96 91 93 80 63 41 54 57 62 58 85 85 64 56 74 73 59 65 42 41
64 62
MEL-D06A 81
348 395 221 262 266 372 287 143 142 281 399 433 319 393 155 304 196 295 343 324
364 270 225 240 255 136 215 400 276 252 196 131 241 257 187 162 128 130 163 111
192 197 178 205 202 192 214 125 143 129 116 122 128 93 121 90 70 59 93 128
96 88 66 63 69 125 94 97 88 115 90 95 83 82 78 82 87 64 89 88
108
MEL-D06B 81
376 385 244 269 280 345 270 142 128 276 383 434 309 367 132 311 198 304 320 308
346 271 222 242 252 142 207 381 281 242 185 123 235 257 183 152 117 128 157 111
191 198 175 207 189 193 215 124 143 130 116 121 132 97 111 92 69 65 85 120
104 86 70 56 74 126 112 96 91 108 114 88 86 70 86 83 81 68 87 92
117
MEL-D07A 93
338 448 455 403 366 370 497 434 261 231 338 357 351 373 213 190 302 332 202 165
131 182 303 276 253 312 128 200 120 177 202 181 173 161 98 132 103 85 169 239
156 124 109 100 174 134 162 158 132 125 175 209 205 248 199 218 145 109 92 142
108 95 102 89 91 67 84 79 63 54 82 99 89 71 71 62 90 107 102 88
86 112 119 89 68 85 109 73 111 62 69 94 111
MEL-D07B 93
347 475 450 419 375 381 495 440 250 231 337 361 345 353 207 188 306 320 203 177
135 180 304 274 247 315 126 212 117 181 199 175 178 162 99 133 106 88 166 238
158 117 112 102 170 137 162 157 135 126 173 184 195 236 194 218 143 108 90 134
100 95 102 90 83 73 87 78 56 56 87 95 79 80 71 64 99 92 105 88
92 107 118 81 73 86 101 82 107 64 73 93 101
MEL-D08A 90
358 408 367 364 412 371 312 170 111 94 89 200 222 183 259 293 512 318 200 142
253 169 204 107 91 141 175 112 105 112 82 136 139 144 89 65 54 59 73 104
110 60 84 46 41 39 37 46 80 65 40 39 36 37 38 48 53 47 47 44
49 69 60 52 56 65 28 28 30 35 44 42 53 41 40 34 32 34 33 38
34 26 37 39 37 44 48 44 47 44
MEL-D08B 90
359 404 359 378 417 365 320 169 107 94 88 203 222 181 254 295 512 326 192 158
230 154 196 108 75 148 160 115 101 114 86 129 134 144 90 62 56 61 78 96
111 59 91 46 37 42 35 45 76 67 40 41 33 37 35 41 56 46 51 42
50 70 59 50 56 39 27 38 37 44 43 48 49 39 33 37 28 32 36 35
38 34 35 39 39 46 52 51 34 18
MEL-D09A 56
459 494 261 202 358 403 366 429 324 282 346 352 295 218 143 336 423 325 354 361
181 228 210 269 348 311 336 258 167 223 136 100 198 348 255 180 179 117 283 187
252 196 97 151 204 176 241 220 186 282 190 155 131 94 89 100
MEL-D09B 56
459 490 270 200 376 420 375 418 311 274 350 358 289 224 135 356 429 321 344 356
174 215 195 282 352 308 326 261 166 225 128 107 209 348 256 172 166 122 283 204
253 212 119 154 202 187 258 216 190 280 191 153 130 97 82 102
MEL-D10A 70
355 359 235 213 227 313 343 363 474 488 263 294 357 145 142 182 184 365 297 296
282 325 307 152 123 95 165 131 201 114 77 123 148 121 77 70 70 91 69 131
77 57 41 60 52 104 71 50 52 33 46 41 35 34 59 83 51 36 23 56
44 60 49 43 41 38 57 51 40 38
MEL-D10B 70
374 359 233 202 195 348 354 361 517 478 293 327 367 136 133 172 159 365 314 300

278 327 310 151 128 93 167 133 199 112 77 126 144 119 67 63 69 96 63 119
81 62 33 60 52 104 70 54 56 37 38 40 41 31 62 79 53 35 30 49
45 57 54 37 44 38 57 47 43 37
MEL-D11A 69
214 213 243 261 302 309 356 322 488 245 188 310 425 436 404 393 459 412 359 209
182 326 351 326 396 231 206 266 357 242 181 139 213 363 366 302 309 115 189 173
271 307 271 268 214 161 176 150 92 182 277 222 165 119 107 156 135 113 86 65
73 74 74 57 70 66 52 72 68
MEL-D11B 69
218 208 239 267 297 313 351 320 482 253 170 324 397 423 409 378 439 387 364 206
182 321 356 317 413 238 208 256 364 232 178 143 199 362 358 301 289 113 183 182
280 298 275 260 221 162 173 153 93 179 261 227 164 117 110 157 138 104 96 67
69 77 68 73 67 65 52 68 63
MEL-D12A 82
147 153 193 262 272 248 193 166 160 90 106 113 105 167 189 203 211 222 156 181
150 179 248 232 280 150 131 125 129 157 140 188 220 191 159 143 151 178 151 124
146 135 127 123 194 204 167 149 155 145 156 117 80 86 110 112 92 62 104 80
67 52 86 96 89 97 41 55 50 73 92 92 112 130 135 105 69 107 95 90
136 60
MEL-D12B 82
150 158 186 286 280 253 198 162 159 100 97 110 107 169 188 209 219 213 152 176
161 174 253 243 273 152 140 116 132 135 126 186 216 207 142 143 158 173 141 116
147 132 130 126 188 200 168 161 155 132 151 118 83 92 106 112 97 61 100 75
62 50 88 98 90 89 43 52 46 85 78 97 111 125 133 122 81 101 83 95
131 66

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 1998). 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 A1 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 A1, 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 A2 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 8–10 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 A2; it is about 150mm long and 10mm 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 A1: 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

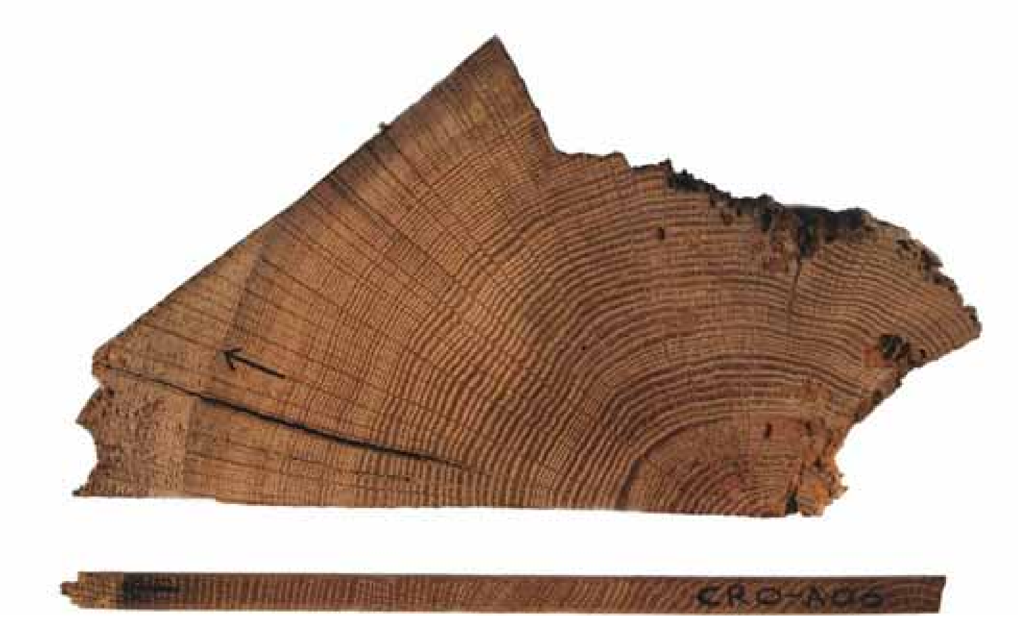


Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

Figure A3: 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

Figure A4: 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 A2. 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 A3).

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 A4). 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 A5 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 A5. 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 A5 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 straightforward 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 (or the last full year before felling, if it was felled in the first three months of the following calendar year, 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 A2, 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 region 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 A2 was taken still had complete sapwood but that some of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 20mm, 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; Miles 1997, 50–5). Hence, provided that 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, fig 8; 34–5, where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storage 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 Figure A6 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 Figure A6. 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 Figure A7. 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

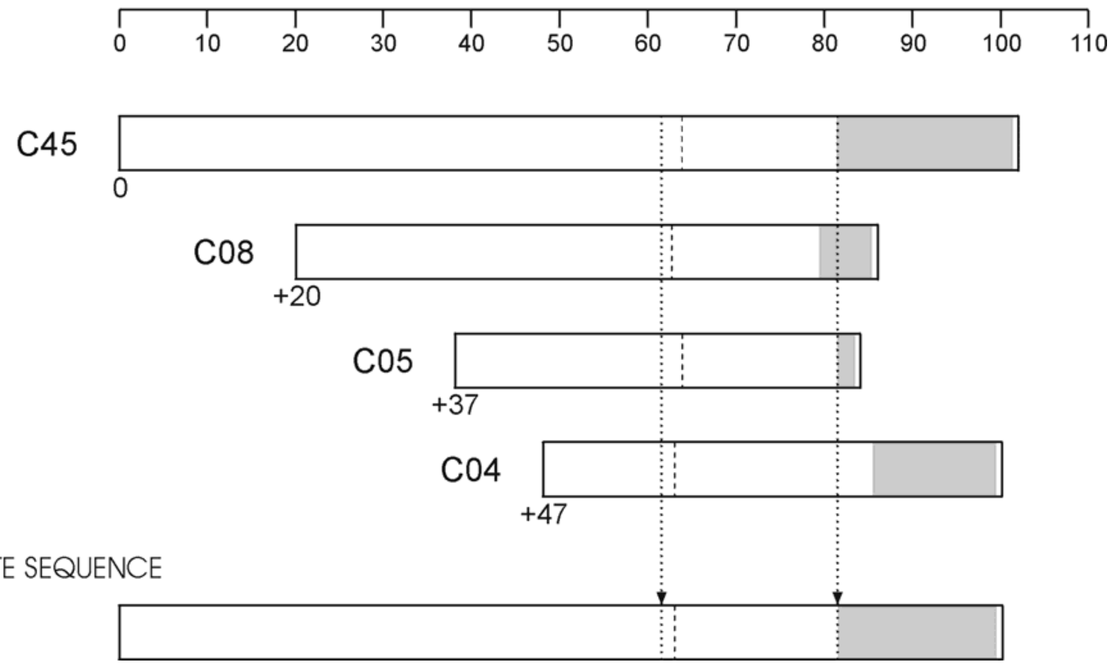


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

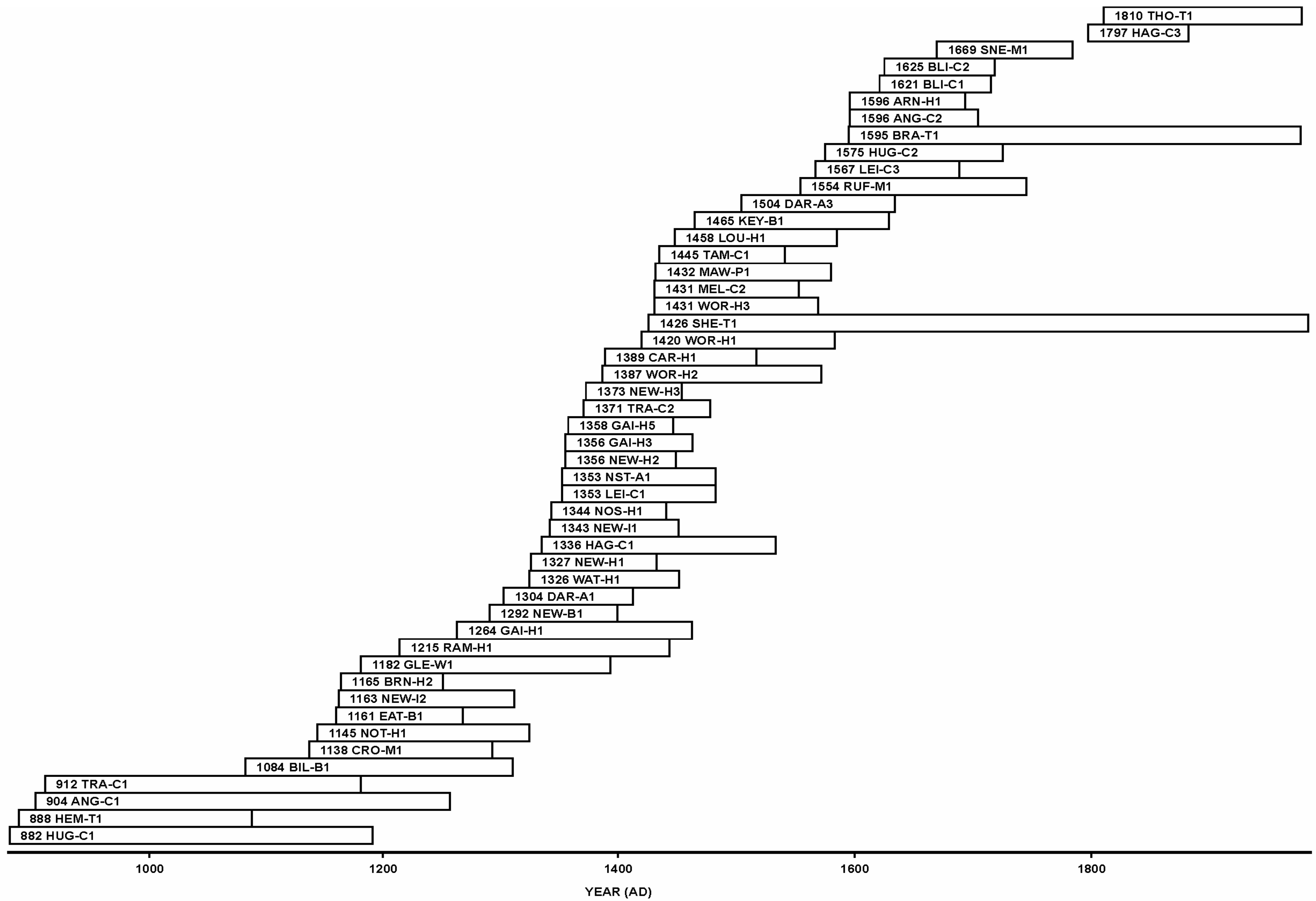
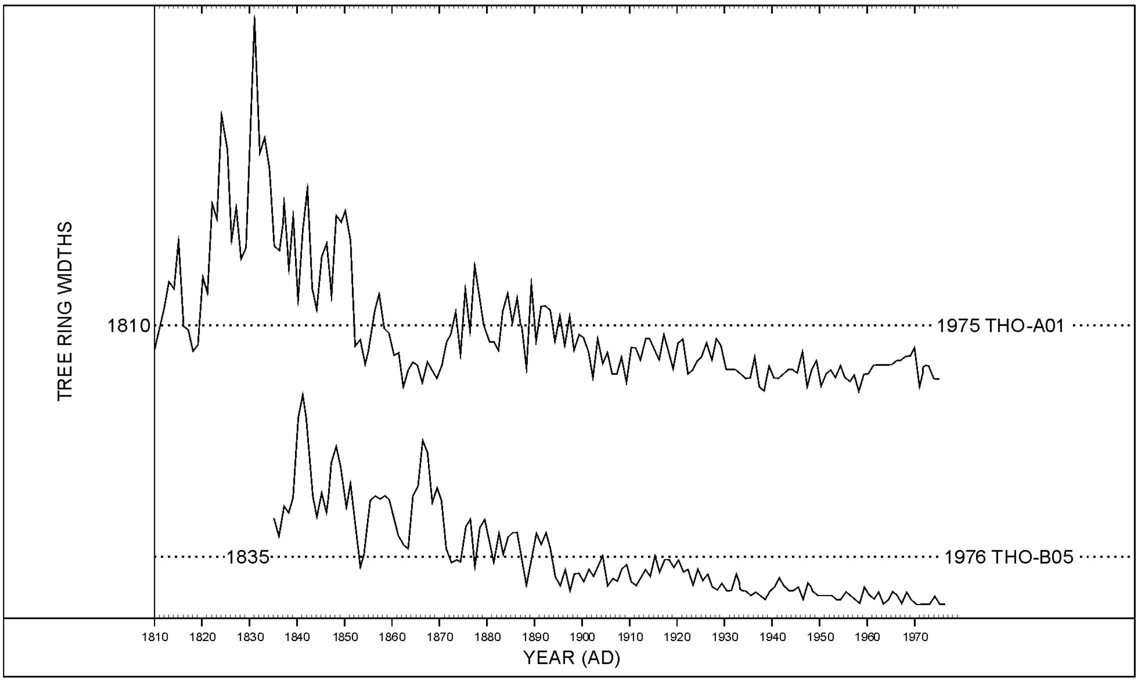


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

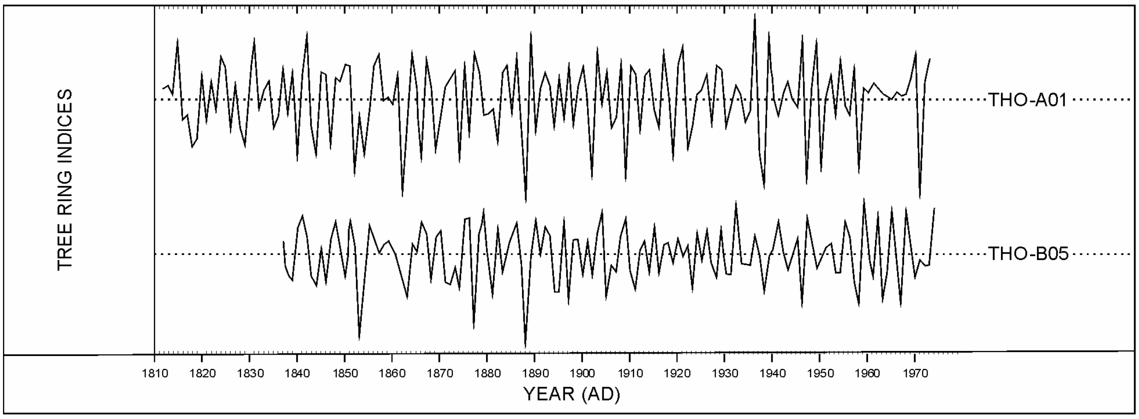


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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 A7 (b): The Baillie-Pilcher indices of the above widths

The growth trends have been removed completely

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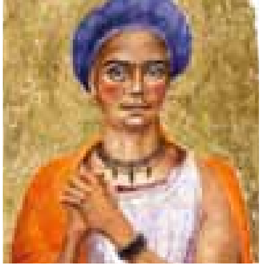


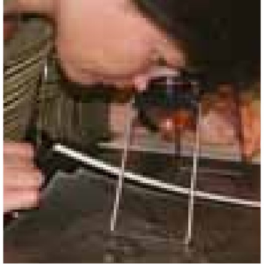


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ENGLISH HERITAGE

ISSN 2046-9799 (Print)
ISSN 2046-9802 (Online)