Research Report Series 18/2025

2 Pottergate, Lincoln

Tree-ring Dating of Oak Timbers

Matt Hurford, Roderick Bale, Alison Arnold and Robert Howard

Scientific Dating

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Summary

Dendrochronological analysis was undertaken on 11 of the 15 oak samples taken from 2 Pottergate, Lincoln. This resulted in the production of two site chronologies, PTGLSQ01 and PTGLSQ02. Site chronology PTGLSQ01, comprising six samples with an overall length of 135 rings, can be dated as spanning the years AD1591 to 1725. PTGLSQ02 comprising two samples and spanning 69 years remains undated. Sample PTG-L10 was dated individually as spanning the years AD 1157–1308. Interpretation of the sapwood and heartwood/sapwood boundaries indicates that roof timbers of the rear wing were felled in, or around, the winter of AD 1725/6, with a ceiling beam in the cellar, a reused timber, likely to be contemporary. The east door jamb of the central partition within the cellar has an estimated felling date in the range of AD 1323–1348, this timber also being reused.

Contributors

Matt Hurford, Roderick Bale, Alison Arnold, and Robert Howard.

Acknowledgements

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Front cover image

2 Pottergate, Lincoln (cropped). [© Mr Terence G. Onyon. Source: Historic England Archive IOE01/12465/31]

Archive location

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Historic Environment Record

Lincolnshire Historic Environment Record, Lancaster House, 36 Orchard Street, Lincoln LN1 1XX

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2020–4

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Introduction

The dendrochronological investigation at 2 Pottergate, Lincoln, is part of a wider study of the buildings in Lincoln Cathedral precincts, which includes the provision of a programme of advanced continued professional development, led by the Nottingham Tree-Ring Dating Laboratory (http://www.tree-ringdating.co.uk/), this being commissioned and funded by Historic England (Project No: 7856).

Number 2 Pottergate is Grade II-listed (List Entry Number 1388733 https://historicengland.org.uk/listing/the-list/list-entry/1388733) and stands immediately north of Pottergate Arch on the east side of Pottergate (Figs 1–2). The ancient houses of Lincoln were subject to a detailed study (Jones et al. 1984), from which the background information below is taken.

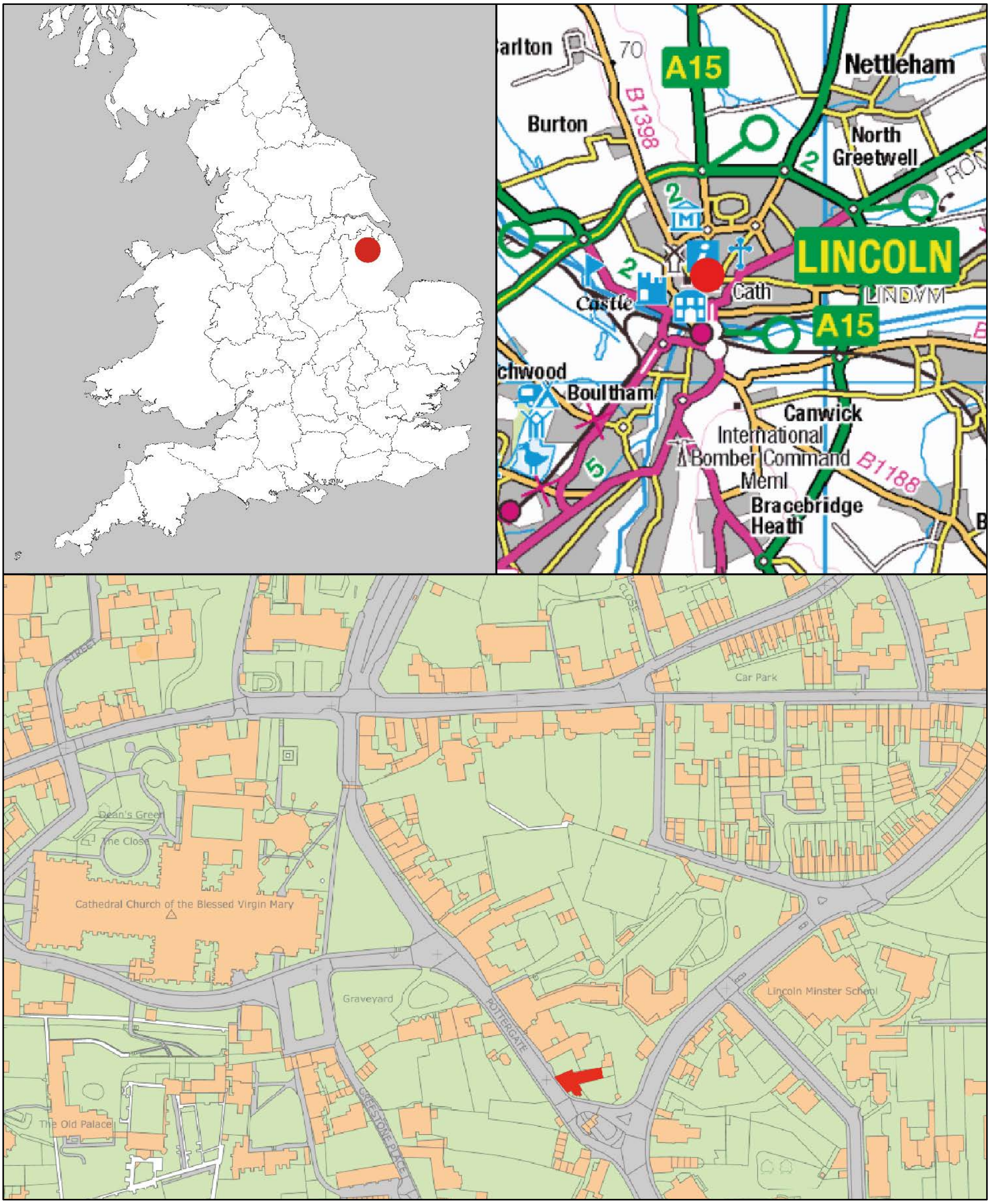

Figure 1: Map to show the location of 2 Pottergate, Lincoln. Top right: Scale: 1:105,000. Bottom: Scale 1:2,500. [© Crown Copyright and database right 2025. All rights reserved. Ordnance Survey Licence number 100024900]

Figure 2: General view of the south gable of the west range and south elevation of the rear wing of 2 Pottergate, viewed looking north. [photograph Matt Hurford]

The property is of L-plan, of two storeys with attics, and of three bays. Fronting Pottergate is the west range, with the rear wing extending to the east, with stairs located between the west range and rear wing (Fig. 3). It is described in leases from AD 1564 until AD 1705/6 as comprising two tenements of messuages belonging to the Fabric, although the extant house is thought to have been largely remodelled during the first half of the eighteenth century, incorporating part of a back wing of medieval origin. It is thought that the west range fronting Pottergate was also raised at this time.

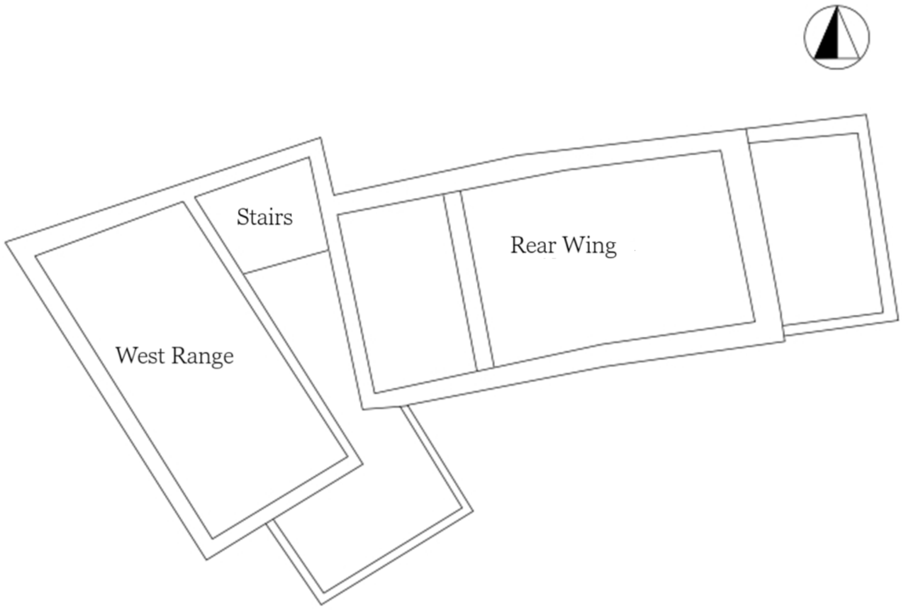

Figure 3: Sketch plan of 2 Pottergate, not to regular scale. [Matt Hurford]

The roof over the rear wing is of clasped purlin type. In total there are 11 pairs of common rafters, with a single set of purlins (of two pieces joined by a splayed scarf), which are clasped between four collars extending between common rafter pairs 2, 5, 8 and 11, with an additional four collars above supporting the square-set ridge (Fig. 4). A number of the common rafters are also of two pieces joined by a splayed scarf. A tiebeam is present at the west end but its relationship to the common rafters cannot be ascertained due to the presence of modern boarding and insulation.

Of note, the northern wall plate has empty mortices for rafters suggesting that the roof may have been remodelled (Fig. 5). This area, however, could not be fully accessed due to the roof sloping down to meet low side walls at eaves level, there being only one small access hatch through to a limited number of timbers.

Figure 4: General view of the roof over the rear wing, viewed looking east. [photograph Matt Hurford]

Figure 5: Empty mortices of the north wall plate viewed looking north. [photograph Matt Hurford]

The cellar (Fig. 6), located beneath the stairs and western part of the rear wing, is also - likely to be associated with the eighteenth-century improvements. It comprises a northern and southern room divided by a brick partition wall with an off-centre doorway and contains several moulded joists and ceiling beams, probably from elsewhere, the profiles suggesting an origin in the sixteenth century or earlier. At the east end of the rear wing is the original ground-floor back kitchen, likely to date to the eighteenth century, with a later nineteenth-century first floor.

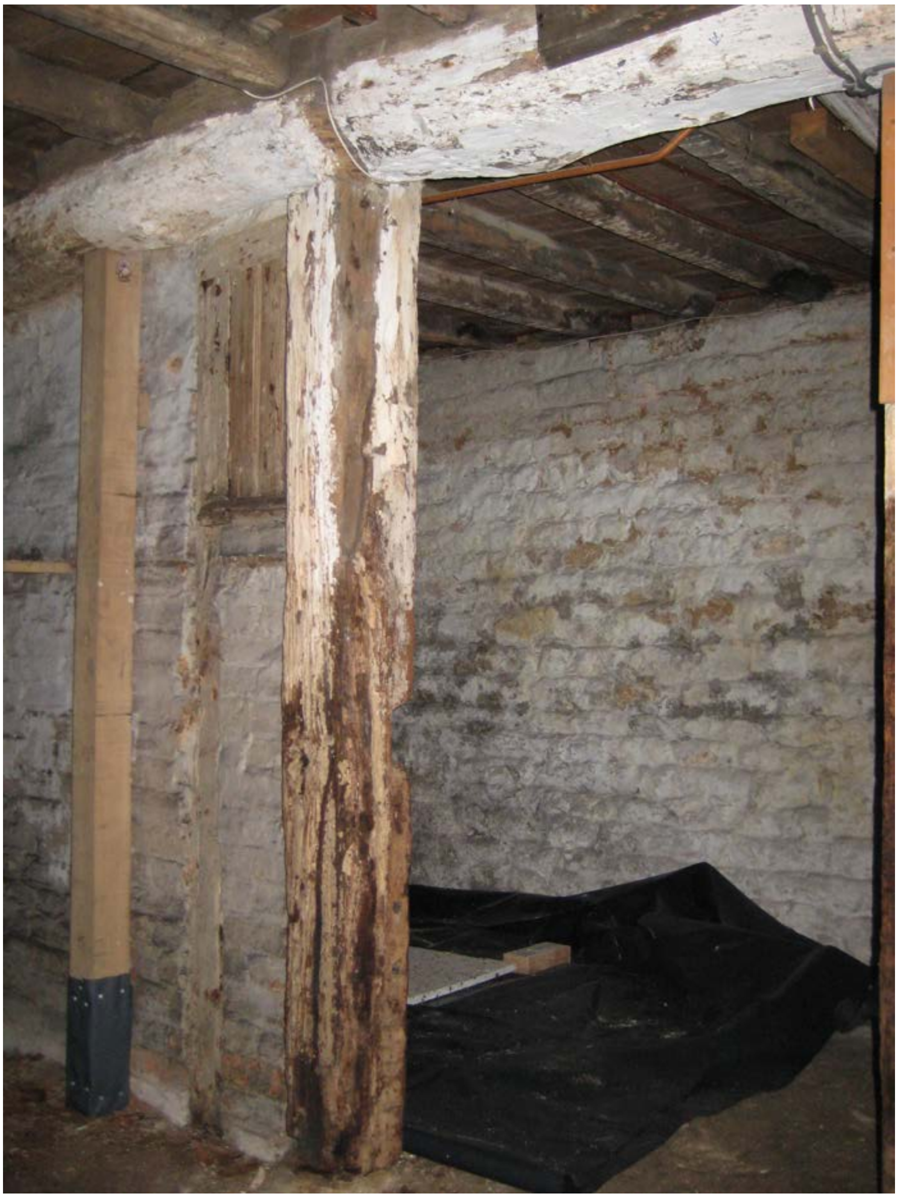

Figure 6: General view of the cellar viewed from the stairs looking south-east. [photograph Matt Hurford]

Sampling

A total of 15 oak (*Quercus* sp.) timbers were sampled, each being given the code PTG-L and numbered 01–15. Seven samples, PTG-L01–PTG-L07 were taken from the roof over the rear wing, with a further sample, PTG-L08, being taken from the stairway between the rear wing and west range. An additional seven samples, PTG-L09–PTG-L15 were taken from the cellar. The west-range roof is a modern softwood replacement and so no samples were taken from there. Additionally, as mentioned above, access was severely restricted in the rear wing, and it was not possible to sample the north wallplate. The positions of the samples are marked on the drawings (Figs 7–8). Details of the samples are given in Table 1. The timbers have been located and numbered following the scheme on the drawings provided.

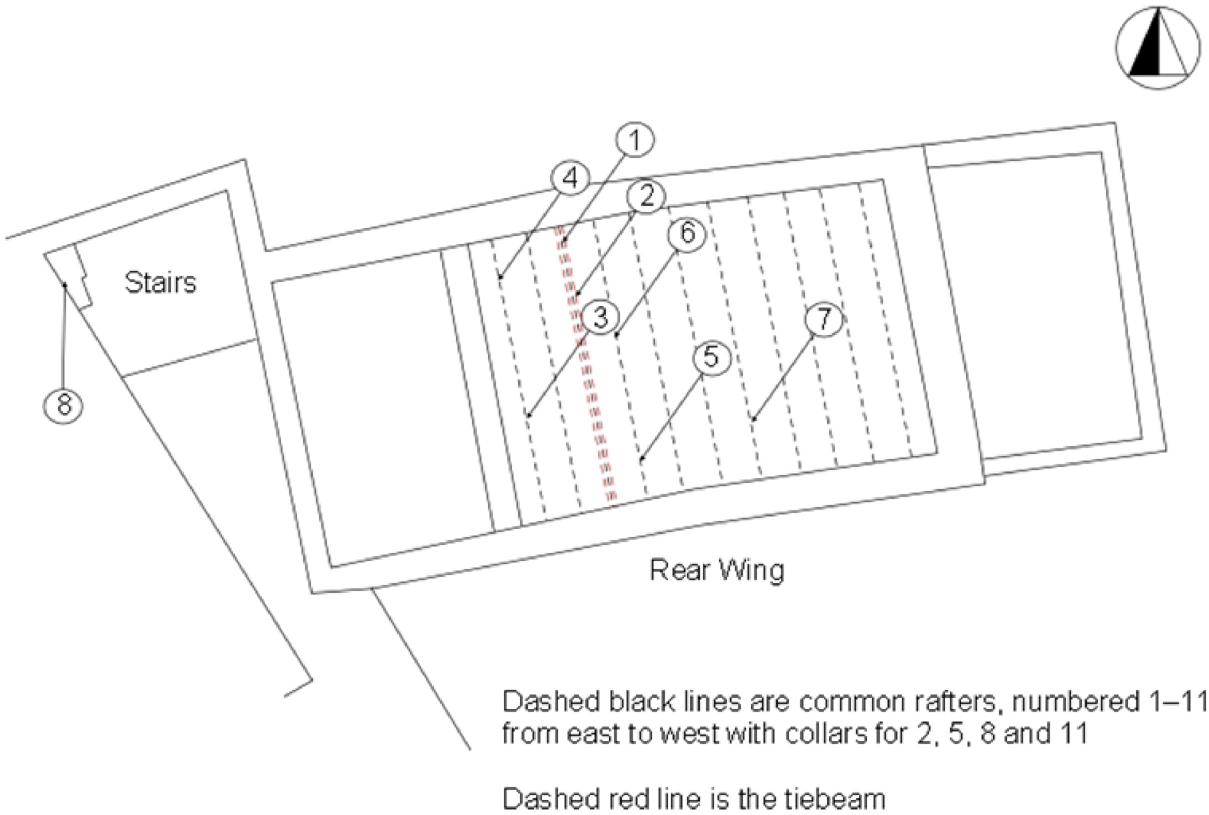

Figure 7: Sketch plan showing the location of samples PTG-L01–PTG-L07 within the attic of the rear range and sample PTG-L08 located within a hatch on the stairs. [Matt Hurford; not to regular scale]

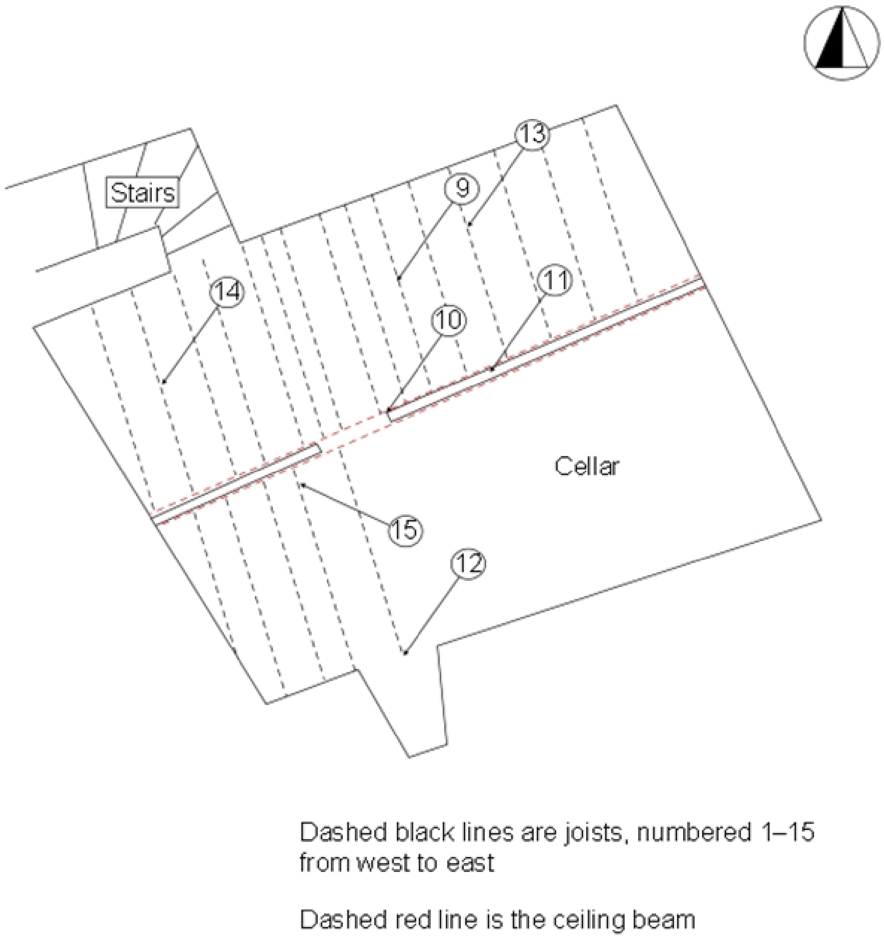

Figure 8: Sketch plan showing the location of samples PTG-L09–15 within the cellar. [Matt Hurford; not to regular scale]

Table 1: Details of tree-ring samples from 2 Pottergate, Lincoln.

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Roof of the Rear Wing						
PTG-L01	North common rafter 9	64	21	----	----	----
PTG-L02	Tiebeam	94	26	1627	1694	1720
PTG-L03	South common rafter 11	97	26	1625	1695	1721
PTG-L04	North common rafter 11	97	17	1624	1703	1720
PTG-L05	South common rafter 8	68	28C	1658	1697	1725
PTG-L06	Collar 8	NM (28)		----	----	----
PTG-L07	South common rafter 5	93	20C	1633	1705	1725
Stairway Between the Rear Wing and West Range						
PTG-L08	Former lintel? located in the hatch	NM (29)		----	----	----
Cellar						
PTG-L09	North room joist 10	NM (29)		----	----	----
PTG-L10	East door jamb of central partition	152	h/s	1157	1308	1308
PTG-L11	West to east ceiling beam	102	h/s	1591	1692	1692
PTG-L12	South room joist 5	59	h/s	----	----	----
PTG-L13	North room joist 12	65	21	----	----	----
PTG-L14	North room joist 2	34	h/s	----	----	----
PTG-L15	South room joist 4	NM (23)		----	----	----

Key: h/s = heartwood/sapwood boundary retained on the sample; C = complete sapwood retained on the sample; NM (XX) = not measured (number of rings counted).

Analysis and Results

All 15 samples were prepared by sanding and polishing at which point it was seen that four of the samples had too few rings for secure dating (<30). These samples were rejected prior to analysis. The remaining 11 samples had their growth-ring widths measured. The data of these measurements are given at the end of the report. All measurements were then compared with each other by the Litton/Zainodin grouping programme (*see* Appendix), resulting in eight samples matching to form two groups.

Firstly, six samples grouped at a minimum *t*-value of t = 4.6. These ring-width series were combined at the relevant offset positions to form PTGLSQ01, a site sequence of 135 rings (Fig. 9). Comparison of this site sequence against the reference chronologies resulted in a secure match at a first-ring date of AD 1591 and a last-measured ring date of AD 1725. The evidence for this dating is given in Table 2.

Two samples matched each other at a value of t = 9.5 and were combined at the relevant offset position to form PTGLSQ02, a site sequence of 69 rings (Fig. 10). This site sequence was compared against a series of relevant reference chronologies for oak but no conclusive cross-matching was identified and so it remains undated.

Attempts were then made to date the remaining three measured, but ungrouped, samples by comparing them individually against the reference chronologies. This resulted in the successful dating of sample PTG-L10 at a first-ring date of AD 1157 and a last-measured ring date of AD 1308. The evidence for this dating is given in Table 3. The remaining samples could not be matched and remain undated.

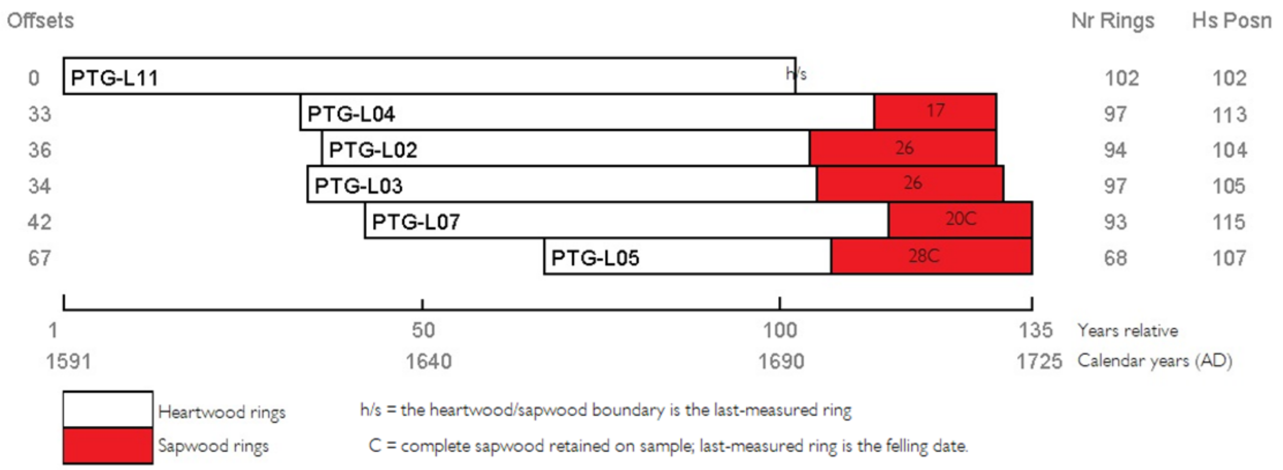

Figure 9: Bar diagram of samples in site sequence PTGLSQ01.

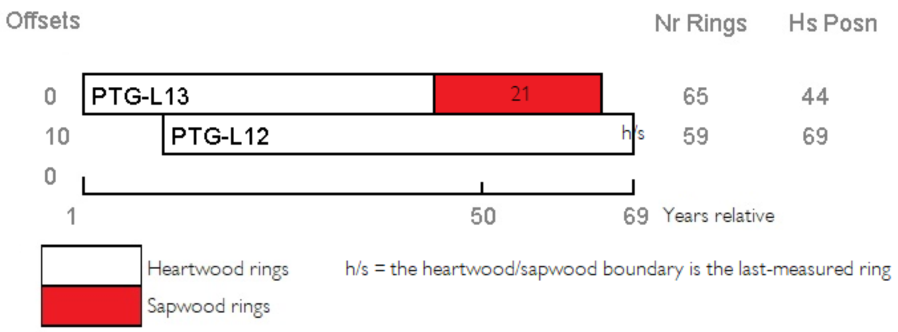

Figure 10: Bar diagram of samples in undated site sequence PTGLSQ02.

Table 2: Results of the cross-matching of site sequence PTGLSQ01 and example reference chronologies when the first ring date is AD 1591 and the last-measured ring date is AD 1725.

Reference chronology	*t*-value	Span of chronology (AD)	Reference
Kirby Hall, Northamptonshire	10.2	1509–1795	Arnold et al. forthcoming
St Hughs' Choir, Lincoln Cathedral, Lincolnshire	10.1	1575–1724	Laxton et al. 1984
Oakham Castle, Rutland	9.6	1598–1737	Arnold and Howard 2013
Worcester Cathedral, Worcestershire	9.6	1484–1772	Arnold et al. 2003
Manor House, Thorpe-by-Water, Rutland	8.6	1622–1688	Arnold and Howard 2021
St Mary's Guildhall, Lincoln, Lincolnshire	8.5	1632–1739	Arnold and Howard 2020 unpubl
Angel Choir, Lincoln Cathedral, Lincolnshire	8.4	1596–1703	Howard et al. 1985
Bolsover Castle (Riding House), Derbyshire	8.4	1494–1744	Howard et al. 2005
Croome Court, Worcestershire	8.1	1639–1753	Arnold et al. 2004
Bardney Barn, Lincolnshire	8.0	1591–1700	Arnold and Howard 2011 unpubl

Table 3: Results of the cross-matching of sample PTG-L10 and example reference chronologies when the first ring date is AD 1157 and the last-measured ring date is AD 1308.

Reference chronology	*t*-value	Span of chronology (AD)	Reference
Severns Castle Road, Nottingham, Nottinghamshire	7.8	1030–1334	Howard et al. 1996
40-44 Castlegate, Newark, Nottinghamshire	7.6	1169–1330	Arnold et al. 2002
60 Stonegate, York, North Yorkshire	7.6	1150–1308	Tyers 2000
Southview Cottage, Norwell, Nottinghamshire	7.5	1132–1306	Hurford et al. 2010
Eaton Bridge, River Idle, Nottinghamshire	7.5	1161–1268	Laxton et al. 1982
Home Farm Cottage, Westhorpe, Nottinghamshire	7.4	1126–1317	Arnold and Howard 2015
22/4 Kirkgate, Newark, Nottinghamshire	6.9	1177–1337	Arnold et al. 2002
Old White Hart, Newark, Nottinghamshire	6.9	1142–1312	Arnold et al. 2002
Til House, Clifton, Nottinghamshire	6.7	1077–1319	Howard et al. 1992
Ulverscroft Priory, Leicestershire	6.5	1219–1463	Arnold et al. 2008

Interpretation

Tree-ring analysis has resulted in the successful dating of seven samples from the property. Where complete sapwood does not exist the 95% confidence limit of 15–40 sapwood rings appropriate for mature oaks in this part of England has been used.

Five of the samples taken from the roof over the rear wing have been dated. Two of these, PTG-L05 and PTG-L07, both common rafters, retain complete sapwood and the last-measured ring date of AD 1725 is the felling date of the timbers represented. As the outermost ring on PTG-L05 and PTG-L07 has earlywood and latewood a winter felling date of AD 1725/26 is suggested. A further three samples from the roof, comprising common rafters PTG-L03 and PTG-L04 and tiebeam PTG-L02, retain incomplete sapwood. These timbers are likely to represent a single felling phase as their heartwood/sapwood boundaries are within nine years of each other, the average date of this boundary being AD 1697. Using the 95% confidence limit of 15–40 sapwood rings and allowing for sample PTG-L03 to have a last-measured ring date of AD 1721 with incomplete sapwood, would give the timbers represented a felling date in the range of AD 1722–37. This estimated range encompasses the precise felling date obtained from samples, PTG-L05 and PTG-L07 and hence, it is probable that these other timbers were also felled in, or around, the winter of AD 1725/6, particularly bearing in mind the overall level of similarity between the ring-width series of these five roof timbers.

Two of the samples taken from timbers in the cellar have also been dated, clearly indicating that the two timbers represented were felled around four centuries apart.

The earliest heartwood/sapwood boundary ring is on sample PTG-L10, taken from the east-door jamb in the cellar. It has a heartwood/sapwood boundary ring date of AD 1308, allowing an estimated felling date to be calculated for the timber represented to within the range of AD 1323–48.

Sample PTG-L11, from a ceiling beam in the cellar, which is a reused timber, has a heartwood/sapwood boundary ring date of AD 1692. Applying the same sapwood estimate as above produces an estimated felling date of AD 1707–32. It is clearly at least broadly coeval with the dated timbers from the roof of the rear wing and thus could also have been felled in, or around, AD 1725/6.

Two further cellar timbers, PTG-L12 and PTG-L13, are represented by the undated site sequence PTGLSQ02. Although it is not possible to say when these two timbers were felled, it can be said, by looking at the relative heartwood/sapwood boundary ring positions

(Fig. 10), that this is unlikely to have been at exactly the same time, with sample PTG-L13 being felled a few decades before PTG-L12.

Discussion

Tree ring analysis on the clasped purlin roof over the rear wing has established that it is constructed of timbers felled in, or around, the winter of AD 1725/6, thus corroborating previous research that suggested a remodelling of this part of the property during the first half of the eighteenth century (Jones et al. 1984, 102). The north wall-plate, located where sampling was not possible due to access issues, contains empty mortices for common rafter feet indicating that either it is a reused timber or that the current roof is a replacement.

It has previously been thought that the excavation of the cellar dates to the first half of the eighteenth century when the other alterations to the rear wing were undertaken, and that the timbers used within its construction were largely reused (Jones et al. 1984, 102–3). The current dendrochronological work would concur with this interpretation, since it has demonstrated that a single dated ceiling beam is likely to be contemporary with the clasped purlin roof (AD 1725/6), although empty mortices indicate that it is a reused timber. Either the cellar was remodelled following its initial construction but incorporated original timbers or the ceiling beam originated from elsewhere. The uncertainty about the origin of the timber renders its use in dating the cellar problematic. The much earlier dated timber, felled during the first half of the fourteenth century, has empty mortices suggesting that it too is reused. The relative dating of the heartwood/sapwood boundaries in undated site chronology PTLGSQ02 indicates that these timbers from the cellar were felled several decades apart, further demonstrating that the timbers within the cellar are disparate and potentially reused.

Although site chronology PTLGSQ01, and the individually dated sample, have been compared to an extensive range of reference chronologies, the highest levels of similarity are found with reference chronologies from the surrounding regions suggesting that the woodland sources from which the timbers were derived is likely to be relatively local.

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Data of measured samples

Measurements in 0.01mm units

PTG-L01A 64
211 289 366 193 226 212 199 168 291 146 314 202 263 288 269 224 199 176 99 100
110 122 93 116 90 88 55 76 42 72 71 72 54 64 139 93 78 75 38 69
80 97 101 86 69 98 150 151 184 210 100 57 39 52 81 107 104 170 199 120
88 113 71 88

PTG-L01B 64
200 288 359 184 237 244 186 168 293 147 310 202 241 267 243 205 179 126 84 99
114 114 80 91 72 66 48 44 38 59 68 82 54 84 137 103 70 81 37 68
76 108 98 107 64 95 181 152 204 194 96 61 40 47 78 117 93 192 205 117
86 113 86 131

PTG-L02A 94
285 266 321 191 297 392 308 172 222 200 307 338 229 242 201 126 115 161 202 343
264 324 255 163 105 125 159 154 244 243 251 219 132 124 121 110 214 223 181 118
151 192 184 175 173 168 190 206 109 61 165 153 110 153 106 160 101 122 95 157
109 88 74 74 75 87 68 78 86 77 152 95 78 71 82 48 74 63 45 51
72 83 96 57 44 47 49 36 50 35 48 43 45 38

PTG-L02B 94
297 276 329 192 283 408 318 172 215 195 312 333 232 242 209 129 122 157 204 340
267 334 236 153 105 139 160 145 252 233 247 223 136 128 129 97 216 234 176 112
151 186 193 160 188 170 183 193 107 53 169 160 118 158 114 158 110 118 103 152
118 86 68 60 70 88 69 80 84 76 136 102 79 66 81 54 73 71 41 52
75 70 85 49 55 55 51 32 42 44 35 36 36 44

PTG-L03A 97
361 393 417 388 398 240 237 343 310 186 235 314 241 341 286 261 263 222 187 219
196 209 127 147 127 94 72 88 123 124 134 147 141 114 75 68 35 32 34 49
40 28 43 40 59 49 53 49 50 34 39 31 52 55 57 42 39 47 39 24
25 24 32 28 18 22 27 27 21 30 21 33 45 41 39 35 43 37 41 46
34 36 31 31 30 28 29 33 31 31 45 53 56 44 56 55 36

PTG-L03B 97
349 375 419 374 401 255 250 344 310 192 234 305 242 341 271 289 289 234 195 232
209 225 153 161 133 97 78 94 130 122 157 153 144 100 83 66 41 31 42 42
38 29 40 47 55 56 50 53 50 42 43 41 47 55 50 48 38 46 38 22
22 26 27 30 22 16 25 27 26 30 23 27 50 37 45 23 38 36 44 55
23 26 41 40 34 28 21 33 19 36 47 42 59 48 56 50 19

PTG-L04A 97
326 313 319 332 297 352 198 256 267 236 138 212 189 164 180 151 175 182 160 137
173 140 143 122 165 117 88 65 90 111 123 189 167 140 99 68 78 66 39 50
61 45 46 49 71 67 62 67 73 90 62 56 40 89 88 80 111 90 80 77
52 29 33 54 55 36 28 41 44 39 42 51 52 47 59 39 37 29 29 39
36 36 29 38 81 74 42 52 74 67 45 45 39 43 53 42 43

PTG-L04B 97
329 309 357 340 318 364 228 269 255 247 138 213 180 162 181 146 179 180 165 138
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42 30 40 49 56 43 28 38 41 34 47 50 55 52 60 49 37 33 29 43
32 37 29 38 75 79 41 56 76 59 56 39 43 44 53 50 34

PTG-L05A 68
203 193 119 112 102 131 146 96 103 145 202 224 218 221 216 251 183 106 83 109
183 149 152 132 174 100 67 59 78 107 76 73 79 90 84 77 94 109 93 106
122 96 104 128 52 63 62 46 61 62 129 108 77 73 93 93 62 58 103 108
85 87 83 151 178 149 192 211

PTG-L05B 68
210 197 116 116 108 134 138 95 111 144 196 222 215 227 219 244 183 104 87 110
156 134 163 127 163 105 64 62 91 104 73 74 72 103 87 72 110 87 91 104
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91 86 95 152 169 128 194 228

PTG-L07A 93
229 150 221 204 188 275 238 262 292 203 177 232 225 204 128 164 140 123 86 81
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65 43 48 36 55 54 56 60 69 71 65 42 40 32 44 48 40 28 33 51
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PTG-L07B 93
230 144 215 205 188 270 235 254 285 199 180 237 201 209 131 177 146 115 76 72
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43 33 40 38 34 39 36 26 31 18 39 24 19 35 31 77 86 40 45 58
73 55 59 37 45 66 70 83 75 65 53 61 46

PTG-L10A 152
221 214 191 214 220 239 238 173 203 144 146 184 114 148 116 115 155 124 184 125
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123 137 132 108 51 53 51 56 69 49 55 72 56 89 118 87 92 74 73 63
43 43 59 71 65 63 68 32 39 59 61 66 79 67 114 93 115 73 60 63
64 63 51 111 148 198 210 173 175 210 147 100 176 186 151 244 204 188 156 125
128 91 142 134 207 184 140 104 146 143 123 138

PTG-L10B 152
233 212 176 221 223 246 228 166 207 151 215 171 121 142 116 102 157 131 180 127
57 42 145 113 138 156 103 68 65 117 126 115 104 86 100 98 125 101 135 102
78 46 109 109 151 52 91 96 154 106 60 76 115 160 188 141 140 114 106 104
125 82 109 100 135 78 80 106 143 120 102 95 87 146 112 91 79 76 101 81
123 140 135 98 47 55 47 52 76 48 55 65 51 87 116 76 91 82 68 51
54 40 47 60 58 62 55 35 48 61 48 83 83 67 110 91 117 81 57 66
58 71 49 108 132 208 203 176 173 216 143 98 192 182 162 252 224 188 161 123

128 80 155 148 213 193 151 104 145 145 115 144

PTG-L11A 102
219 192 138 197 195 234 243 215 147 85 245 220 223 259 134 223 227 221 181 168
187 168 237 155 166 146 140 129 119 135 127 128 93 111 48 51 57 65 61 52
45 64 69 33 47 31 54 53 43 70 53 33 55 107 78 53 49 59 43 20
38 41 32 36 66 73 72 46 54 55 39 60 64 53 44 37 47 88 89 61
112 125 123 119 93 77 142 126 175 180 158 199 158 129 73 101 100 65 53 52
69 83

PTG-L11B 102
209 174 124 219 189 225 249 212 140 102 238 196 220 249 145 220 236 215 184 172
194 164 256 170 154 141 130 153 124 121 147 144 88 110 43 58 57 74 73 48
54 56 64 36 56 29 50 58 54 42 68 42 57 99 74 55 59 51 53 25
41 36 26 39 69 70 68 55 54 50 44 60 60 54 48 44 35 81 87 62
141 140 120 135 85 68 125 155 160 193 167 212 142 129 73 101 110 58 54 60
68 63

PTG-L12A 59
217 141 94 120 147 203 124 217 191 205 175 158 174 138 204 239 299 259 184 115
129 248 281 307 294 267 315 251 246 228 267 248 193 218 195 252 219 228 176 159
118 97 123 134 102 98 127 130 117 123 93 120 81 129 131 178 160 169 134

PTG-L12B 58
264 134 95 117 138 212 120 223 187 201 151 145 174 122 210 244 306 232 190 118
128 260 278 309 299 267 312 253 255 212 275 265 199 220 188 249 219 220 170 161
123 91 120 138 92 98 133 137 110 129 97 109 94 121 132 189 157 172

PTG-L13A 65
330 187 266 148 123 128 163 105 130 176 164 106 101 152 162 195 124 229 188 153
150 121 157 121 162 310 422 295 164 104 115 157 222 219 182 191 260 196 174 176
197 214 160 138 89 173 138 156 111 95 65 61 92 114 84 84 145 129 98 98
110 110 97 136 114

PTG-L13B 65
337 191 279 150 117 129 167 102 122 179 160 104 106 138 175 210 134 224 198 152
146 132 159 124 161 338 436 283 167 98 108 158 227 251 207 200 256 196 174 179
195 217 164 140 101 182 146 172 118 102 76 73 96 111 78 103 158 163 94 128
108 122 108 130 107

PTG-L14A 34
374 385 405 288 127 168 136 107 151 248 105 118 128 198 187 118 61 48 54 77
92 122 158 125 119 157 152 148 197 108 91 80 72 107

PTG-L14B 34
371 384 406 284 129 161 138 118 151 255 102 120 121 201 192 117 61 48 52 82
94 121 157 134 120 154 143 137 211 104 116 83 78 109

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 Nottingham Tree-ring Dating Laboratory's Monograph, An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Buildings (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

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.

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.

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).

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 (i.e. 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).

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; e.g. 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 Figure 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).

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, 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 complement 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.

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 (e.g. Baltic boards), then some allowance has to be made for this.

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.

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 AD 1810 is very apparent as is the smaller later growth from about AD 1900 onwards when the tree is maturing. A similar phenomenon can be observed in the lower sequence of (a) starting in AD 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

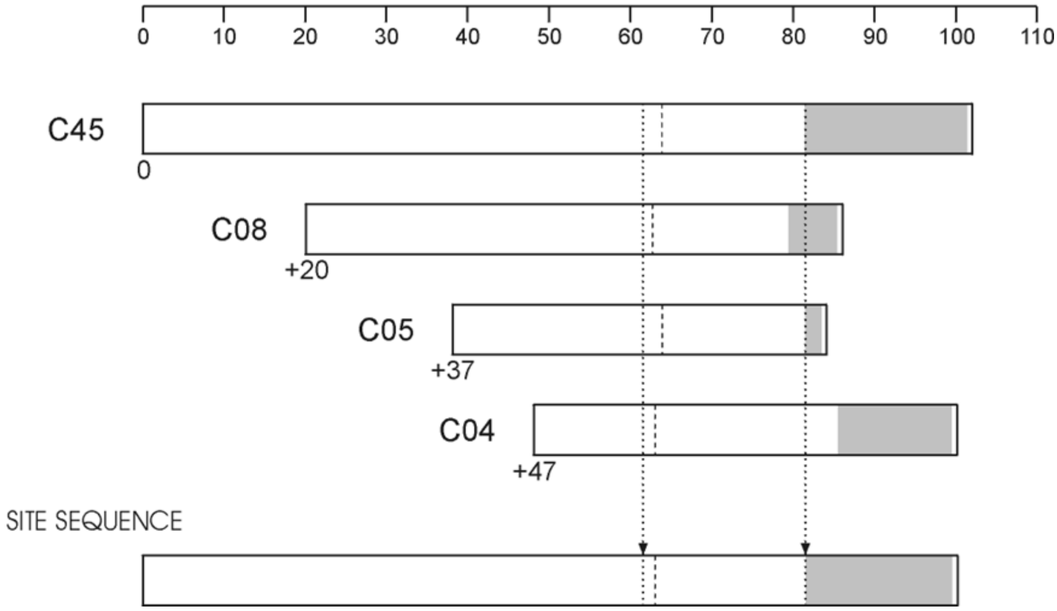


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them. The bar diagram represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are 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.

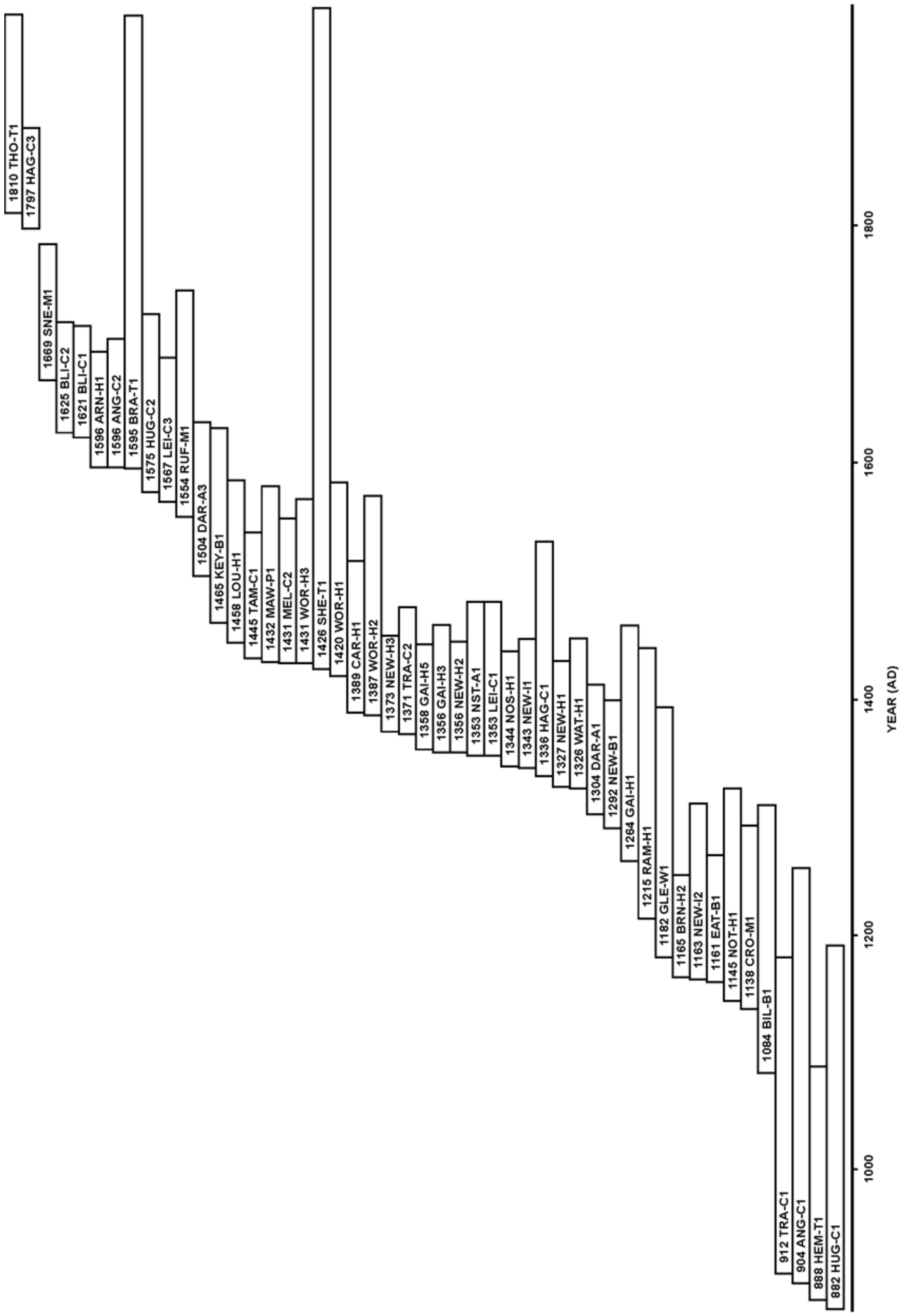
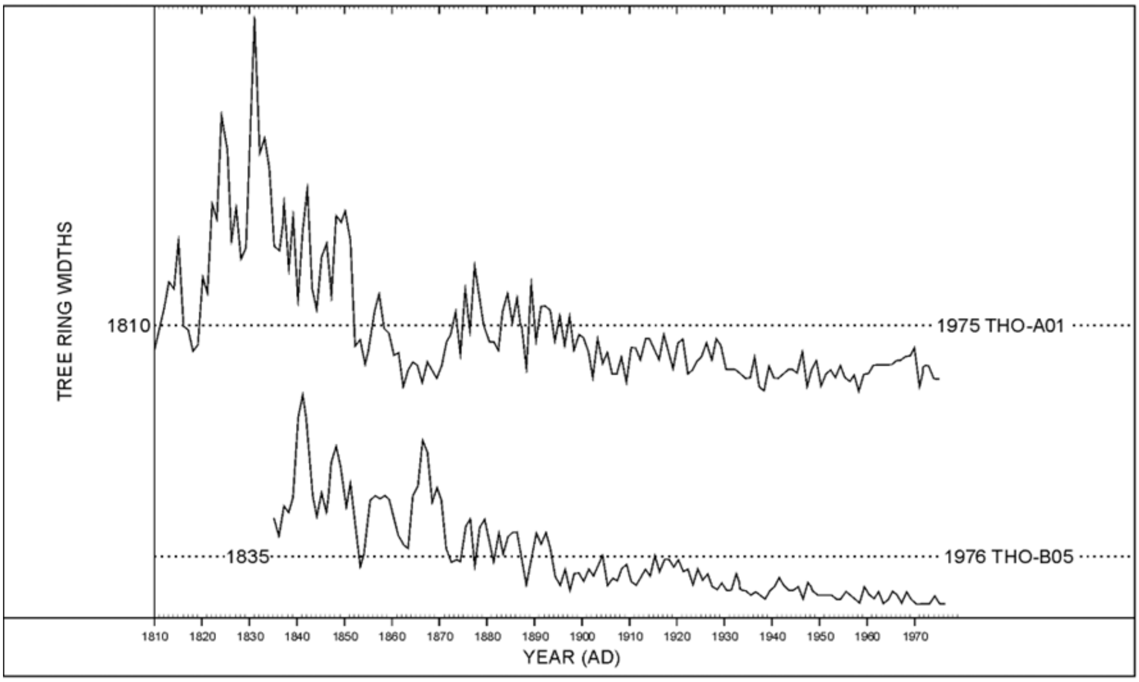


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

(a)



(b)

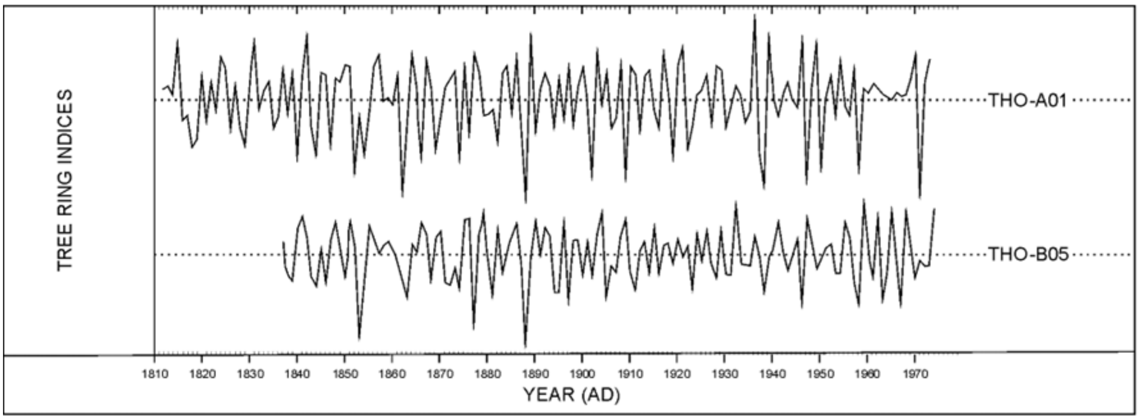


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young 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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