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COCKLE PARK TOWER, HEBRON, MORPETH, NORTHUMBERLAND
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

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SUMMARY

Samples were taken from the roof of the main range and from the roof of a short cross-wing of this building. Subsequent tree-ring analysis of these resulted in the construction of a single site sequence, containing 15 samples and spanning the period AD 1394–1602. Additionally, sample CKL-P15 was dated individually to a first-ring date of AD 1418 and a last-measured ring date of AD 1481.

Two of the dated samples are from trees felled in AD 1602, with several others having an estimated felling date range consistent with them also having been felled at this time. Dendrochronology has demonstrated that the main range roof is constructed from timbers felled in AD 1602 with construction likely to have occurred soon after. The *terminus post quem* dates gained for two timbers of the short cross-wing roof make it possible that this roof also dates to the early-seventeenth century, but this cannot be proven by dendrochronology.

CONTRIBUTORS

Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS

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ARCHIVE LOCATION

Northumberland Historic Environment Record
Community and Environmental Services
Northumberland County Council
County Hall
Morpeth NE61 2EF

DATE OF INVESTIGATION

2009

CONTACT DETAILS

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INTRODUCTION

Cockle Park Tower is a Grade-I listed tower house located near Morpeth, about 18 miles north of Newcastle upon Tyne (Figs 1 and 2; NZ 201 912). It is believed to have been built for Sir William, 4th Lord Ogle, in about AD 1520, passing at some later date to the Bothal Estates, which in turn came under the ownership of the Dukes of Portland. By AD 1648, when it was home to troops during the Civil War, it is recorded as being just a farmhouse, having lost much of its status.

The building is L-shaped in plan, with corner turrets and a parapet, and with a stair turret projecting at the northern end of the east face and a further seventeenth-century stair projection in the centre of the west wall. In the eighteenth century, the tower was divided into two by the insertion of a brick wall. To the north of this wall, at ground-floor level, are the remains of the medieval barrel vault and an original doorway. Access to the first floor of this part of the building is via the external staircase. Many of the features in the second floor were removed and taken to Bothal Castle in the nineteenth century. The part of the building to the south of the wall was completely altered in about AD 1800, with all original features being removed.

Within the main north-south range roof there are five principal-rafter trusses, with tiebeams, collars, and trenched purlins (Fig 3). At the north end of this range is a short cross–wing, extending out to the east. The roof here has a single truss of principal rafters and tiebeam (Fig 4).

During the nineteenth century, Cockle Park became an experimental farm for the Dukes of Portland. In AD 1902 the building was in the ownership of the county council and came into the ownership of Newcastle University as part of Cockle Park Farm.

This description is largely based on its Listed Buildings Description (www.imagesofengland.org.uk).

SAMPLING

Tree-ring dating of the timbers at Cockle Park Tower was requested by Martin Roberts to inform advice on this Building at Risk and an English Heritage grant application submitted in relation to it. It was hoped that by providing a date for the timbers of the main range roof and of the short cross–wing roof, it would be possible to provide a construction date for these roofs, thereby establishing whether they were primary to the building, as had been suggested, and the relationship between them.

In accordance with the brief provided by English Heritage, a total of 17 timbers was sampled. Each sample was given the code CKL-P (for Cockle Park) and numbered 01–17. Samples CKL-P01–14 were taken from the main roof, whilst CKL-P15–17 were taken from the small side roof. Within the main roof only the principal rafters and collars were thought suitable for analysis with the common rafters being deemed to have too few rings for secure dating. The location of samples was noted at the time of sampling and has been marked on Figures 5–11. Further details relating to the samples can be found in Table 1. The roof trusses of the main range roof have been numbered from north to south.

ANALYSIS AND RESULTS

All 17 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. These samples were compared with each other by the Litton/Zainodin grouping procedure (see Appendix).

Fifteen samples matched each other and were combined at the relevant offset positions to form CKLPSQ01, a site sequence of 209 rings. This site sequence was compared against the relevant reference chronologies, where it was found to match consistently and securely at a first-ring date of AD 1394 and a last-ring date of AD 1602. The evidence for this dating is given in Table 2.

Attempts to date the remaining two samples by individually comparing them against the reference chronologies resulted in sample CKL-P15 being found to match consistently at a first-ring date of AD 1418 and a last-measured ring date of AD 1481. The results for the dating can be found in Table 3.

Two of the samples from the main range roof (CKL-P03 and CKL-P04), both principal rafters from truss 3, have complete sapwood and the last-ring date of AD 1602, the felling date of the timbers represented. A further seven of the dated samples have the heartwood/sapwood boundary ring, the dates of which are broadly contemporary, varying by only nine years, and suggestive of a single felling. The average heartwood/sapwood boundary ring date is AD 1581, which allows an estimated felling date to be calculated for the timbers represented of AD 1602–21; this takes into consideration sample CKL-P13 having a last-measured ring date of AD 1601 with incomplete sapwood. This felling date range is consistent with these timbers also having been felled in AD 1602.

The remaining seven dated samples (two of which are from the short cross–wing roof) do not have the heartwood/sapwood boundary ring, and so it is not possible to calculate an estimated felling date range for these timbers. However, with last-measured ring dates ranging from AD 1481 (CKL-P15) to AD 1583 (CKL-P16), it is possible that these represent timbers which were also felled in AD 1602.

DISCUSSION

Prior to tree-ring analysis being undertaken, Cockle Park Tower was believed to date to the early-sixteenth century, with the entire roof structure thought to be sixteenth- or seventeenth century, and possibly contemporary with the original building.

It is now known that the main range roof utilises at least two timbers which were felled in AD 1602, with several others also thought likely to have been felled at this time. This suggests construction of this roof occurred in the first few years of the seventeenth century. Given that the building is thought to date to the early-sixteenth century, the implication is that the roof is a replacement rather than primary to the tower.

It is unfortunate that the short cross–wing roof does not contain a great deal of timber, and of these timbers only a very small number were deemed suitable for analysis. Although two of these timbers, the two principal rafters from truss 1, were successfully dated, neither has the heartwood/sapwood boundary ring, which means an estimated felling date range cannot be calculated for either of them. With last-measured ring dates of AD 1481 (CKL-P15) and AD 1583 (CKL-P16), these timbers would be estimated to have been felled in AD 1497 and AD 1599, respectively, at the earliest. This allows for them both to have been felled in AD 1602 (with the earlier sample representing the inner portion of a much longer-lived tree), at the same time as the timbers from the main roof. Sample CKL-P16 matches CKL-P13 from the main roof at a value of t=11.3; a similarity which could suggest both beams were cut from the same tree, supporting the contemporaneous nature of the two roofs. However, in the absence of sapwood and bark edge, this cannot be proved dendrochronologically and it is equally possible that these two timbers represent separate felling/s with the small roof being of a different date to that of the main one.

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TABLES AND FIGURES

Table 1: Details of tree-ring samples from Cockle Park Tower

Sample number	Sample location	Total rings	Sapwood rings*	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Main roof						
CKL-P01	East principal rafter, truss 2	127	--	1454	----	1580
CKL-P02	Collar, truss 2	113	--	1451	----	1563
CKL-P03	East principal rafter, truss 3	139	24C	1464	1578	1602
CKL-P04	West principal rafter, truss 3	90	20C	1513	1582	1602
CKL-P05	West principal rafter, truss 4	97	--	1476	----	1572
CKL-P06	Collar, truss 4	102	--	1394	----	1495
CKL-P07	East principal rafter, truss 5	151	04	1435	1581	1585
CKL-P08	East principal rafter, truss 6	151	h/s	1430	1580	1580
CKL-P09	Collar, truss 5	101	13	1497	1584	1597
CKL-P10	Collar, truss 6	71	--	1480	----	1550
CKL-P11	West principal rafter, truss 5	129	17	1472	1583	1600
CKL-P12	East upper purlin, truss 4–5	119	h/s	1457	1575	1575
CKL-P13	East upper purlin, truss 6–S gable	125	21	1477	1580	1601
CKL-P14	West principal rafter, truss 6	90	07	1502	1584	1591
Side roof						
CKL-P15	North principal rafter, truss 1	64	--	1418	----	1481
CKL-P16	South principal rafter, truss 1	117	--	1467	----	1583
CKL-P17	South common rafter 5, from east	108	10	----	----	----

*h/s = the heartwood/sapwood boundary ring 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 CKLPSQ01 and relevant reference chronologies when the first-ring date is AD 1394 and the last-ring date is AD 1602

Reference chronology	*t*-value	Span of chronology	Reference
Low Harperley Farmhouse, Wolsingham, County Durham	8.3	AD 1356–1604	Arnold *et al* 2006
Aydon Castle (latrine block), Corbridge, Northumberland	8.1	AD 1406–1545	Arnold *et al* 2002
Durham Cathedral (refectory roof), Durham	7.5	AD 1431–1683	Arnold *et al* 2007
1–2 The College, Cathedral Precinct, Durham	6.9	AD 1364–1531	Howard *et al* 1992
Moot Hall, Hexham, Northumberland	6.0	AD 1341–1539	Arnold *et al* 2004a
Unthank Hall, Stanhope, Durham	5.9	AD 1386–1592	Howard *et al* 2001a
Hallgarth Manor Cottages, Pittington, Durham	5.8	AD 1336–1624	Howard *et al* 2001b

Table 3: Results of the cross-matching of sample CKL-P15 site sequence CKLPSQ01 and relevant reference chronologies when the first-ring date is AD 1418 and the last-ring date is AD 1481

Reference chronology	*t*-value	Span of chronology	Reference
Headlands Hall, Liversedge, West Yorkshire	7.8	AD 1388–1487	Tyers 2001
Ordsall Hall, Stockport, Greater Manchester	6.9	AD 1368–1534	Arnold *et al* 2004b
All Hallows' Church, Kirkburton, West Yorkshire	6.1	AD 1306–1633	Arnold and Howard 2007
Houndhill barn, Barnsley, South Yorkshire	6.1	AD 1369–1470	Groves and Hillam 1990
Tunstall Hall Farm, Hartlepool, Cleveland	5.5	AD 1316–1484	Howard *et al* 2002
Norton Conyers Hall, West Yorkshire	5.4	AD 1365–1486	Arnold and Howard 2008 unpubl
Seaton Holme, Easington, Durham	5.4	AD 1375–1489	Howard *et al* 1988 unpubl

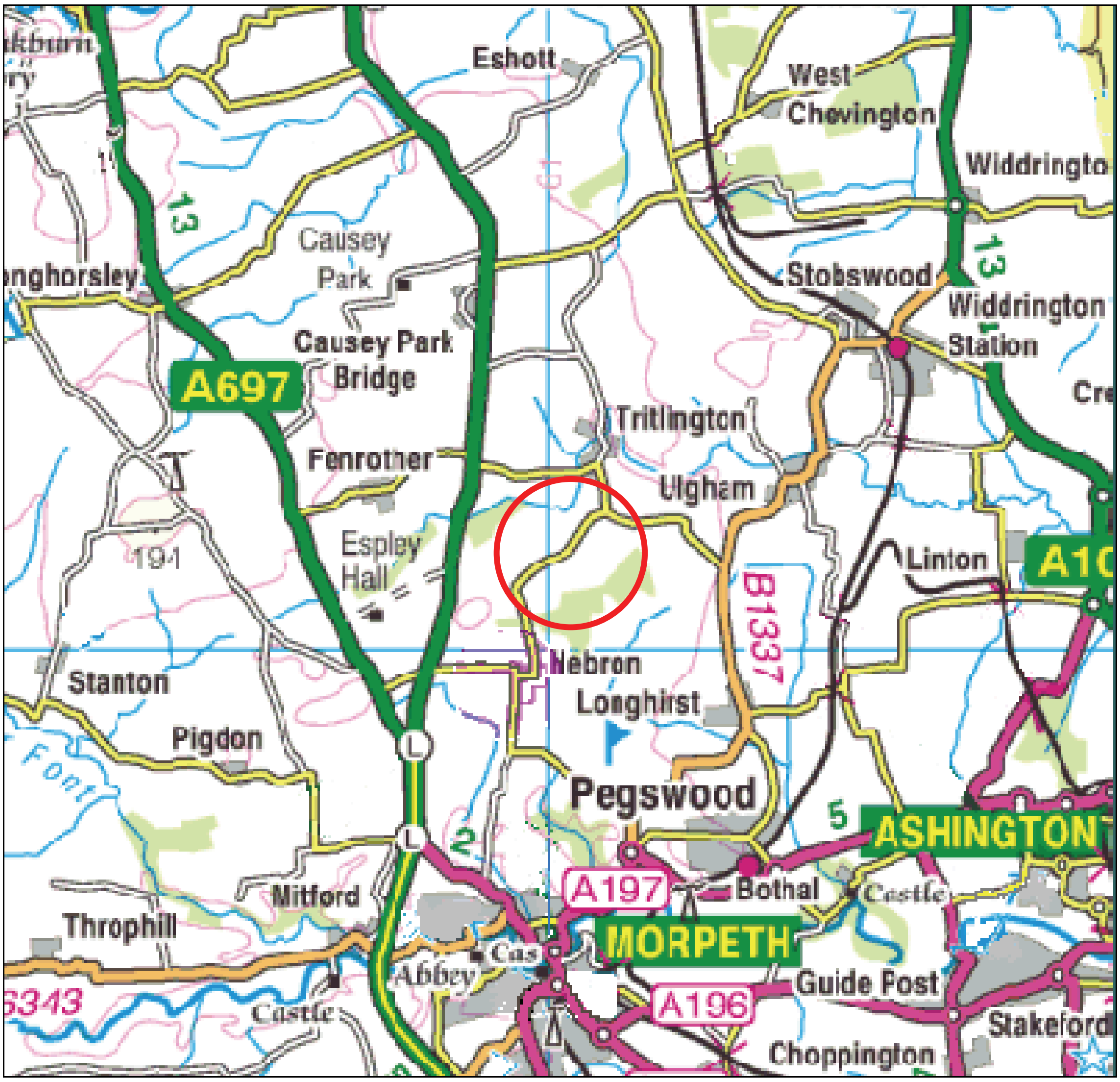


Figure 1: Map to show the general location of Cockle Park (based on the Ordnance Survey map with permission of the Controller of Her Majesty's Stationery Office, © Crown Copyright)

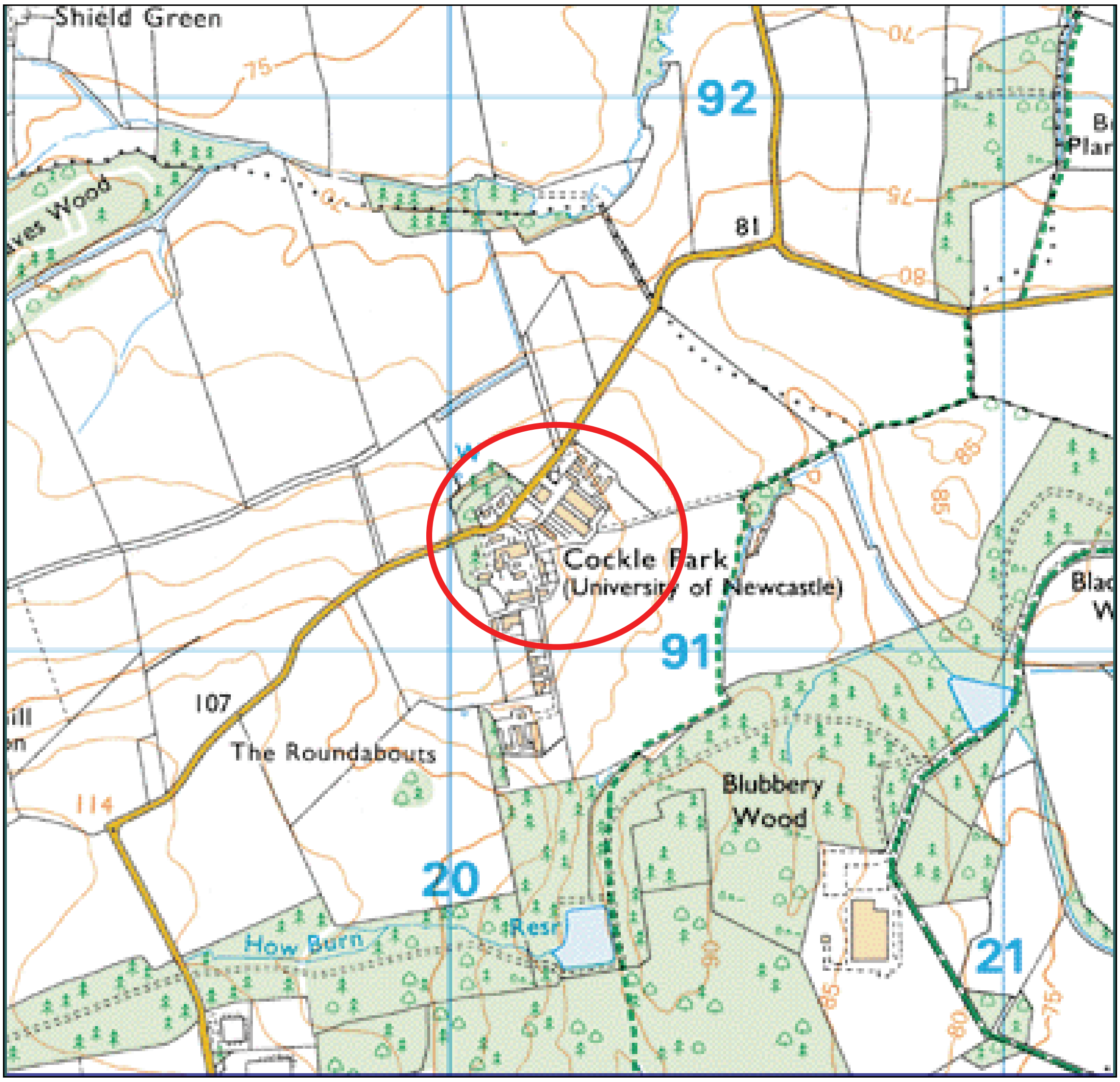


Figure 2: Map to show the location of Cockle Park (based on the Ordnance Survey map with permission of the Controller of Her Majesty's Stationery Office, © Crown Copyright)

Figure 3: Cockle Park Tower; main range roof looking south (truss 3 in the foreground)

Figure 4: Cockle Park Tower; short cross–wing roof looking east (truss 1)

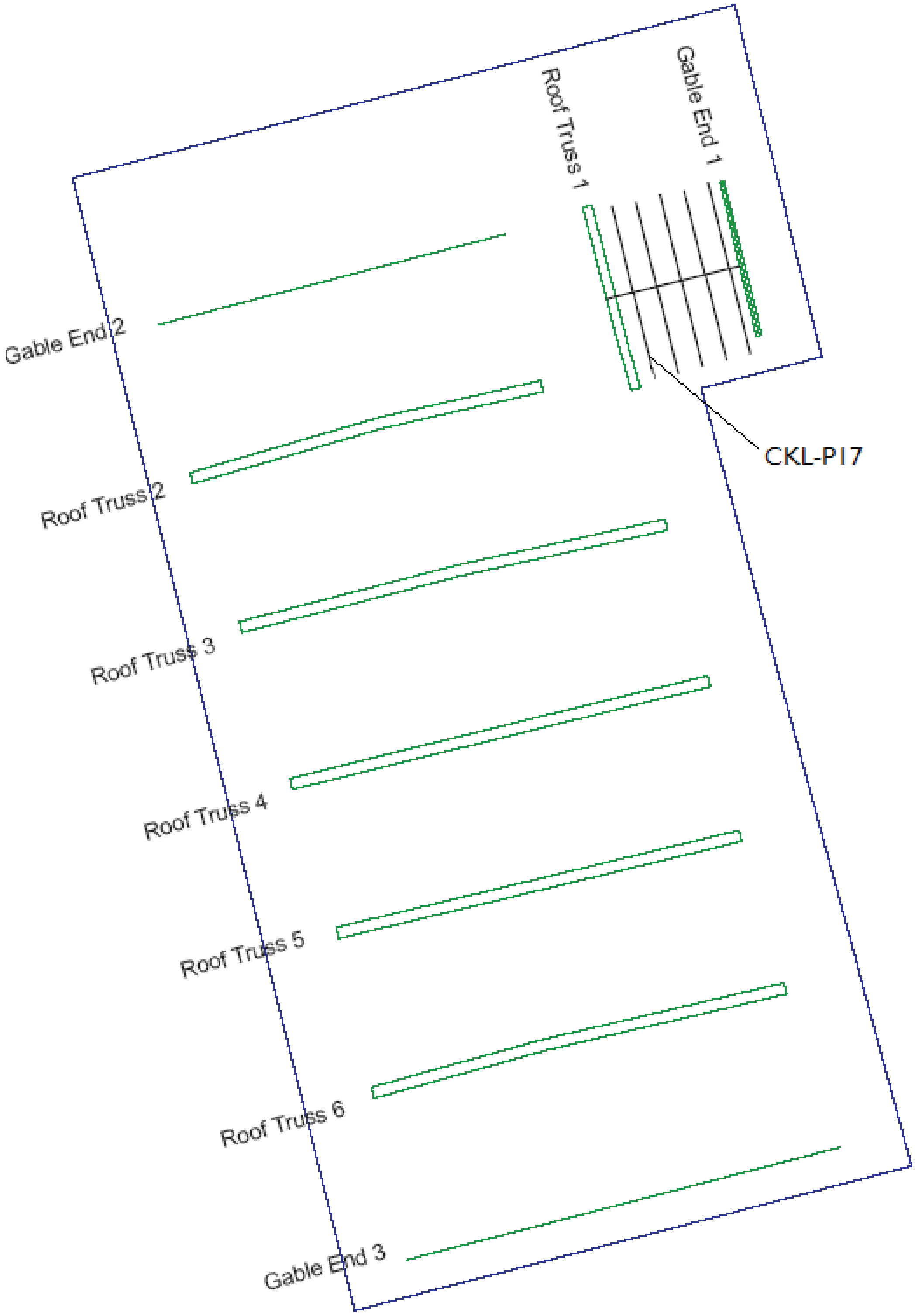


Figure 5: Plan at roof level, showing the location of trusses and the position of sample CKL-P17 (after Ian Wells)

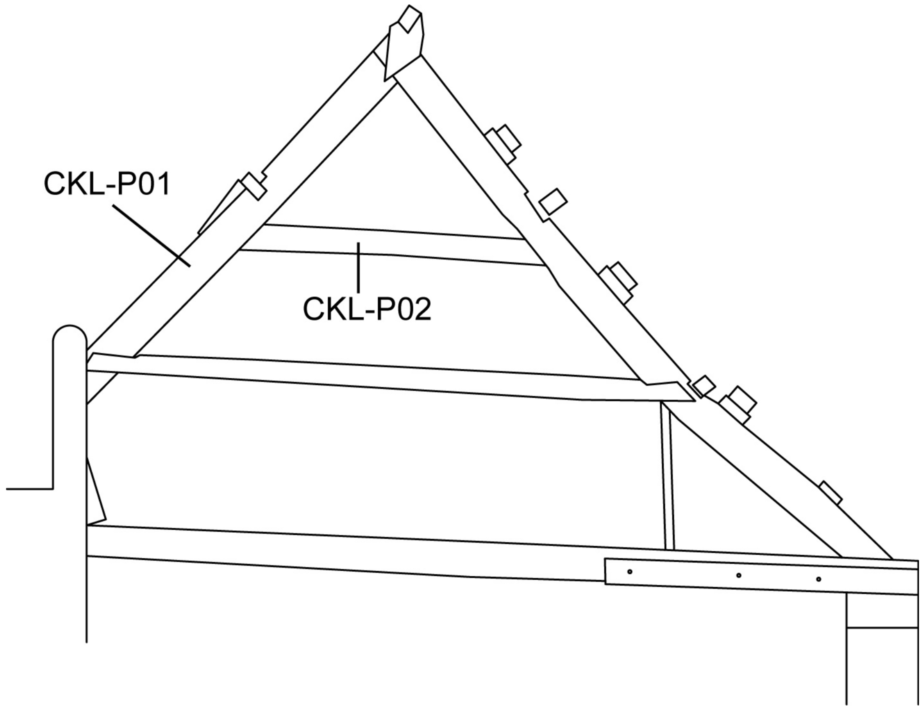


Figure 6: Truss 2 looking south, showing the location of samples CKL-P01 and CKL-P02 (after Ian Wells)

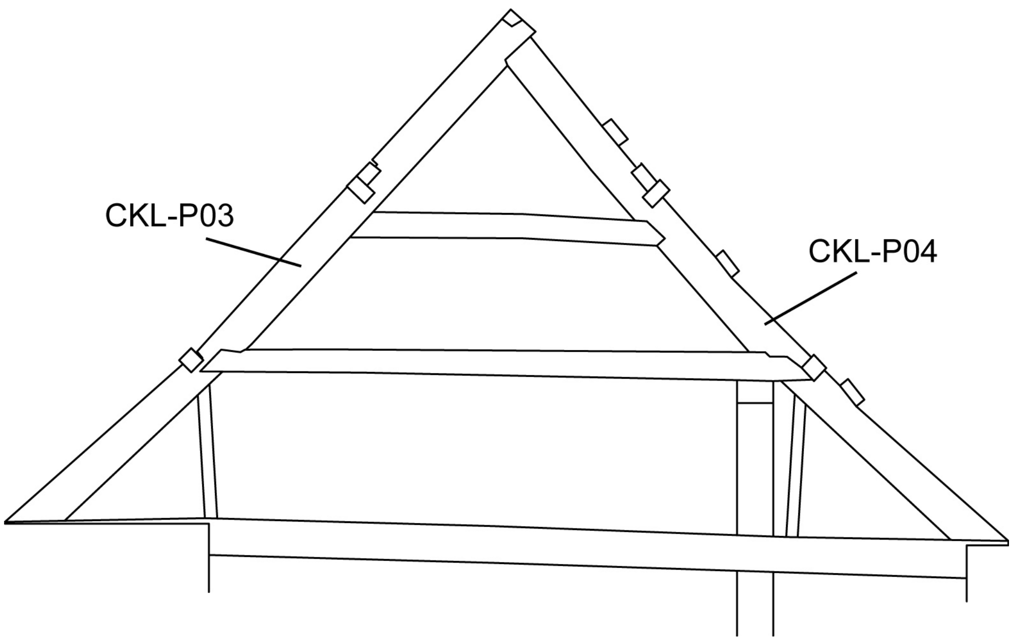


Figure 7: Truss 3 looking south, showing the location of samples CKL-P03 and CKL-P04 (after Ian Wells)

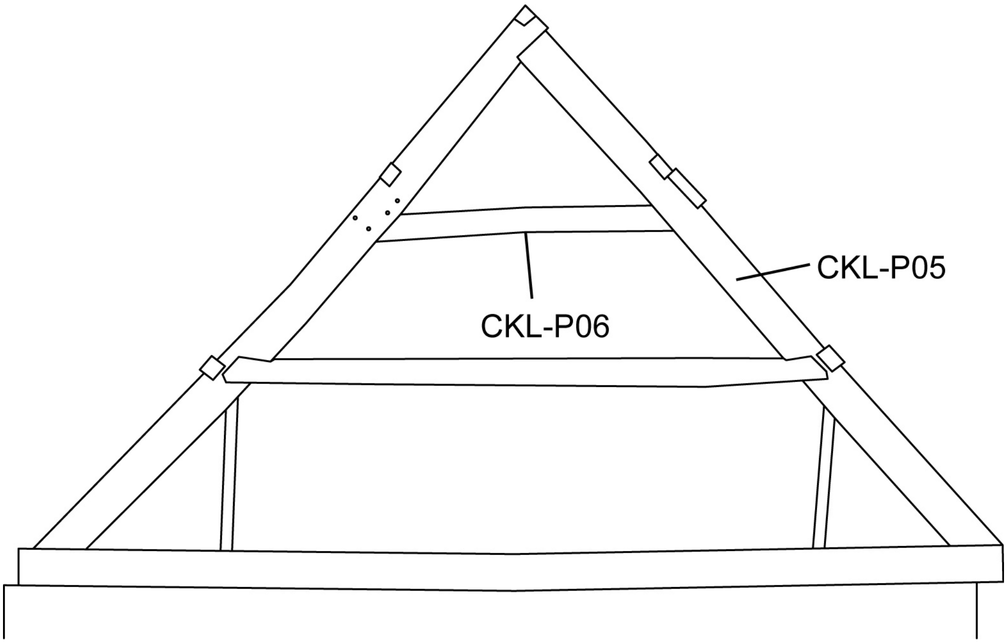


Figure 8: Truss 4 looking south, showing the location of samples CKL-P05 and CKL-P06 (after Ian Wells)

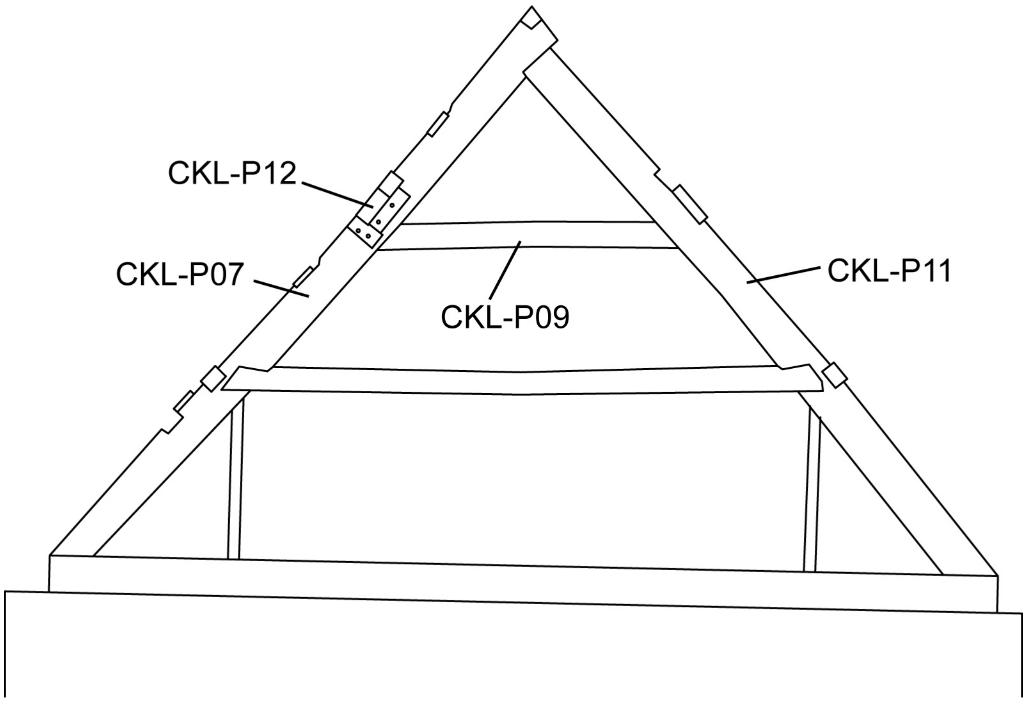


Figure 9: Truss 5 looking south, showing the location of samples CKL-P07, CKL-P09, CKL-P11, and CKL-P12 (after Ian Wells)

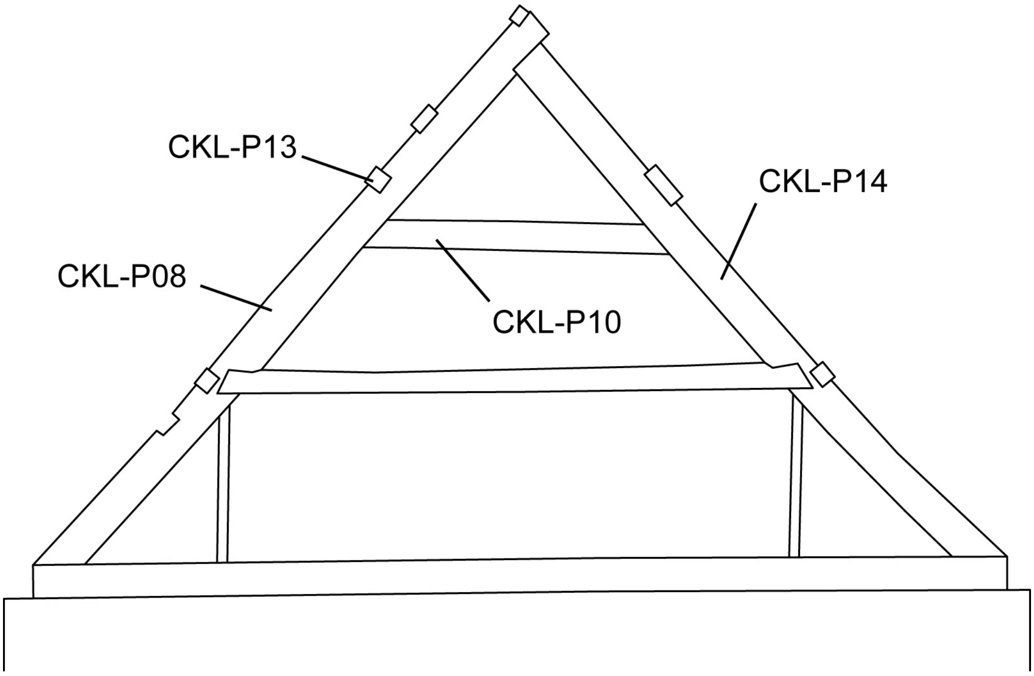


Figure 10: Truss 6 looking south, showing the location of samples CKL-P08, CKL-P10, CKL-P13, and CKL-P14 (after Ian Wells)

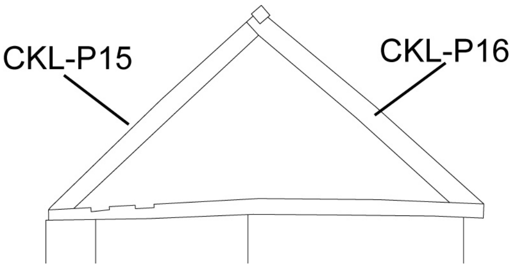
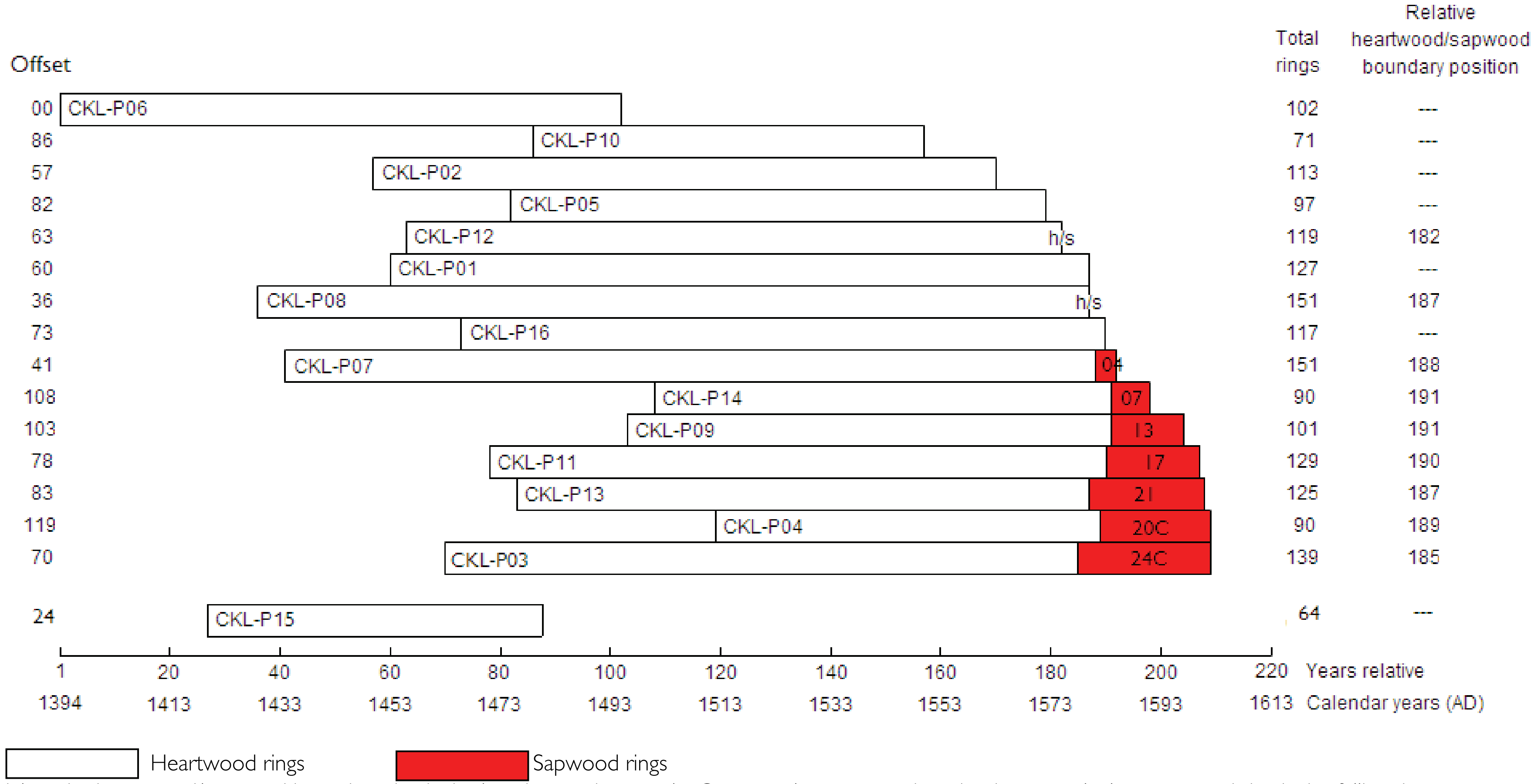


Figure 11: Truss 1 looking east, showing the location of samples CKL-P15 and CKL-P16 (after Ian Wells)



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 12: Bar diagram of dated samples

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

CKL-P01A 127
328 262 280 433 329 195 160 143 123 139 193 207 220 257 285 241 226 291 165 218
223 353 347 275 222 106 93 94 44 63 75 114 143 146 149 190 191 148 141 132
123 139 122 154 170 161 102 112 105 108 160 183 194 161 227 289 247 240 188 158
144 158 161 134 186 203 193 144 94 65 75 156 161 151 146 199 196 134 123 104
105 111 120 100 110 162 137 97 94 85 98 97 157 139 182 137 169 140 106 116
99 108 124 105 84 122 124 150 168 188 218 115 170 145 144 160 168 150 134 173
171 209 204 195 152 169 127
CKL-P01B 127
325 250 288 419 321 194 157 149 127 137 171 216 219 253 278 246 232 278 168 232
214 352 329 265 219 111 88 99 48 55 82 107 142 149 148 192 187 161 123 140
116 148 124 142 157 160 99 111 95 120 152 170 192 146 219 290 258 248 193 160
144 159 161 133 186 203 196 150 88 81 59 150 170 147 148 207 193 138 122 101
105 110 116 104 105 164 138 97 86 96 91 101 158 132 184 140 168 141 102 124
96 115 112 112 78 121 127 149 167 188 216 113 170 147 142 161 168 148 138 159
181 207 212 190 155 154 136
CKL-P02A 113
118 185 157 175 146 208 207 130 92 77 71 80 51 92 122 151 194 233 160 173
138 83 99 125 161 164 157 115 71 118 115 60 91 114 136 156 164 127 104 134
97 64 66 78 90 104 97 76 73 51 77 88 121 92 104 99 73 156 148 161
143 89 98 122 138 129 98 139 135 116 86 55 46 56 74 84 63 112 97 96
86 84 82 90 102 154 158 161 213 160 81 65 95 147 100 147 149 165 109 110
137 87 127 99 97 149 168 136 137 141 207 202 209
CKL-P02B 113
109 184 156 179 141 212 213 147 93 76 68 78 55 89 118 156 201 227 163 172
136 88 96 138 167 169 158 107 61 104 102 58 78 117 132 154 167 128 100 129
112 47 66 83 86 107 95 78 67 60 76 94 114 92 108 96 77 143 152 162
137 98 96 127 136 124 107 138 119 128 87 44 58 57 75 79 68 109 100 98
75 91 85 87 104 154 150 162 215 155 94 75 94 133 97 145 148 166 112 110
134 96 119 100 102 152 156 142 137 140 212 202 211
CKL-P03A 123
87 97 153 132 148 86 98 94 45 84 86 174 139 126 96 77 71 82 37 45
55 73 69 105 92 79 114 100 70 86 83 80 100 89 129 127 93 104 113 133
163 169 161 133 166 190 145 154 112 110 92 127 141 132 136 150 141 89 72 55
90 122 127 124 120 165 200 137 139 101 121 136 148 125 117 187 128 78 71 92
103 109 156 119 159 136 158 113 73 84 76 111 154 155 84 115 87 119 122 176
211 105 141 107 92 141 149 138 130 161 130 143 129 105 104 117 141 87 85 85
106 85 129
CKL-P03B 76
139 118 176 178 154 142 126 117 147 149 119 119 166 148 112 72 91 127 107 155
132 177 144 169 122 125 106 97 131 159 153 101 126 99 114 131 167 235 133 132
114 111 167 190 199 190 210 151 154 120 100 87 125 107 94 67 69 94 79 99
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82 97 115 118 140 115 179 127 90 76 80 74 123 125 123 155 161 209 156 132
121 116 138 120 105 150 205 176 137 115 112 116 201 149 147 133 116 140 119 106
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112 126 142 110 110 155 205 180 137 106 103 120 199 153 147 133 109 151 116 114
131 116 106 109 100 102 117 119 143 169 160 182 129 139 135 114 138 148 153 134
162 159 161 149 127 104 106 124 79 67 124 98 108 133 117 87 116 85 86 82
72 78 91 64 81 81 96 94 62 68
CKL-P05A 97
442 619 400 195 126 127 58 68 77 86 75 88 74 105 92 92 76 80 61 81
72 64 73 66 52 67 45 69 73 99 77 74 90 72 72 79 76 58 58 76
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CKL-P08A 151
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CKL-P10B 71
139 164 75 126 171 179 183 263 218 207 188 197 138 121 140 177 205 208 171 83
67 90 105 139 116 168 193 164 158 235 209 252 158 139 177 164 182 176 263 262
272 187 140 198 285 269 277 205 277 247 288 222 228 161 251 248 203 221 291 284
200 197 139 114 135 172 150 153 166 149 163
CKL-P11A 129
65 90 100 153 164 175 155 107 96 138 50 57 71 115 130 151 145 171 171 209
114 158 127 196 135 154 130 169 119 104 136 131 124 156 129 107 123 116 130 122
103 55 73 77 87 99 103 118 91 96 62 47 76 72 100 106 93 85 111 87
78 83 91 95 79 65 73 86 86 76 52 51 56 70 72 70 84 65 89 83
52 84 67 95 81 101 95 114 130 124 175 150 173 127 139 167 145 186 155 183
168 169 170 155 163 168 148 134 140 108 97 114 160 164 179 154 127 149 126 114
117 108 115 119 102 128 116 115 144

CKL-P11B 129
72 93 99 156 166 173 157 111 94 135 58 57 70 118 126 148 149 172 170 186
152 161 121 185 130 151 127 147 117 115 148 119 123 151 139 102 126 114 121 128
102 62 69 78 87 97 103 122 92 91 50 57 78 75 94 110 93 82 111 90
80 79 94 97 78 64 71 88 85 78 58 51 55 69 74 75 79 73 93 74
56 89 60 98 83 101 86 117 123 136 159 150 175 125 138 159 137 188 167 195
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CKL-P12A 119
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88 104 69 70 43 53 66 92 97 89 84 109 116 117 96 77 58 62 66 75
79 83 89 87 87 63 43 53 97 91 78 75 139 103 93 85 67 83 84 88
94 89 106 101 67 45 72 70 74 78 72 77 60 59 53 53 42 44 67 71
63 38 58 55 62 80 81 82 70 60 57 40 49 74 68 86 104 92 125
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148 109 88 86 107 63 56 69 78 110 136 108 111 134 74 64 49 53 75 87
90 112 96 56 61 46 63 97 89 96 79 105 116 122 97 73 60 60 62 76
73 82 92 88 80 65 53 55 90 94 81 82 146 100 85 82 79 75 84 94
91 82 106 96 66 59 55 69 77 84 66 84 54 60 59 49 44 42 65 60
64 48 58 53 62 68 84 81 63 58 53 39 54 69 73 84 100 93 125
CKL-P13A 125
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78 74 89 63 72 75 106 130 97 83 49 88 72 76 84 63 74 64 68 81
79 102 102 74 70 47 44 70 93 68 59 54 90 73 74 83 78 87 82 96
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106 110 115 139 122 103 110 142 152 173 166 130 143 141 130 126 146 147 145 121
121 127 173 136 121
CKL-P14A 90
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CKL-P14B 90
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113 133 161 81 125 95 83 111 141 119 136 149 165 162 177 127 96 91 101 116
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CKL-P15A 64
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127 133 137 126 123 141 158 143 180 180 194 123 134 132 80 91 138 137 130 91
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CKL-P15B 64
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162 136 187 217 136 200 211 112 72 60 121 134 126 167 212 163 202 180 176 169
138 123 135 128 125 137 156 148 217 181 187 128 137 134 75 99 139 143 122 90
70 48 81 92
CKL-P16A 117
153 181 129 138 139 98 136 130 193 190 156 94 80 88 98 67 70 82 121 106
108 90 83 69 65 58 44 55 65 90 66 55 68 59 57 71 90 122 100 93
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114 146 194 166 194 232 207 246 191 182 169 164 229 154 89 72 57 79 90 151
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120 139 197 172 187 227 210 246 200 170 176 164 220 166 87 67 59 68 101 158
168 197 120 169 168 140 161 137 108 178 168 145 148 155 171 138 160 157 76 129
136 134 117 177 152 137 163 155 131 103 90 96 131 148 139 109 98
CKL-P17A 108
144 123 130 111 101 136 128 108 117 142 175 123 131 109 139 109 91 112 138 125
120 173 137 114 112 79 111 163 185 136 84 82 70 76 79 92 93 109 101 87
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91 74 71 81 74 71 55 58 66 59 87 97 98 136 157 127 103 77 80 91
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CKL-P17B 108
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93 91 85 109 74 88 79 85 73 70 90 47 57 42 45 54 72 63 62 75
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APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

Tree-ring dating, or dendrochronology as it is known, is discussed in some detail in the Laboratory's Monograph, *An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular 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 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

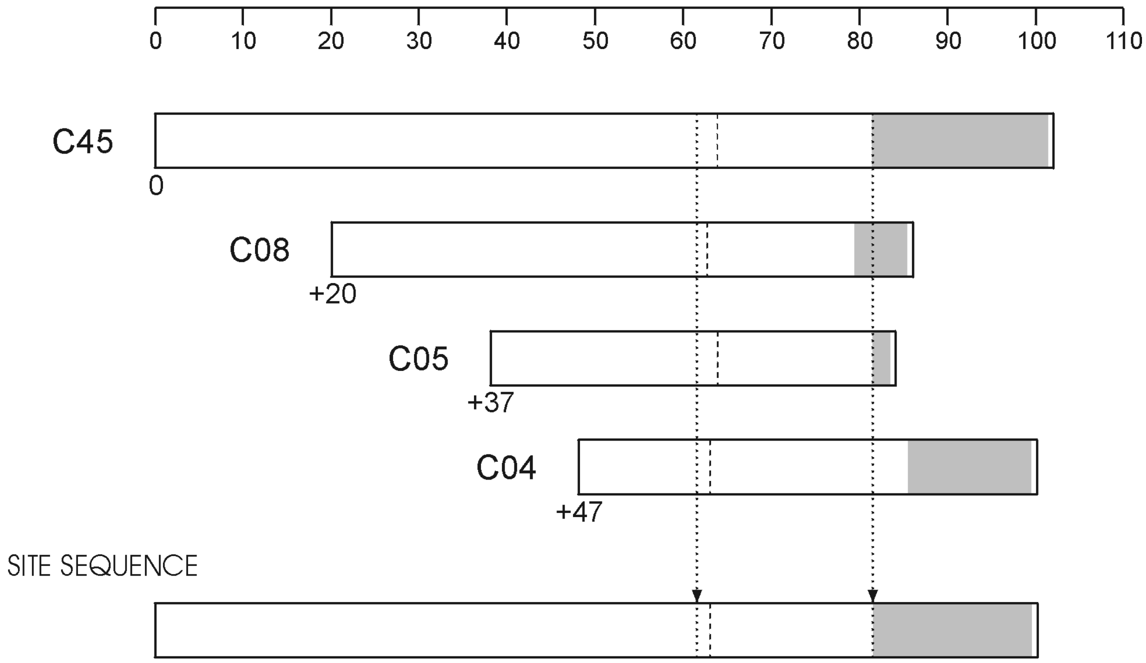


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

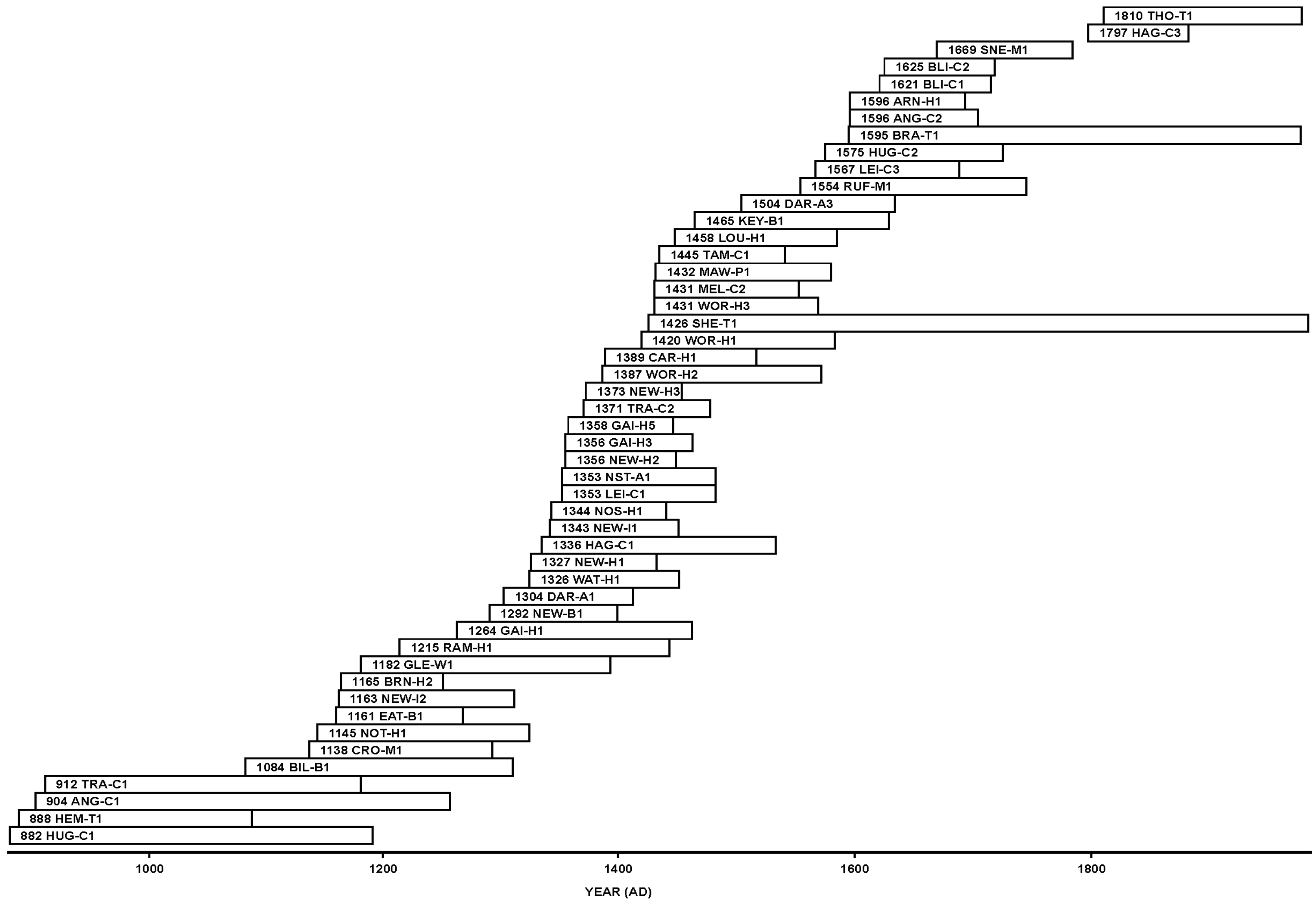
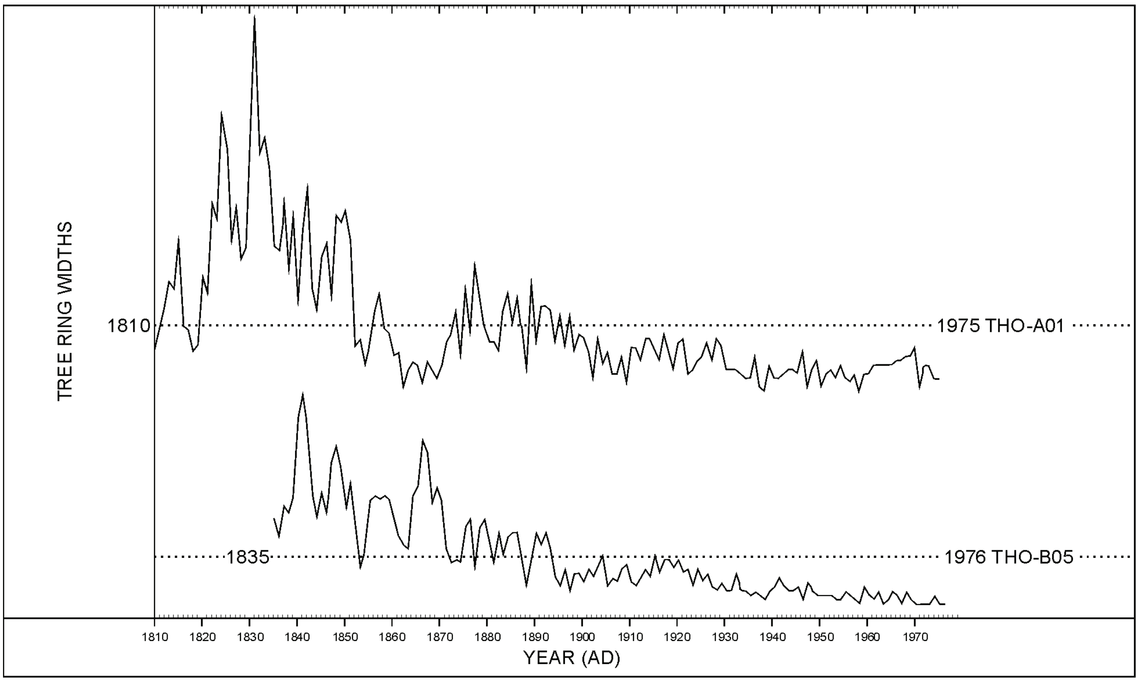


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

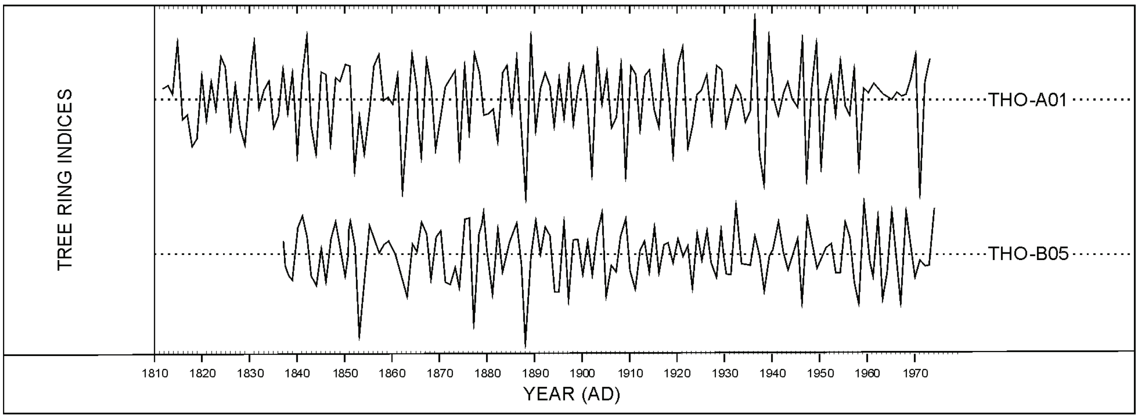


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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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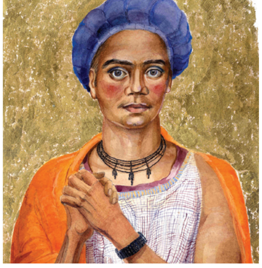



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We make the results of our work available through the Research Department Report Series, and through journal publications and monographs. Our publication Research News, which appears three times a year, aims to keep our partners within and outside English Heritage up-to-date with our projects and activities. A full list of Research Department Reports, with abstracts and information on how to obtain copies, may be found on www.english-heritage.org.uk/researchreports

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