Centre for Archaeology Report 36/2002

Tree-Ring Analysis of Timbers from the Latrine Block, Aydon Castle, Corbridge, Northumberland

A J Arnold, Dr R R Laxton and Dr C D Litton

ISSN 1473-9224

The Centre for Archaeology Reports Series incorporates the former Ancient Monuments Laboratory Report Series. Copies of Ancient Monuments Laboratory Reports will continue to be available from the Centre for Archaeology (see back of cover for details).

Centre for Archaeology Report 36/2002

Tree-Ring Analysis of Timbers from the Latrine Block, Aydon Castle, Corbridge, Northumberland

A J Arnold[1], Dr R R Laxton[2] and Dr C D Litton[2]

Summary

Fourteen samples were obtained from timbers of the roof structure and attic floor structure of the latrine block at the castle. This resulted in the production of a single site sequence and individually dated sample.

Twelve samples grouped to form a site chronology of 140 rings, AYDASQ01, which spans the period AD 1406-AD 1545. Of the twelve samples, six have complete sapwood; five of these have a last ring date of AD 1541, whilst the sixth is AD 1545, these being the felling dates of the timbers represented. A seventh sample is also estimated to have come from a timber felled in *c* AD 1541. Analysis of the heartwood/sapwood boundary ring date on the other samples points towards a felling date for these timbers within the range AD 1536-61, consistent with either an AD 1541 or AD 1545 felling. Two samples in the site sequence do not have the heartwood/sapwood boundary ring and, therefore, estimated felling date ranges cannot be calculated for them. However, with last-ring dates of AD 1505 and AD 1518 it is entirely possible that they also had felling dates of AD 1541/45.

Attempts to date the remaining two samples individually resulted in sample AYL-A13 being matched at a first-date of AD 1398 and a last-ring date of AD 1450, however, again without the heartwood/sapwood ring date it is not possible to calculate an estimated felling date range for it, except to say it would be AD 1466 at the earliest. The final sample could not be matched and remains undated.

Tree-ring analysis has resulted in the dating of thirteen of the timbers used in the construction of the latrine roof and attic floor. Six of the timbers from the roof are from trees felled in AD 1541 and one from the floor from a tree felled in AD 1545. It is quite likely that the other timbers are also from trees felled in either AD 1541 or AD 1545. There is no indication that the attic-floor is inserted to explain the slight difference in date, of at least one of the timbers. Instead this might suggest that preparations for the construction, with the felling of some trees, begun in AD 1541, when the castle first passed into the hands of the Carnaby family, but construction did not actually start until *c* AD 1545 or soon after, under the direction of Cuthbert Carnaby.

Keywords
Dendrochronology
Standing Building

Author's addresses
[1] Department of Archaeology, University of Nottingham, University Park, Nottingham, NG7 2RD
[2] Department of Mathematics, University of Nottingham, University Park, Nottingham, NG7 2RD

TREE-RING ANALYSIS OF TIMBERS FROM THE LATRINE BLOCK, AYDON CASTLE, CORBRIDGE, NORTHUMBERLAND

Introduction

Aydon Castle, about a mile and a half to the north-north-east of Corbridge (Fig 1; NZ 002 663), was largely built by a Suffolk merchant, Robert de Reymes, in the late-thirteenth century, as an undefended house. However, almost immediately, the house had to be fortified. Attacked by the Scots in AD 1315, and later seized by English rebels, the building was subject to numerous repairs and modifications in the fourteenth century. The castle stayed in the hands of the de Reymes family, in a gradually deteriorating state, until AD 1541 when Robert Reymes IX granted his half of the manor of Aydon to Sir Reynold Carnaby. Sir Reynold died in AD 1543 at which point Aydon passed to his younger brother Cuthbert who immediately began a programme of repairs and alterations to the castle (Dixon 1988). This almost certainly included work on the kitchen block, where roof timbers have already been dated to winter/early spring AD 1543/4 by the Sheffield Dendrochronology Laboratory (Hillam and Groves 1991). Growing debts forced the Carnaby family to sell Aydon in AD 1654, when it was converted into a farmhouse and remained so until 1966 when the Ministry of Works took it over and began a number of repairs.

The earliest part of the surviving building is the hall, the chamber block, and the projecting garderobe wing. It is the attic floor and roof beams of the latrine block that are under investigation here, although they are not thought to represent the earliest roof. There is evidence visible in the face of the east wall of the solar block of an earlier, more steeply-pitched roof, thought to be of typical earlier medieval common-rafter type. This is then believed to have been altered again in the later medieval period, being replaced by a very low-pitched roof. The roof structure as seen today has three principal rafter trusses, numbered 1-3, from east to west, with purlins and nailed collars, although the empty mortices for collars are obvious. The floor frame is of three and a half bays, with the half bay at the east end. The beams are labelled A-E, from the east end; beam C is modern. The joists simply rest loosely in their mortices (Ryder 2002).

Sampling and analysis by tree-ring dating was commissioned and funded by English Heritage. It was hoped that tree-ring dating of the roof timbers would allow more to be learnt about the development of the roof, and allow comparison with the date already found for the kitchen block mentioned above.

The Laboratory would like to thank Douglas Jones, the area manager for the castle, David Sherlock, and Martin Roberts of English Heritage for arranging access to the site. Thanks are also given to Peter Ryder for allowing us to see his report of the timbers and use his drawings to illustrate and locate the samples (Figs 2-5; Ryder 2002)

Sampling

Fourteen core samples were taken from oak timbers of the latrine block of the castle, eight from principal rafters and purlins of the roof structure and six from main beams and joists of the attic-floor structure. Each sample was given the code AYD-A (for Aydon Castle) and numbered 01-14. The positions of all samples were noted at the time of sampling and have been marked on Figures 2-5. Further details relating to the samples are recorded in Table 1.

Analysis and Results

Each sample was prepared by sanding and polishing and its growth-ring widths measured; the data of these measurements are given at the end of the report. The growth-ring widths of the samples were compared with each other by the Litton/Zainodin grouping procedure (see appendix). At a least value of t=6 twelve of the samples matched and site sequence AYDASQ01 of 140 rings was constructed containing these samples at the offsets shown in the bar diagram (Fig 6). This site sequence was successfully matched against the relevant reference chronologies for oak at a first-ring date of AD 1406 and a last-ring date of AD 1545. The evidence for this dating is given by the t-values in Table 2.

Attempts were then made to date the remaining two samples, AYD-A09 and AYD-A13, individually by again comparing them against the reference chronologies. As a result AYD-A13 was matched at a first-ring date of AD 1398 and a last-ring date of AD 1450. The evidence for this dating is given by the *t*-values in Table 3.

Sample AYD-A09 could not be matched and remains undated.

Interpretation

Analysis of samples from the latrine block at Aydon Castle has resulted in the production of one site chronology and one individually dated sample. Site chronology, AYDASQ01, contained twelve samples and spanned the period AD 1406-AD 1545. Seven of the samples are from timbers which had complete sapwood, six of these samples retained this complete sapwood during the sampling process. Samples AYD-A01, A02, A03, A04, and A07 have complete sapwood and last-ring dates of AD 1541, this being the felling date of the timbers represented. Sample AYD-A11 has complete sapwood and a last-ring date of AD 1545, this being the felling date of the timber represented. The final sample that came from a timber with complete sapwood, AYD-A06, lost *c* 2mm of sapwood during the sampling process. By looking at the last 2mm worth of ring pattern on this sample it is possible to estimate that *c* 2-3 rings have been lost, which added to the last ring date of AD 1538 gives a felling date for the timber represented of AD 1540/41. Three more of the samples in this site chronology, AYD-A05, A08, and A14, have the heartwood/sapwood boundary ring, the average of which is AD 1521. This allows an estimated felling date for the represented timbers to be calculated to within the range AD 1536-61. The final two samples in this site sequence, AYD-A10 and A12 do not have this ring and, therefore, estimated felling date ranges cannot be calculated for the timbers they were taken from. However, with last-ring dates of AD 1518 and AD 1505, these would be AD 1534 and AD 1521 respectively, at the earliest, making an AD 1541 or AD 1545 felling date also possible.

Sample AYD-A13 was dated individually to a first-ring date of AD 1398 and a last-ring date of AD 1450. However, again this sample does not have the heartwood/sapwood ring date and so an estimated felling date range cannot be calculated, except to say that this would be AD 1466 at the earliest. All felling date ranges have been calculated using the 95% confidence limit of 15-40 sapwood rings for mature oak trees within this region.

The final sample, AYD-A09 could not be matched and so the timber it represents remains undated at present.

Discussion

Following analysis by tree-ring dating it has been possible to obtain dates for thirteen of the timbers in the latrine block. Five of these have been found to have a felling date of AD 1541, with a sixth also thought quite likely to have this date. A seventh sample is now known to have been from a tree felled in AD 1545, four years later. A further three are from trees felled sometime between AD 1536-61, making it possible for them to have been felled in either AD 1541 or AD 1545. Although felling date ranges could not be calculated for the final three dated samples it is also possible they are from trees felled in either AD 1541 or AD 1545. The timbers felled in AD 1541 are all from the roof structure, whereas the one felled in AD 1545 is one of the attic-floor main beams.

The matching between some of the samples is of a level to suggest that the timbers they are taken from are actually from the same tree. This is the situation with AYD-A01, AYD-A04, and AYD-A06, all from roof timbers and AYD-A10, AYD-A11, and AYD-A12, all from timbers of the floor frame. However, there is no instance where a timber from the roof appears to come from the same tree as a timber from the floor frame, perhaps suggesting that the roof timbers were prepared and ready to erect in AD 1541 or very soon after but not until AD 1545 were those from the floor frame ready.

The reason for this difference in date may be explained in several ways, one of which is that the roof and floor were put in AD 1541 or soon after with the timbers represented by AYD-A10, AYD-A11, and AYD-A12 later insertions. However, there is no structural evidence of later insertion and the attic floor and roof, as surviving, are believed to be contemporary (Ryder pers comm). Another, perhaps more likely, solution to the difference in date could be that when Sir Reynold Carnaby took possession of Aydon in AD 1541, he began preparations for repairs/alterations to the castle, in the form of felling of trees. However, immediately after this acquisition of Aydon other farmsteads owned by the Carnaby family were being attacked and Reynold's father badly wounded (Dixon 1988). This may have caused an interruption to the construction plans, these being further delayed by Reynold's death in AD 1543 and building works only begun by Cuthbert Carnaby in or soon after AD 1545.

The site sequences from the latrine block and the kitchen range match each other very highly (t=8.1). Both also match 1-2 The College, Cathedral Precincts at high levels (the latrine block t=10.3 and the kitchen range t=12.3). This suggests that not only were the two parts of Aydon Castle constructed from timbers from the same locality but that the same source was also used by the builders of the Cathedral precincts at Durham.

Bibliography

Baillie, M G L, 1977a The Belfast oak chronology to AD 1001, *Tree-ring Bulletin*, **37**, 1-12

Baillie, M G L, 1977b An oak chronology for South-central Scotland, *Tree-ring Bulletin*, **37**, 33-44

Baillie, M G L, and Pilcher, J R, 1982 unpubl A master tree-ring chronology for England, unpubl computer file *MGB-E01*, Queens Univ, Belfast

Dixon, P, 1988 *Aydon Castle*, English Heritage

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1986 Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect*, **17**, 52

Hillam, J, and Groves, C, 1991 Tree-ring dating of oak timbers from Aydon Castle, Corbridge, Northumberland, Anc Mon Lab Rep, **42/91**

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1991 Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect*, **22**, 40-3

Howard, R E, Laxton, R R, and Litton, C D, Nottingham University, Thornes, R, and Hook, R, Royal Commission on the Historical Monuments of England, 1992a Nottingham University Tree-Ring Dating Laboratory: Truncated principal trusses project, *Vernacular Architect*, **23**, 59-61

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1992b Nottingham University Tree-Ring Dating Laboratory Results, *Vernacular Architect*, **23**, 51-6

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1994 Nottingham University Tree-Ring Dating Laboratory results: general list, *Vernacular Architect*, **25**, 36-40

Howard, R E, Laxton, R R, Litton, C D, Nottingham University Tree-Ring Dating Laboratory, and Roberts, H M, North East Vernacular Architect Group, 1996a Nottingham University Tree-Ring Dating Laboratory: buildings of the religious estates in Medieval Durham; dendrochronological survey, 1994-5, *Vernacular Architect*, **27**, 85-6

Howard, R E, Laxton, R R, and Litton, C D, Nottingham University Tree-Ring Dating Laboratory; Morrison, A, Planning Dept, Derbyshire CC, Sewell, J, Peak Park Joint Planning Board, and Hook, R, RCHME, York, 1996b Nottingham University Tree-Ring Dating Laboratory results: Derbyshire, Peak Park and RCHME dendrochronology survey, 1995-96, *Vernacular Architect*, **27**,81-2

Howard, R E, Laxton, R R, and Litton, C D, NottinghamUniversity Tree-ring Dating Laboratory, and Jennings, N, 1997a Nottingham University Tree-ring Dating Laboratory; dendrochronological survey of clay dabbings on the Solway Plain, *Vernacular Architect*, **28**, 133-4

Howard, R E, Laxton, R R, and Litton, C D, 1997b Nottingham University Tree-Ring Dating Laboratory: dendrochronological dating for English Heritage, *Vernacular Architect*, **28**, 130-2

Laxton, R R, and Litton, C D, 1988 An East Midlands master tree-ring chronology and its uses in dating vernacular buildings, University of Nottingham, Dept of Classical and Archaeol Studies, Monograph Series, **III**

Ryder, P F, 2002 unpubl *Aydon Castle, The Latrine Block Roof Structure*, report for English Heritage

Siebenlist-Kerner, V, 1978 Chronology, 1341-1636, for hillside oaks from Western England and Wales, in *Dendrochronology in Europe* (ed J M Fletcher), BAR Int Ser, **51**, 295-301

Table 1: Details of tree-ring samples from the Latrine Block, Aydon Castle, Corbridge, Northumberland

Sample number	Sample location	Total rings	Sapwood rings*	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
AYD-A01	North principal rafter, truss 1	92	23C	1450	1518	1541
AYD-A02	South principal rafter, truss 1	75	24C	1467	1417	1541
AYD-A03	North principal rafter, truss 2	75	25C	1467	1516	1541
AYD-A04	South principal rafter, truss 2	136	29C	1406	1512	1541
AYD-A05	North principal rafter, truss 3	60	01	1459	1517	1518
AYD-A06	South principal rafter, truss 3	111	20c(+2-3 rings lost)	1428	1525	1538
AYD-A07	North purlin	63	13C	1479	1521	1541
AYD-A08	South purlin	44	04	1488	1527	1531
AYD-A09	Attic floor, beam A	68	--	----	----	----
AYD-A10	Attic floor, beam B	87	--	1432	----	1518
AYD-A11	Attic floor, beam D	135	18C	1411	1527	1545
AYD-A12	Attic floor, beam E	77	--	1429	----	1505
AYD-A13	Common joist, number 3, beam A-B	53	--	1398	----	1450
AYD-A14	Common joist, number 5, beam B-C	49	h/s	1472	1520	1520

*h/s = the heartwood/sapwood boundary is the last ring on the sample
C = complete sapwood retained on sample, last measured ring is the felling date
c(+x-y lost) = complete sapwood on timber, some lost in sampling (estimated number of sapwood rings lost in brackets)

Table 2: Results of the cross-matching of site sequence AYDASQ01 and relevant reference chronologies when the first-ring date is AD 1406 and the last-ring date is AD 1545

Reference chronology	*t*-value	Span of chronology	Reference
East Midlands	6.0	AD 882-1981	Laxton and Litton 1988
Belfast	5.8	AD 1001-1970	Baillie 1977a
Western England and Wales	5.6	AD 1341-1636	Siebenlist-Kerner 1978
England	5.6	AD 404-1981	Baillie and Pilcher 1982 unpubl
1-2 The College, Cathedral Precinct, Durham, Tyne and Wear	10.3	AD 1364-1531	Howard *et al* 1992a
Aydon Castle, kitchen range, Corbridge, Northumberland	8.1	AD 1424-1543	Hillam and Groves 1991
Nether Levens Hall, Kendal, Cumbria	7.0	AD 1395-1541	Howard *et al* 1991
Kepier Hospital, Durham, Tyne and Wear	6.1	AD 1304-1522	Howard *et al* 1996a
Hitchins Onset, Scaleby, Carlisle, Cumbria	6.1	AD 1364-1491	Howard *et al* 1997a
Manor Farm, Upper Midhope, Bradfield, S Yorks	5.7	AD 1380-1550	Howard *et al* 1996b
35 The Close, Newcastle-upon-Tyne, Tyne and Wear	5.6	AD 1365-1513	Howard *et al* 1991

Table 3: Results of the cross-matching of sample AYD-A13 and relevant reference chronologies when the first-ring date is AD 1398 and the last-ring date is AD 1450

Reference chronology	*t*-value	Span of chronology	Reference
South Central Scotland	6.2	AD 946-1975	Baillie 1977b
England	4.7	AD 404-1981	Baillie and Pilcher 1982 unpubl
Western England and Wales	4.5	AD 1341-1636	Siebenlist-Kerner 1978
Horbury Hall, Horbury, Wakefield, W Yorks	6.8	AD 1368-1473	Howard *et al* 1992b
Lounge Opencast Coal pit, Coleorton, Leics	5.3	AD 1371-1463	Howard *et al* 1992b
Ordsall Hall, Taylorson St, Salford, Cheshire	5.1	AD 1385-1512	Howard *et al* 1994
North Transept, Durham Cathedral, Tyne and Wear	5.0	AD 1320-1457	Howard *et al* 1992a
Governors House, Newark, Notts	5.0	AD 1373-1453	Howard *et al* 1986
Mercers Hall, Gloucester, Glos	4.6	AD 1289-1541	Howard *et al* 1997b

Figure 1: Map showing the location of Aydon Castle (based upon the Ordnance Survey map

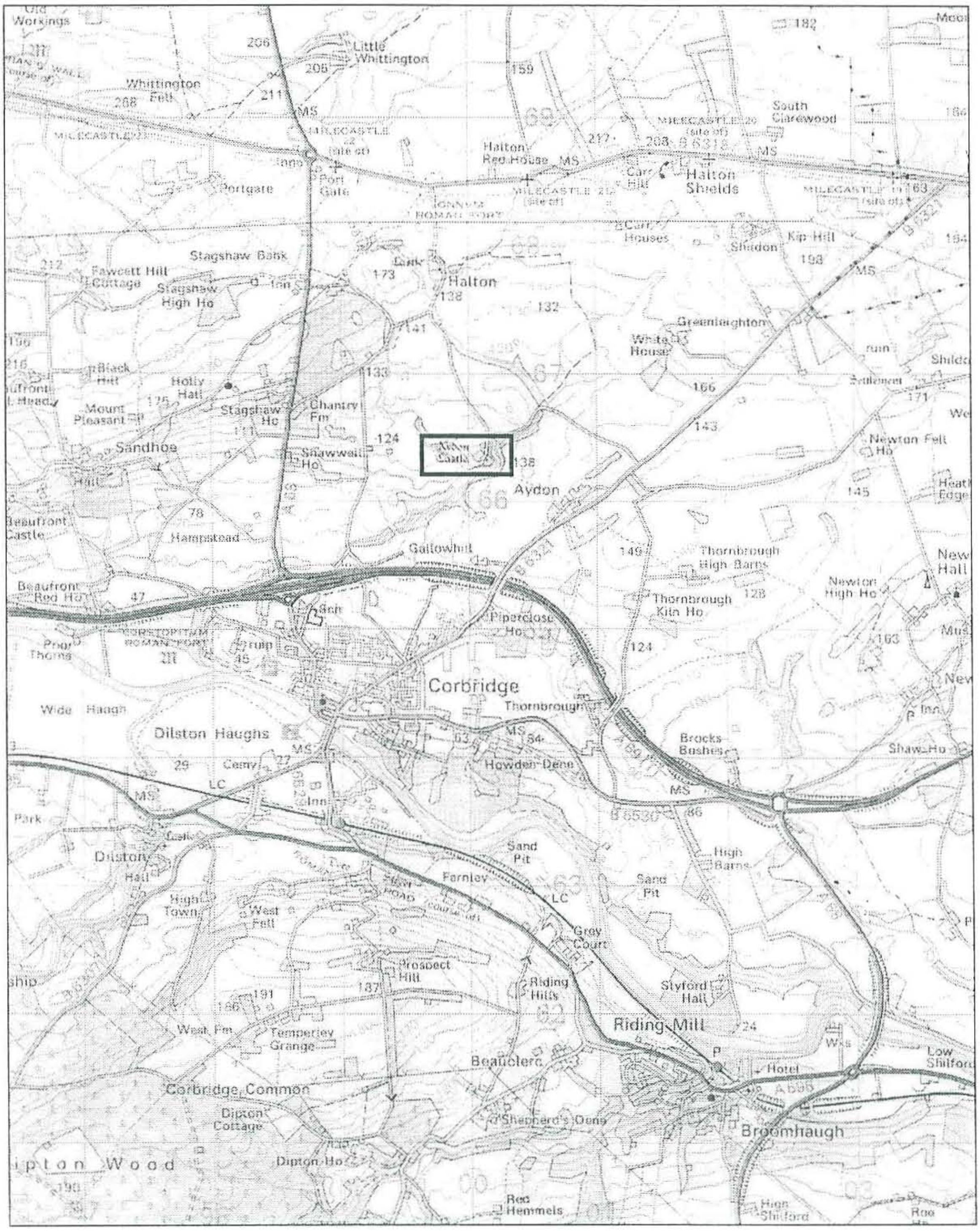


Figure 2: The Latrine Block Roof, Aydon Castle, showing the location of samples AYD-A01-A02, from Ryder 2002

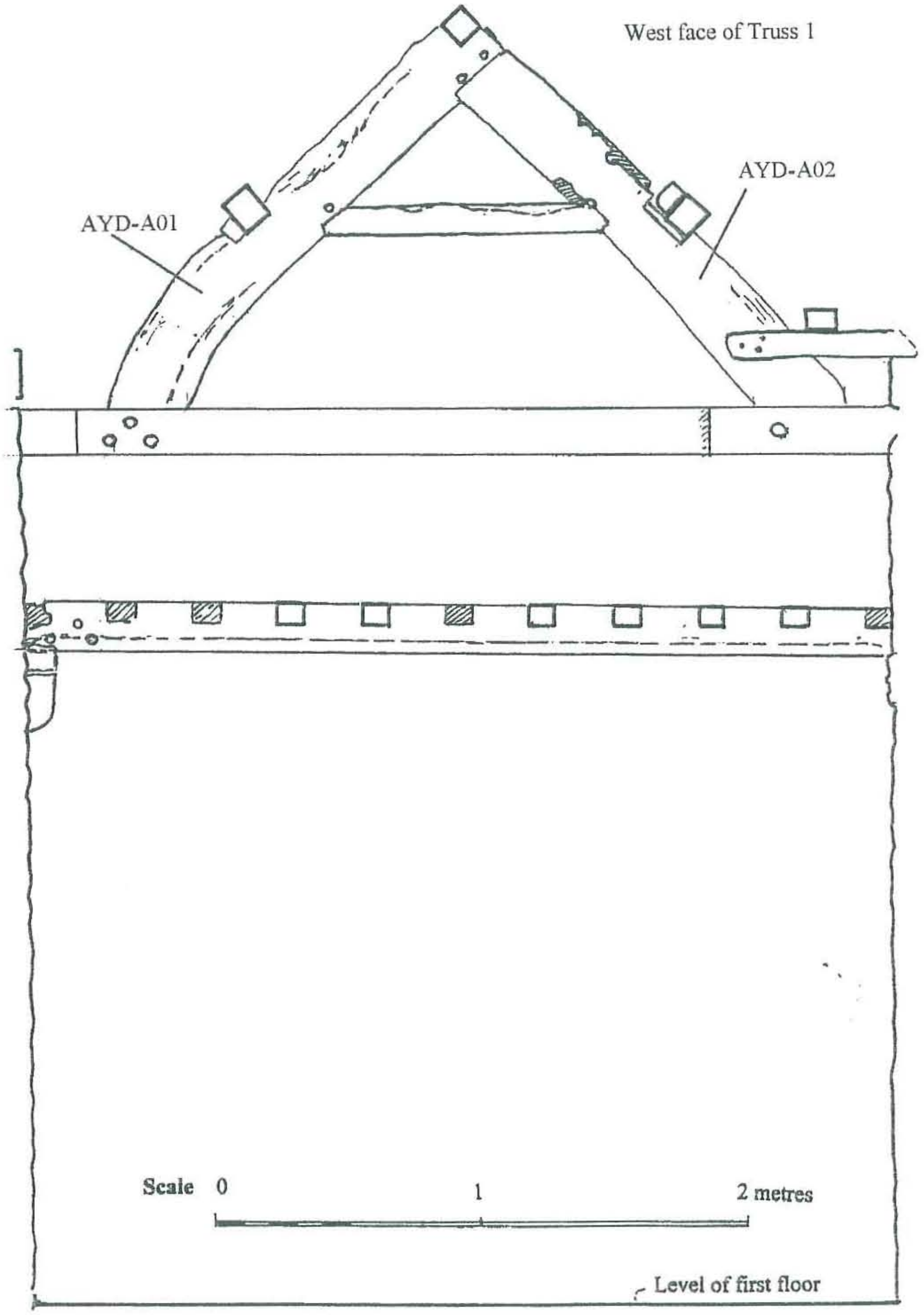


Figure 3: The Latrine Block Roof, Aydon Castle, showing the location of samples AYD-A03-A04, and AYD-A07-AYD-A08, from Ryder 2002

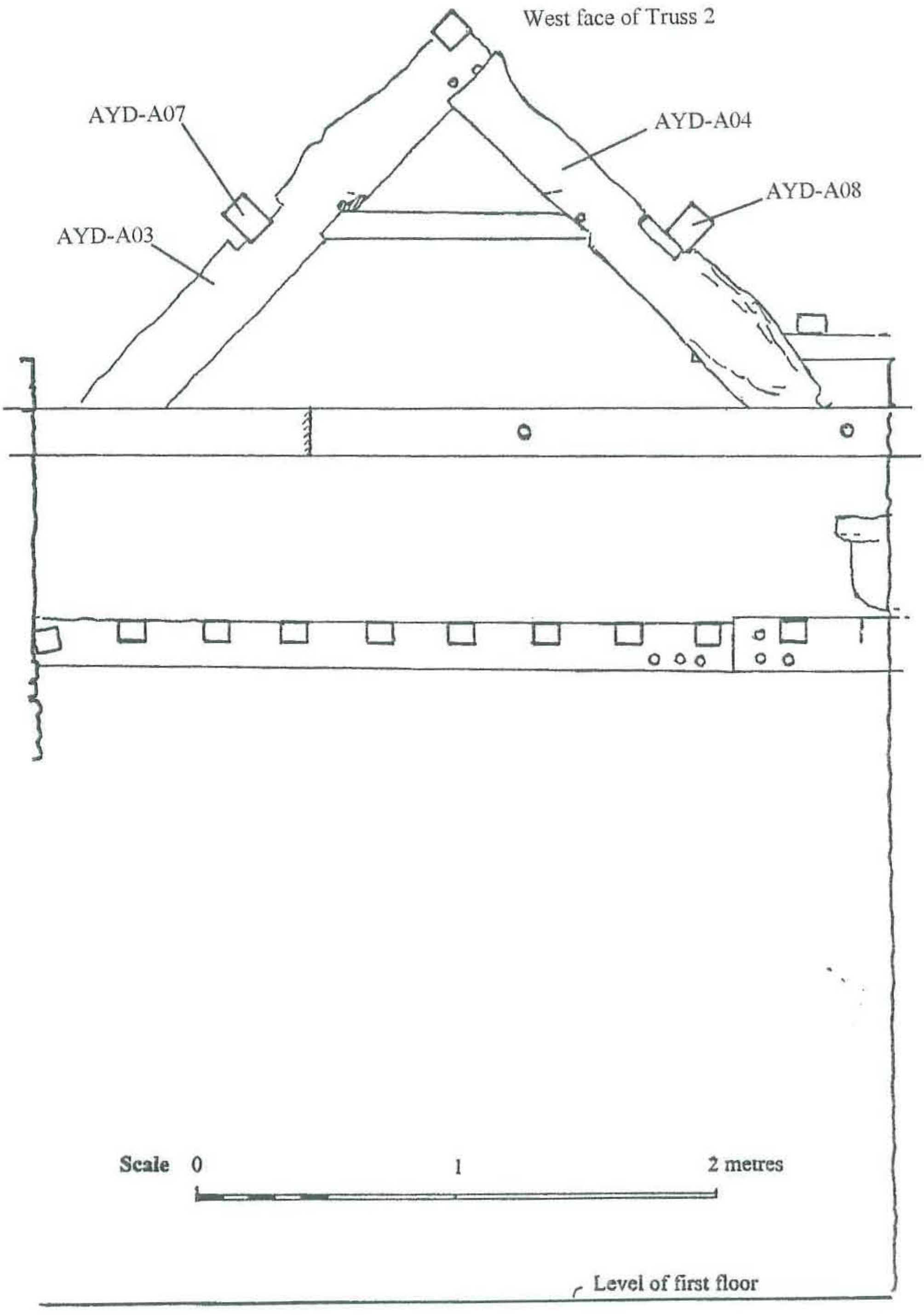


Figure 4: The Latrine Block Roof, Aydon Castle, showing the location of samples AYD-A05-A06, from Ryder 2002

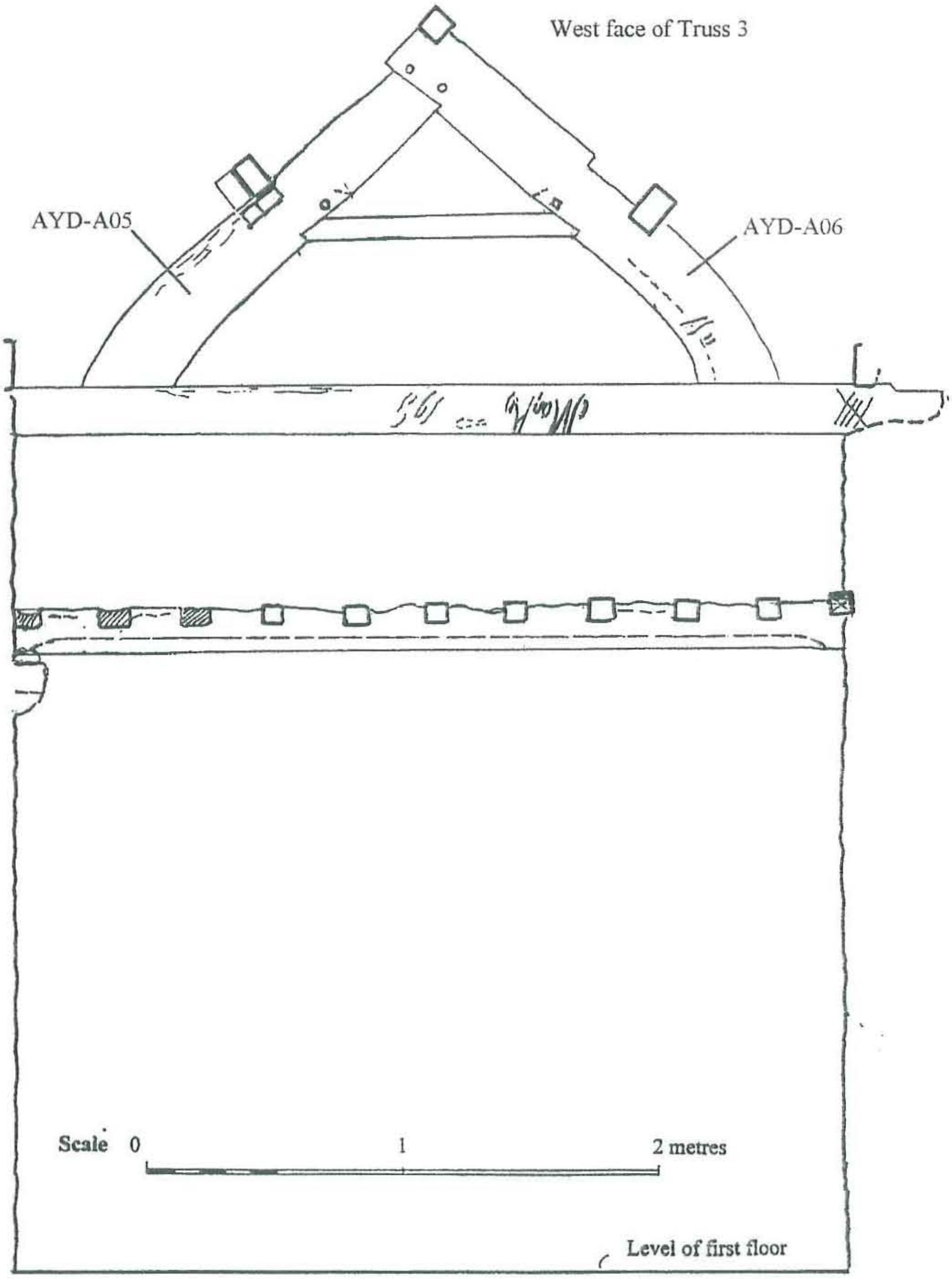


Figure 5: Plan of Attic Floor Frame, Aydon Castle, showing the location of samples AYD-A09-A14, from Ryder 2002

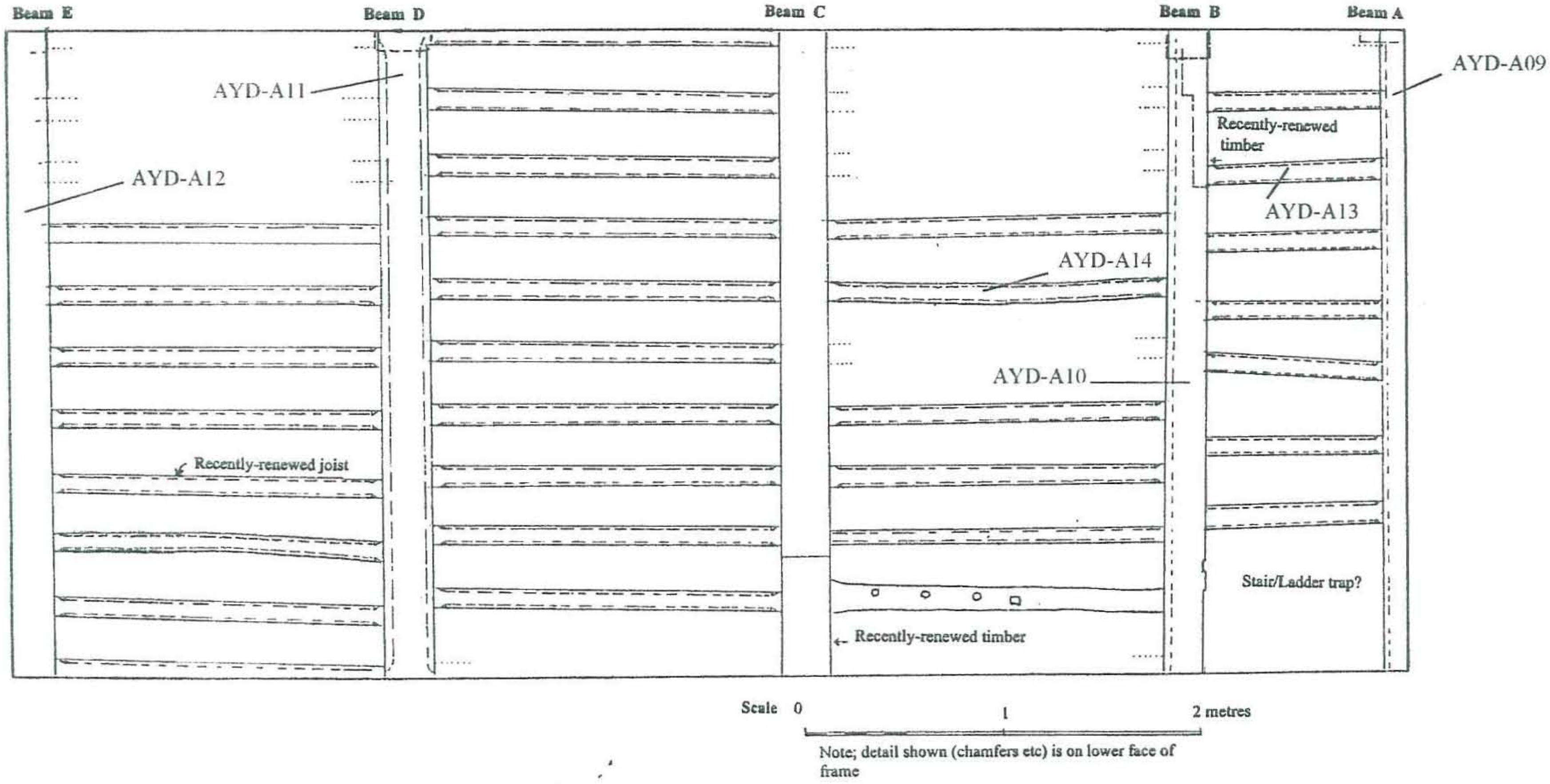
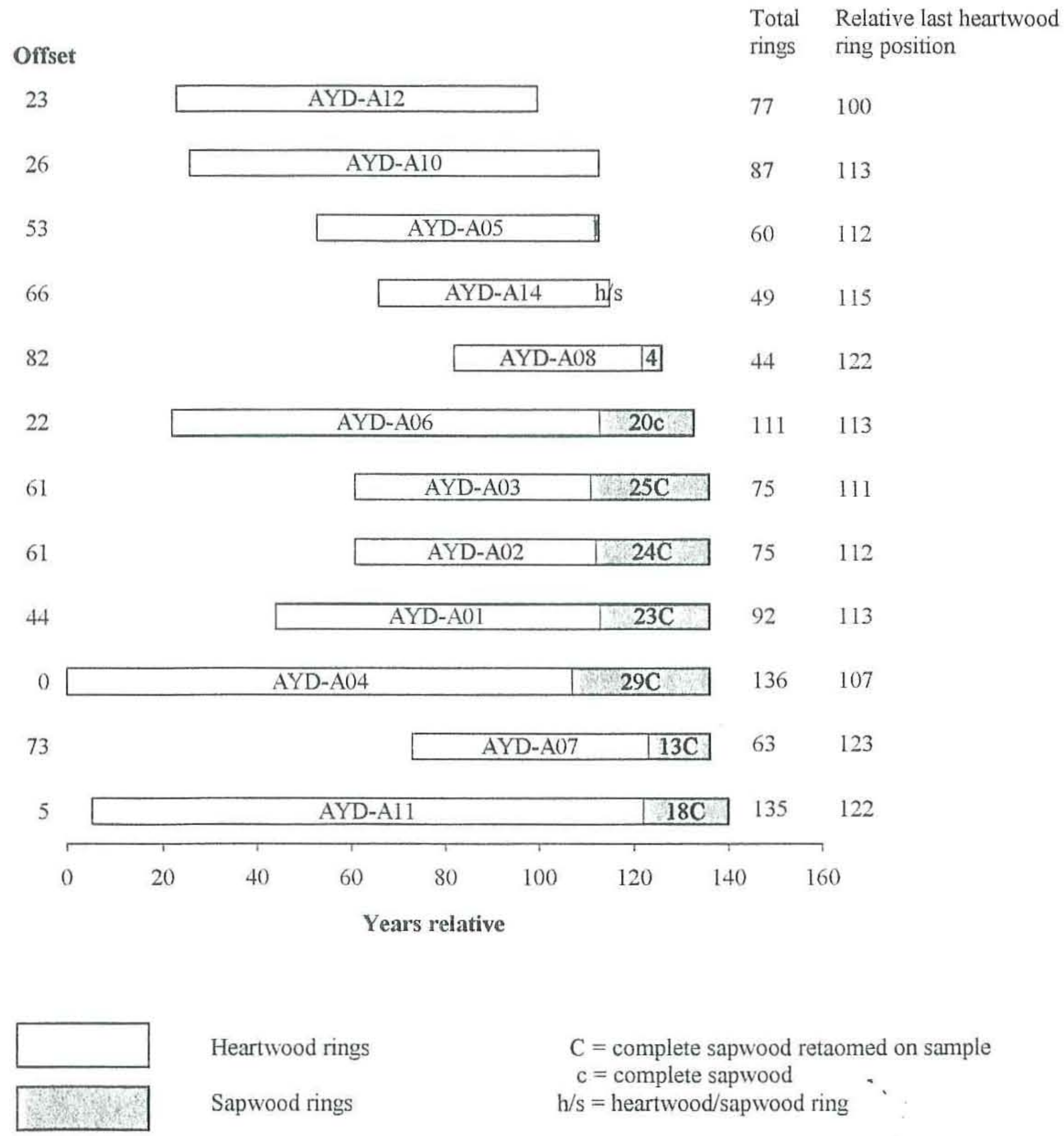


Figure 6: Bar diagram of samples in site sequence AYDASQ01



Data of measured samples – measurements in 0.01mm units

AYD-A01A 92
108 120 152 152 150 141 179 175 141 128 156 116 171 214 200 135 209 188 189 176
161 238 144 200 85 158 157 137 148 140 159 204 190 128 148 166 177 206 161 156
132 127 185 106 115 174 170 121 128 136 172 125 172 139 212 124 130 126 163 159
166 165 143 112 134 152 150 110 148 184 210 182 108 112 108 177 189 195 195 198
206 219 157 144 182 186 204 136 137 201 222 79
AYD-A01B 92
111 126 143 159 158 125 183 177 141 128 153 124 166 214 197 133 211 182 191 171
162 236 145 199 79 169 152 127 150 141 153 203 200 120 147 168 169 208 166 129
141 131 188 108 124 153 179 123 130 147 170 141 178 140 188 134 117 117 154 148
159 157 136 111 129 150 162 98 158 169 204 177 116 108 102 196 203 200 185 231
219 192 192 154 160 184 196 164 152 187 215 83
AYD-A02A 66
273 330 253 281 231 141 114 107 161 168 196 168 223 251 219 197 174 132 256 207
257 250 198 195 174 166 83 111 132 144 127 138 181 203 125 127 121 168 170 160
100 130 108 87 129 101 100 91 74 104 112 109 137 81 113 80 74 58 91 124
110 123 102 151 118 150
AYD-A02B 60
232 218 221 260 252 261 218 171 174 146 190 99 125 148 169 136 145 196 224 135
148 113 172 202 157 111 142 123 131 127 102 110 102 86 121 97 109 128 103 108
83 47 57 96 120 112 133 103 123 123 107 85 74 101 118 107 133 89 72 125
AYD-A03A 75
161 244 235 309 217 149 118 107 179 165 293 197 247 232 220 274 310 270 369 234
320 205 169 203 181 244 137 157 185 201 206 215 239 218 137 119 122 202 206 155
105 139 147 121 119 123 110 96 118 132 135 145 139 132 139 105 49 91 122 123
110 115 111 109 91 97 79 115 132 170 130 99 154 160 85
AYD-A03B 75
164 241 266 285 209 121 116 117 178 167 228 228 272 228 227 269 308 269 363 236
308 219 171 222 173 249 139 147 171 209 207 212 244 210 151 120 119 188 201 169
98 137 147 123 120 104 108 98 106 136 145 151 146 139 139 97 49 88 116 139
106 109 103 89 100 88 79 113 129 161 125 104 152 153 95
AYD-A04A 136
132 223 175 136 159 182 168 186 150 137 129 153 131 151 186 157 142 177 179 141
122 124 105 111 130 180 131 124 130 142 109 114 115 79 82 59 75 114 139 131
148 125 104 148 164 168 179 151 173 135 171 180 135 108 83 101 100 98 92 93
114 117 140 117 145 196 116 155 52 108 83 72 101 66 91 97 82 55 57 85
85 127 98 83 87 83 93 67 62 74 77 65 80 77 78 70 73 45 85 81
94 106 90 112 124 124 112 116 125 153 132 105 127 138 100 101 42 42 89 134
167 138 146 152 161 147 105 162 122 115 113 118 108 131 118 57
AYD-A04B 136
155 180 179 185 134 160 169 177 157 134 136 149 133 150 180 160 138 176 189 144
120 132 114 115 131 156 128 107 129 150 99 124 116 86 70 76 64 103 119 168
161 132 113 169 152 159 154 164 171 134 171 177 137 107 79 106 113 88 103 85
126 130 158 124 138 194 105 152 67 85 81 58 99 61 86 105 86 55 58 80
94 125 91 83 99 86 101 67 47 73 90 66 74 69 80 64 68 53 78 84
99 93 96 113 133 111 123 134 103 152 113 127 131 130 110 94 51 39 89 134
173 149 124 158 154 144 114 142 138 100 105 114 118 138 130 57
AYD-A05A 60
217 229 126 213 217 197 177 280 309 334 323 304 327 200 157 144 279 264 357 246
381 296 277 320 312 309 389 389 414 267 208 241 195 287 147 160 229 335 262 284
299 246 126 114 99 145 174 192 127 184 200 183 197 171 244 220 180 178 154 179
AYD-A05B 60
212 219 131 209 216 195 175 262 291 335 324 305 314 187 164 145 273 258 347 245
360 293 273 317 325 302 388 391 414 260 210 232 204 287 133 164 220 332 261 273
307 242 130 119 102 139 164 191 129 189 187 183 213 176 225 210 192 178 153 177

AYD-A06A 111
153 166 191 167 202 210 238 248 246 208 191 169 203 223 224 200 224 222 189 220
187 187 166 173 202 203 212 162 191 189 158 129 134 172 212 204 209 169 195 175
162 161 151 210 111 157 73 135 168 112 124 100 130 161 161 123 122 141 157 184
141 159 177 161 200 107 115 171 199 125 146 150 154 119 141 104 158 132 156 123
147 180 159 177 144 156 179 195 196 152 227 245 253 206 150 103 161 256 251 206
214 252 261 205 186 201 195 149 200 124 139
AYD-A06B 111
148 169 208 174 203 212 248 245 248 263 191 168 207 223 218 203 223 219 194 225
194 180 166 174 206 201 210 168 201 186 159 130 131 174 218 189 220 152 191 176
165 160 150 209 113 160 77 132 163 122 126 97 129 167 165 135 123 135 145 193
140 160 184 171 219 88 104 184 190 139 134 142 155 121 131 111 160 127 161 115
150 168 166 177 140 154 179 200 196 151 229 240 253 211 142 104 165 260 253 206
216 244 261 211 193 190 178 169 202 118 142
AYD-A07A 63
283 420 432 355 310 330 294 210 302 278 311 335 253 209 163 245 225 289 202 167
190 237 213 233 108 247 317 291 205 159 263 172 169 138 158 118 161 124 126 162
191 171 206 153 64 75 163 201 164 179 199 159 203 209 176 206 247 205 222 181
226 253 119
AYD-A07B 63
282 421 432 351 312 338 297 211 299 275 308 343 256 214 171 248 222 285 209 162
175 213 209 238 107 250 318 297 198 180 249 160 163 142 152 114 161 131 123 178
207 184 194 133 48 77 167 208 154 189 196 159 204 208 188 195 252 198 221 176
234 258 123
AYD-A08A 44
179 206 254 236 201 110 111 152 198 161 161 203 191 172 145 86 252 341 282 182
175 254 185 166 167 194 185 223 170 171 260 194 159 181 108 52 70 171 307 236
240 220 121 121
AYD-A08B 44
173 215 298 234 196 107 114 157 200 157 174 205 187 174 143 84 234 334 274 181
179 253 185 164 166 208 176 226 150 156 249 186 170 192 111 47 59 176 285 232
245 216 139 128
AYD-A09A 68
377 361 315 283 254 257 224 278 291 264 205 139 217 213 248 299 351 310 266 237
376 337 370 320 309 353 262 231 243 380 303 284 351 362 284 259 172 284 380 366
295 308 381 355 436 375 358 298 252 298 324 350 350 333 294 323 196 203 259 263
262 233 103 43 44 44 29 31
AYD-A09B 68
355 383 334 271 268 263 206 290 295 261 224 146 214 204 250 296 353 302 258 240
382 339 357 317 304 342 262 227 240 378 299 276 356 360 296 249 167 268 384 356
283 305 380 348 436 364 357 298 253 291 327 343 343 328 288 337 185 204 270 269
263 244 104 43 51 36 30 34
AYD-A10A 87
324 264 219 261 273 352 358 307 305 370 316 292 360 322 226 236 284 260 237 234
280 248 297 278 287 307 222 217 222 195 195 199 172 186 187 255 296 268 280 306
151 106 147 278 272 240 207 298 293 311 141 229 193 294 249 336 232 215 214 128
100 73 86 156 193 137 131 161 118 125 75 84 112 136 143 91 147 148 198 198
151 204 223 234 281 166 142
AYD-A10B 87
333 267 223 252 261 372 374 307 311 374 319 312 345 327 219 257 290 277 239 236
266 249 294 278 286 312 219 217 223 200 190 201 171 185 188 256 295 271 283 314
143 111 148 277 268 242 212 296 304 303 147 224 202 293 247 343 229 216 214 127
108 75 87 150 196 149 117 171 105 130 83 84 104 149 136 101 148 155 163 211
157 192 243 217 286 168 139

AYD-A11A 118
168 204 175 151 159 182 226 196 148 254 239 177 219 235 152 97 221 228 314 248
240 290 218 165 147 184 224 215 172 158 195 173 133 171 113 122 150 172 189 144
128 167 157 189 174 241 231 165 163 176 172 157 193 189 122 89 152 188 172 189
200 118 90 118 222 275 265 229 253 272 257 112 201 187 202 193 314 187 201 173
108 99 57 93 117 200 130 134 142 95 101 68 92 144 150 153 97 161 145 146
158 133 162 213 163 175 80 195 195 148 147 103 78 121 171 210 180 173
AYD-A11B 74
72 74 86 225 280 227 204 236 218 214 110 177 163 194 158 276 176 159 145 113
83 74 75 124 183 151 149 173 125 138 79 109 188 226 187 121 167 176 221 208
173 211 206 195 210 115 198 200 156 154 110 86 117 169 174 145 143 149 114 187
108 119 107 155 173 177 126 174 139 162 109 155 158 137
AYD-A12A 77
334 284 282 279 217 174 184 165 281 305 237 279 293 244 198 253 216 168 173 219
202 149 171 178 187 226 224 237 266 150 165 231 185 206 152 161 119 161 184 252
209 207 232 116 100 99 203 243 135 196 203 227 189 93 101 112 192 180 240 145
136 140 102 64 56 61 109 139 104 118 122 95 89 62 63 97 101
AYD-A12B 77
323 297 281 270 225 170 180 150 280 298 238 264 307 245 198 255 215 161 181 215
203 153 168 175 185 215 227 241 253 163 161 231 193 203 153 159 119 149 191 253
205 209 229 114 103 93 202 245 143 192 203 221 194 97 97 118 190 172 243 155
140 139 99 66 54 65 102 143 99 122 127 86 89 63 69 70 91
AYD-A13A 48
164 287 361 261 250 285 275 218 125 149 157 184 157 108 145 152 113 175 161 138
171 187 193 213 235 246 267 193 201 241 138 148 161 155 208 221 151 171 201 205
200 235 172 202 200 184 124 101
AYD-A13B 41
294 336 291 181 145 168 190 265 224 222 287 269 204 139 157 171 153 150 98 159
127 115 171 172 130 175 179 150 239 246 266 257 190 178 186 115 129 139 159 221
225
AYD-A14A 49
233 141 112 167 201 185 173 150 181 182 184 183 191 231 183 251 212 167 157 175
176 169 114 150 230 185 165 157 154 141 154 113 145 190 188 179 192 223 200 175
172 161 159 196 176 168 175 228 173
AYD-A14B 49
189 139 105 179 197 183 172 150 182 181 180 184 200 217 199 263 206 179 152 171
176 168 128 155 215 183 164 159 171 136 148 107 149 182 195 182 201 206 197 171
177 164 167 178 188 165 190 218 183

APPENDIX

Tree-Ring Dating

The Principles of Tree-Ring Dating

Tree-ring dating, or *dendrochronology* as it is known, is discussed in some detail in the Laboratory's Monograph, '*An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Buildings*' (Laxton and Litton 1988b) and, for example, in *Tree-Ring Dating and Archaeology* (Baillie 1982) or *A Slice Through Time* (Baillie 1995). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The *width* of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring..

If the bark is still on the sample, as in Figure 1, then the date of the last ring will be the date of felling of the oak from which it was cut. There is much evidence that in medieval times oaks cut down for building purposes were used almost immediately, usually within the year or so (Rackham 1976). Hence if bark is present on several main timbers in a building, none of which appear reused or are later insertions, and if they all have the same date for their last ring, then we can be quite confident that this is the date of construction. If there is no bark on the sample, then we have to make an estimate of the felling date; how this is done is explained below.

The Practice of Tree-Ring Dating at the University of Nottingham Tree-Ring dating Laboratory

1. ***Inspecting the Building and Sampling the Timbers.*** Together with a building historian we inspect the timbers in a building to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can sample *in situ* timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer rings than this, 50 for example, sequences of widths become difficult to match to a unique position within a master sequence of ring widths and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure 2 has about 120 rings; about 20 of which are sapwood rings. Similarly the core has just over 100 rings.

   To ensure that we are getting the date of the building as a whole, or the whole of a phase of construction if there is more than one, about 8 to 10 samples per phase are usually taken. Sometimes we take many more, especially if the construction is complicated One reason for taking so many samples is that, in general, some will fail to give a date. There may be many reasons why a particular sequence of ring widths from a sample of timber fails to give a date even though others from the same building do. For example, a particular tree may have grown in an odd ecological niche, so odd indeed that the widths of its rings were determined by factors other than the local climate! In such circumstances it will be impossible to date a timber from this tree using the master sequence whose widths, we can assume, were predominantly determined by the local climate at the time.

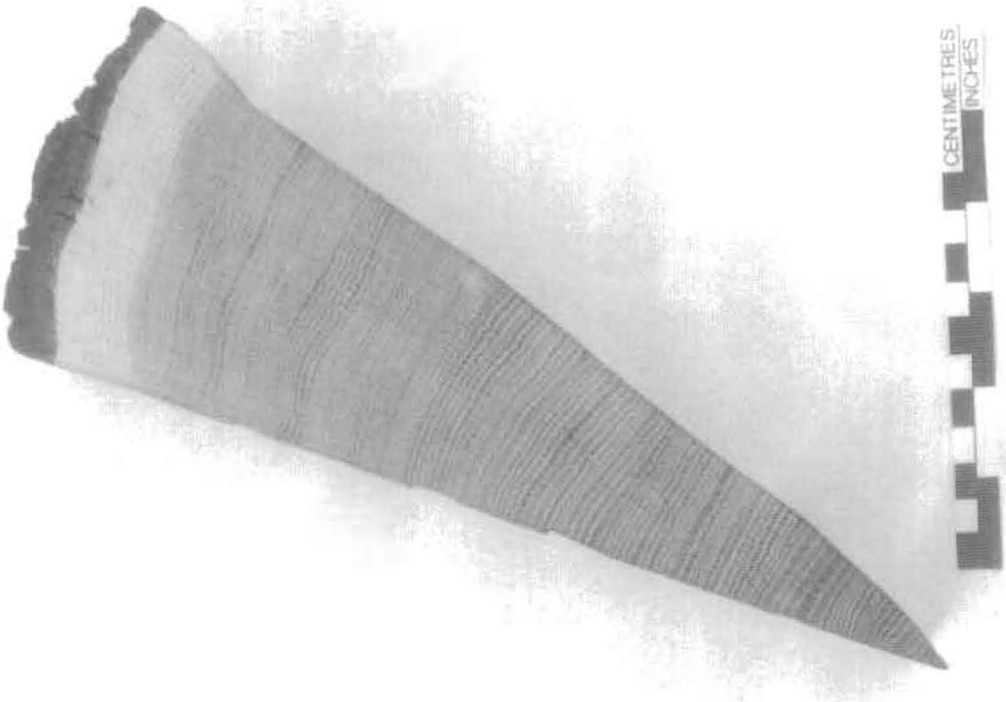


Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

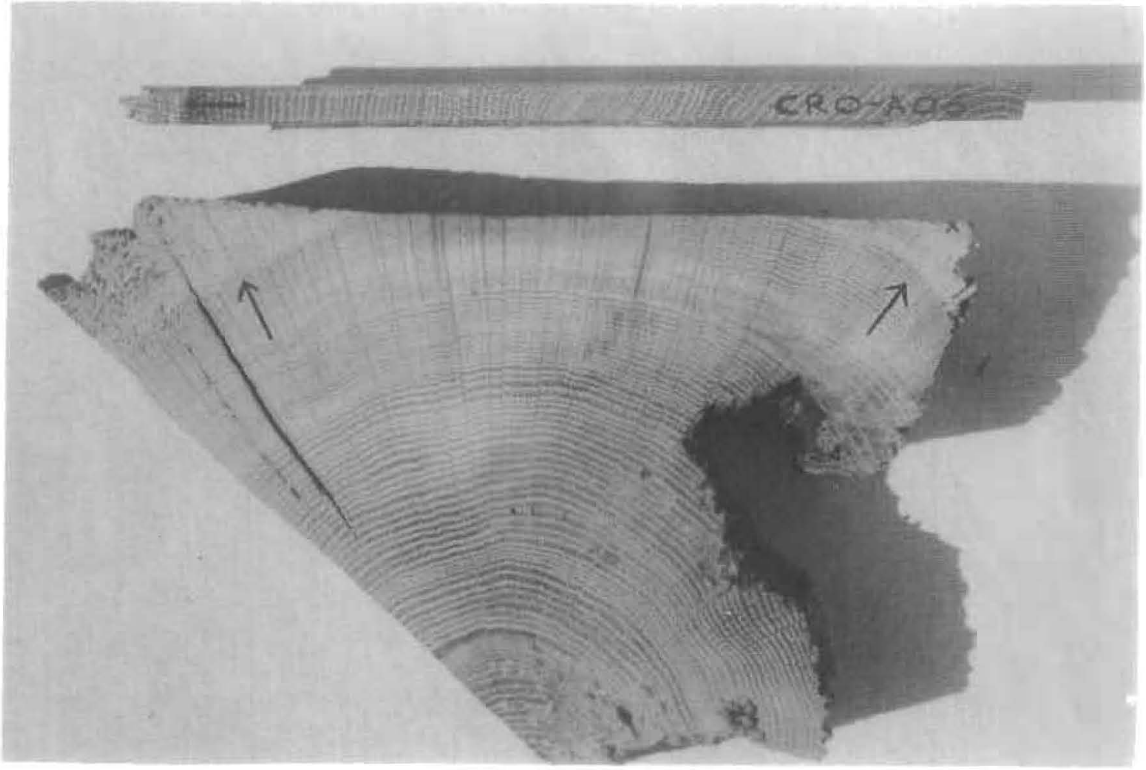


Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

Fig 3. Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measured twice to ensure that an error has not been made. This type of apparatus is needed to process a large number of samples on a regular basis.

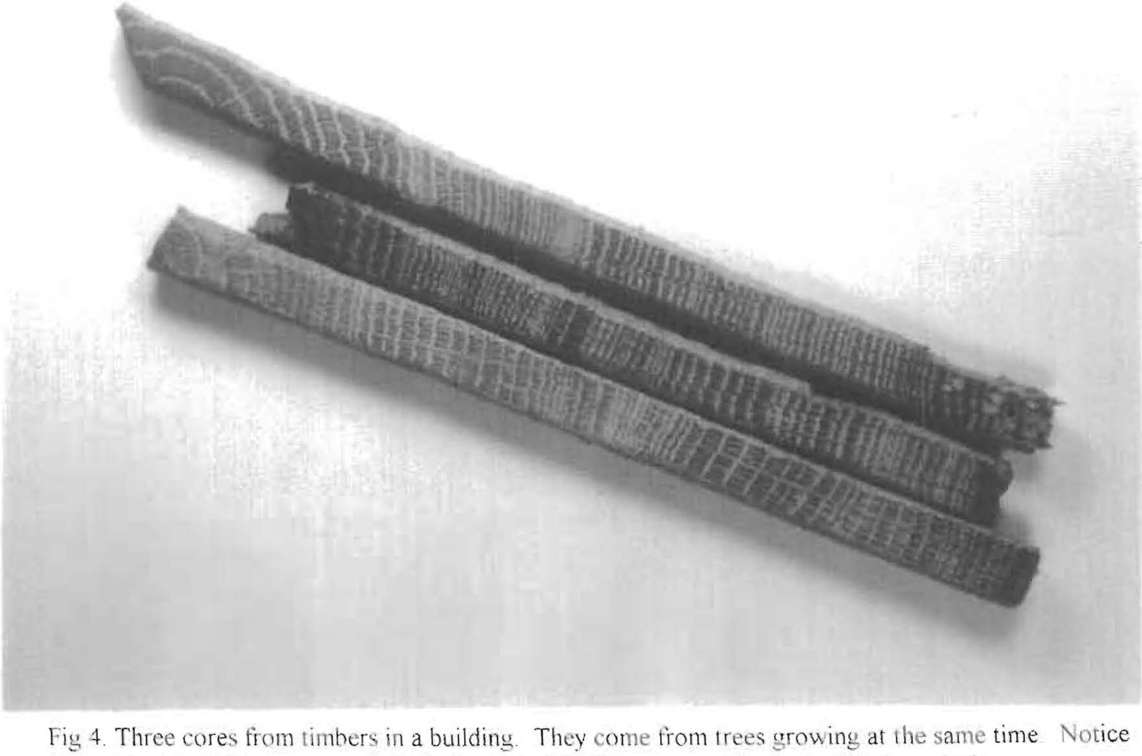


Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

Sampling is done by coring into the timber with a hollow corer attached to an electric drill and usually from its outer rings inwards towards where the centre of the tree, the pith, is judged to be. An illustration of a core is shown in Figure 2; it is about 15cm long and 1cm diameter. Great care has to be taken to ensure that as few as possible of the outer rings are lost This can be difficult as these outer rings are often very soft (see below on sapwood) Each sample is given a code which identifies uniquely which timber it comes from, which building it is from and where the building is located. For example, CRO-A06 is the sixth core taken from the first building (A) sampled by the Laboratory in Cropwell Bishop. Where it came from in that building will be shown in the sampling records and drawings. No structural damage is done to any timbers by coring, nor does it weaken them.

During the initial inspecton of the building and its timbers the dendrochronologist may come to the conclusion that, as far as can be judged, none of the timbers have sufficient rings in them for dating purposes and may advise against sampling to save further unwarranted expense.

All sampling by the Laboratory is undertaken according to current Health and Safety Standards.
The Laboratory is insured with the CBA.

2. ***Measuring Ring Widths.*** Each core is sanded down with a belt sander using medium-grit paper and then finished by hand with flourgrade-grit paper. The rings are then clearly visible and differentiated from each other with a result very much like that shown in Figure 2. The core is then mounted on a movable table below a microscope and the ring-widths measured individually from the innermost ring to the outermost. The widths are automatically recorded in a computer file as they are measured (see Fig 3).

3. ***Cross-matching and Dating the Samples.*** Because of the factors besides the local climate which may determine the annual widths of a tree's rings, no two sequences of ring widths from different oaks growing at the same time are exactly alike (Fig 4). Indeed, the sequences may not be exactly alike even when the trees are growing near to each other. Consequently, in the Laboratory we do not attempt to match two sequences of ring widths by eye, or graphically, or by any other subjective method. Instead, it is done objectively (ie statistically) on a computer by a process called cross-matching. The output from the computer tells us the extent of correlation between two sample sequences of widths or, if we are dating, between a sample sequence of widths and the master, at each relative position of one to the other (offsets). The extent of the correlation at an offset is determined by the *t-value* (defined in almost any introductory book on statistics). That offset with the maximum t-value among the t-values at all the offsets will be the best candidate for dating one sequence relative to the other. If one of these is a master chronology, then this will date the other. Experiments carried out in the past with sequences from oaks of known date suggest that a t-value of at least 4.5, and preferably 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton *et al* 1988a,b; Howard *et al* 1984 - 1995).

   This is illustrated in Fig 5 with timbers from one of the roofs of Lincoln Cathedral. Here four sequences of ring widths, LIN- C04, 05, 08, and 45, have been cross-matched with each other. The ring widths themselves have been omitted in the *bar-diagram*, as is usual, but the offsets at which they best cross-match each other are shown; eg. C08 matches C45 best when it is at a position starting 20 rings after the first ring of 45. and similarly for the others. The actual t-values between the four at these offsets of best correlations are in the matrix. Thus at the offset of +20 rings, the t-value between C45 and C08 is 5.6 and is the maximum between these two whatever the position of one sequence relative to the other.

   It is standard practice in our Laboratory first to cross-match as many as possible of the sequences of the samples in a building and then to form an average from them. This average is called a site sequence of the building being dated and is illustrated in Fig 5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences from four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

This straightforward method of cross-matching several sample sequences with each other one at a time is called the 'maximal t-value' method. The actual method of cross-matching a group of sequences of ring-widths used in the Laboratory involves grouping and averaging the ring-width sequences and is called the 'Litton-Zainodin Grouping Procedure'. This was developed and tested in the Laboratory and has been published (Litton and Zainodin 1991; Laxton *et al* 1988a). To illustrate the difference between the two approaches with the above example, consider sequences C08 and C05. They are the most similar pair with a t-value of 10.4. Therefore, these two are first averaged with the first ring of C05 at +17 rings relative to C08 (the offset at which they match each other). This average sequence is then used in place of the individual sequences C08 and C05. The cross-matching continues in this way gradually building up averages at each stage eventually to form the site sequence.

4. ***Estimating the Felling Date.*** If the bark is present on a sample, then the date of its last ring is the date of the felling of its tree. Actually it could be the year after if it had been felled in the first three months before any new growth had started, but this is not too important a consideration in most cases. The actual bark may not be present on a timber in a building, though the dendrochronologist who is sampling can often see from its surface that only the bark is missing. In these cases the date of the last ring is still the date of felling.

   Quite often some, though not all, of the original outer rings are missing on a timber. The outer rings on an oak, called sapwood rings, are usually lighter than the inner rings, the heartwood, and so are relatively easy to identify. For example, they can be seen in two upper corners of the rafter and at the outer end of the core in Figure 2. More importantly for dendrochronology, the sapwood is relatively soft and so liable to insect attack and wear and tear. The builder, therefore, may remove some of the sapwood for precisely for these reasons. Nevertheless, if at least some of the sapwood rings are left on a sample, we will know that not too many rings have been lost since felling. Thus in these circumstances the date of the present last ring is at least close to the date of the original last ring on the tree, and so to the date of felling.

   Various estimates have been made for the average number of sapwood rings in a mature oak. One estimate is 30 rings, based on data from living oaks. So, in the case of the core in Figure 2 where 9 sapwood rings remain, this would give an estimate for the felling date of 21 (= 30 - 9) years later than of the date of the last ring on the core. Actually, it is better in these situations to give an estimated range for the felling date. Another estimate is that in 95% of mature oaks there are between 15 and 50 sapwood rings. So in this example this would mean that the felling took place between 6 (= 15 - 9) and 41 (= 50 - 9) years after the date of the last ring on the core and is expected to be right in at least 95% of the cases (Hughes *et al* 1981; see also Hillam *et al* 1987).

   Data from the Laboratory has shown that when sequences are considered together in groups, rather than separately, the estimates for the number of sapwood can be put at between 15 and 40 rings in 95% of the cases with the expected number being 25 rings. We would use these estimates, for example, in calculating the range for the common felling date of the four sequences from Lincoln Cathedral using the average position of the heartwood/sapwood boundary (Fig 5). These new estimates are now used by us in all our publications except for timbers from Kent and Nottinghamshire where 25 and between 15 to 35 sapwood rings, respectively, is used instead (Pearson 1995).

   More precise estimates of the felling date and range can often be obtained using knowledge of a particular case and information gathered at the time of sampling. For example, at the time of sampling the dendrochronologist may have noted that the timber from which the core of Figure 2 was taken still had complete sapwood. Sapwood rings were only lost in coring, because of their softness. By measuring in the timber the depth of sapwood lost, say 2 cm., a reasonable estimate can be made of the number of sapwood rings missing from the core, say 12 to 15 rings in this case. By adding on 12 to 15 years to the date of the last ring on the sample a good tight estimate for the range of the felling date can be obtained, which is often better than the 15 to 40 years later we would have estimated without this observation.

T-value/Offset Matrix

	C45	C08	C05	C04
C45		+20	+37	+47
C08	5.6		+17	+27
C05	5.2	10.4		+10
C04	5.9	3.7	5.1	

Bar Diagram

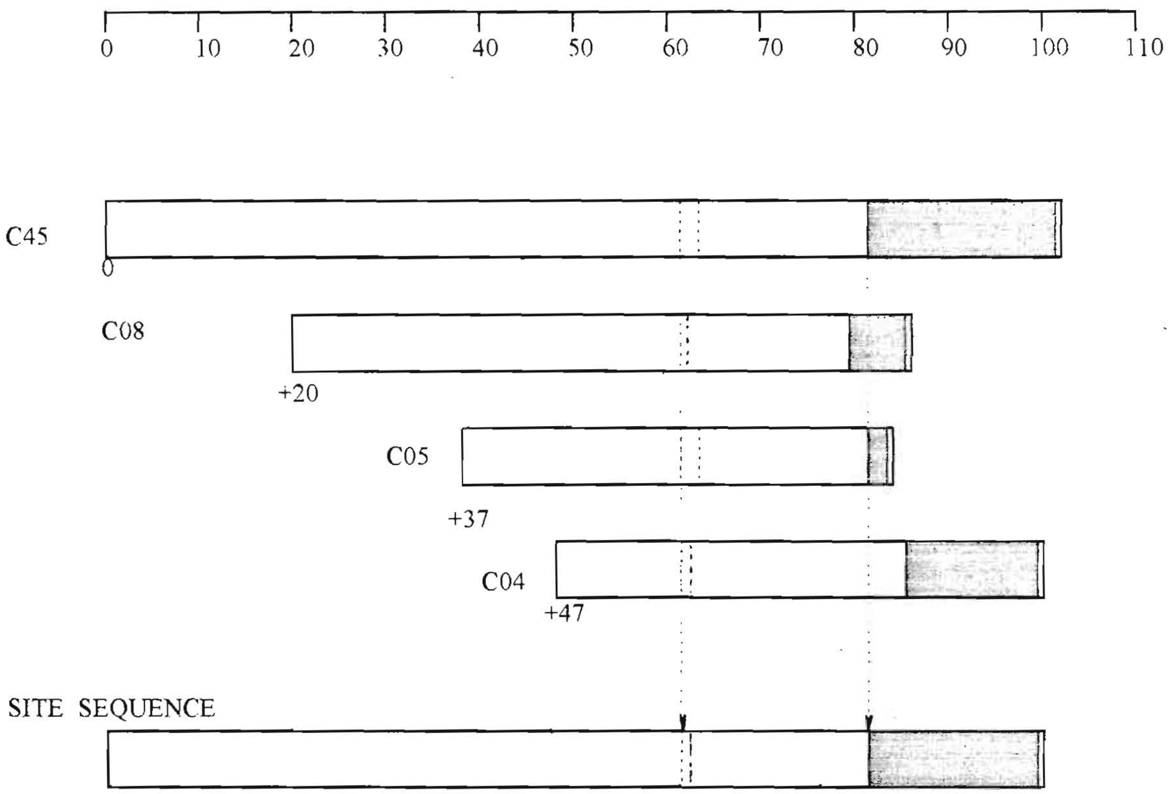


Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.
The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set at relative positions *(offsets)* to each other at which they have maximum correlation as measured by the *t-values*.
The *t-value/offset* matrix contains the maximum t-values below the diagonal and the offsets above it.
Thus, the maximum t-value between C08 and C45 occurs at the offset of +20 rings and the t-value is then 5.6.
The *site sequence* is composed of the average of the corresponding widths, as illustrated with one width.

Even if all the sapwood rings are missing on all the timbers sampled, an estimate of the felling date is still possible in certain cases. For provided the original last heartwood ring of the tree, called the heartwood/sapwood boundary (H/S), is still on some of the samples, an estimate for the felling date of the group of trees can be obtained by adding on the full 25 years, or 15 to 40 for the range of felling dates.

If none of the timbers have their heartwood/sapwood boundaries, then only a *post quem* date for felling is possible.

5. ***Estimating the Date of Construction.*** There is a considerable body of evidence in the data collected by the Laboratory that the oak timbers used in vernacular buildings, at least, were used 'green' (see also Rackham (1976)). Hence provided the samples are taken *in situ,* and several dated with the same estimated common felling date, then this felling date will give an estimated date for the construction of the building, or for the phase of construction. If for some reason or other we are rather restricted in what samples we can take, then an estimated common felling date may not be such a precise estimate of the date of construction. More sampling may be needed for this.

6. ***Master Chronological Sequences.*** Ultimately, to date a sequence of ring widths, or a site sequence, we need a master sequence of dated ring widths with which to cross-match it, a Master Chronology. To construct such a sequence we have to start with a sequence of widths whose dates are known and this means beginning with a sequence from an oak tree whose date of felling is known. In Fig 6 such a sequence is SHE-T, which came from a tree in Sherwood Forest which was blown down in a recent gale. After this other sequences which cross-match with it are added and gradually the sequence is 'pushed back in time' as far as the age of samples will allow. This process is illustrated in Fig 6. We have a master chronological sequence of widths for Nottinghamshire and East Midlands oak for each year from AD 882 to 1981. It is described in great detail in Laxton and Litton 1988b, but the components it contains are shown here in the form of a bar diagram. As can be seen, it is well replicated in that for each year in this period there are several sample sequences having widths for that year. The master is the average of these. This master can now be used to date oak from this area and from the surrounding areas where the climate is very similar to that in the East Midlands. The Laboratory has also constructed a master for Kent (Laxton and Litton 1989). The method the Laboratory uses to construct a master sequence, such as the East Midlands and Kent, is completely objective and uses the Litton-Zainodin grouping procedure (Laxton *et al* 1988a). Other laboratories and individuals have constructed masters for other areas and have made them available. As well as these masters, local (dated) site chronologies can be used to date other buildings from nearby. The Laboratory has hundreds of these site sequences from many parts of England and Wales covering many short periods.

7. ***Ring-width Indices.*** Tree-ring dating can be done by cross-matching the ring widths themselves, as described above. However, it is advantageous to modify the widths first. Because different trees grow at different rates and because a young oak grows in a different way from an older oak, irrespective of the climate, the widths are first standardized before any matching between them is attempted. These standard widths are known as ring-width indices and were first used in dendrochronology by Baillie and Pilcher (1973). The exact form they take is explained in this paper and in the appendix of Laxton and Litton (1988b) and is illustrated in the graphs in Fig 7. Here ring-widths are plotted vertically, one for each year of growth. In the upper sequence (a), the generally large early growth after 1810 is very apparent as is the smaller generally later growth from about 1900 onwards. A similar difference can be observed in the lower sequence starting in 1835. In both the widths are also changing rapidly from year to year. The peaks are the wide rings and the troughs are the narrow rings, hopefully corresponding to good and poor growing seasons, respectively. The two corresponding sequences of Baillie-Pilcher indices are plotted in (b) where the differences in the early and late growths have been removed and only the rapidly changing peaks and troughs remain only associated with the common climatic signal and so make cross-matching easier.

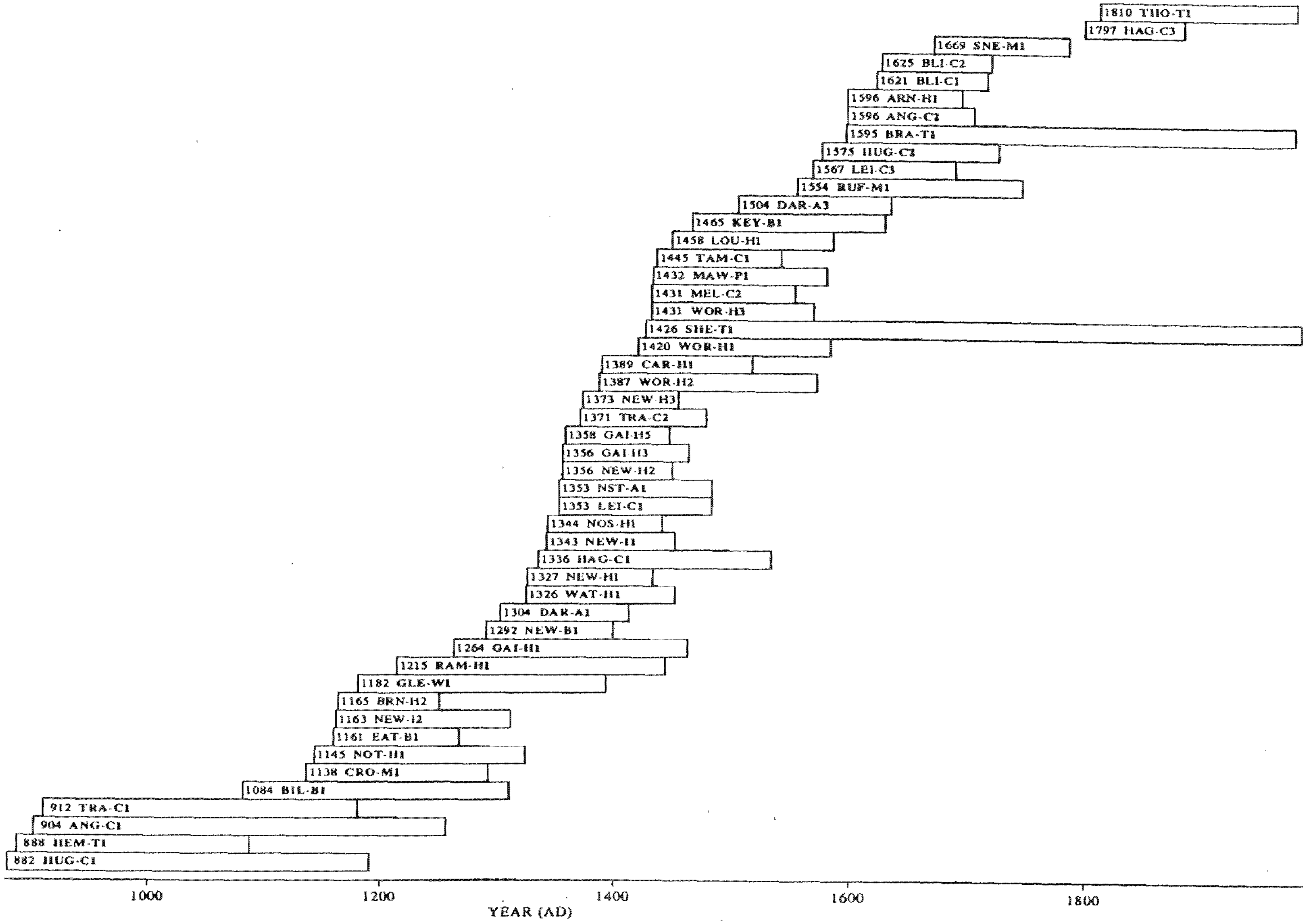


Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

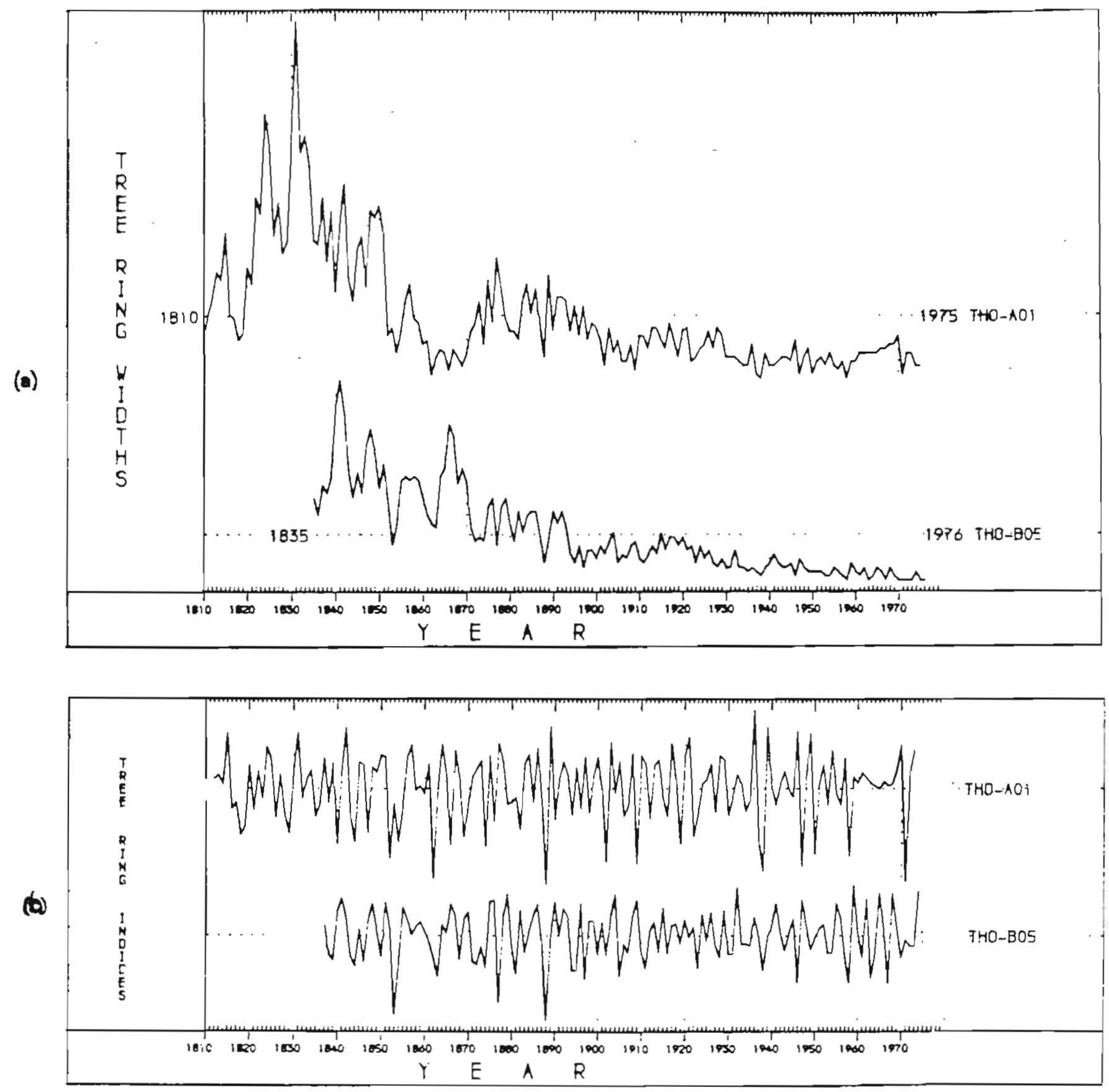


Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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

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

REFERENCES

Baillie, M G L, 1982 *Tree-Ring Dating and Archaeology*, London.

Baillie, M G L, 1995 *A Slice Through Time*, London

Baillie, M G L, and Pilcher, J R, 1973, A simple cross-dating program for tree-ring research, *Tree-Ring Bulletin*, **33**, 7-14

Hillam, J, Morgan, R A, and Tyers, I, 1987, Sapwood estimates and the dating of short ring sequences, *Applications of tree-ring studies*, BAR Int Ser, **3**, 165-85

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1984-95, Nottingham University Tree-Ring Dating Laboratory Results, *Vernacular Architecture*, **15 - 26**

Hughes, M K, Milson, S J, and Legett, P A, 1981 Sapwood estimates in the interpretation of tree-ring dates, *J Archaeol Sci*, **8**, 381-90

Laxton, R R, Litton, R R, and Zainodin, H J, 1988a An objective method for forming a master ring-width sequence, *P A C T*, **22**, 25-35

Laxton, R R, and Litton, C D, 1988b *An East Midlands Master Chronology and its use for dating vernacular buildings*, University of Nottingham, Department of Archaeology Publication, Monograph Series III

Laxton, R R, and Litton, C D, 1989 Construction of a Kent Master Dendrochronological Sequence for Oak, A.D. 1158 to 1540, *Medieval Archaeol*, **33**, 90-8

Litton, C D, and Zainodin, H J, 1991 Statistical models of Dendrochronology, *J Archaeol Sci*, **18**, 429-40

Pearson, S, 1995 *The Medieval Houses of Kent, An Historical Analysis*, London

Rackham, O, 1976 *Trees and Woodland in the British Landscape*, London