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Summary

Forty-three samples were obtained from timbers of the street front and rear range roofs of both numbers 17 and 19 St Mary's Chare, Hexham. Of these 43 samples, 39 were analysed by tree-ring dating, this analysis producing two site chronologies. The first site chronology comprises 33 samples having a combined overall length of 154 rings, these dated as spanning the years AD 1536 to AD 1689.

The second site chronology comprises two samples with an overall length of 79 rings. This second site chronology cannot be dated.

Interpretation of the sapwood on the dated samples would indicate that the roofs of both the front and rear range of number 17 are constructed of timbers felled in AD 1682. It is further indicated that the roofs of the front and rear range of number 19 are both constructed of timbers felled a few years later in AD 1689.

Keywords

Dendrochronology
Standing Building

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Introduction

Numbers 17 and 19 are a pair of inter-related town houses on the west side of St Mary's Chare, formerly one of the principal streets of the town of Hexham, (NY 396 640; Fig 1). Both houses are similar to each other with number 17, the northern of the two, comprising a four-bay, two storey, north-to-south block, with attics, fronting the street. Number 19 is similar, but this roof comprises four cruck trusses forming a five-bay roof. Illustrations of the facades of each are shown in Figures 2 and 3. Both houses have four-bay rear ranges extending back, east-to-west, into their burgage plots. These rear yards adjoin the precinct of the medieval Augustinian Priory the wall of which forms the western boundary of the site.

The two houses are both generally believed, on stylistic evidence, to be of late seventeenth-century date, although an AD 1992 report by the Royal Commission on the Historical Monuments of England, suggests that number 19 is of the early-eighteenth century. The form of the roof of each part of the building, the two front ranges and the two rear ranges, although having large degrees of similarity, do show some differences.

The crucks of the front range roof of number 17, for example, are jointed. This means that they are made from two pieces of timber, a post and a principal rafter, rather than from a single, curved, piece. The trusses of this roof have collars and carry double purlins. The crucks in the roofs of the other three ranges appear to be made from single curved timbers in the form of true crucks. Furthermore, whilst the front range of number 17, and both the front and rear range roofs of number 19 employ double purlins, the rear range roof of number 17 has only single purlins.

A further difference is to be seen in the carpentry, or conversion, of the timbers in these roofs. The timbers of the front range roof of number 17 are generally very squarely and neatly cut. The joints are also tight fitting, the assembly of them being marked in very clear modern looking Arabic numerals. The timbers in the other three roofs are less neatly cut, much more uneven, and are altogether much more crude looking. The jointing of these roofs tends to be noted in larger Roman numerals.

Sampling

Sampling and analysis by tree-ring dating of the timbers of 17 and 19 St Mary's Chare were commissioned by English Heritage, this being requested to inform an ongoing programme of repair and conservation work. The English Heritage brief called for the sampling of roof timbers from four specific areas, there being no timbers other than those in the roofs available elsewhere in the building.

Firstly the brief requested the sampling of roof timbers of the four-bay frontage block of number 17, comprising the three sets of well carpentered jointed upper crucks, with collars and double purlins. Secondly timbers of the rear range roof of number 17 were also to be sampled. This roof also consisted of three pairs of upper crucks, although these were stylistically different to those of the front range. Samples were also to be obtained from the roofs of the front and rear ranges of number 19, both roofs consisting of upper crucks, the front range of four trusses, the rear range of three trusses.

For the purposes of tree-ring analysis, given the slight stylistic variations between the roofs, and thus the possibility of different construction dates, each roof area was treated as an individual site with sufficient samples obtained from each for reliable analysis. Thus from these sets of timbers a total of 43 core samples was obtained, with the samples being distributed fairly evenly through the four areas under consideration. Each of these samples was given the code HEX-A (for Hexham, site "A"), and numbered 01–43. Thirteen samples, HEX-A01-A13 were obtained from the front range of number 17, with a further ten samples being obtained from the roofs of each of the other three ranges.

The approximate positions of the 43 timbers cored are shown here in Figures 4a/b. These figures, provided by English Heritage, are based on drawings made by Kevin Doonan Architects, and amended by Peter Ryder. The exact positions of the timbers are not shown. Details of the samples are given in Table 1. In this report the timbers have been numbered and described from north to south, or east to west, as appropriate.

Timbers were selected for sampling on the basis of their appearing to be original or related to their respected phases, and in appearing to have sufficient rings for satisfactory analysis by tree-ring dating. Timbers were also selected on the basis of their having sapwood or at least the heartwood/sapwood boundary.

The Laboratory would like to take this opportunity to thank Alan Graham, site agent, for arranging access to the site and for helping during sampling. We would also like to thank "Bodyworks" Health and Beauty Parlour, of number 19 for being so helpful and accommodating in assisting with sampling, despite the inconvenience caused. We must also thank the owner of The Clock Shop, who allowed us unhindered access to private apartments to the rear of number 17.

The Laboratory must once again thank both Peter Ryder, Historic Buildings Consultant, and Martin Roberts of English Heritage north-east office for allowing us to use their drawings and descriptions in the introduction to this report.

Analysis

Each of the 43 samples obtained was prepared by sanding and polishing. It was seen at this point that four samples, HEX-A12, -A13, -A14, and -A34, had too few rings for satisfactory analysis and these were rejected. The annual growth-ring widths of the remaining 39 samples were measured, the data of these measurements being given at the end of the report. These data were then compared with each other by the Litton/Zainodin grouping procedure (see appendix).

At a minimum *t*-value of 4.5 two site chronologies could be created. The first, HEXASQ01, comprises 33 samples, the relative position of the cross-matching samples being shown in the bar diagram, Figure 5. This site chronology has a combined overall length of 154 rings. The second site chronology, HEXASQ02, comprises 2 samples, the relative position of the cross-matching samples being shown in the bar diagram, Figure 6. This site chronology has a combined overall length of 79 rings.

Both site chronologies were compared with a large number of reference chronologies for oak. This indicated a cross-match for site chronology HEXASQ01 only with a number of these when the date of its first ring is AD 1536 and the date of its last ring is AD 1689. Evidence for this dating is given in the *t*-values of Table 2.

Both site chronologies were also compared with each other, and with the four remaining measured but ungrouped samples, but there was no further satisfactory cross-matching. These four ungrouped samples were then compared individually with a full range of reference chronologies, but again there was no cross-matching, and these samples must remain undated.

Interpretation

Analysis by dendrochronology has produced a single dated site chronology comprising samples from 33 timbers, with a combined overall length of 154 rings. This site chronology is dated as spanning the years AD 1536 to AD 1689.

Five samples from the front range roof of number 17, HEX-A01, -A02, -A04, -A08, and -A11, and one sample from the rear range of number 17, HEX-A16, retain complete sapwood. In each of the six cases the last measured ring date is the same, AD 1682. This is thus the felling date of the timbers represented. The relative positions of the heartwood/sapwood boundaries on the other dated samples from these two roofs would suggest that it is highly probable that these other timbers were felled at this time too. There is certainly no structural indication that the two roofs are other than of a single build.

Three samples from the front range roof of number 19, HEX-A26, -A27, and -A30, and one sample from the rear range of number 19, HEX-A35, also retain complete sapwood. In these cases the last measured complete sapwood ring date is slightly later at AD 1689. The relative positions of the heartwood/sapwood boundaries on the other dated samples from these two roofs would again suggest that it is highly probable that these other timbers were felled in AD 1689 too. Again there is no structural evidence that the two roofs are other than of a single build.

Conclusion

Analysis by dendrochronology has produced a single dated site chronology comprising samples from 33 timbers, with a combined overall length of 154 rings. This site chronology is dated as spanning the years AD 1536 to AD 1689.

Samples with complete sapwood have been obtained from each of the four roof ranges under consideration. This means that the samples have the last rings produced by the trees they represent before they were felled.

This tree-ring analysis indicates that the roofs of both the front and rear ranges of number 17 are constructed of timbers felled in AD 1682, whilst the roofs of the front and rear ranges of number 19 are both constructed of timbers felled a few years later in AD 1689.

Tree-ring dating has thus confirmed the general late-seventeenth century date attributed to these buildings, by giving a much more precise date for the felling of the timber, and showing that the two buildings were in fact constructed a few years apart. This programme of dendrochronology has refuted an earlier suggestion that number 19 might be of early-eighteenth century date and in doing so shown the value of tree-ring dating, even where a general date has been attributed on stylistic grounds.

Six measured samples remain undated, HEX-A20, -A21, -A32, -A40, -A42, and -A43, though two of these, -A42 and -A43 do cross-match with each other. Some of these samples have low numbers of rings, and a few samples, HEX-A32, and -A42 / -A43 for example, have growth rings which show narrow bands, possibly brought about by stressful growing conditions. It is likely that these factors account for these samples not cross-matching with the others and dating.

Three observations might be made about the material from this site. The first is that the t-values of the cross-matching of the individual samples tend to suggest that, whilst all the timber used may have come from the same general woodland source, the timber used within each distinct roof has come from a more localised stand or copse. Values in excess of t=6 and t=7 are found between samples from different roofs, but some values in excess of t=10 and t=11, are seen between samples within roofs. Some samples, HEX-A42 and -A43 for example, are from timbers probably derived from the same tree.

The second observation concerns the total number of sapwood rings found on some of the samples. The usual 95% confidence limit for the number of sapwood rings on mature oaks from this part of England is in the range 15 to 40 rings. It will be seen from Table 1 and the bar diagram Figure 5, that a number of samples have less than 15 sapwood rings, although the sapwood on them is complete. The lowest figure found is 11 sapwood rings, on sample HEX-A08, with others having 12–14 sapwood rings to complete. The greatest number of sapwood rings may be found on sample HEX-A15 which, based upon its being felled in AD 1682, would have had a maximum of 29 sapwood rings.

The final observation concerns the reference chronologies used in Table 2 for dating. It will be seen from this Table that some of these are from areas other than the north of England, from Derbyshire and Nottinghamshire for example. This use of more widespread reference chronologies is due to the fact that there are few, if any, reference chronologies available for northern England that cover the late- sixteenth and seventeenth centuries. In this respect the material from 17 and 19 St Mary's Chare is particularly valuable in providing data for a poorly represented period.

Bibliography

Baillie, M G L, 1977 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-EOI,* Queens Univ, Belfast

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1994 List 57 no 10a - Nottingham University Tree-ring Dating Laboratory Results: general list, *Vernacular Architect*, **25**, 36-40

Howard, R E, Laxton, R R, Litton, C D, Morrison A, Sewell, J, and Hook, R, 1995 List 61 no 1 - Nottingham University Tree-Ring Dating Laboratory: Derbyshire, Peak Park and RCHME dendrochronological Survey 1994 - 95, *Vernacular Architect,* **26**, 53 – 4

Howard, R E, Laxton, R R, and Litton, C D, 2003 *Tree-ring analysis of timbers from Staircase House (30A & 31 Market Place), Stockport, Greater Manchester*, Centre for Archaeol Rep **12/2003**

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

Table 1: Details of samples from 17 and 19, St Mary's Chare, Hexham, Northumberland.

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Front range number 17					
HEX-A01	East lower purlin, north gable – truss 1	117	13C	AD 1566	AD 1669	AD 1682
HEX-A02	West lower purlin, north gable – truss 1	114	14C	AD 1569	AD 1668	AD 1682
HEX-A03	East wall post, truss 1	72	14	AD 1608	AD 1665	AD 1679
HEX-A04	West lower purlin, truss 1 – 2	130	15C	AD 1553	AD 1667	AD 1682
HEX-A05	West principal rafter (cruck), truss 1	73	no h/s	AD 1566	------	AD 1638
HEX-A06	East principal rafter (cruck), truss 2	108	13	AD 1562	AD 1656	AD 1669
HEX-A07	West principal rafter (cruck), truss 2	71	no h/s	AD 1560	------	AD 1630
HEX-A08	West wall post, truss 2	96	11C	AD 1587	AD 1671	AD 1682
HEX-A09	East lower purlin truss 1 – 2	136	6	AD 1536	AD 1665	AD 1671
HEX-A10	East principal rafter (cruck) truss 3	103	h/s	AD 1569	AD 1671	AD 1671
HEX-A11	East post, truss 3	111	12C	AD 1572	AD 1670	AD 1682
HEX-A12	West principal rafter (cruck), truss 3	nm	---	-------	------	------
HEX-A13	East lower purlin, truss 1 – south gable	nm	---	------	------	------
	Rear range number 17					
HEX-A14	North cruck blade, truss 1 (east end)	nm	h/s	------	------	------
HEX-A15	South cruck blade, truss 1	104	27	AD 1577	AD 1653	AD 1680
HEX-A16	North cruck blade, truss 2	110	13C	AD 1573	AD 1669	AD 1682
HEX-A17	South cruck blade, truss 2	122	5	AD 1552	AD 1668	AD 1673
HEX-A18	North stub tie, truss 2	109	17	AD 1564	AD 1655	AD 1672
HEX-A19	South stub tie, truss 2	97	h/s	AD 1559	AD 1655	AD 1655
HEX-A20	North cruck blade, truss 3	62	h/s	------	------	------
HEX-A21	South cruck blade, truss 3	54	h/s	------	------	------
HEX-A22	North stub tie, truss 3	65	no h/s	AD 1572	------	AD 1636
HEX-A23	South stub tie, truss 3	97	15	AD 1574	AD 1655	AD 1670

Table 1: Continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Front range number 19					
HEX-A24	East cruck blade, truss 1	114	15	AD 1570	AD 1668	AD 1683
HEX-A25	East lower purlin, truss 1 – 2	86	13	AD 1597	AD 1669	AD 1682
HEX-A26	East cruck blade, truss 2	82	20C	AD 1608	AD 1669	AD 1689
HEX-A27	Collar, truss 2	99	25C	AD 1591	AD 1664	AD 1689
HEX-A28	East cruck blade, truss 3	81	14	AD 1606	AD 1672	AD 1686
HEX-A29	West cruck blade, truss 3	106	7	AD 1569	AD 1667	AD 1674
HEX-A30	Collar, truss 3	66	20C	AD 1624	AD 1669	AD 1689
HEX-A31	East cruck blade, truss 4	89	13	AD 1592	AD 1667	AD 1680
HEX-A32	Collar, truss 4	55	no h/s	------	------	------
HEX-A33	West principal rafter, truss 4	131	16	AD 1549	AD 1663	AD 1679
	Rear range number 19					
HEX-A34	South cruck blade, truss 1	nm	---	------	------	------
HEX-A35	South purlin, truss 1 – 2	101	20C	AD 1589	AD 1669	AD 1689
HEX-A36	North cruck blade, truss 2	88	8	AD 1595	AD 1674	AD 1682
HEX-A37	South cruck blade, truss 2	112	7	AD 1570	AD 1674	AD 1681
HEX-A38	Collar, truss 2	131	18	AD 1553	AD 1665	AD 1683
HEX-A39	North cruck blade, truss 3	85	17	AD 1599	AD 1666	AD 1683
HEX-A40	South cruck blade, truss 3	54	no h/s	------	------	------
HEX-A41	Collar, truss 3	90	no h/s	AD 1561	------	AD 1650
HEX-A42	North purlin, truss 3 to west gable	77	no h/s	------	------	------
HEX-A43	South purlin, truss 3 to west gable	78	no h/s	------	------	------

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

Table 2: Results of the cross-matching of chronology HEXASQ01 and relevant reference chronologies when the date of the first ring is AD 1536 and the last ring date is AD 1689

Reference chronology	Span of chronology	*t*-value	
England	AD 401 – 1981	7.5	(Baillie and Pilcher 1982 unpubl)
Scotland	AD 946 – 1975	7.2	(Baillie 1977)
Rufford Mill, Notts	AD 1554 – 1744	7.0	(Laxton and Litton 1988)
Staircase House, Stockport, Greater Manchester	AD 1489 – 1656	6.7	(Howard *et al* 2003)
15/17 St John's Street, Wirksworth, Derbys	AD 1586 – 1676	5.7	(Howard *et al* 1995)
Brewhouse Yard Museum, Nottm	AD 1544 – 1701	5.2	(Howard *et al* 1994)
East Midlands	AD 882 – 1981	4.5	(Laxton and Litton 1988)

Figure 1: Map to show general location of St Mary's Chare

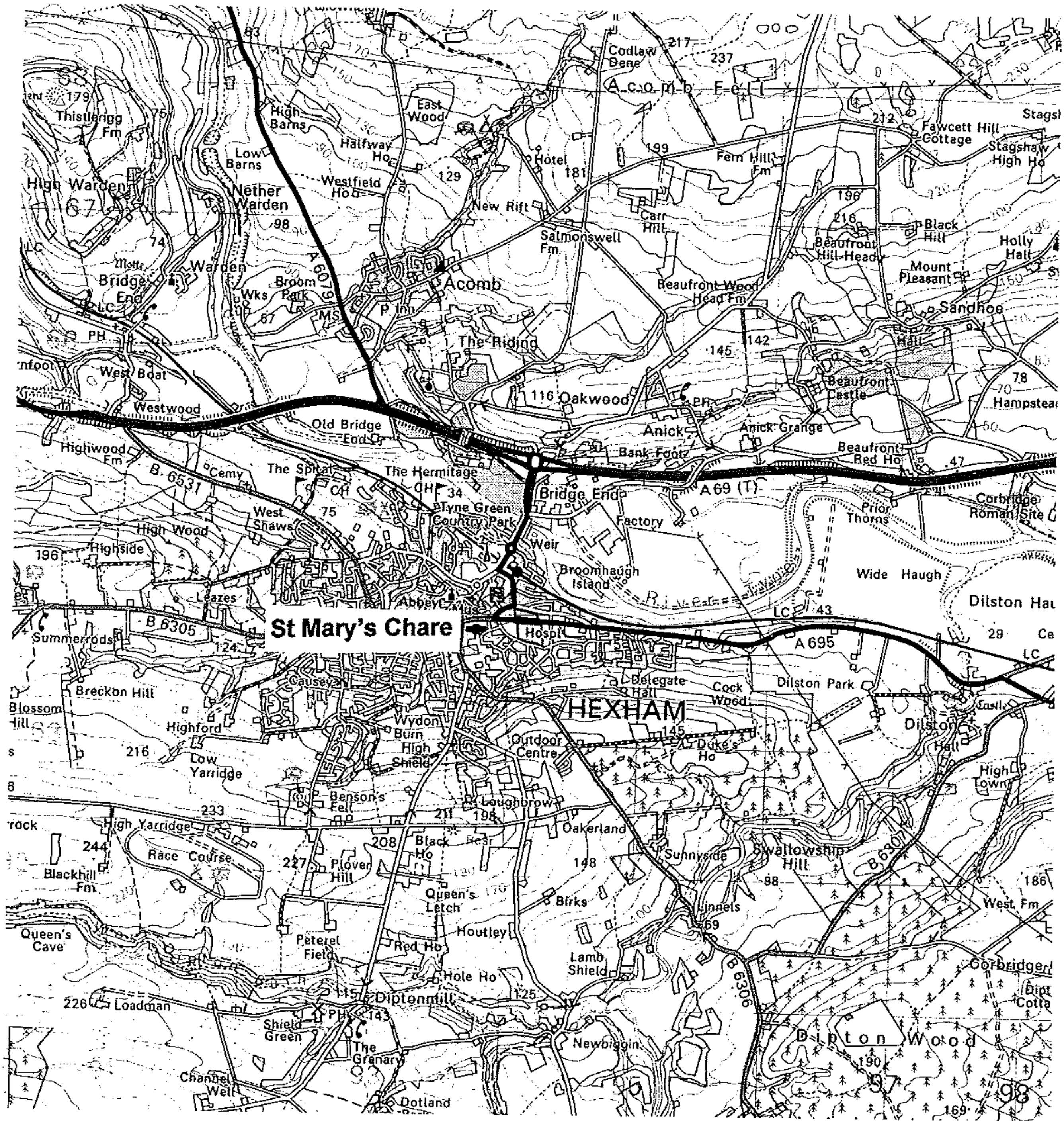


Figure 2: Front elevation of 17 St Mary's Chare

Figure 3: Front elevation of 19 St Mary's Chare

Figure 4a: Plan to show approximate position of sampled timbers from number 17

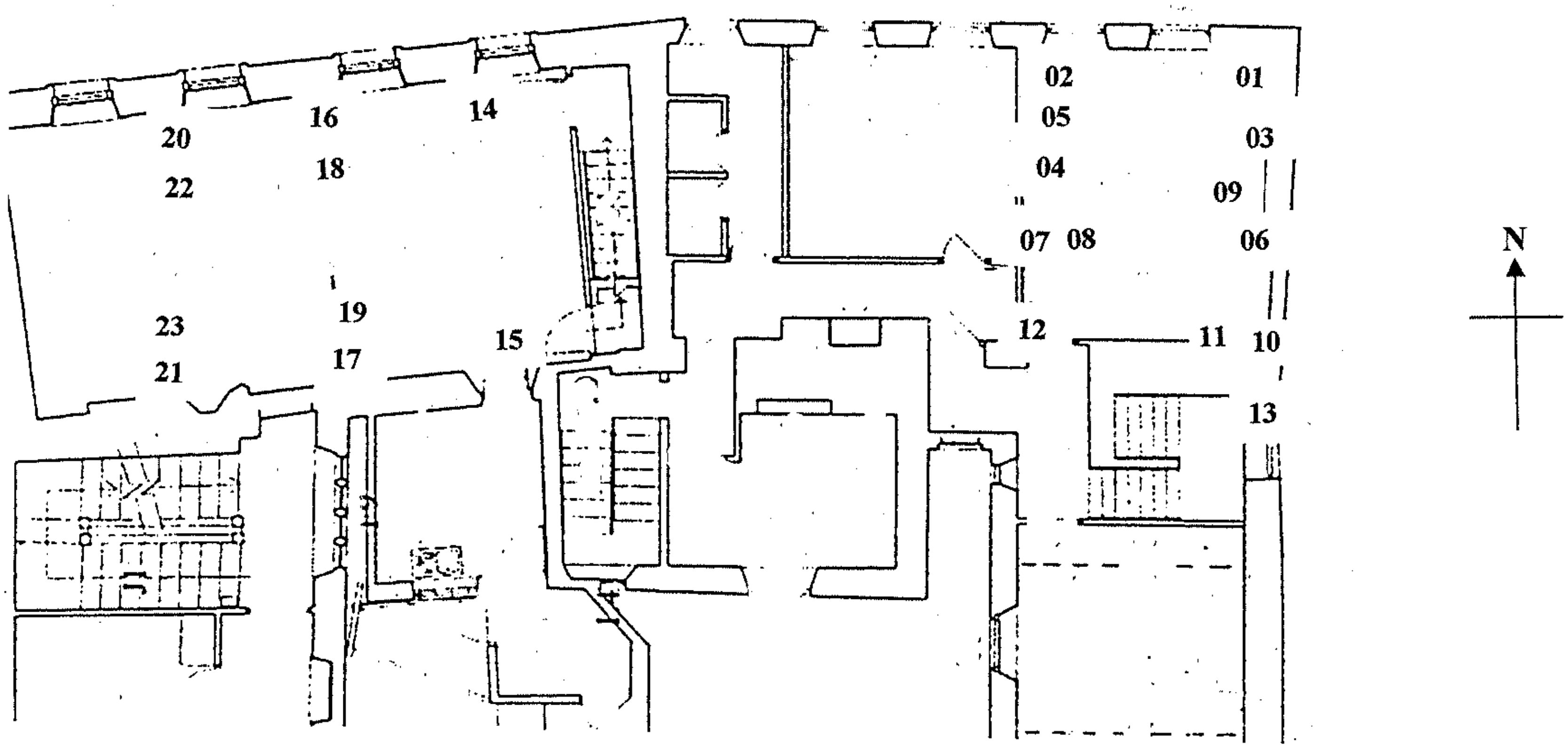


Figure 4b: Plan to show approximate position of sampled timbers from number 19

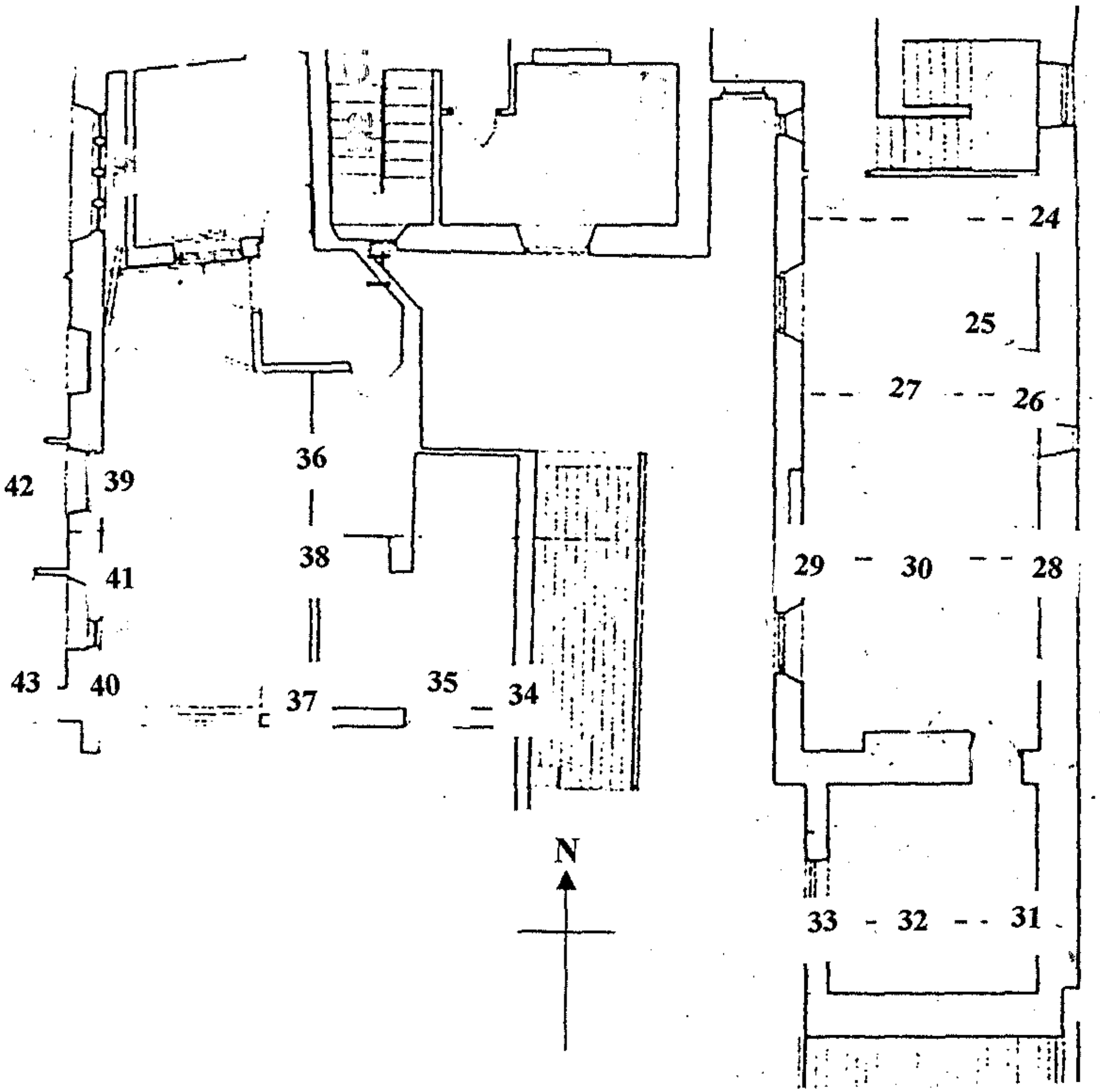
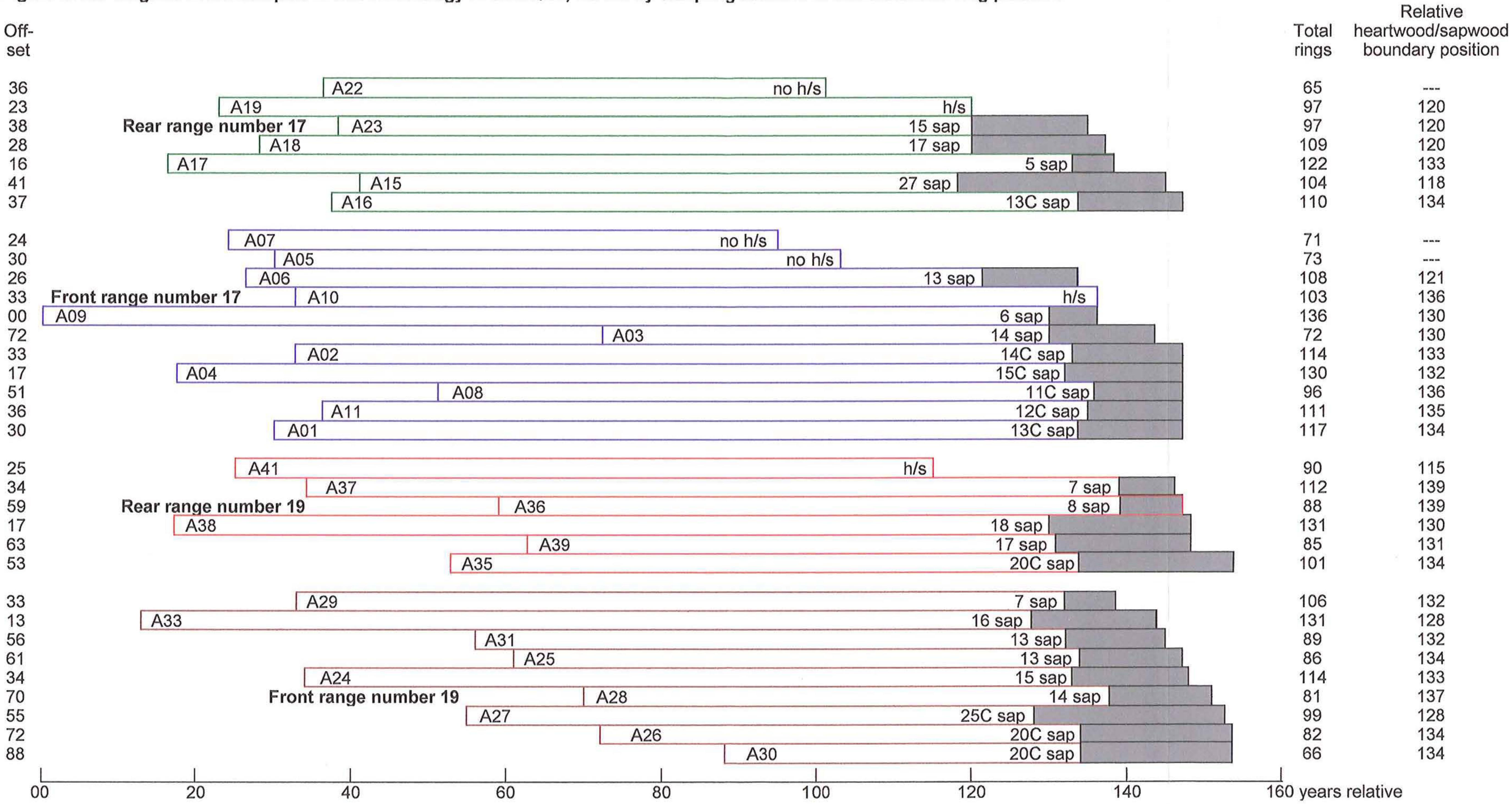
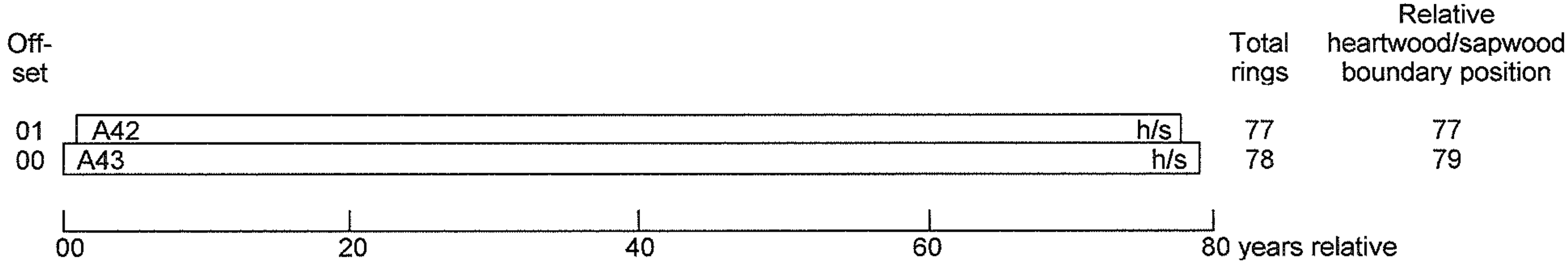


Figure 5: Bar diagram of the samples in site chronology HEXASQO1, sorted by sampling location in last measured ring position



white bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample
C = complete sapwood retained on sample, the last measured ring date is the felling date of the timber

Figure 6: Bar diagram of the samples in site chronology HEXASQ02



white bars = heartwood rings
h/s = heartwood/sapwood boundary is last ring on sample

Data of measured samples – measurements in 0.01 mm units

HEX-A01A 117
154 171 179 230 230 196 169 172 221 184 157 151 117 141 132 99 132 138 171 161
173 194 155 160 197 168 192 236 263 228 169 142 112 95 128 112 140 151 154 148
129 137 136 136 136 153 149 199 176 183 111 168 112 140 120 122 107 99 77 74
122 121 102 115 107 131 107 103 115 140 163 175 186 142 141 187 111 54 110 127
117 89 102 53 62 59 71 67 116 91 108 62 54 56 63 63 84 69 76 86
82 90 85 95 101 87 133 122 89 72 95 116 140 136 91 121 139
HEX-A01B 117
137 166 167 233 239 227 177 174 219 184 153 152 110 133 134 101 127 139 172 165
170 178 132 173 187 162 204 240 286 242 169 139 117 92 128 131 133 146 165 134
146 136 134 137 130 162 149 174 174 191 109 165 111 146 127 118 102 100 71 78
124 127 98 110 113 124 104 112 119 133 165 178 184 135 154 183 107 61 109 121
130 93 98 48 62 60 69 74 122 81 112 56 55 56 63 59 87 73 78 75
90 79 99 77 115 90 125 119 87 73 102 122 141 124 95 121 132
HEX-A02A 114
149 186 262 181 206 316 267 181 235 258 369 358 314 160 142 175 278 220 199 116
152 158 131 180 198 137 165 115 68 43 35 56 46 72 100 90 86 75 54 100
94 92 71 103 111 109 73 48 63 100 84 92 90 83 63 40 42 57 77 83
89 99 71 63 33 26 44 36 76 123 69 99 74 34 31 43 41 73 88 87
97 72 58 55 120 131 137 174 103 81 77 99 121 115 138 96 101 83 72 72
113 141 105 110 146 124 67 89 92 87 125 69 67 82
HEX-A02B 114
106 172 272 195 207 282 196 140 225 228 373 363 309 156 135 178 283 256 206 110
164 158 144 185 202 132 155 110 80 39 36 56 71 57 116 97 94 75 59 85
82 93 84 88 104 113 74 50 65 93 72 97 91 80 63 39 46 55 80 86
96 98 73 65 32 36 26 50 71 120 66 105 70 32 29 40 39 79 81 93
100 63 71 49 121 136 138 162 98 84 82 91 120 114 149 84 107 83 70 64
99 120 103 128 140 124 76 80 98 93 130 64 68 71
HEX-A03A 72
97 95 116 109 145 194 220 160 96 123 110 106 105 110 113 91 72 96 74 82
71 121 90 92 128 79 62 86 90 114 156 87 118 114 50 39 66 80 126 106
111 111 110 116 114 168 250 282 257 183 132 135 145 133 126 108 124 161 204 131
109 147 189 166 175 197 153 79 102 121 103 107
HEX-A03B 72
116 94 125 96 143 188 223 137 95 117 113 113 101 118 98 77 85 89 75 83
73 128 84 92 121 81 63 81 98 111 156 88 121 105 51 45 63 82 119 109
112 130 127 102 128 164 273 270 258 174 147 139 132 136 121 109 121 160 219 134
98 132 218 149 171 196 140 80 93 127 99 137
HEX-A04A 130
184 170 134 207 210 200 161 210 152 136 115 94 50 85 79 91 73 102 80 85
69 78 77 34 39 45 63 98 70 34 62 73 91 130 117 67 132 100 75 99
125 150 140 98 106 49 28 36 41 43 60 109 81 102 74 72 46 86 54 65
88 130 98 45 75 59 67 80 75 77 76 75 53 113 106 95 127 103 115 71
64 46 55 139 165 260 177 245 172 79 46 77 101 177 158 117 77 44 47 43
70 118 111 150 88 69 84 94 100 97 136 188 181 165 90 74 138 213 223 245
297 231 92 130 112 150 231 207 175 227
HEX-A04B 130
172 180 138 204 208 203 162 214 145 133 126 90 57 76 88 82 80 94 89 80
76 84 69 34 35 39 65 102 81 35 62 67 94 132 123 90 115 104 80 95
121 149 131 104 115 42 30 30 36 47 55 120 68 102 73 70 55 77 60 65
84 125 102 47 74 67 57 86 74 81 79 61 61 87 113 93 122 109 127 66

61 52 58 144 161 258 176 247 170 61 58 80 103 178 156 119 80 41 47 35
80 113 114 148 91 75 69 108 99 97 129 192 185 165 89 85 117 222 226 236
288 233 95 124 121 142 241 201 171 241
HEX-A05A 73
231 230 190 186 224 274 207 233 184 167 148 139 146 200 200 178 145 162 198 133
160 172 124 118 120 111 130 145 176 129 107 89 116 85 123 117 104 122 98 108
78 76 59 62 86 67 56 76 94 94 56 66 82 70 78 73 122 126 114 95
164 186 163 218 166 187 183 151 132 183 247 236 247
HEX-A05B 73
206 231 180 186 266 275 202 209 212 202 157 132 150 183 179 169 165 163 188 141
183 170 115 115 137 98 153 153 184 134 119 94 115 79 122 118 110 109 109 99
86 78 69 73 82 64 61 73 101 83 66 80 57 83 90 71 154 121 108 102
155 193 136 181 180 177 189 142 118 168 243 239 242
HEX-A06A 108
281 435 369 182 267 369 379 247 203 162 146 220 234 352 184 159 254 267 174 128
124 132 169 145 203 189 132 133 149 105 136 133 134 83 73 87 64 51 88 61
59 56 69 55 51 71 65 40 60 45 103 95 57 58 39 35 36 37 49 53
35 67 52 47 31 27 28 28 40 27 30 31 27 42 65 127 200 257 284 190
56 47 63 57 100 114 183 118 86 68 51 62 82 158 260 190 252 240 174 169
144 286 261 372 371 221 274 365
HEX-A06B 108
282 431 367 183 259 368 389 236 205 169 143 209 243 355 174 172 248 273 175 123
117 128 172 149 202 185 106 136 150 98 118 133 144 93 67 80 69 58 84 57
67 54 64 56 42 76 72 49 43 66 92 97 62 60 37 34 43 34 45 50
36 73 49 46 30 31 28 33 35 30 28 35 23 42 66 121 220 249 281 188
55 46 65 61 97 111 182 119 88 69 52 58 86 156 254 203 243 235 200 171
160 287 314 337 366 209 246 332
HEX-A07A 71
158 86 100 103 79 22 97 202 118 104 133 207 151 230 293 218 139 144 176 200
246 144 60 96 130 178 229 235 182 219 112 93 157 211 270 227 182 193 172 139
214 169 160 267 231 276 246 223 217 242 275 206 245 247 246 246 93 180 174 188
210 224 198 172 108 172 204 247 288 269 259
HEX-A07B 71
178 111 109 107 92 23 100 199 124 110 119 212 137 239 282 231 133 148 176 195
249 145 59 102 129 186 227 235 184 217 117 90 161 224 275 222 188 175 173 133
218 178 160 265 234 266 241 216 208 223 289 205 246 252 229 253 90 181 187 194
216 220 197 192 113 169 217 241 270 277 209
HEX-A08A 96
162 161 159 180 179 167 238 236 205 197 198 190 136 166 161 166 156 198 147 145
107 154 117 132 111 166 193 191 205 128 168 175 185 180 176 216 182 171 160 177
212 220 219 153 179 198 169 142 155 196 216 252 172 200 212 156 103 118 152 200
158 114 125 109 119 127 186 210 218 254 167 154 174 172 136 203 156 147 191 157
156 223 234 307 194 260 231 194 157 190 178 227 204 165 166 189
HEX-A08B 96
125 152 154 181 169 178 239 216 245 185 182 196 145 172 142 180 157 180 165 151
111 143 117 144 118 169 224 174 184 123 175 177 204 172 185 201 206 174 154 163
212 215 224 157 175 201 163 137 149 208 210 247 173 191 215 169 90 116 156 191
151 118 120 112 114 132 186 217 217 246 171 154 172 167 145 207 158 139 198 156
152 227 225 315 193 260 234 200 152 190 176 198 230 163 166 211
HEX-A09A 136
122 91 75 117 238 202 283 309 225 264 228 204 201 288 313 301 222 231 183 193
199 192 262 240 144 193 158 155 172 103 108 118 122 134 107 115 89 133 125 96
79 86 86 85 93 94 66 62 86 72 81 69 54 58 74 48 65 72 69 85
45 40 40 58 50 59 50 69 62 85 58 73 67 50 51 52 53 42 67 53
42 62 59 51 48 62 57 56 36 52 44 45 55 57 58 44 50 44 38 25

31 55 62 42 53 50 41 40 53 56 74 57 60 49 58 46 47 70 71 64
91 49 64 70 64 71 85 120 126 153 134 64 82 84 87 125
HEX-A09B 136
102 97 72 117 238 194 296 316 225 258 212 195 196 272 299 289 202 248 211 199
193 217 253 240 128 185 151 151 163 88 119 113 125 124 118 117 99 127 128 99
85 87 76 100 89 91 58 64 71 82 76 61 60 60 73 50 53 74 71 81
53 49 35 45 50 62 49 69 85 72 60 70 66 54 54 47 60 42 66 49
47 64 59 58 44 67 55 56 40 43 45 43 50 52 57 51 40 39 39 22
44 59 53 43 49 55 45 37 39 65 82 59 48 58 54 44 52 74 62 72
81 58 64 67 71 67 77 126 122 141 120 76 85 72 111 118
HEX-A10A 103
102 100 91 74 101 106 109 93 77 90 110 106 88 77 98 103 84 72 76 66
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63 60 68 72 57 47 99 184 190 275 307 319 331 156 131 159 295 348 340 263
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302 454 334
HEX-A10B 103
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64 102 98 86 107 101 63 41 63 71 76 64 64 55 51 29 27 27 54 66
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293 494 302
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163 119 92 151 235 212 266 197 195 228 170 76 107 123 208 119 100 91 86 72
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179 155 132 89 93 115 144 128 70 109 118
HEX-A11B 111
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138 154 191 158 142 127 124 86 129 115 106 137 122 113 107 73 102 92 146 115
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74 81 56 68 56 47 42 42 48 56 59 55 43 48 39 49 53 68 76 72
58 57 61 60 59 73 84 57 90 61 67 67 54 104 86 115 112 74 52 59
67 86 107 91
HEX-A15B 104
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54 53 66 57 81 76 78 99 77 83 77 84 74 62 75 63 68 78 98 72
109 78 70 87 71 79 57 54 68 75 78 84 112 120 80 68 56 50 46 50
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159 174 135 75 119 107 102 118 132 120 97 63 62 49 66 75 116 84 61 72
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287 254 193 211 150 167 207 206 177 187
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47 37 40 56 73 120 96 119 129 71 35 61 114 136 150 120 120 141 79 65
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286 277 193 199 166 155 199 203 160 200
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123 153 171 155 56 94 103 105 148 109 83 100 121 138 114 109 74 84 72 67
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124 158 208 184 129 172 174 133 183 167 133 128 100 64 52 50 52 80 78 44
52 35 25 36 31 46 94 98 126 161 59 42 44 81 132 136 109 106 106 66
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252 288
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114 157 205 200 108 175 186 128 178 162 145 135 80 72 50 55 43 87 67 56
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HEX-A19B 97
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62 122 139 139 156 207 105 139 156 173 122 125 121 112 89 130 103 77 85 102
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344 322
HEX-A20B 62
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252 181 182 104 80 83 107 113 129 116 195 157 139 156 180 159 156 134 173 158
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HEX-A29A 106
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HEX-A33B 131
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HEX-A43A 78
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79 116 121 119 236 190 246 172 86 128 93 90 152 241 247 265 220 211

APPENDIX

Tree-Ring Dating

The Principles of Tree-Ring Dating

Tree-ring dating, or *dendrochronology* as it is known, is discussed in some detail in the Laboratory's Monograph, '*An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Building*' (Laxton and Litton 1988) and, *Dendrochronology; Guidelines on Producing and Interpreting Dendrochronological Dates* (English Heritage 1988). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The *width* of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure 1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths for oaks, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of oak timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring.

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

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

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

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

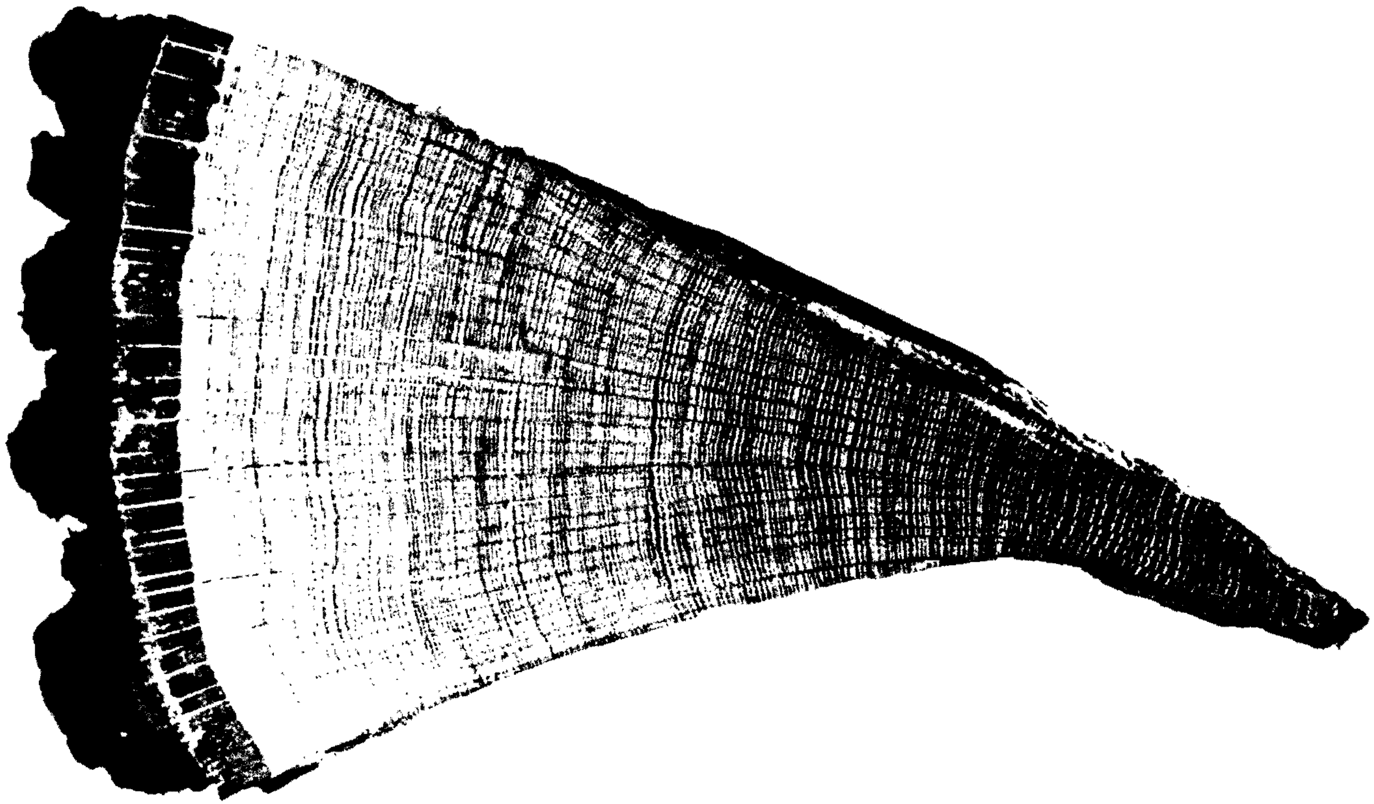


Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can determined by counting back from the outside ring, which grew in 1976.

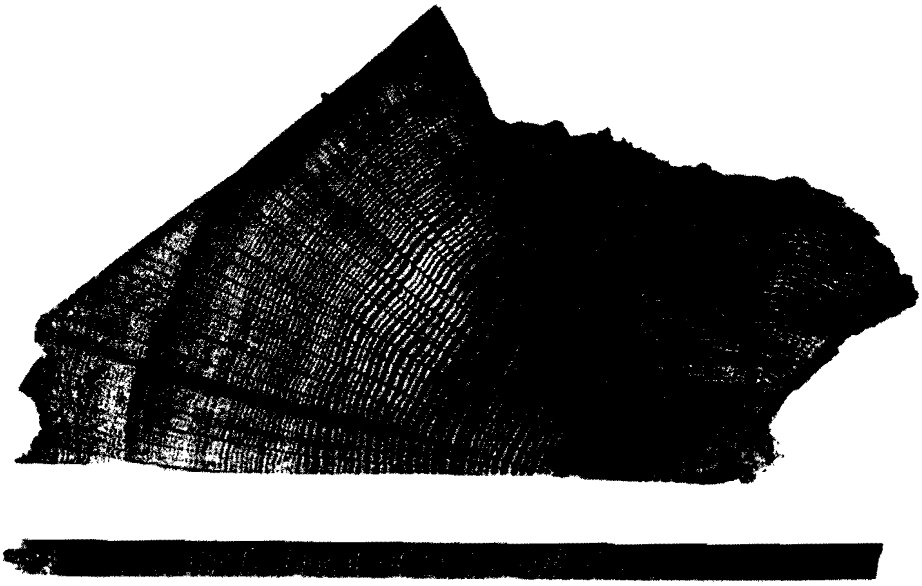


Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the left hand corner, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

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 measure twice to ensure that an error has not been made. This type of apparatus is needed to process a large number of samples on a regular basis.

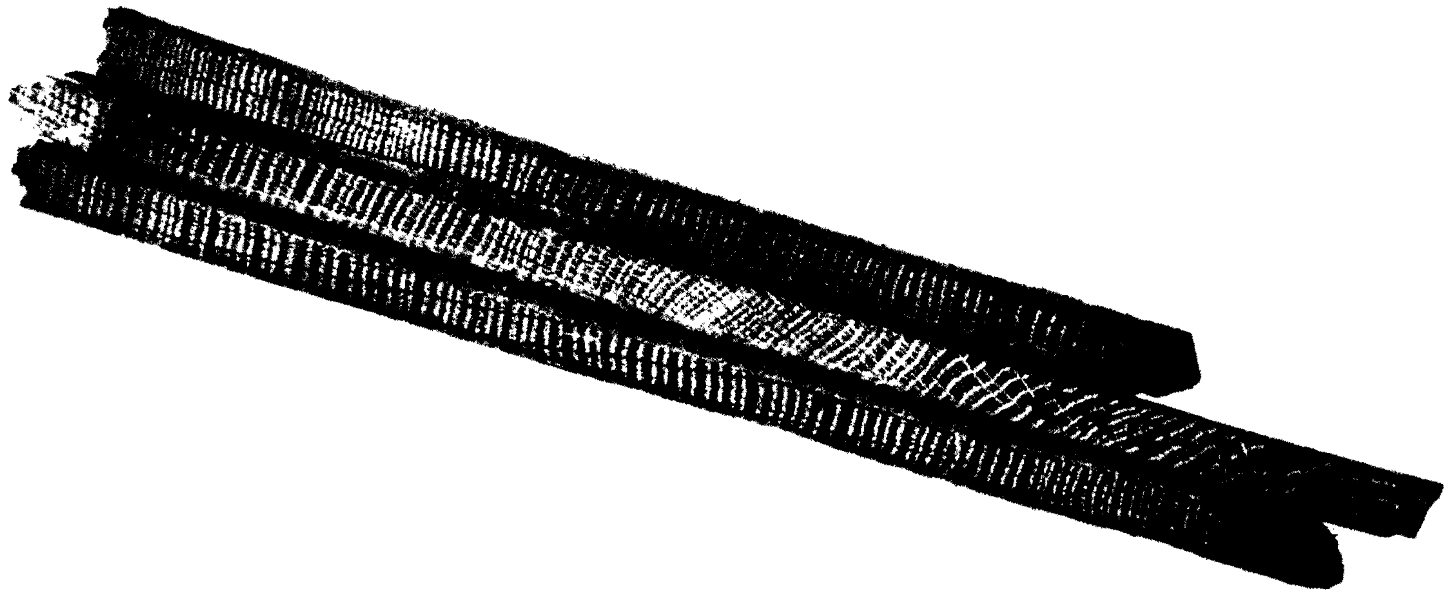


Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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 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.

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

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

This is illustrated in 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 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 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 of the four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. Thus in Fig 5 if the widths shown are 0.8mm for C45, 0.2mm for C08, 0.7mm for C05, and 0.3mm for C04, then the corresponding width of the site sequence is the average of these, 0.55mm. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

The straightforward method of cross-matching several sample sequences with each other one at a time is called the 'maximal *t*-value' method. The actual method of cross-matching a group of sequences of ring-widths used in the Laboratory involves grouping and averaging the ring-width sequences and is called the 'Litton-Zainodin Grouping Procedure'. It is a modification of the straight forward method and was successfully developed and tested in the Laboratory and has been published (Litton and Zainodin 1991; Laxton *et al* 1988).

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

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

Various estimates have been made and used for the average number of sapwood rings in mature oak trees (English Heritage 1998). A fairly conservative range is between 15 and 50 and that this holds for 95% of mature oaks. This means, of course, that in a small number of cases there could be fewer than 15 and more than 50 sapwood rings. For example, the core CRO-A06 has only 9 sapwood rings and some have obviously been lost over time – either they were removed originally by the carpenter and/or they rotted away in the building and/or they were lost in the coring. It is not known exactly how many sapwood rings are missing, but using the above range the Laboratory would estimate between a minimum of 6 (=15-9) and a maximum of 41 (=50-9). If the last ring of CRO-A06 has been dated to 1500, say, then the estimated felling-date range for the tree from which it came originally would be between 1506 and 1541. The Laboratory uses this estimate for sapwood in areas of England where it has no prior information. It also uses it when dealing with samples with very many rings, about 120 to the last heartwood ring. But in other areas of England where the Laboratory has accumulated a number of samples with complete sapwood, that is, no sapwood lost since felling, other estimates in place of the conservative range of 15 to 50 are used. In the East Midlands (Laxton *et al* 2001) and the east to the south down to Kent (Pearson 1995) where it has sampled extensively in the past, the Laboratory uses the shorter estimate of 15 to 35 sapwood rings in 95% of mature oaks growing in these parts. Since the sample CRO-A06 comes from a house in Cropwell Bishop in the East Midlands, a better estimate of sapwood rings lost since felling is between a minimum of 6 (=15-9) and 26 (=35-9) and the felling would be estimated to have taken place between 1506 and 1526, a shorter period than before. (Oak boards quite often come from the Baltic and in these cases the 95% confidence limits for sapwood are 9 to 36 (Howard *et al* 1992, 56)).

Even more precise estimates of the felling date and range can often be obtained using knowledge of a particular case and information gathered at the time of sampling. For example, at the time of sampling the dendrochronologist may have noted that the timber from which the core of Figure 2 was taken still had complete sapwood but that none of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 2 cm, a reasonable estimate can be made of the number of sapwood rings lost, say 12 to 15 rings in this case. By adding on 12 to 15 years to the date of the last ring on the sample a good tight estimate for the range of the felling date can be obtained, which is often better than the 15 to 35 years later we would have estimated without this observation. In the example, the felling is now estimated to *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

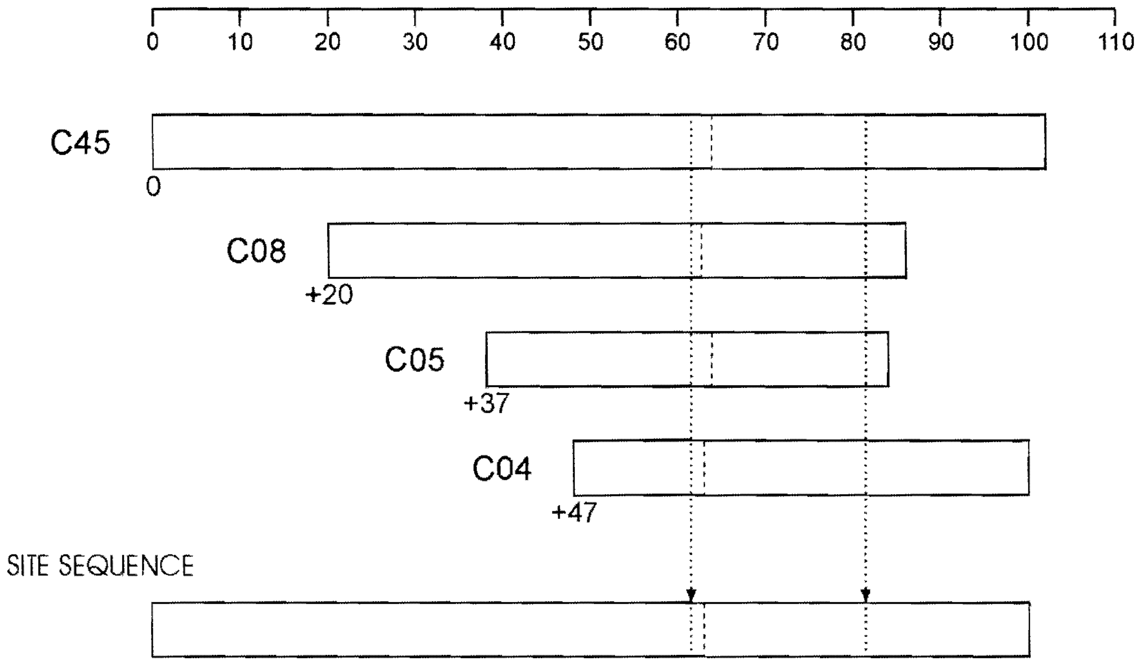


Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

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.

have taken place between AD 1512 and 1515, which is much more precise than without this extra information.

Even if all the sapwood rings are missing on a sample, but none of the heartwood rings are, then an estimate of the felling-date range is possible by adding on the full compliment of, say, 15 to 35 years to the date of the last heartwood ring (called the heartwood/sapwood boundary or transition ring and denoted H/S). Fortunately it is often easy for a trained dendrochronologist to identify this boundary on a timber. If a timber does not have its heartwood/sapwood boundary, then only a *post quem* date for felling is possible.

5. ***Estimating the Date of Construction***. There is a considerable body of evidence collected by dendrochronologists over the years that oak timbers used in buildings were not seasoned in medieval or early modern times (English Heritage 1998 and Miles 1997, 50-55). Hence provided all the samples in a building have estimated felling-date ranges broadly in agreement with each other, so that they appear to have been felled as a group, then this should give an accurate estimate of the period when the structure was built, or soon after (Laxton *et al* 2001, figure 8 and pages 34-5 where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storing before use or if there is evidence the oak came from abroad (eg Baltic boards), then some allowance has to be made for this.

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

7. ***Ring-width Indices***. Tree-ring dating can be done by cross-matching the ring widths themselves, as described above. However, it is advantageous to modify the widths first. Because different trees grow at different rates and because a young oak grows in a different way from an older oak, irrespective of the climate, the widths are first standardized before any matching between them is attempted. These standard widths are known as ring-width indices and were first used in dendrochronology by Baillie and Pilcher (1973). The exact form they take is explained in this paper and in the appendix of Laxton and Litton (1988) and is illustrated in the graphs in Fig 7. Here ring-widths are plotted vertically, one for each year of growth. In the upper sequence of (a), the generally large early growth after 1810 is very apparent as is the smaller later growth from about 1900 onwards when the tree is maturing. A similar phenomena 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.

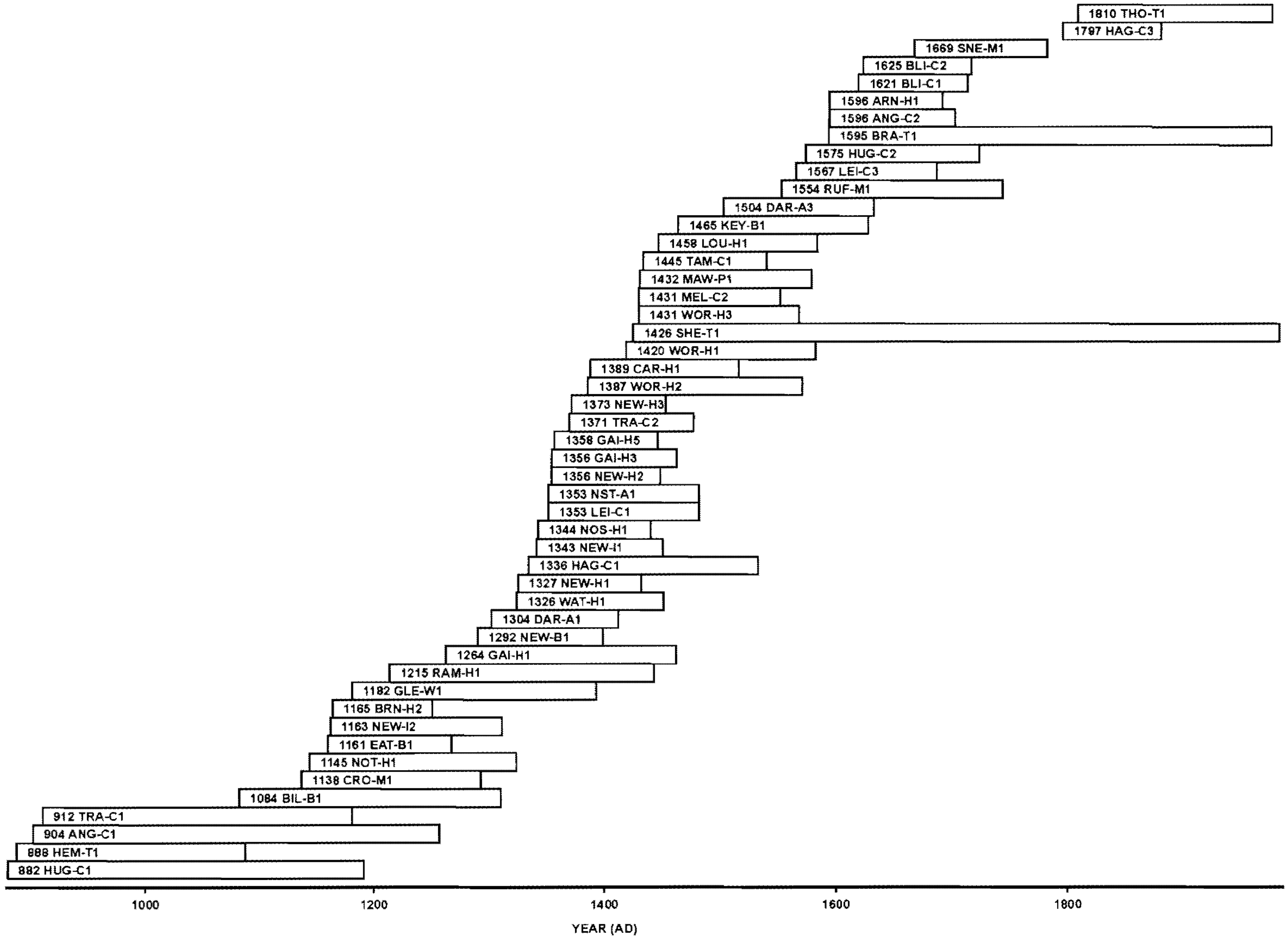
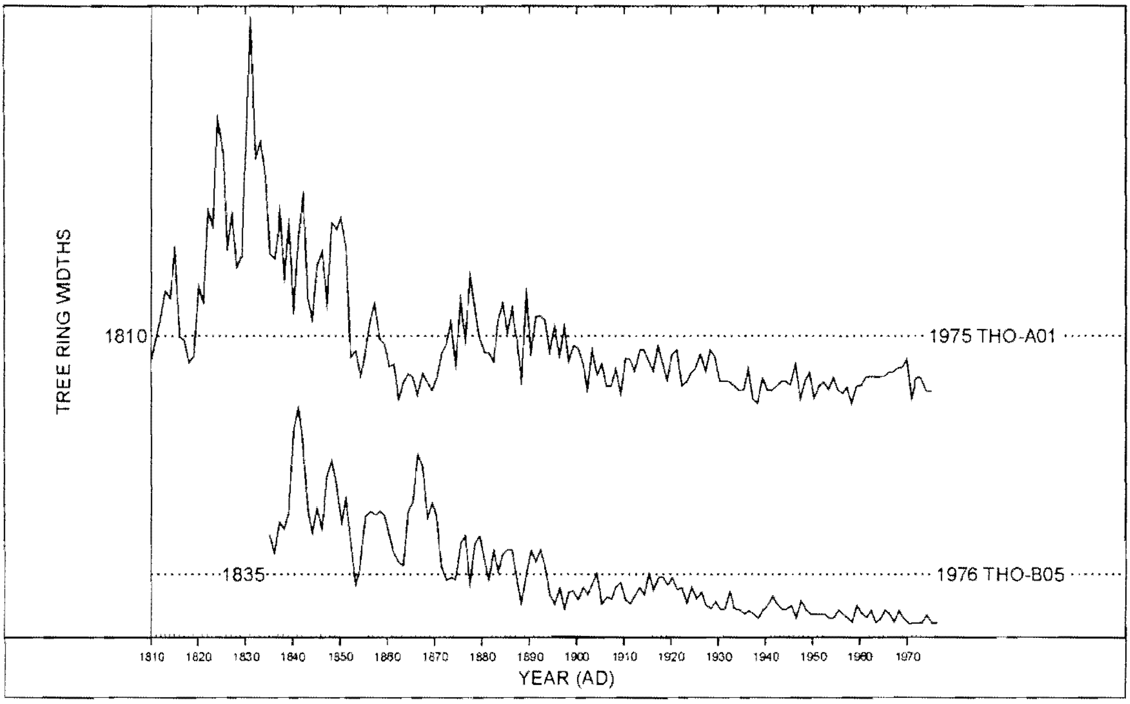


Fig. 6 Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

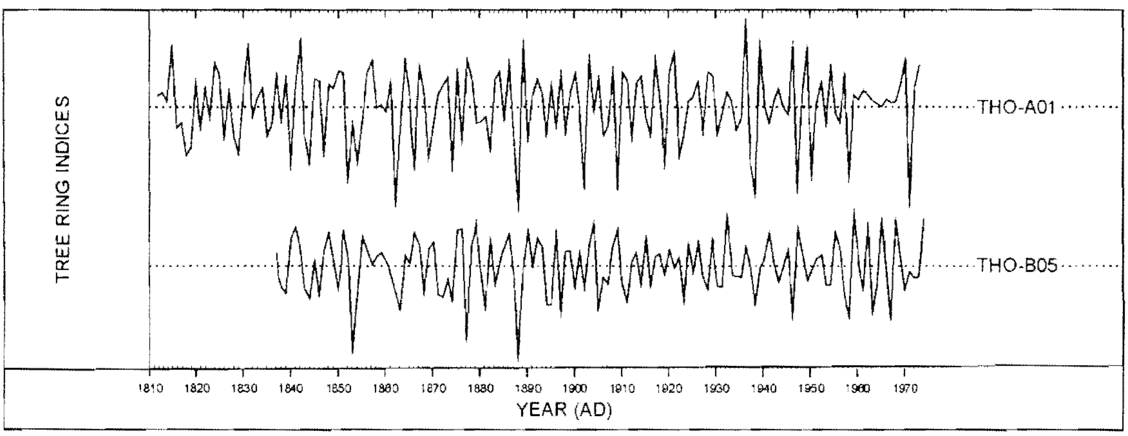


Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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

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

REFERENCES

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

English Heritage, 1998 *Dendrochronology; Guidelines on Producing and Interpreting Dendrochronological Dates*, London

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

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

Laxton, R R, and Litton, C D, 1988 *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, AD 1158 to 1540, *Medieval Archaeol*, **33**, 90-8

Laxon, R R, Litton, C D, and Howard, R E, 2001 *Timber; Dendrochronology of Roof Timbers at Lincoln Cathedral*, English Heritage Research Transactions, **7**

Litton, C D, and Zainodin, H J, 1991 Statistical models of Dendrochronology, *J Archaeol Sci*,**18**, 29-40

Miles, D W H, 1997 The interpretation, presentation and use of tree-ring dates, *Vernacular Architecture*, **28**, 40-56

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

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