Centre for Archaeology Report 96/2001

Tree-Ring Analysis of Timbers from Halton Castle, near Corbridge, Northumberland

R E Howard, 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 96/2001

Tree-Ring Analysis of Timbers from Halton Castle, near Corbridge, Northumberland

R E Howard[1], Dr R R Laxton[2] and Dr C D Litton[2]

Summary

Sixteen samples were obtained from three potential roof phases of the north range of Halton Castle, a potential early fourteenth-century phase, a possible late medieval phase and a sixteenth- or seventeenth-century phase. Only twelve of these samples were analysed, the remaining four samples having too few rings.

This analysis produced two site chronologies. The first site chronology, consisting of eight samples all from the suggested sixteenth- or seventeenth-century phase, has 164 rings spanning the period AD 1396 - AD 1559. Interpretation of the sapwood would indicate that all such timbers were felled in AD 1559.

A second site chronology consisting of three samples from the possible late medieval phase has 79 rings. This site chronology could not be dated.

The remaining single sample, from the potential early fourteenth-century phase, could not be dated either.

The samples from two of the three potential phases have not been dated by dendrochronology. The fact that the three groups of samples fail to cross-match with each other lends some support, albeit weak, to the archaeological interpretation. Certainly the results do not contradict it.

Keywords

Dendrochronology
Standing Building

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

TREE-RING ANALYSIS OF TIMBERS FROM HALTON CASTLE, NEAR CORBRIDGE, NORTHUMBERLAND

Introduction

The present house at Halton Castle is an assemblage of elements of widely differing dates. It stands some 500m south of Hadrian's Wall and about 3.5km north of Corbridge (NY 977678; Fig 1). The site has undergone several interpretations most notably by Borne and Dixon (1978) and more recently by Peter Ryder (1999 unpubl). The older parts of the house are now at the rear of the premises and are T-shaped in plan. They comprise a north range, running east–west, with a short block (the link block) joining it to a four-storey tower to the south. It is believed that the majority of the north range, particularly the western and upper portions, was built *c* AD 1300. (A plan of the site is given in Figure 2).

In this early fourteenth-century form the north range appears to have been the principal part of the house containing a central hall with service rooms to the west and a solar at the eastern end. The lower portions of the eastern end are now represented only by footings and a plinth. This plinth is on a slightly different alignment than the rest of the north range and, having thirteenth-century characteristics, appears earlier than the extant fabric. It is suggested by Peter Ryder that this might indicate that the present hall and solar were pre-dated by some earlier structure which was rebuilt and extended westwards in *c* AD 1300.

It is believed that the tower was built *c* AD 1400. On the east side of the tower is what has been termed the "Mansion" a five-bay two-storeyed block forming, in effect, a self contained house. This part of the house was erected *c* AD 1696. The building has undergone substantial twentieth-century repairs (Fig 2) flowing a fire.

During AD 1997 the attics of the north range, the possible earliest phase of the building, were refurbished and its roof structure temporarily exposed. This allowed for the archaeological recording of the multi-phase timberwork to be undertaken and it is with these roof timbers that this report is concerned. Also in AD 1997 the roof of the tower was repaired more fully exposing the timber-work here too.

Sampling and analysis by tree-ring dating was commissioned by English Heritage in February AD 2001. The purpose of this was to establish if possible a chronology for the development of the site and inform possible future work. Analysis at Halton Castle would also provide information on the wider study of fortified house in Northumberland and with the development of a regional roof typology.

The Laboratory would like to take this opportunity to thank Sir and Lady Hugh Blackett, for allowing sampling, for their help and their enthusiasm for the project. We would also like to thank Peter Ryder for help in the interpretation of the roof and for providing a copy of his survey report, much of which is used here. We would also like to thank Martin Roberts of English Heritage North East Region for arranging access and for assisting during sampling.

The north range roof

The roof structure of the north range is of five bays with four trusses, described here from west to east. A plan of the roof showing the proposed phasing is provided in Figure 3, with the three non-modern trusses being shown individually in Figures 4a-c. Trusses 1 and 2 are of simple principal-rafter form, the principals morticed and pegged at the apex, with slightly arched collars and two levels of purlins to each slope; the lower purlins on each slope are modern replacements. Between trusses 1 and 2 runs a diagonally set ridge-beam. The common rafters in the first two bays were not exposed at the time of sampling, being hidden beneath the modern ceiling. It is believed that trusses 1 and 2 represent what is described in the English Heritage brief as phase 3 timbers, possibly dating to the sixteenth or seventeenth centuries.

The third bay contains three pairs of common-rafter frames with collars (frames 1, 3, and 4 in Figure 3), plus a fourth single rafter to the south side (frame 2), its northern counterpart having been lost some time in the past. The southern rafter of frame 4 is not shown in figure 3 because it has been cut at purlin level and does not exist at the plan level. The feet of the rafters are designated "F" in Figure 3. These common rafters are described as being of heavy flat section and according to the details provided may represent phase 1 timbers, dating to *c* AD 1300.

Truss 3 is believed to be the oldest surviving main truss, and is of truncated principal form with a collar. The tie beam is cambered and has braces to the principals as well as a central upright between tiebeam and collar. The south principal of truss 3 has a backing rafter attached to it, the north principal does not. The purlins and common rafters of bay three were not visible at the time of sampling. According to the details given this represents phase 2 of the roof of the northern range and is believed to be late medieval in date. Roofs such as this are considered a great rarity in Northumberland, especially in a secular context (Roberts *et al* 1999). Although fragmentary, Peter Ryder considers Halton to be potentially one of the earliest in this group.

Bays 4 and 5 again contain double purlins to both slopes, and several pairs of common rafters. All these are modern softwood replacements.

Sampling

All the visible and accessible oak timbers in the roof of the north range were examined as to their suitability for tree-ring analysis. There appeared to be considerable variation between the timbers of the supposed constructional phases. All timbers associated with trusses 1 and 2, that is all possible phase 3 timbers, appeared to have sufficient rings.

The timbers of the common-rafter frames of bay 3, that is the potential phase 1 timbers, all appeared to have very few rings. This made them likely to be unsuitable for analysis by tree-ring dating as any results obtained would be unreliable and highly misleading. However, given the possible antiquity and importance of the building a few of the more promising timbers were sampled.

The timbers of principal truss 3, potential phase 2, appeared marginal, having possibly only just sufficient rings for satisfactory analysis.

The timbers of the tower ceiling were also examined, all be it, due to their height, from a distance. While they do appear to be suitable for analysis by tree-ring dating gaining access to them would require the clearing of the room of furniture and the erection of a scaffolding tower. Given the nature of this part of the building this would require considerable disruption and effort. It was thus not possible to sample them at this time.

Thus, from the timbers available a total of sixteen core samples was taken. Each sample was given the code HTC-A (for Halton Castle, site "A"), and numbered 01 – 16. Eight samples, HTC-A01 – 08, were obtained from trusses 1 and 2, the phase 3 timbers, with a further four samples, HTC-A09 – 12, being taken from the common-rafter frames of bay 3, the phase 1 timbers. Four samples, HTC-A13 – 16, were then obtained from the most suitable timbers of truss 3, the phase 2 timbers. This is a lower number of samples than might usually be taken from a building with this many sections or phases, but was a consequence of the lack of suitable timbers.

The positions of these samples are marked on drawings made by Peter Ryder and provided by English Heritage, reproduced here as Figures 4a-d. Details of the samples are given in Table 1.

Analysis

Each of the sixteen samples was prepared by sanding and polishing. It was seen at this stage that a number of these had indeed too few rings, between 25 – 35, for satisfactory analysis, and they were rejected. Most of these timbers are from the common-rafter frames of bay 3 (phase 1 timbers), with one sample being from truss 3 (phase 2 timbers), see Table 1. The ring-width sequences of the remaining twelve samples were then measured and analysed.

At a minimum *t*-value of 4.5 two groups of samples formed. All eight samples from trusses 1 and 2 cross-matched with each other at relative positions as shown in the bar diagram Figure 5. The growth-ring widths of these eight samples were combined at these relative off-set positions to form HTCASQ01, a site chronology of 164 rings. Site chronology HTCASQ01 was compared with a series of relevant reference chronologies for oak, giving it a first ring date of AD 1396 and a last measured ring date of AD 1559. Evidence for this dating is given in the *t*-values of Table 2.

Two of the samples, HTC-A04 and HTC-A08, in site chronology HTCASQ01 retain complete sapwood, that is, they have the last growth-ring produced by the trees from which they were taken, before they were felled. In each case the last measured complete sapwood ring is the same, AD 1559. Given that the relative positions of the heartwood/sapwood boundaries on all the other samples in site chronology HTCASQ01 are consistent with a group of timbers having a single felling date, it is estimated that AD 1559 is the felling date of all the timbers represented.

The second group to form, at a *t*-value of 4.5, consisted of two samples, HTC-A14 and A16, both from truss 3. If the cross-matching value is reduced to t=4.0, slightly lower than usual minimum value for the Laboratory, but still above the accepted minimum of t=3.5, a third sample from truss 3, HTC-A13, can be combined with the first two. The cross-matching positions of these three samples are shown in Figure 6.

Given that the relative positions of the heartwood/sapwood boundaries on the three samples are consistent with a group of timbers having a single felling date, and that all three samples are from timbers of the same potential phase, the samples were combined at these relative positions to form HTCASQ02, a site chronology of 79 rings. Site chronology HTCASQ02 was compared with a series of relevant reference chronologies for oak but there was no satisfactory cross-matching at any position and these timbers must remain undated.

For the purpose of checking each site sequence was compared with the other, and with the remaining single ungrouped sample, HTC-A09, but there was no further satisfactory cross-matching. Given that sample HTC-A09 has relatively few rings, less than the usual accepted minimum of 54 rings required for reliable analysis, it was not compared individually with the reference chronologies.

Interpretation and conclusion

Analysis by dendrochronology has produced two site chronologies from three potential phases of timber felling. It would appear that the timbers of trusses 1 and 2 (represented by site chronology HTCASQ01) are of a single phase, and that these were all felled in AD 1559. Given that a sixteenth- or seventeenth-century date was proposed for this phase of the roof, such a felling date might be considered slightly earlier than expected.

A second site chronology (HTCASQ02) was created from the timbers of truss 3, for which a late medieval date was proposed. This site chronology cannot be dated and the date for these timbers thus remains unknown. It cannot be shown on the basis of tree-ring analysis alone that this phase of timber is different to that of the timbers from trusses 1 and 2, or indeed the common rafter frames of bay 3. However, the lack of cross-matching between samples from them may be considered weak evidence supporting the archaeological interpretation that three phases of construction are represented in the timbers of the north range roof.

The tree-ring analysis would certainly support the view that each of the three timbers in truss 3 represented by this site chronology are of a similar source and date. Indeed, the exceptionally high *t*-values between some of the eight samples HTC-A01 – A08, and between A14 and A16 suggests that they may be from trees growing adjacent to each other in the same woods and that some timbers may be from the same tree. Should work be undertaken on the ceiling or roof of the tower at any time in the future it would certainly be worth having a closer inspection of the timbers.

Bibliography

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

Borne, P, and Dixon, P, 1978 Halton Castle Reconsidered, *Archaeologia Aeliana,* 5 ser, **VI**, 131-9

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1991 List 29 nos 2a, 10 - 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, 1992 List 47 no 3 - 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, 1994 List 57 no 3 - Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect*, **25**, 36 – 40

Howard, R E, Laxton, R R, and Litton, C D, Nottingham University, Roberts, M, North East Vernacular Architecture Group, 1996 List 67 no 1 - Nottingham University Tree-Ring Dating Laboratory: Buildings of the religious estates in medieval Durham; dendrochronological survey, 1994 - 5, *Vernacular Architect*, **27**, 85 – 6

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**

Roberts, M, North East Vernacular Architecture Group, Laxton, R, Howard, R, and Litton, C, Nottingham University Tree-Ring Dating Laboratory, 1999 The Buildings of the religious estates in Medieval Durham, *Durham Archaeol J* **14/15**, 141-60

Ryder, P, 1999 unpubl *Halton Castle: some archaeological/structural observations*

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 samples from Halton Castle, near Corbridge, Northumberland

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Phase 3 timbers					
HTC-A01	South principal rafter, truss 1	107	h/s	AD 1428	AD 1534	AD 1534
HTC-A02	North principal rafter, truss 1	83	16	AD 1468	AD 1534	AD 1550
HTC-A03	Collar, truss 1	76	h/s	AD 1444	AD 1519	AD 1519
HTC-A04	North purlin, truss 1 – west gable	150	34C	AD 1410	AD 1525	AD 1559
HTC-A05	South principal rafter, truss 2	118	10	AD 1408	AD 1515	AD 1525
HTC-A06	North principal rafter, truss 2	92	16	AD 1451	AD 1526	AD 1542
HTC-A07	Collar, truss 2	128	h/s	AD 1396	AD 1523	AD 1523
HTC-A08	South purlin, truss 1 – 2	156	34C	AD 1404	AD 1525	AD 1559
	Phase 1 timbers					
HTC-A09	South common rafter, frame 2	50	5	------	------	------
HTC-A10	South common rafter, frame 3	nm	--	------	------	------
HTC-A11	Collar, frame 3	nm	--	------	------	------
HTC-A12	Collar, frame 4	nm	--	------	------	------
	Phase 2 timbers					
HTC-A13	North principal rafter, truss 3	57	13	------	------	------
HTC-A14	South backing rafter, truss 3	77	11	------	------	------
HTC-A15	Collar, truss 3	nm	--	------	------	------
HTC-A16	South principal rafter, truss 3	56	12	------	------	------

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

Table 2: Results of the cross-matching of site chronology HTCASQ01 and relevant reference chronologies when first ring date is AD 1396 and last ring date is AD 1559

Reference chronology	Span of chronology	t-value	
East Midlands	AD 882 – 1981	5.9	(Laxton and Litton 1988)
England	AD 401 – 1981	7.2	(Baillie and Pilcher 1982 unpubl)
Wales and West Midlands	AD 1341 – 1636	6.8	(Siebenlist-Kerner 1978)
Nether Levens Hall, Cumbria	AD 1395 – 1541	6.8	(Howard *et al* 1991)
35 The Close, Newcastle	AD 1365 – 1513	6.7	(Howard *et al* 1991)
1-2 The College, Durham	AD 1364 – 1531	8.5	(Howard *et al* 1992)
Escomb Church, Co Durham	AD 1398 – 1469	6.8	(Howard *et al* 1994)
Kepier Hospital, Durham	AD 1304 – 1522	5.4	(Howard *et al* 1996)

Figure 1: Map to show general location of Halton Castle

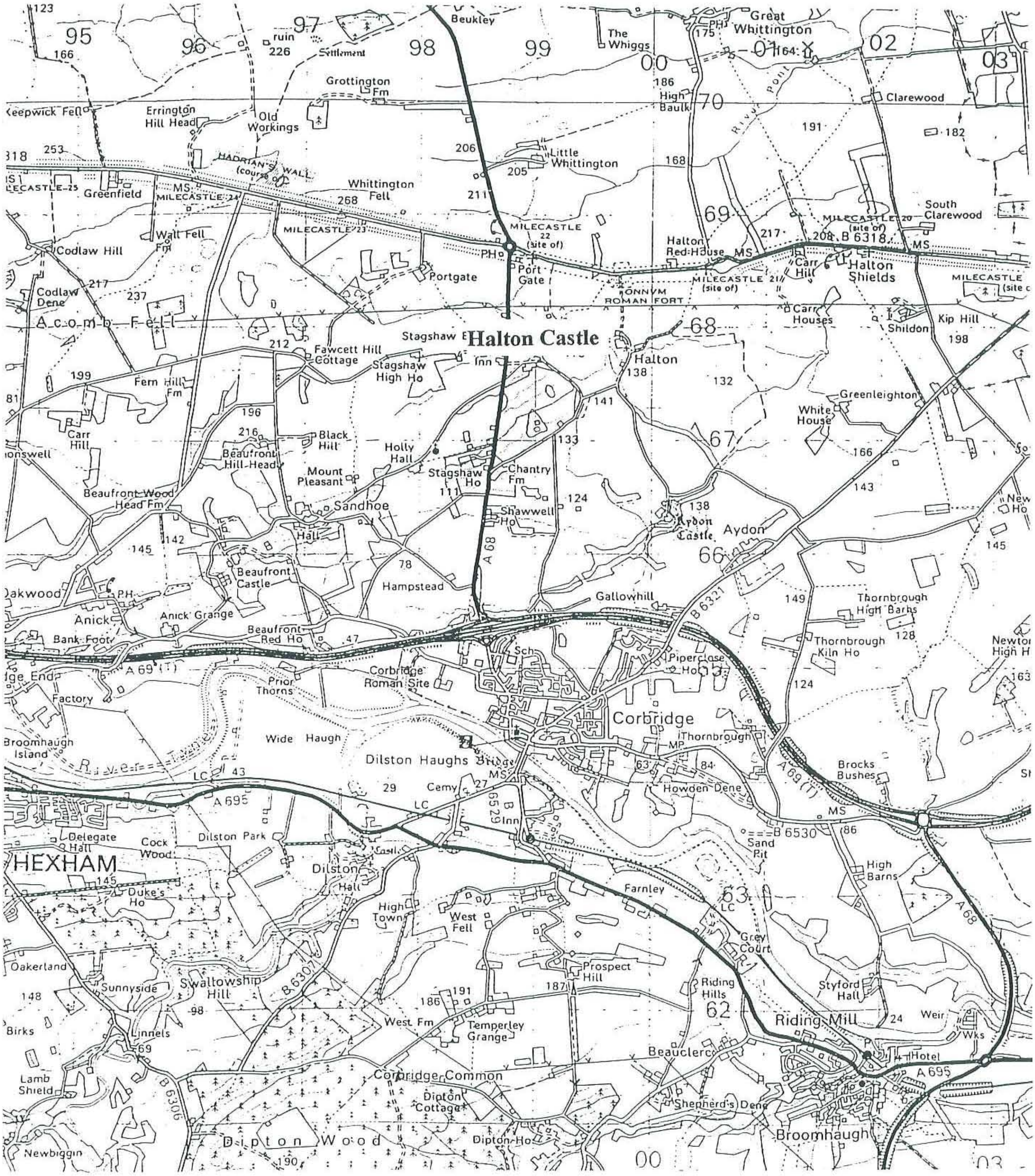


Figure 2: Plan of Halton Castle showing proposed phases (after Borne and Dixon (1978) amended)

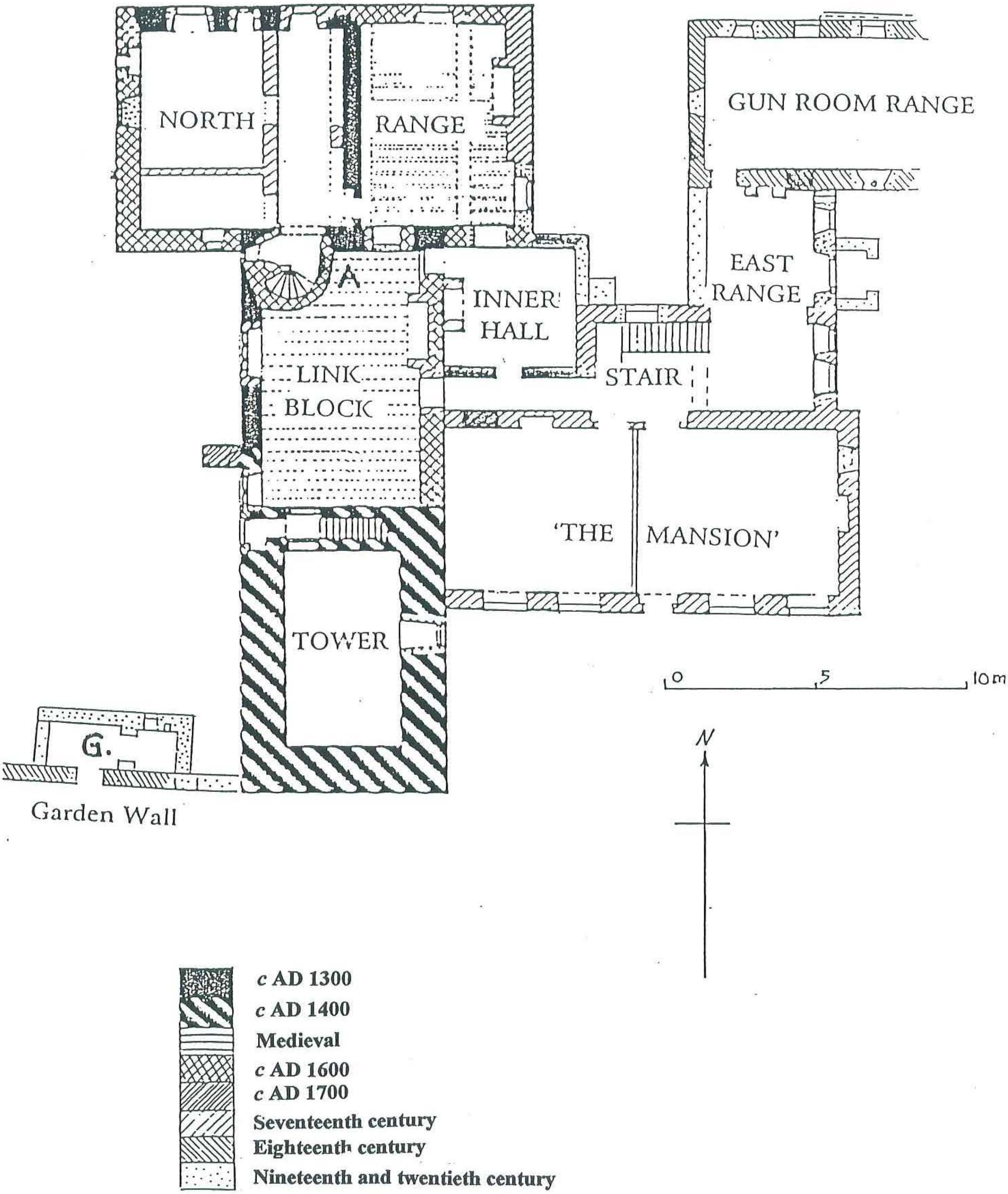


Figure 3: Plan of the timbers of the north range roof with suggested phases (after Ryder 1999 unpubl)

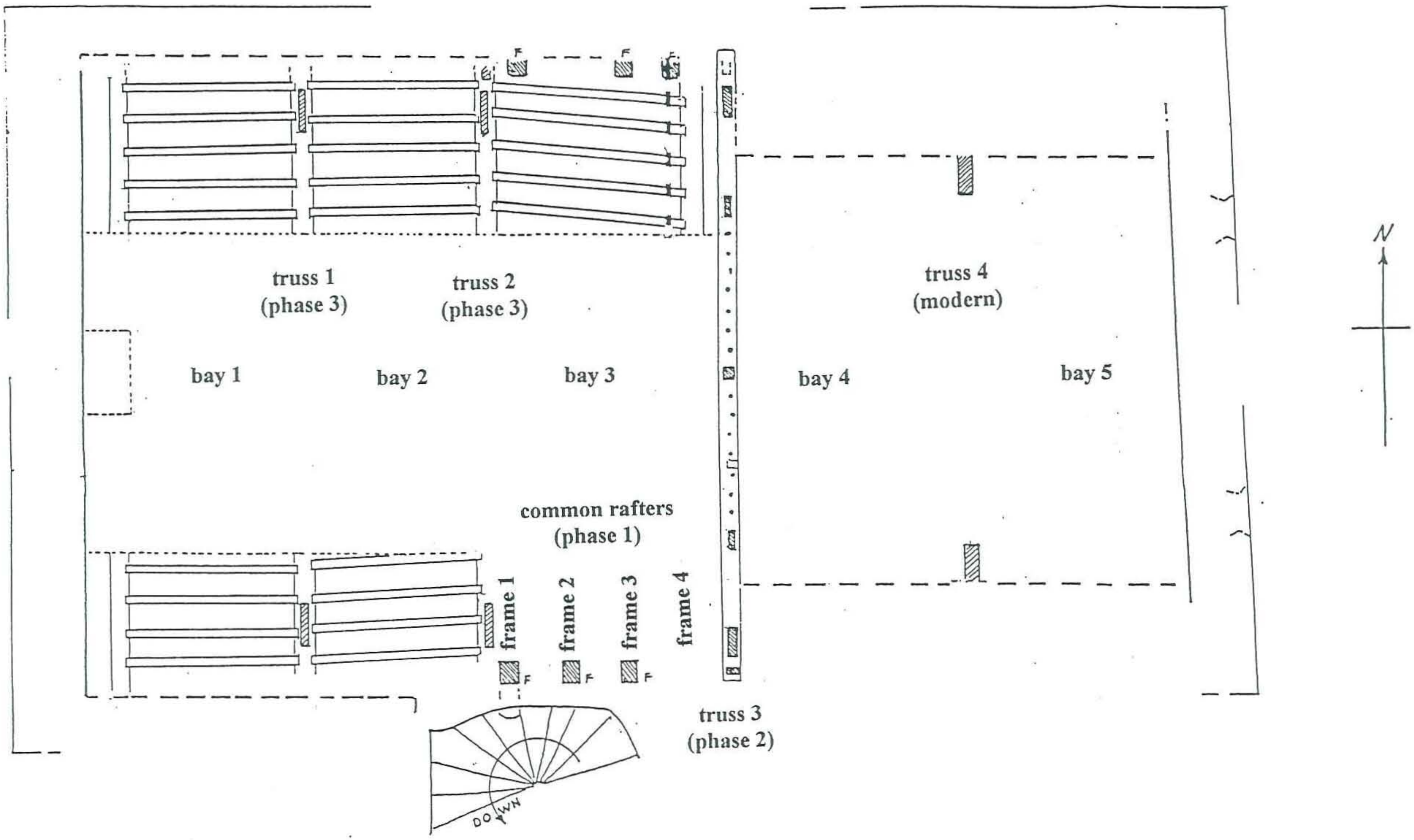


Figure 4a: Truss 1 showing sample locations (viewed from the west)

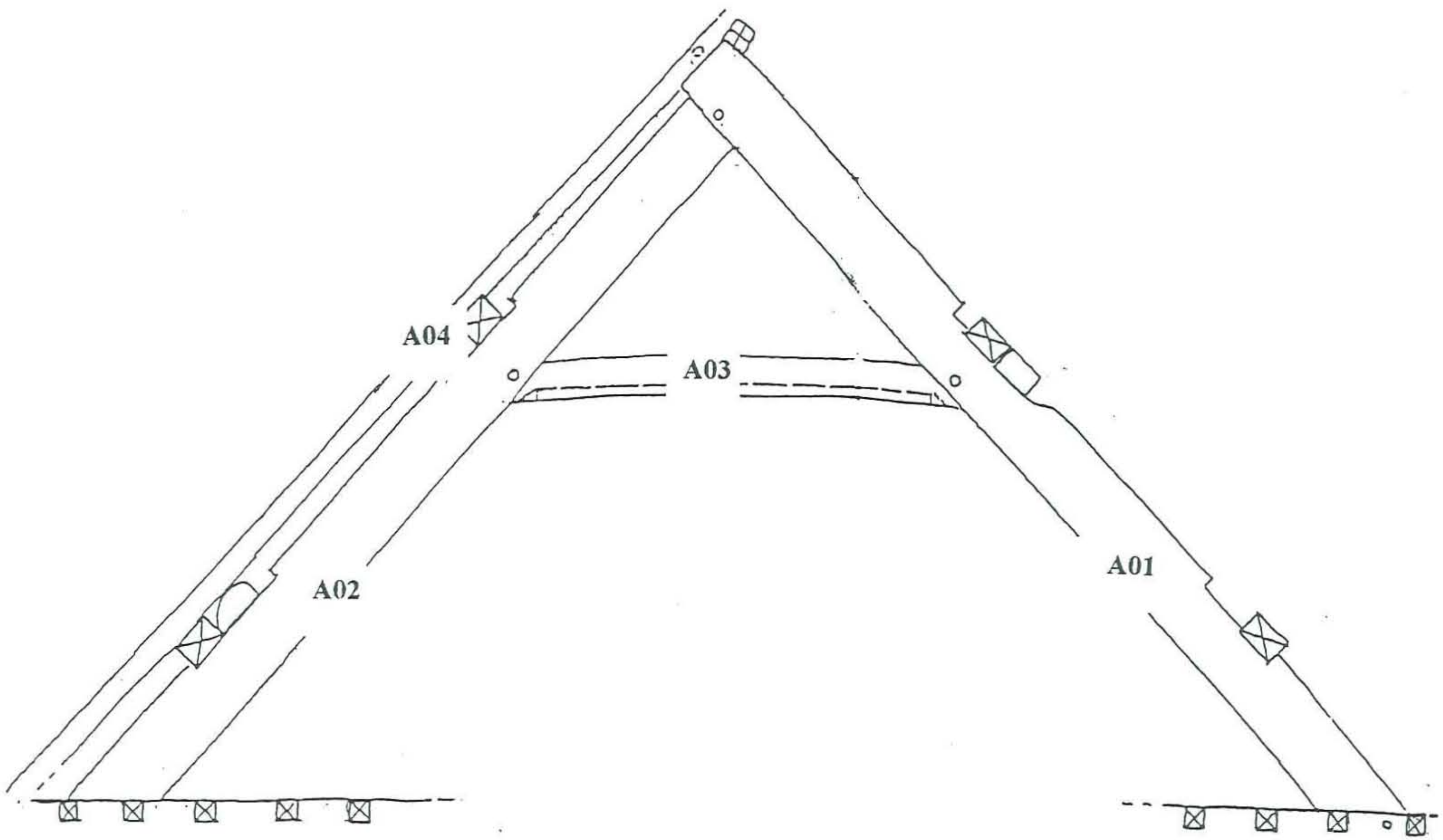


Figure 4b: Truss 2 showing sample locations (viewed from the west)

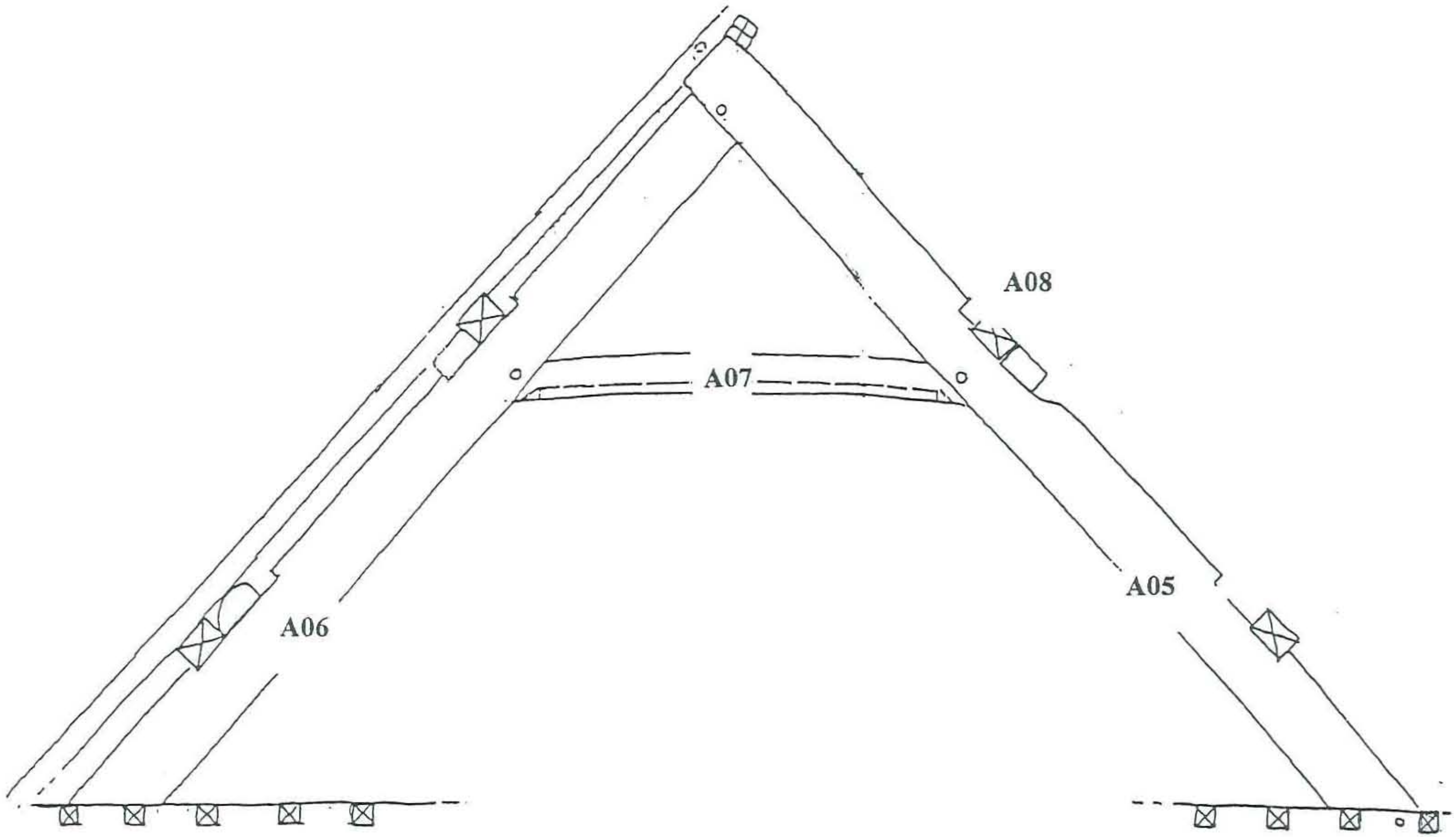


Figure 4c: Truss 3 showing sample locations (viewed from the west)

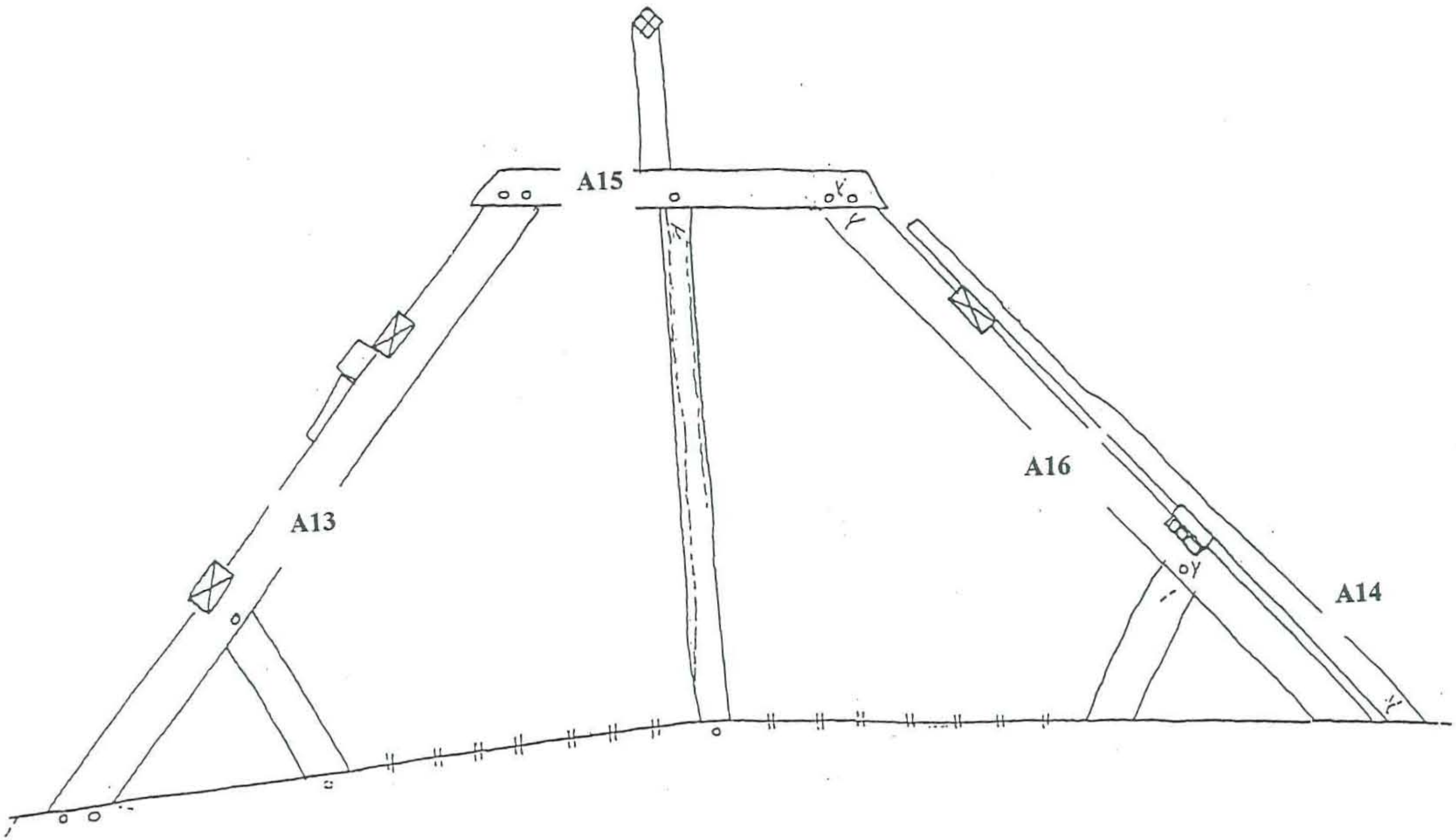


Figure 4d: Drawing to show location of samples from the common rafter frames

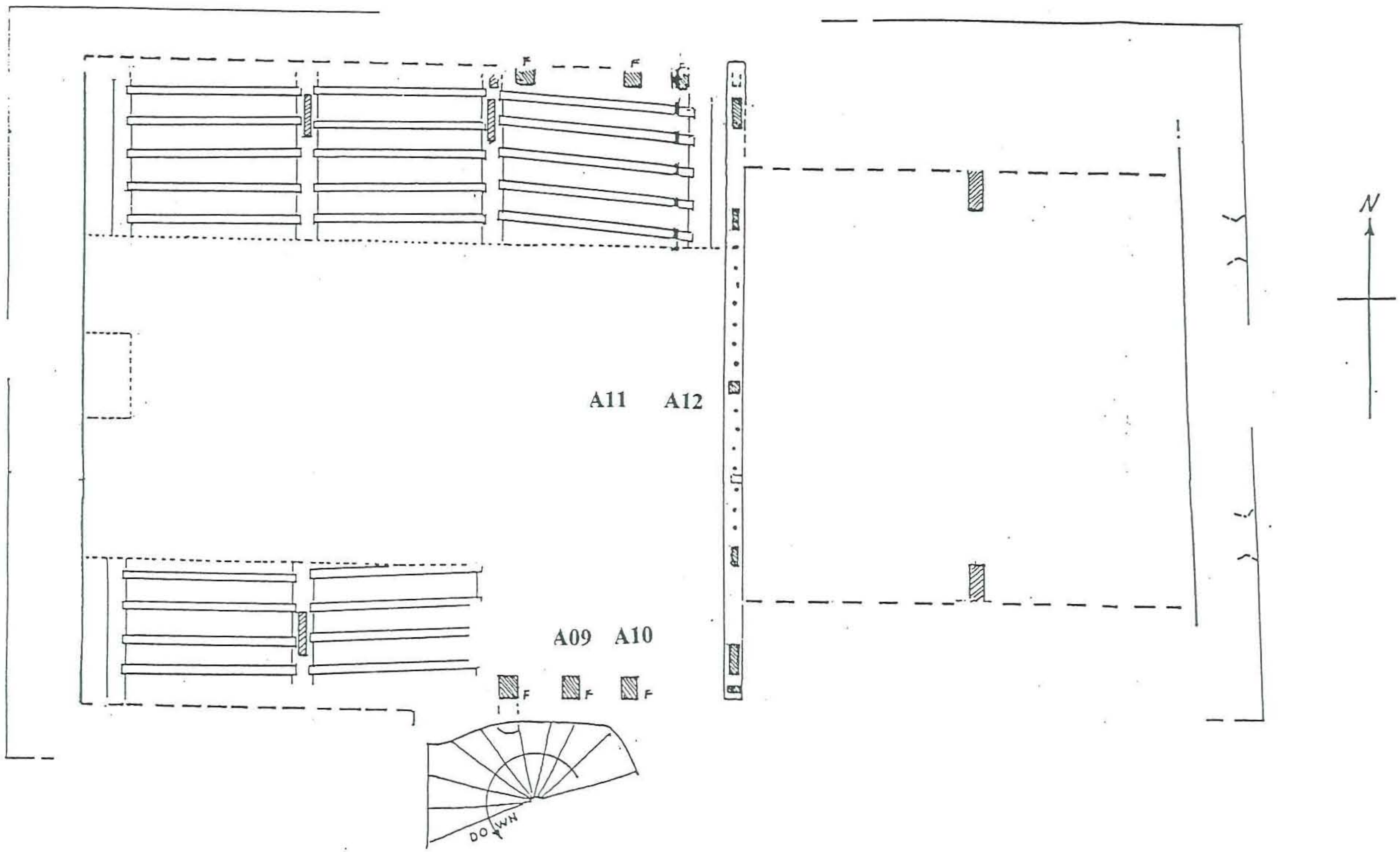
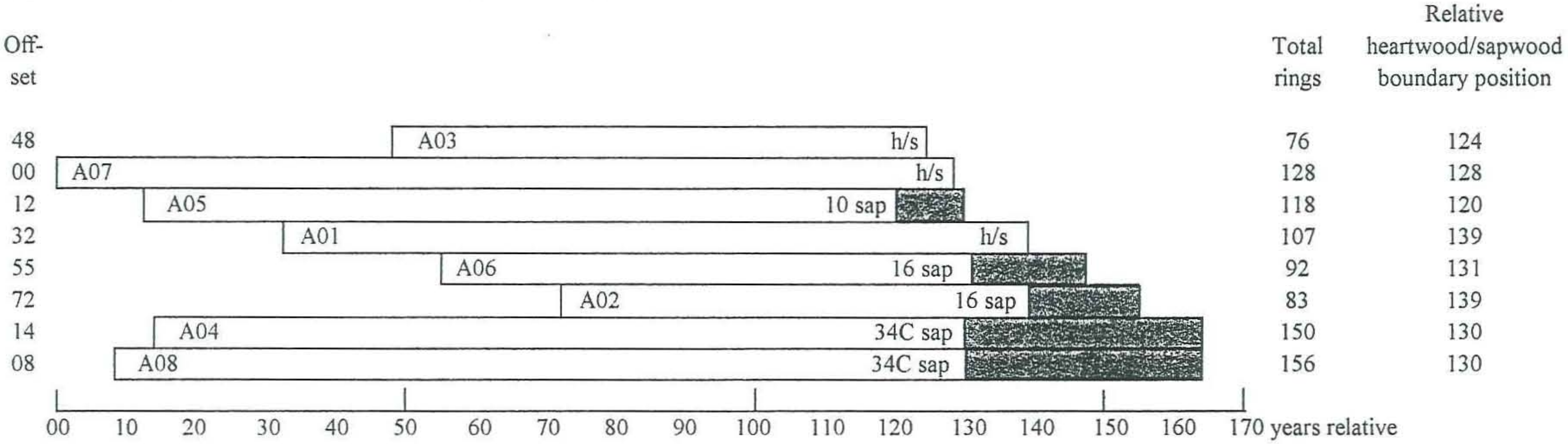
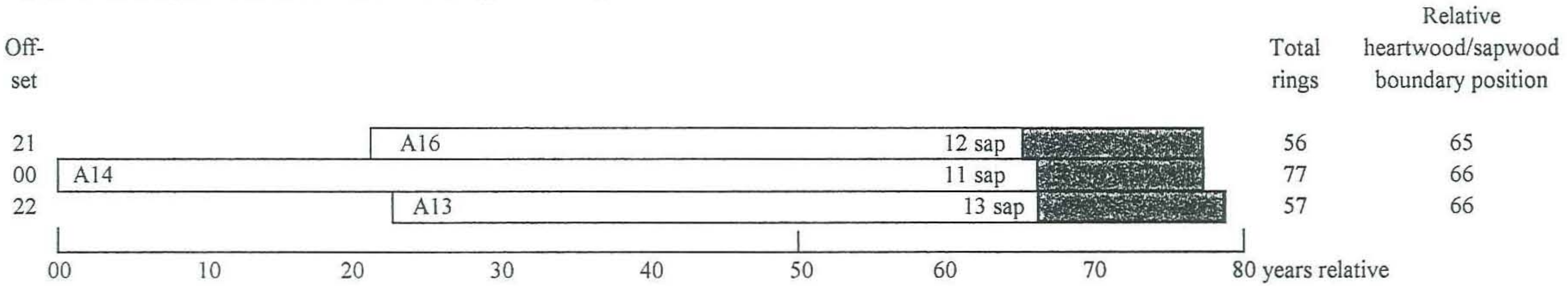


Figure 5: Bar diagram of samples in site chronology HTCASQ01



White bars = heartwood rings, shaded areas = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample
C = complete sapwood retained on the sample

Figure 6: Bar diagram of samples in site chronology HTCASQ02



White bars = heartwood rings, shaded areas = sapwood rings

Data of measured samples – measurements in 0.01 mm units

HTC-A01A 107
422 363 328 264 369 276 408 346 321 361 348 212 275 269 232 228 301 289 212 217
188 209 179 237 245 230 249 182 227 302 204 193 179 195 182 165 154 169 186 248
242 162 154 181 137 73 61 99 148 192 135 118 184 162 115 141 138 146 182 215
166 135 134 105 85 89 78 21 29 39 38 55 48 37 24 51 81 87 69 77
83 108 92 99 85 83 92 94 118 121 115 122 94 98 119 108 149 167 141 124
125 95 132 109 114 110 149
HTC-A01B 107
326 384 335 291 362 269 423 336 340 364 348 215 274 261 230 236 317 292 205 215
191 207 182 243 235 244 242 188 221 296 209 214 201 176 198 155 148 175 180 248
233 159 162 164 135 72 63 105 144 167 141 135 164 154 135 134 136 146 168 217
155 146 119 101 96 88 79 24 31 43 43 56 52 37 32 43 86 87 72 81
81 102 103 95 88 80 91 103 119 107 115 116 96 101 113 103 131 179 146 124
118 111 125 116 117 112 142
HTC-A02A 83
252 213 280 293 142 100 84 159 245 209 185 161 187 212 207 229 204 209 196 306
193 180 200 137 119 91 82 49 56 46 51 67 55 34 34 42 54 61 64 57
47 71 65 70 73 72 75 81 92 89 77 114 90 100 114 80 141 182 138 126
112 131 118 130 131 124 122 168 170 220 88 160 199 147 122 96 122 119 80 110
106 165 195
HTC-A02B 83
276 214 276 291 164 91 83 163 231 214 201 169 173 209 215 241 205 207 203 323
201 174 192 135 124 90 80 56 53 55 45 59 51 38 36 42 63 62 60 62
65 73 64 72 66 71 76 80 87 97 100 106 91 107 102 96 127 155 145 122
115 126 121 118 135 114 125 155 163 187 129 172 189 157 108 157 138 102 72 104
128 175 165
HTC-A03A 76
206 190 138 155 174 151 91 108 124 124 107 108 103 119 102 106 128 134 131 119
93 114 141 136 149 141 114 92 83 66 43 119 126 118 70 104 69 117 116 79
75 57 67 65 64 49 54 41 50 59 44 70 45 83 46 81 73 68 66 73
95 69 60 67 72 77 70 67 74 70 72 83 89 77 86 75
HTC-A03B 76
211 190 136 155 178 150 99 99 127 128 112 99 105 125 110 104 123 133 125 112
94 112 147 137 142 148 109 113 69 74 52 112 132 116 73 99 66 129 112 90
72 56 77 54 67 50 61 39 47 50 55 63 41 78 58 79 71 73 65 76
95 69 64 67 69 71 71 72 64 78 74 80 91 79 84 89
HTC-A04A 150
167 142 172 200 150 157 149 207 223 148 220 177 181 157 190 155 184 171 170 255
197 150 212 157 178 177 170 149 170 123 129 148 151 163 205 208 159 100 111 114
113 118 131 115 133 97 102 85 72 88 101 99 99 104 94 80 88 122 118 82
99 99 45 29 26 19 32 42 38 49 47 65 48 56 61 42 61 83 66 52
66 53 63 46 45 55 60 71 57 54 48 24 28 32 41 44 40 36 28 40
29 28 28 23 34 32 49 35 37 45 35 36 28 26 22 27 37 33 31 23
19 23 30 37 34 38 31 48 28 40 43 43 36 41 47 49 40 46 61 42
48 69 69 64 48 101 63 68 71 119

HTC-A04B 150
179 138 153 172 148 145 210 194 207 139 241 171 181 158 201 184 181 154 182 244
188 153 210 161 173 182 168 154 164 123 131 145 143 151 199 202 160 97 117 112
114 110 131 123 134 95 100 74 69 94 108 95 106 95 93 93 94 124 127 80
97 116 41 27 26 17 38 38 35 52 47 62 55 53 60 42 61 82 67 52
64 52 66 48 43 49 64 69 61 52 46 31 19 32 42 44 43 28 30 48
32 26 24 24 36 30 47 32 33 45 31 35 30 24 24 27 41 27 32 25
21 21 32 35 33 32 39 45 35 35 43 45 36 42 46 42 47 48 61 45
61 62 66 68 47 90 76 62 73 118
HTC-A05A 118
136 237 208 146 118 87 96 175 119 143 164 167 305 254 270 365 307 409 339 414
323 332 324 264 357 319 425 355 331 344 299 224 277 298 218 284 323 274 214 168
244 205 181 211 267 286 251 154 246 265 180 192 182 207 244 184 148 180 210 276
278 203 195 240 153 108 88 118 189 153 163 139 199 190 159 167 169 172 160 215
163 147 143 122 100 104 96 33 43 43 39 40 55 37 39 51 71 77 65 61
75 86 78 71 65 78 86 98 125 111 102 122 104 102 120 87 147 172
HTC-A05B 118
148 256 227 166 122 93 102 179 125 145 166 159 311 252 264 356 322 410 354 408
319 333 314 273 358 314 422 362 331 341 300 223 275 301 216 285 316 285 208 172
234 207 176 216 267 284 254 154 233 281 187 191 175 211 249 174 158 187 199 273
275 221 181 243 151 102 90 116 187 163 155 137 211 180 168 162 171 170 161 216
161 146 142 121 102 107 93 32 40 43 39 43 55 44 35 49 77 73 64 56
85 88 71 73 69 72 84 96 126 115 98 130 105 99 120 85 131 196
HTC-A06A 92
286 378 357 337 212 346 300 248 280 240 269 281 227 207 193 246 315 232 175 211
210 127 83 71 128 178 151 144 129 147 173 181 191 172 173 158 221 156 163 173
107 84 82 75 43 43 46 44 47 53 38 33 51 58 79 64 63 69 87 79
89 81 83 85 101 102 101 113 125 101 107 115 94 136 158 139 123 96 120 111
116 105 113 102 116 127 122 109 120 135 123 149
HTC-A06B 92
286 375 319 342 219 335 300 274 250 204 264 287 211 210 200 252 281 252 182 213
209 125 79 81 119 175 159 133 134 143 187 183 193 163 170 165 225 154 162 152
101 81 84 76 42 46 38 46 50 57 33 35 45 67 68 69 66 63 86 84
84 81 71 92 98 93 94 111 112 105 107 113 88 141 160 144 113 103 118 105
118 107 109 107 115 119 135 93 128 137 119 147
HTC-A07A 128
176 193 273 174 239 238 179 237 208 190 201 165 160 119 93 146 139 77 100 112
120 113 107 109 156 125 121 93 99 117 112 121 180 198 175 186 214 147 181 185
130 109 159 138 192 168 116 162 164 173 122 136 135 123 96 78 98 82 80 79
71 68 57 55 49 58 65 44 60 73 61 97 115 74 60 61 55 67 49 78
84 99 84 70 69 91 88 97 71 61 96 96 85 91 78 67 51 52 64 76
79 74 75 99 67 48 64 53 200 176 88 77 78 63 42 46 47 50 42 52
50 45 40 44 35 35 37 50
HTC-A07B 128
167 234 275 177 239 226 188 234 201 179 174 162 176 120 108 131 133 71 106 116
119 103 124 87 150 122 128 87 100 102 123 121 189 187 175 162 192 140 178 170
137 114 158 126 194 161 112 156 177 167 120 142 143 107 93 71 97 81 72 80
71 67 51 52 52 62 58 46 65 54 75 103 109 79 52 68 57 68 46 80
74 108 77 62 75 90 86 94 66 69 89 96 76 81 76 65 57 66 58 63
79 70 79 91 68 58 62 49 197 185 89 79 80 73 44 45 43 50 50 42
48 45 40 45 43 30 38 48

HTC-A08A 156
227 216 196 154 164 149 189 147 166 184 174 193 170 212 221 140 230 116 165 155
175 162 141 104 148 219 145 132 170 163 142 141 114 140 134 97 118 136 86 98
126 142 102 80 85 95 65 79 112 126 122 103 105 91 59 76 82 74 76 52
44 62 59 76 85 51 67 64 37 34 37 54 71 70 61 68 75 82 70 65
80 81 103 131 100 92 103 97 118 86 63 107 133 115 110 94 75 44 40 41
50 77 60 62 80 74 60 66 60 62 67 60 67 58 56 73 59 55 51 48
45 43 63 69 56 47 40 50 47 46 52 39 65 57 44 59 62 65 58 62
62 53 57 36 57 63 48 70 42 57 57 66 67 55 62 73
HTC-A08B 156
253 216 201 167 164 153 186 141 157 201 190 189 185 204 227 135 212 132 172 178
159 141 150 120 144 206 145 151 182 144 141 144 129 139 127 110 118 141 93 86
128 146 101 80 78 97 73 75 106 131 141 105 101 90 74 67 80 76 67 47
53 52 66 72 90 58 60 62 40 38 32 50 70 68 56 65 86 85 67 81
70 74 102 126 92 87 103 96 116 90 69 96 124 116 108 91 76 40 40 45
56 72 63 71 72 83 61 60 69 63 59 62 65 68 55 68 58 62 49 43
44 45 59 63 60 48 37 46 48 52 58 40 56 63 41 56 67 66 48 66
57 55 47 55 59 62 56 56 46 58 53 65 59 50 64 83
HTC-A09A 50
451 487 318 285 364 303 270 241 355 346 253 224 289 286 256 381 393 342 254 244
249 243 196 175 216 205 199 204 226 189 164 165 91 124 127 181 123 152 181 118
128 151 175 223 206 208 163 180 263 229
HTC-A09B 50
419 486 328 279 362 298 274 245 348 402 264 218 278 285 251 370 401 317 265 238
261 243 199 180 225 202 188 213 226 199 149 165 134 135 130 186 150 136 186 111
126 146 176 179 209 193 178 185 180 133
HTC-A13A 57
284 309 297 260 337 275 151 101 125 152 129 141 243 271 250 211 193 193 183 179
167 175 219 263 259 316 245 286 238 216 134 88 141 184 251 289 209 209 225 231
220 222 209 269 266 258 264 206 236 218 195 158 159 193 211 178 231
HTC-A13B 57
300 308 291 257 346 274 148 100 124 158 121 142 246 285 246 198 191 195 173 178
162 182 202 264 266 306 242 290 221 204 127 90 144 195 249 292 206 221 217 246
222 230 218 267 281 259 267 200 224 217 198 167 161 195 209 170 213
HTC-A14A 77
396 223 147 199 218 215 179 282 197 252 248 340 343 320 350 234 300 295 275 263
363 278 279 287 299 228 209 204 189 175 210 261 156 273 280 264 231 168 198 162
156 166 203 141 112 148 172 183 229 161 202 239 116 86 148 193 263 219 203 204
218 212 250 249 254 385 320 193 265 283 323 285 208 157 120 155 210
HTC-A14B 77
377 227 143 200 224 219 193 267 187 253 246 320 339 342 353 226 324 289 275 275
369 301 280 291 285 214 215 217 184 191 241 287 156 274 280 260 233 167 187 174
151 181 204 150 111 143 183 181 224 163 212 227 116 91 152 178 279 213 206 201
216 211 247 249 252 366 304 204 268 260 320 297 226 166 137 165 202
HTC-A16A 56
184 326 332 323 298 325 288 194 139 180 219 201 164 236 314 261 257 279 247 235
175 164 201 228 226 251 242 219 234 191 171 104 69 125 141 217 246 152 166 165
153 181 192 168 271 255 222 241 206 253 214 181 172 160 177 244

HTC-A16B 56
200 341 340 315 300 329 290 191 149 174 229 208 173 234 250 258 261 275 239 259
200 175 204 227 226 247 224 237 236 194 169 108 70 131 140 214 246 156 148 162
180 174 205 178 241 263 222 234 203 260 217 173 169 154 177 231

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.

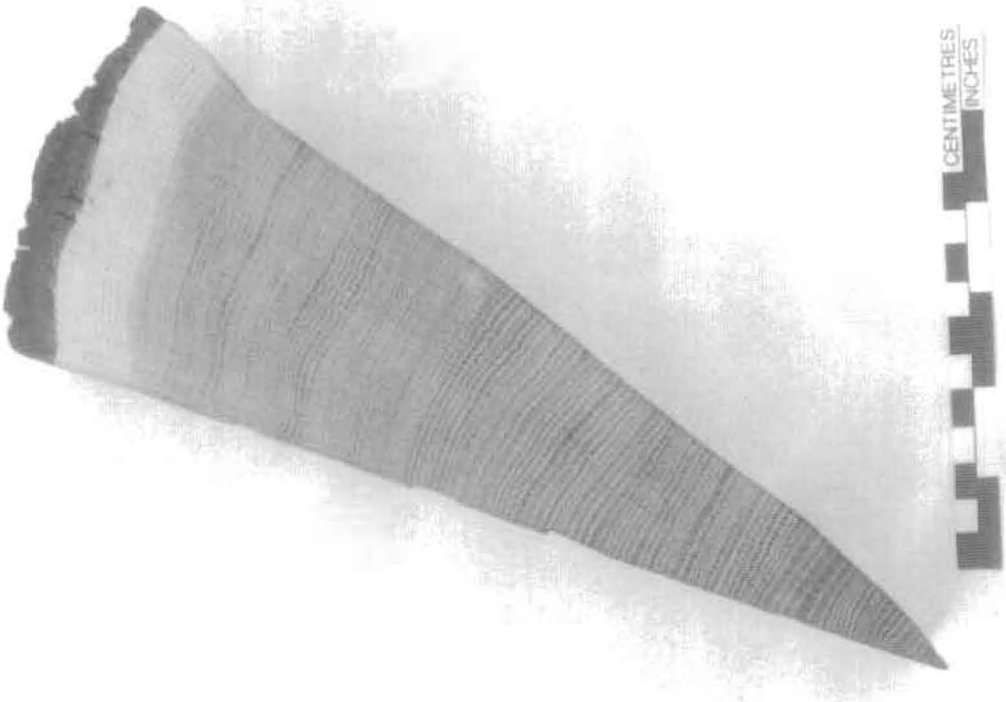


Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

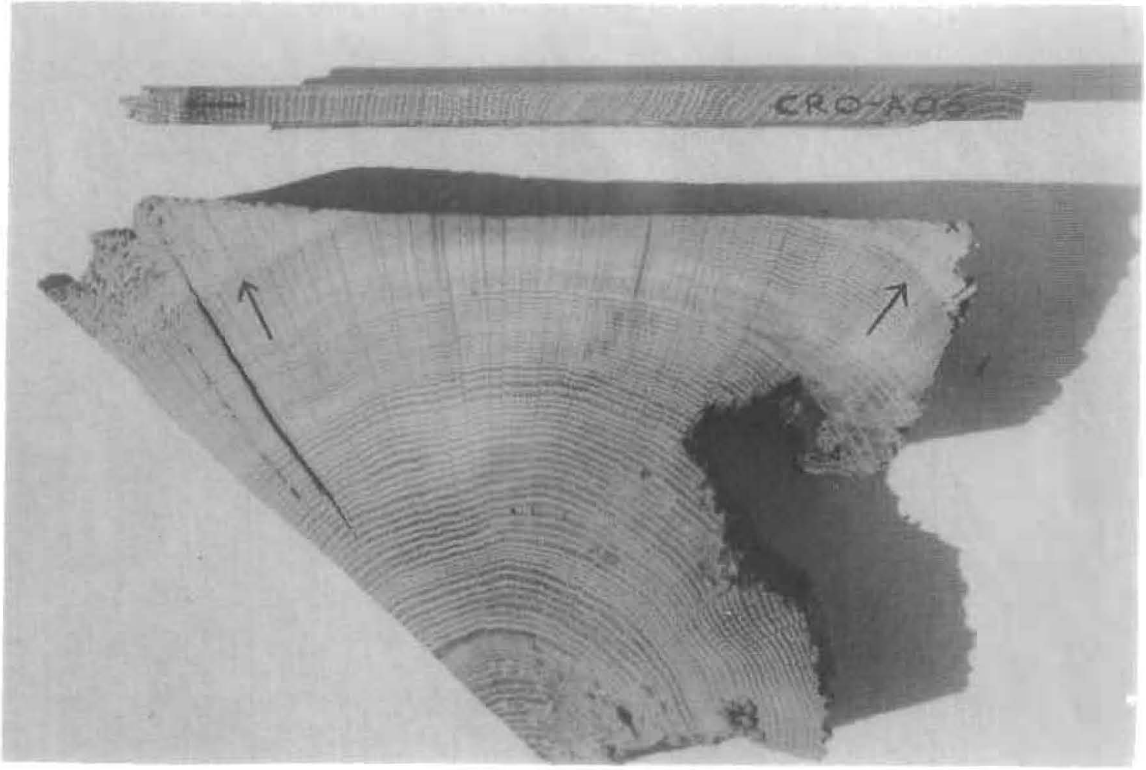


Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

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.

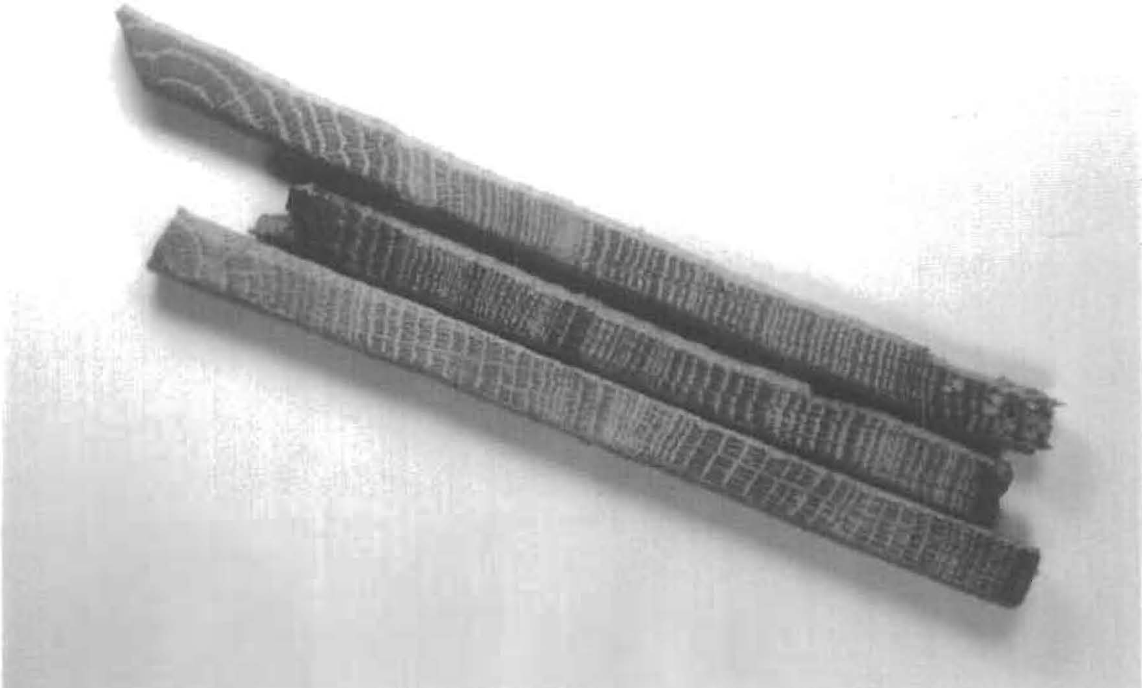


Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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

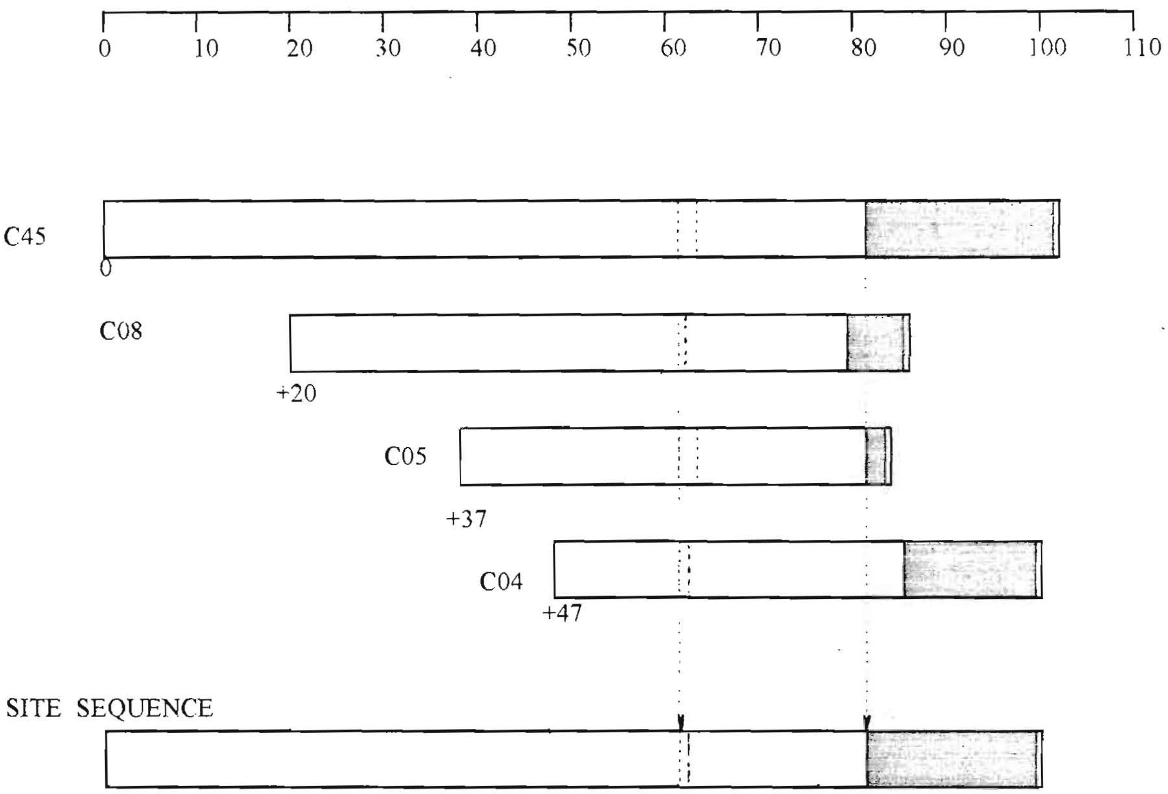


Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.
The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set 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.

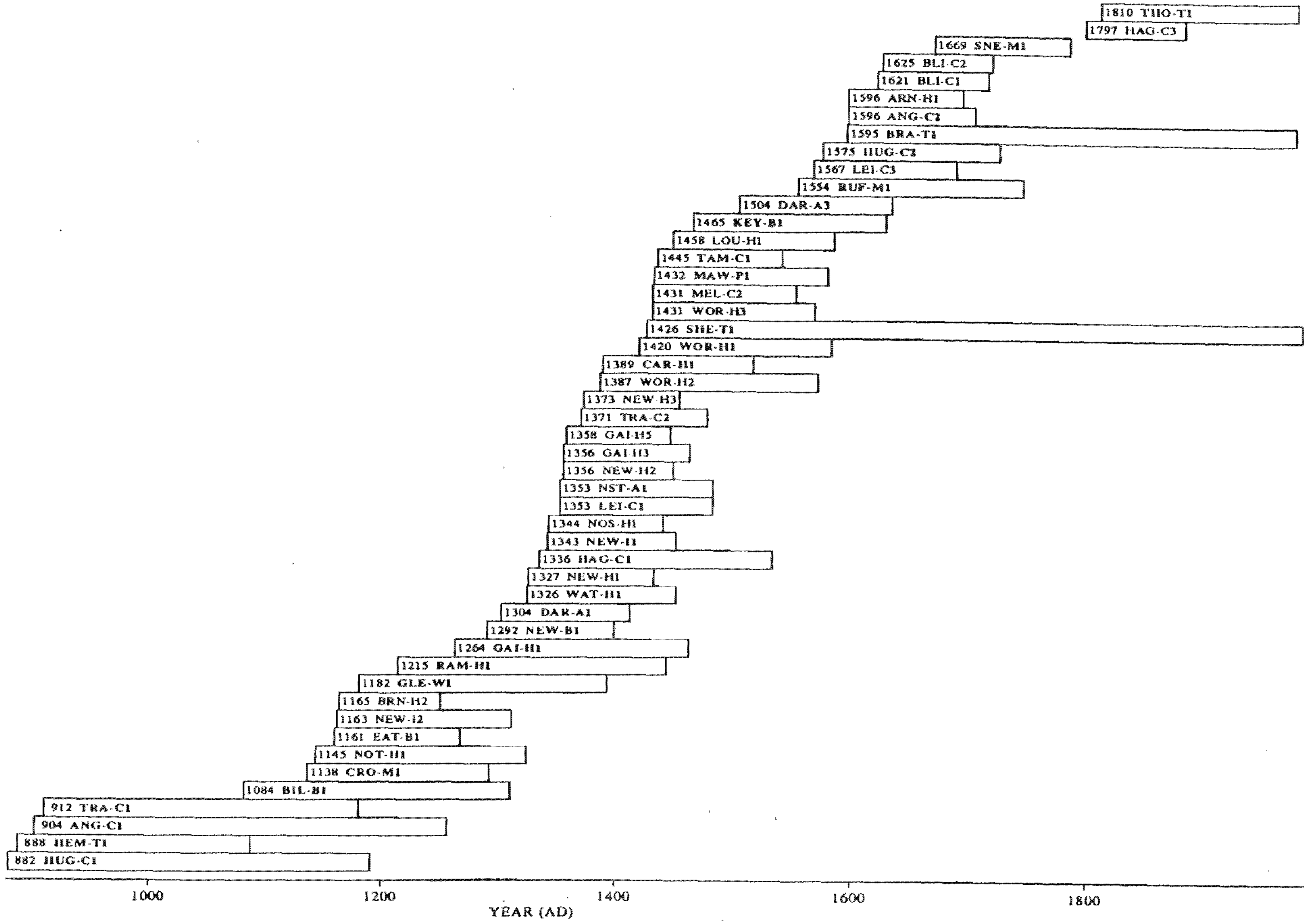


Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

(a)

(b)

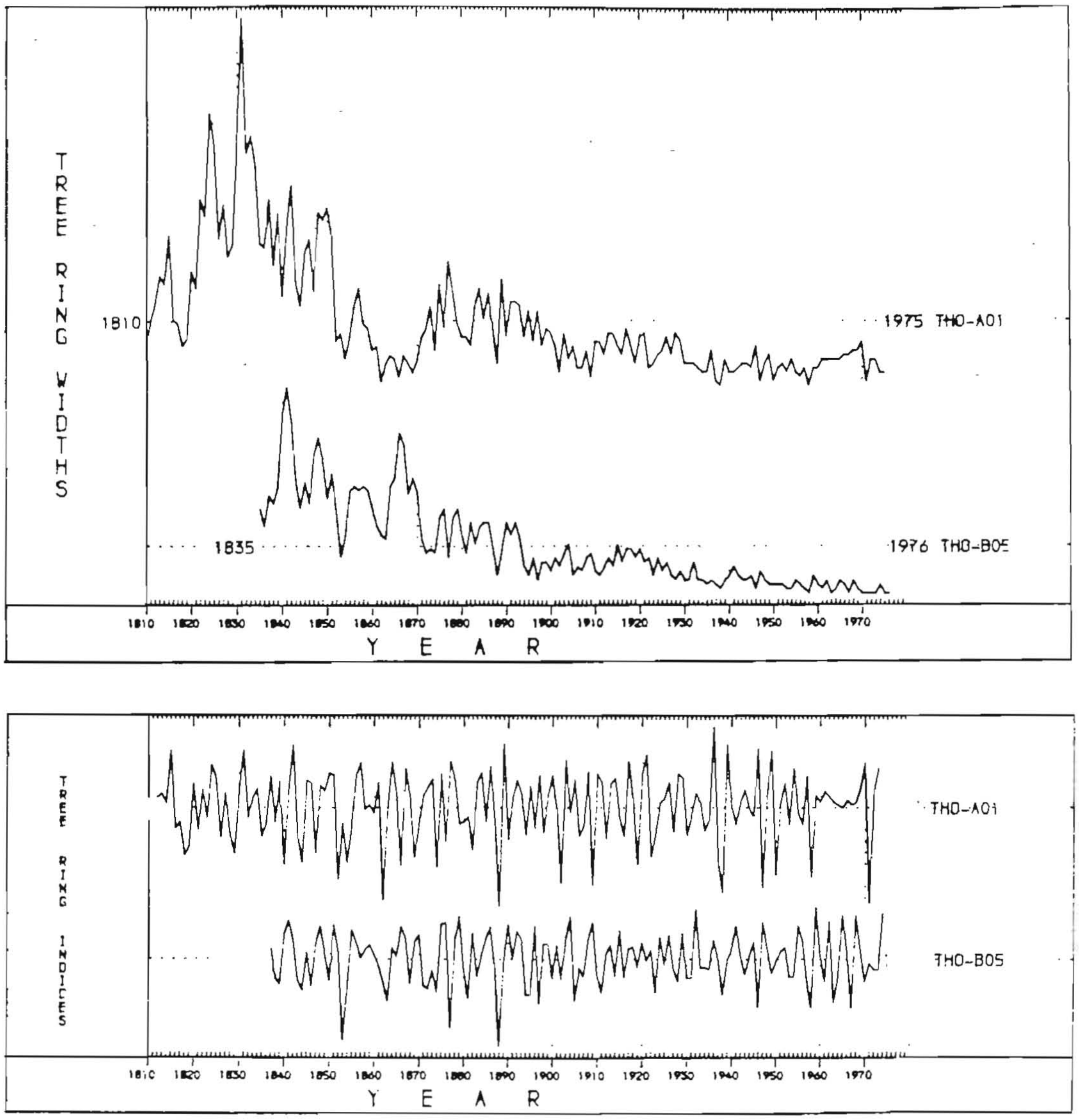


Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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

(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