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LAWRENCEHOLME FARM, OULTON, CUMBRIA
TREE-RING ANALYSIS OF TIMBERS FROM THE BUILDINGS

SCIENTIFIC DATING REPORT

Alison Arnold, Robert Howard and Cliff Litton

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Research Department Report Series 86/2007

Lawrenceholme Farm, Oulton, Cumbria
Tree-Ring Analysis of Timbers from Buildings

Alison Arnold[1], Robert Howard[1] and Cliff Litton[2]

Summary

A total of 31 samples was obtained from the timbers within four separate buildings at Lawrenceholme Farm, Oulton. Of these 31 samples, 22 were measured, nine samples having too few rings for reliable analysis. From these measured data, five separate site chronologies, accounting for a total of 11 samples, were created. These chronologies have overall lengths of between 68 and 162 rings.

Despite being compared to an extensive collection of reference chronologies, none of the five site chronologies, nor the 11 remaining measured but ungrouped samples, could be dated.

Keywords

Dendrochronology
Standing Building

Authors' Addresses

[1] Nottingham Tree-Ring Dating Laboratory, 20 Hillcrest Grove, Sherwood, Nottingham, NG5 1FT
Telephone: 0115 9603833
Email: AlisonArnold@tree-ringdating.co.uk, RobertHoward@tree-ringdating.co.uk

[2] Department of Mathematics, University of Nottingham, University Park, Nottingham, NG7 2RD.
Telephone: 0115 951 4960. Email: cdl@maths.nottingham.ac.uk

Introduction

Lawrenceholme (Laurrence Island) (NGR NY232526, Figs 1 and 2), situated in Wedholme Flow (a marsh), was, in the nineteenth century, a settlement of two farms with a number of bothies and outbuildings. According to local tradition, it once contained a hermit. There are presently on the site two mainly clay dabbin houses (house 'A' and house 'B') as well as a fine two-storey stone house (house 'C'), now used for storage. There is also a mixed stone/clay cruck barn (barn 1), plus a mainly clay dabbin cruck barn (barn 2). There is also a series of modern farm buildings. Although the clay dabbin house, 'A' was inhabited within living memory, only the more recent clay building, house 'B', is now lived in. The mixed stone/clay cruck barn (barn 1) is attached to the older, uninhabited, stone house (house 'C'). The second cruck dabbin barn is attached to the uninhabited clay dabbin house 'A'.

Sampling and analysis by tree-ring dating of timbers from the four clay buildings at Lawrenceholme Farm were commissioned by English Heritage. This analysis was undertaken as a part of a pilot research project on the clay buildings of the Solway Plain in Cumbria, which aims to develop a firm evidence base for this nationally important and threatened building type. The project ultimately aims to understand the significance of these historic structures and to inform their conservation, by raising awareness of their historical significance and extent, and promoting a programme of training in the specific craft skills necessary to repair and maintain these buildings.

Sampling

From the timbers available, a total of 31 core samples was obtained, the samples being spread as evenly and as widely as possible between the four clay buildings. This total, which comprised all of the suitable timbers, might have been considered insufficient to date some of the structures investigated, apart from the fact that they were part of the pilot project. Each sample was given the code LRH-A (for Lawrenceholme, site 'A') and numbered 01–31. The positions of these samples are marked on Figures 3 and 4a–d. Details of the samples are given in Table 1. In this Table, all frames or trusses, and individual timbers, are identified and numbered according to the plans provided.

The Laboratory would like to take this opportunity to particularly thank Mr and Mrs McKie of Lawrenceholme Farm for their help and cooperation during sampling. We would also like to thank Nina Jennings for her constant efforts in promoting this project, for arranging access to the site, and for providing the details in the introduction above. The Laboratory would also like to thank Peter Messenger for his helpful discussions on the possible phasing and interpretation of the building.

Analysis

Each of the 31 samples obtained was prepared by sanding and polishing. It was seen at this time that nine samples, LRH-A03, A04, A13, A14, A15, A19, A23, A25, and A29, had less than the minimum of 54 rings required for reliable tree-ring dating and were rejected from the programme of analysis. The annual growth-ring widths of all the remaining 22 samples were, however, measured, the data of these measurements being given at the end of the report.

The growth-ring widths of all 22 measured samples were compared with each other by the Litton/Zainodin grouping procedure (see Appendix). At a minimum value of t=4.5, five groups, comprising one group of three samples and four groups of two samples each, could be formed. The cross-matching samples were combined with each other at their indicated positions (see bar diagrams Figs 5–9) to form site chronologies LRHASQ01–SQ05. These site chronologies range in length from 68 rings to 162 rings.

Each of the five site chronologies, plus the remaining 11 measured but ungrouped samples, was then compared to an extensive collection of reference chronologies for oak. There was, however, no satisfactory cross-matching at any position. All the samples must, therefore, remain undated for the moment.

Interpretation and conclusion

Although there is no dating for any site chronology or any of the individual samples, it would appear very likely that some of the grouped samples represent timbers felled at the same time. Samples LRH-A27 and A30, for example, representing the two principal rafters of the same truss in house 'A', have identical relative heartwood/boundary positions in site chronology LRHASQ03. Samples LRH-A26 and A28, also from house 'A', also have the same relative heartwood/sapwood boundary positions as each other in site chronology LRHASQ04. A third example of identical relative heartwood/sapwood boundaries may be seen with samples LRH-A01 and A02 in site chronology LRHASQ05. In this case the samples represent the two blades of a single cruck truss in cruck barn 1. In each case it is very likely that the pairs of timbers represented by each individual site chronology were felled at the same time.

Such an interpretation is further supported by the fact that the pairs of samples cross-match with each other with values high enough to suggest that the timbers might be derived from the same tree, or at least from trees growing very close to each other. Samples LRH-A27 and A30, for example cross-match each other with a value of t=10.3. While this does not prove that the timbers were from the same tree, it is unlikely that two different trees which were once growing close to each other were felled at different times and yet ended up as one of a pair of cruck blades or rafters.

Table 1: Details of samples from buildings at Lawrenceholme Farm, Cumbria

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Cruck barn 1					
LRH-A01	Cruck blade A	61	21C	------	------	------
LRH-A02	Cruck blade A1	63	15	------	------	------
LRH-A03	North-west purlin	nm	---	------	------	------
LRH-A04	South-west purlin	nm	---	------	------	------
LRH-A05	Ridge to west	59	8	------	------	------
LRH-A06	North-east purlin	54	h/s	------	------	------
LRH-A07	South-east purlin	75	17	------	------	------
LRH-A08	Collar A – A1	59	29C	------	------	------
	Cruck barn 2					
LRH-A09	Cruck blade B1	162	h/s	------	------	------
LRH-A10	Backing rafter B1	100	h/s	------	------	------
LRH-A11	Purlin A1 – B1	55	h/s	------	------	------
LRH-A12	Cruck blade A	54	h/s	------	------	------
LRH-A13	Collar A – A1	nm	---	------	------	------
LRH-A14	Backing rafter A1	nm	---	------	------	------
LRH-A15	Collar B – B1	nm	---	------	------	------
LRH-A16	Cruck blade A1	83	10	------	------	------

Table 1: Continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	House A (east section)					
LRH-A17	South-west purlin	58	18	------	------	------
LRH-A18	North-west purlin	77	41C	------	------	------
LRH-A19	West ridge beam	nm	---	------	------	------
LRH-A20	West lintel to doorway	62	h/s	------	------	------
LRH-A21	Middle lintel to doorway	92	no h/s	------	------	------
LRH-A22	East lintel to doorway	85	no h/s	------	------	------
LRH-A23	Lower south-east purlin	nm	---	------	------	------
LRH-A24	East ridge	62	h/s	------	------	------
LRH-A25	Lower north-east purlin	nm	---	------	------	------
	House A (west section)					
				------	------	------
LRH-A26	Lower south-east purlin	74	20C	------	------	------
LRH-A27	North principal rafter	66	19	------	------	------
LRH-A28	Upper south-east purlin	70	20C	------	------	------
LRH-A29	Collar	nm	---	------	------	------
LRH-A30	South principal rafter	68	21C	------	------	------
LRH-A31	South common rafter 3	89	h/s	------	------	------

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

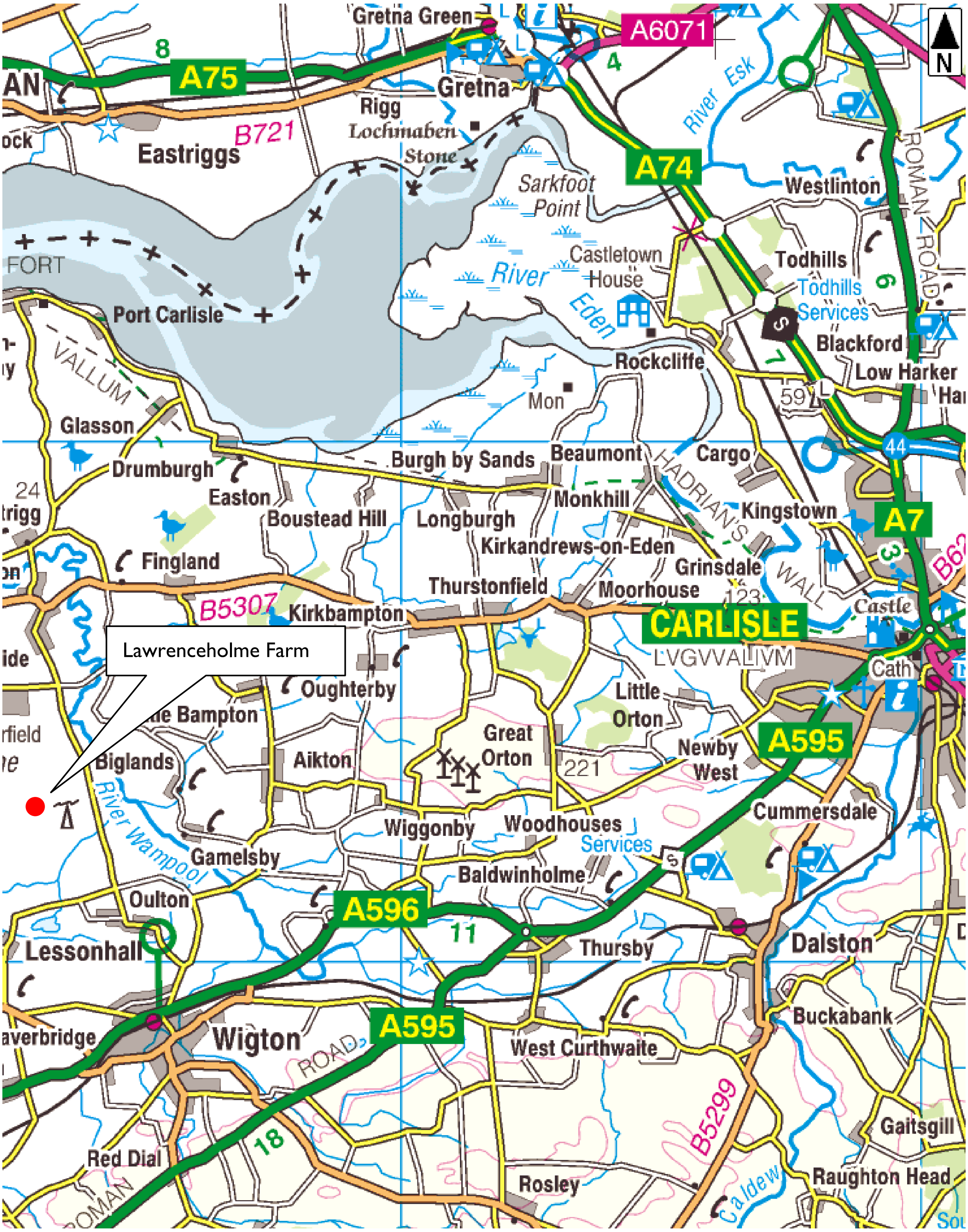


Figure 1: Map showing the location of Lawrenceholme Farm, Oulton, Cumbria.

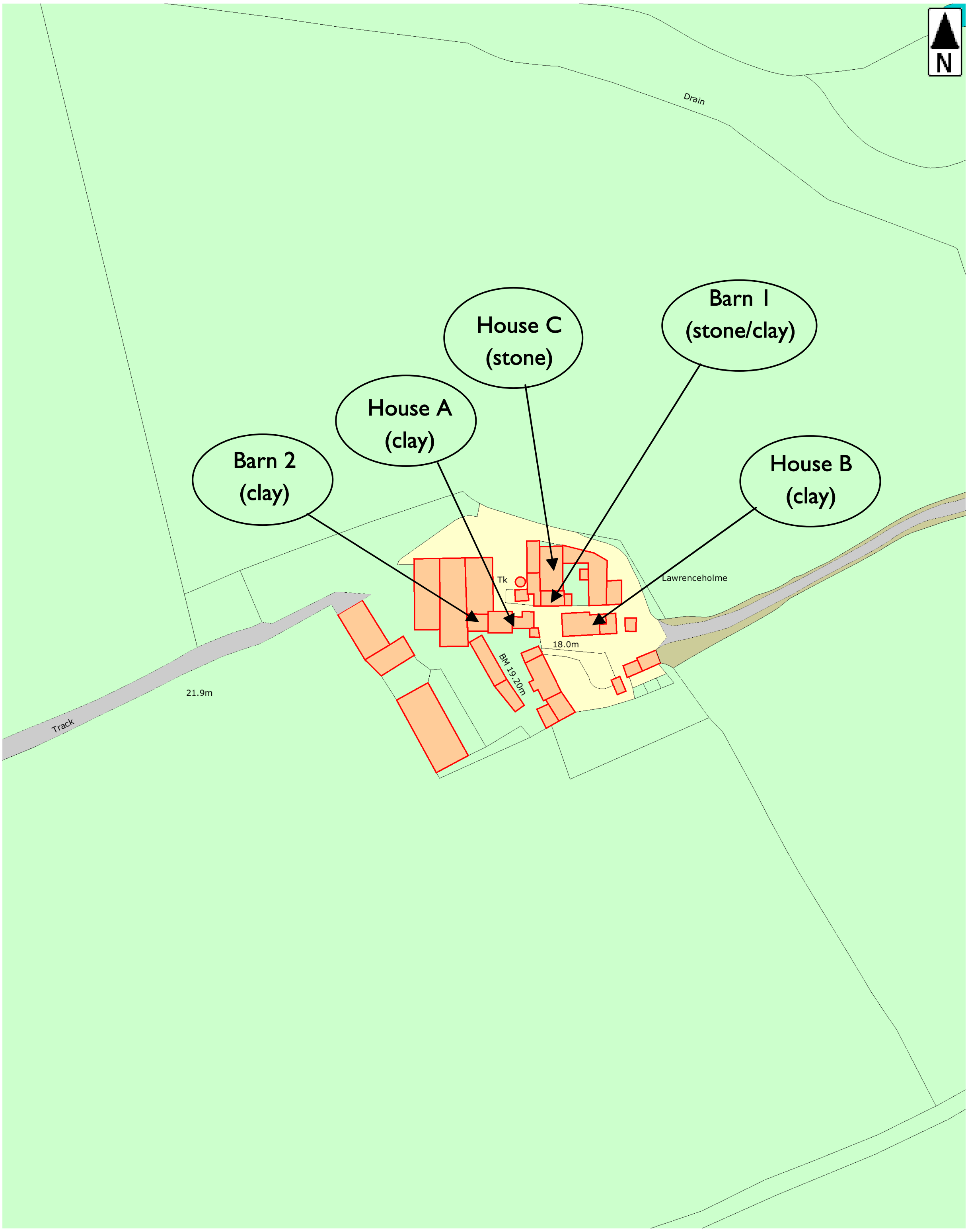


Figure 2: Map of Lawrenceholme Farm, Oulton, Cumbria.

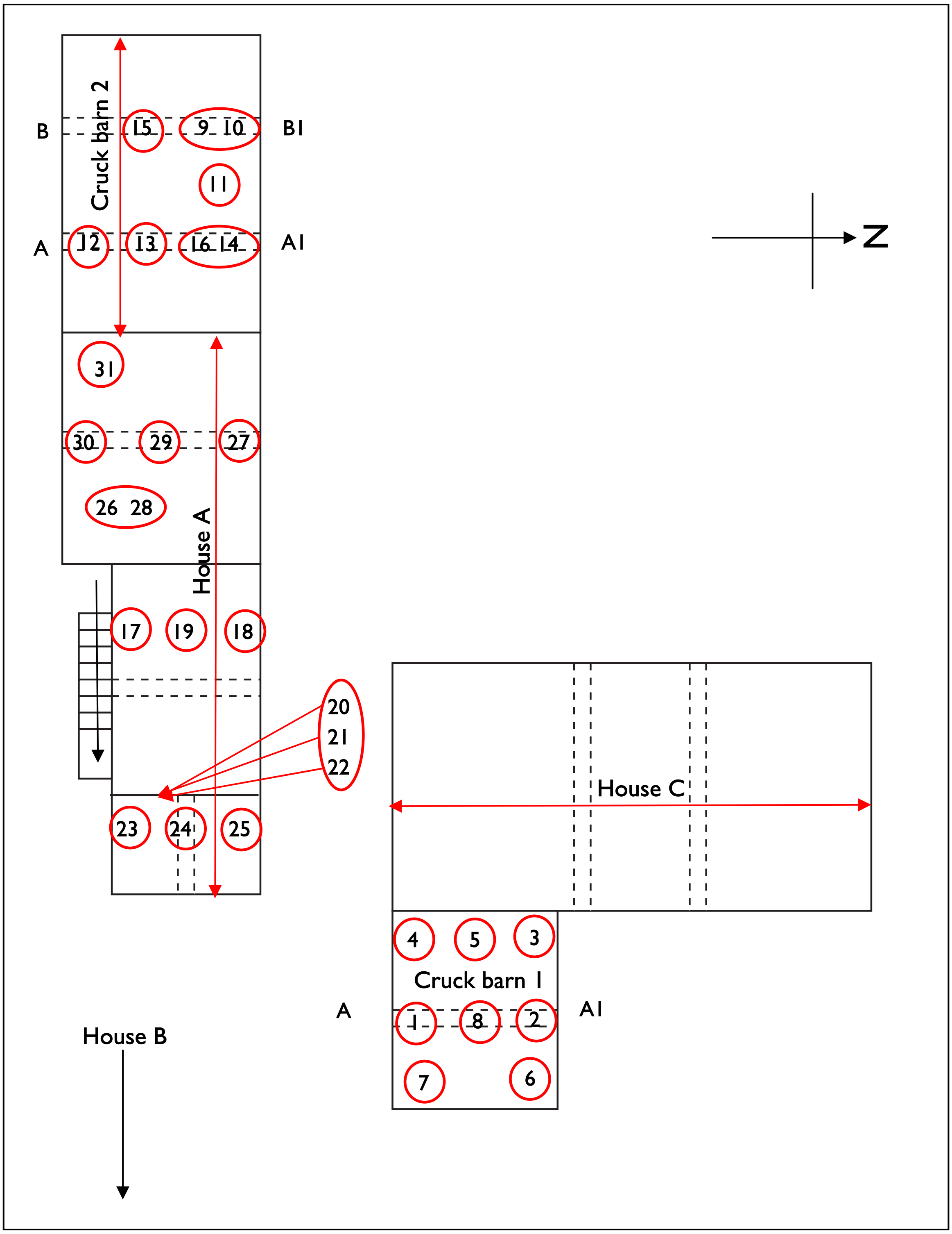


Figure 3: Schematic plan of clay buildings at Lawrenceholme Farm, indicating the positions of the timbers sampled for dendrochronology. Based on original drawings by Nina Jennings

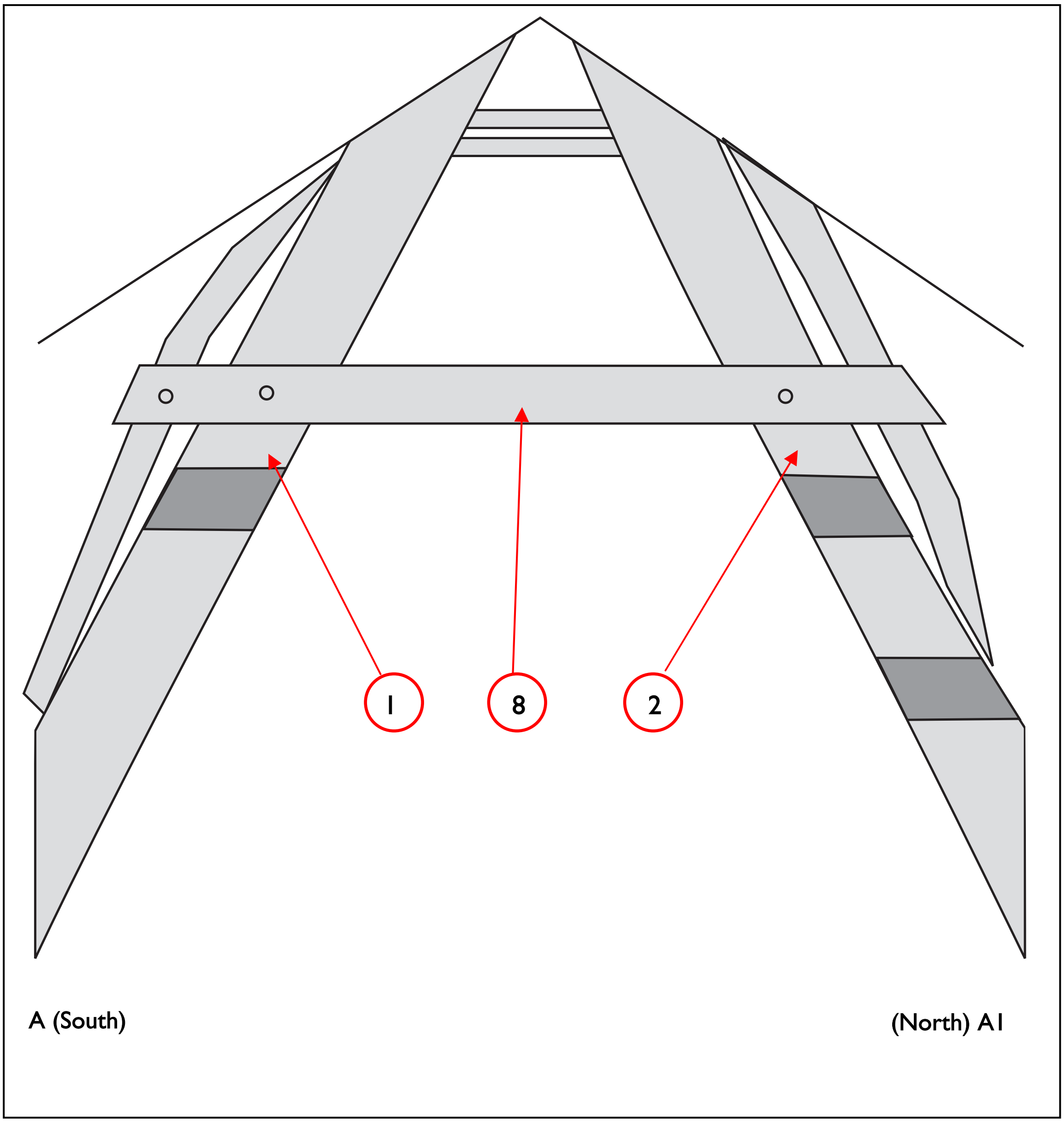


Figure 4a: Barn 1 – schematic section of cruck truss A-A1 (truncated by modern roof line) to show sampled timbers. Shaded areas indicate redundant half-lap joints (viewed from the east looking west)

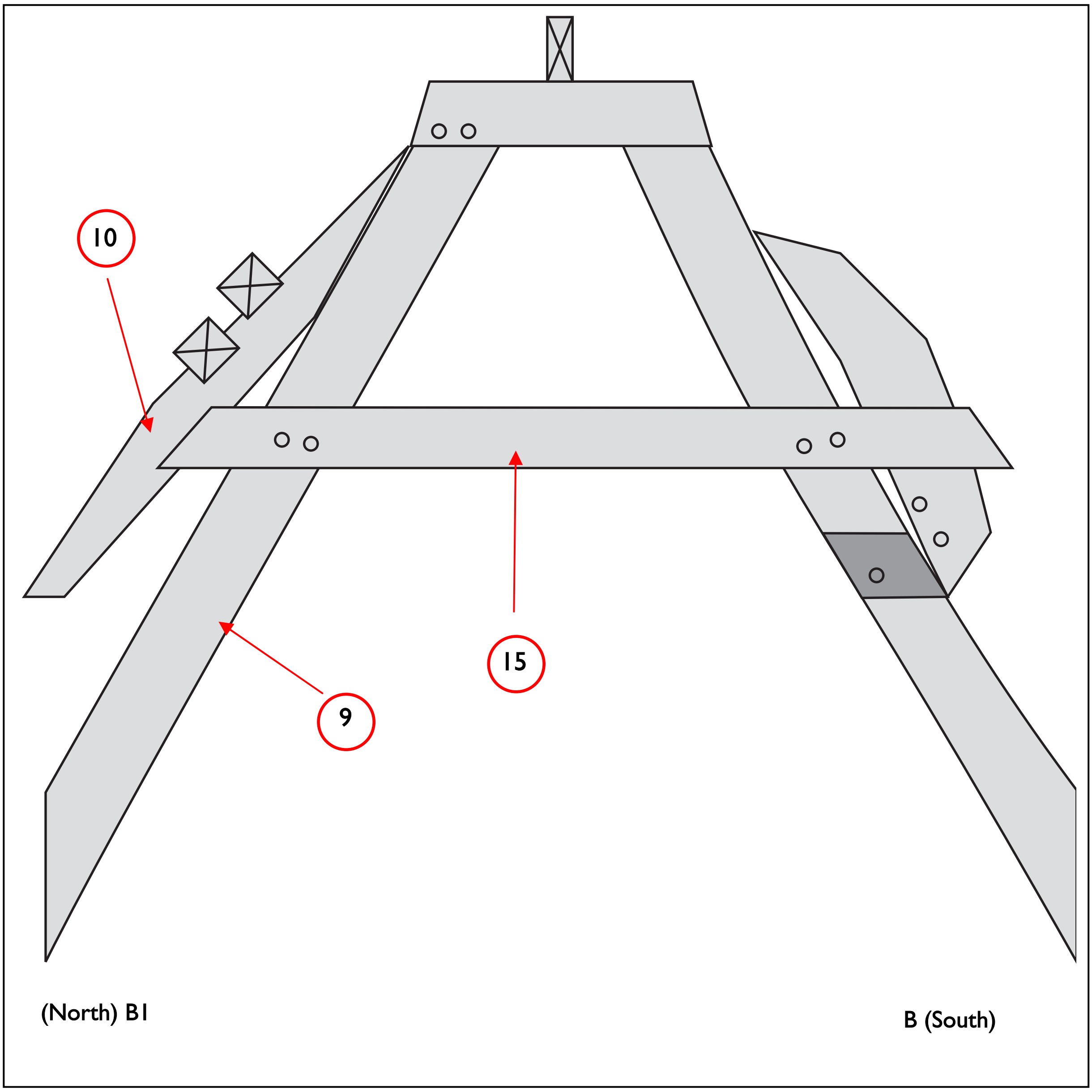


Figure 4b: Barn 2 – schematic section of truss B-B1 to show sampled timbers. The shaded area indicates a redundant half-lap joint (viewed from the west looking east)

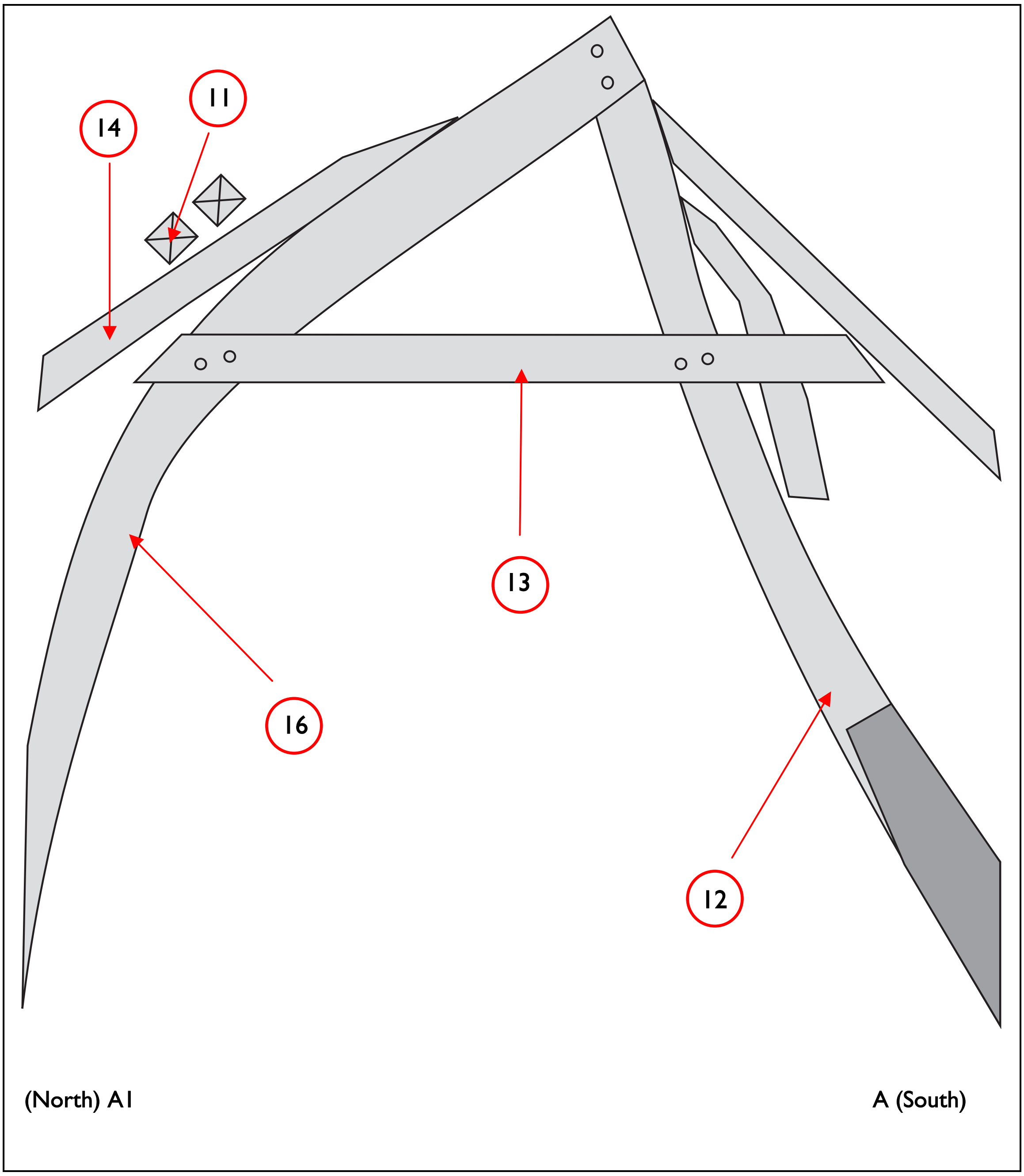


Figure 4c: Barn 2 – schematic section of truss A-A1 to show sampled timbers. The shaded area indicates a redundant half-lap joint (viewed from the west looking east)

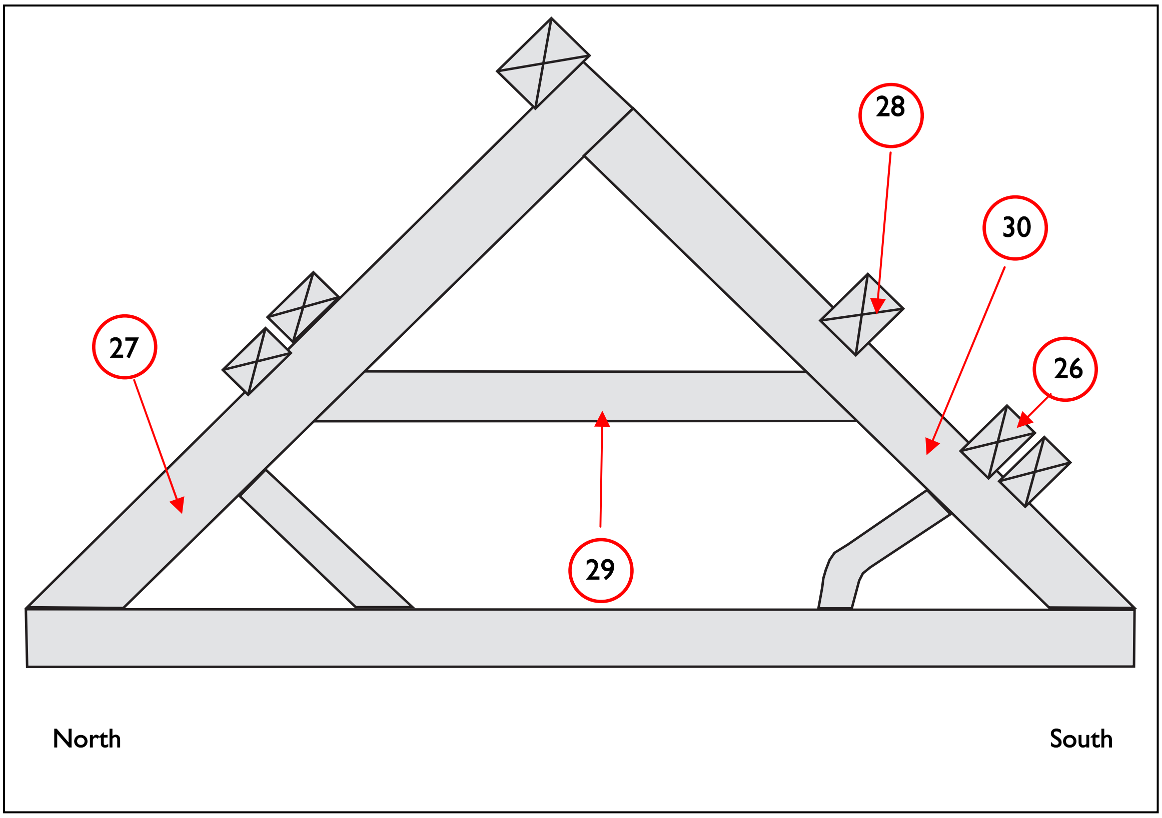


Figure 4d: House A – schematic section of west wing central truss to show sampled timbers (viewed from the west looking east)

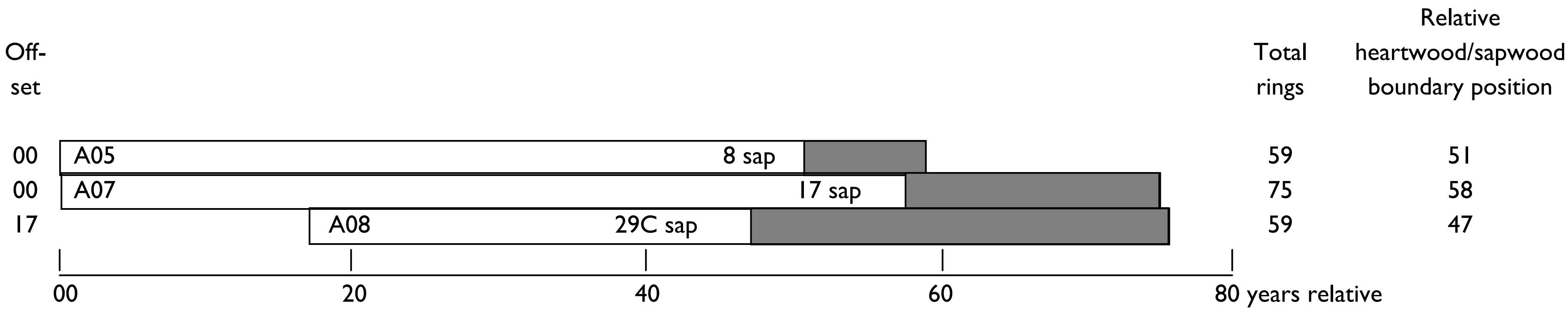
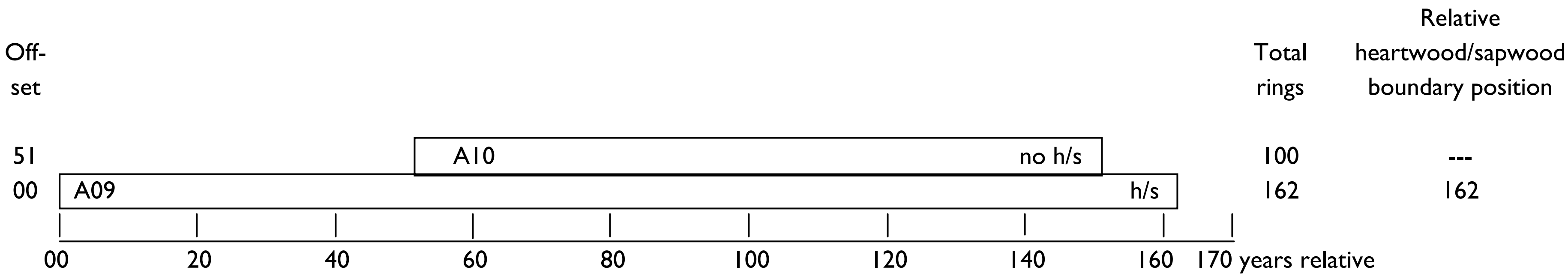


Figure 5: Bar diagram of the samples in site chronology LRHASQ01



white bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample
C = complete sapwood retained on sample

Figure 6: Bar diagram of the samples in site chronology LRHASQ02

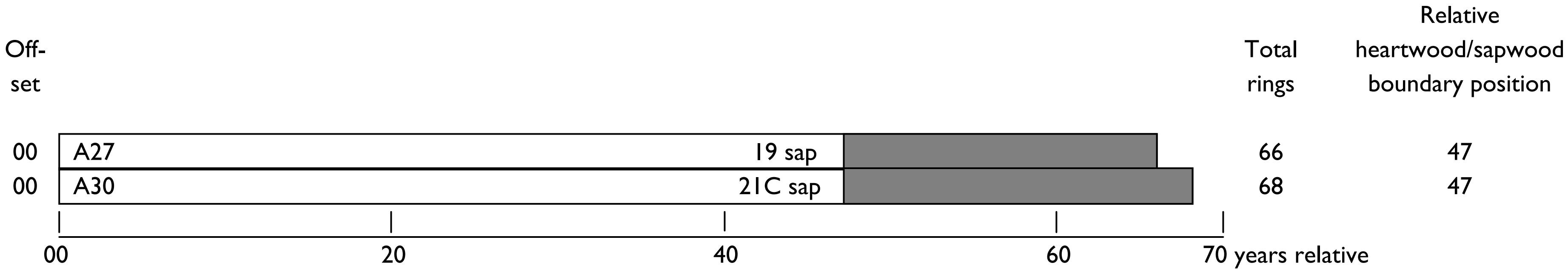
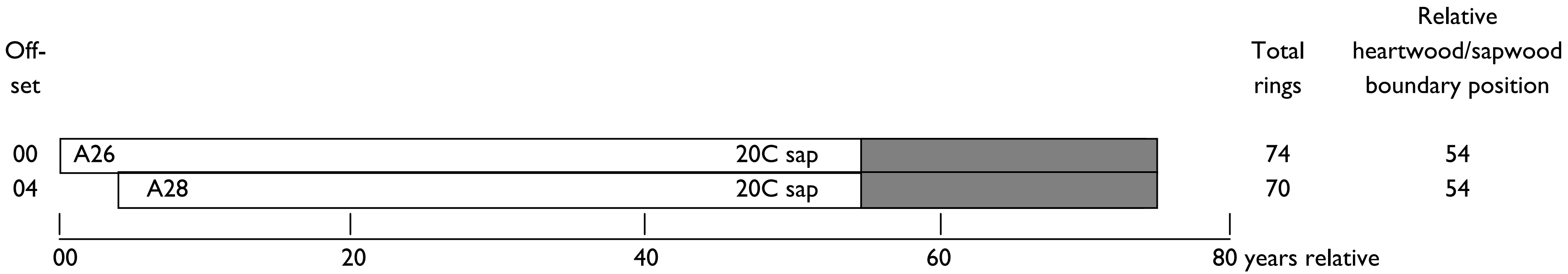
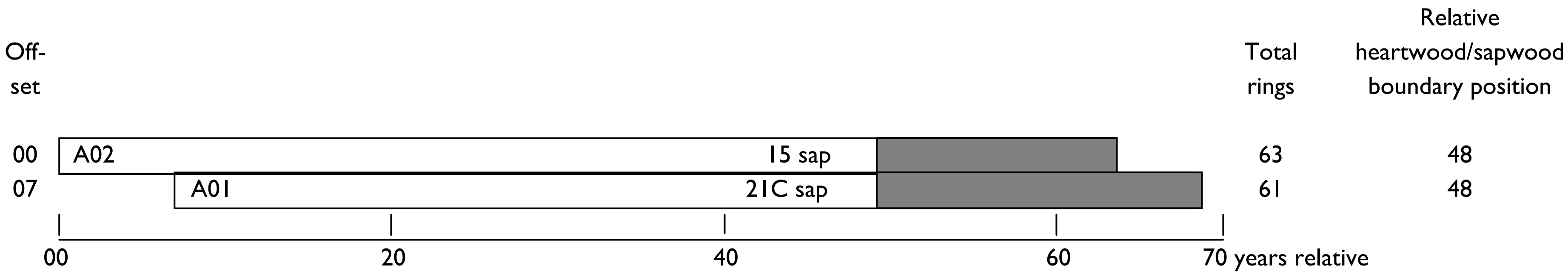


Figure 7: Bar diagram of the samples in site chronology LRHASQ03



white bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample
C = complete sapwood retained on sample

Figure 8: Bar diagram of the samples in site chronology LRHASQ04



white bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample
C = complete sapwood retained on sample

Figure 9: Bar diagram of the samples in site chronology LRHASQ05

Data of measured samples – measurements in 0.01 mm units

LRH-A01A 61
528 461 556 421 509 502 546 343 360 331 205 261 252 398 418 524 271 88 132 211
270 234 187 222 265 251 241 346 296 406 383 397 318 416 332 178 97 101 169 260
88 75 115 127 167 111 87 164 186 206 84 74 73 65 83 120 165 270 251 288
329
LRH-A01B 61
547 471 567 457 505 489 545 346 359 335 221 272 269 387 431 512 266 101 129 201
274 229 187 226 260 259 236 346 294 406 384 399 321 426 337 172 125 88 165 263
90 77 110 126 161 117 80 174 178 207 83 70 77 58 79 134 170 261 254 293
328
LRH-A02A 63
297 322 375 339 248 426 433 297 301 377 321 430 441 322 275 368 410 375 410 267
332 338 380 224 120 88 112 138 164 127 138 182 207 219 249 280 308 313 406 361
293 234 185 134 132 201 308 121 46 88 96 157 99 86 189 199 197 137 59 77
101 154 171
LRH-A02B 63
318 320 398 308 330 353 350 326 297 361 327 422 429 323 264 367 420 367 412 267
339 328 415 225 115 87 126 154 159 128 139 179 206 218 255 282 302 299 394 342
288 229 191 135 131 204 290 132 60 82 90 162 99 74 187 193 204 133 70 70
113 146 187
LRH-A05A 59
180 150 170 152 166 249 160 163 121 146 440 289 269 242 199 168 166 236 142 136
187 223 172 151 198 154 208 113 143 96 191 177 163 183 234 224 186 114 84 89
86 100 126 120 179 134 233 159 129 87 89 45 46 70 55 52 64 80 147
LRH-A05B 59
159 153 180 158 155 243 183 184 131 157 484 339 276 239 196 163 174 218 147 134
196 227 171 154 196 169 191 119 147 95 188 172 168 167 239 226 178 114 76 94
82 101 125 126 180 133 234 153 138 86 95 39 63 64 72 46 52 77 186
LRH-A06A 54
292 420 375 273 186 186 210 195 195 158 120 190 198 154 181 207 190 174 236 181
183 240 215 183 193 194 155 163 137 179 164 179 185 208 130 174 192 221 134 146
192 130 134 145 152 128 146 162 128 113 167 151 132 99
LRH-A06B 54
269 457 357 272 188 198 225 177 193 158 126 198 199 157 179 204 177 185 231 191
186 228 224 180 184 191 167 168 134 182 166 186 174 208 133 181 188 228 124 154
179 125 131 141 157 134 137 164 124 109 161 148 121 96
LRH-A07A 75
366 291 395 206 271 283 266 258 210 139 279 289 251 228 204 96 116 135 98 63
107 130 125 183 158 113 141 125 175 146 214 182 133 114 148 180 177 50 56 49
60 68 98 110 134 104 164 119 94 53 62 39 57 106 185 153 128 203 84 51
38 42 36 56 51 62 74 54 100 151 140 130 187 105 152
LRH-A07B 75
368 294 398 219 257 282 261 269 202 137 271 299 258 219 205 95 120 121 105 71
102 127 131 183 168 125 135 134 163 142 212 176 134 115 159 175 171 58 55 48
66 64 98 101 136 103 171 123 90 52 57 42 59 102 190 149 136 207 88 47

36 39 42 52 53 57 76 60 97 149 139 133 182 106 154
LRH-A08A 59
155 188 262 271 320 360 451 404 333 244 181 230 147 271 283 292 215 201 201 145
85 85 49 83 69 99 145 140 110 164 132 95 82 104 76 73 83 132 100 111
99 62 72 56 53 75 83 101 123 98 84 123 129 129 114 189 99 126 174
LRH-A08B 59
173 188 271 291 319 360 446 401 346 253 190 223 156 279 268 291 209 211 197 152
73 83 54 87 70 106 138 149 114 157 110 107 81 104 74 67 89 127 103 98
99 54 85 58 46 82 74 105 112 118 80 119 147 125 109 171 123 125 157
LRH-A09A 162
196 131 75 186 117 143 187 165 184 337 189 138 133 120 92 149 128 173 119 95
78 172 159 240 279 244 160 119 68 104 152 175 158 196 227 147 117 132 97 82
110 141 100 158 132 145 86 90 60 75 37 35 57 68 86 76 104 139 93 126
233 135 140 183 125 136 153 167 136 161 158 99 74 71 49 120 156 99 90 71
73 71 81 72 68 73 66 67 40 31 32 36 42 29 33 44 58 45 50 51
43 57 70 63 82 124 77 36 51 37 44 70 79 50 69 86 115 60 67 100
83 104 98 80 112 173 110 112 221 134 95 90 112 67 103 82 90 123 86 80
66 85 64 83 114 88 91 68 63 135 80 106 94 126 66 54 58 107 89 62
48 65
LRH-A09B 162
210 122 86 168 133 128 184 153 180 309 179 130 136 116 91 158 145 185 105 85
82 165 163 240 283 251 181 93 67 113 147 167 163 187 227 174 115 148 98 96
126 123 110 164 131 140 103 70 75 67 35 40 55 73 88 73 117 139 89 135
214 141 155 172 132 130 157 164 138 166 158 105 82 67 48 119 154 104 78 83
77 75 77 76 74 77 66 63 29 37 34 32 36 34 26 50 59 43 53 48
45 45 79 74 75 119 79 45 41 39 47 67 79 55 68 82 113 63 61 101
81 113 93 82 115 165 140 95 210 140 98 87 115 69 99 88 80 114 99 68
76 85 59 101 105 93 86 70 68 120 66 113 106 125 46 54 65 96 80 73
54 72
LRH-A10A 100
78 71 124 169 188 177 142 119 147 213 128 148 189 161 176 172 222 145 138 152
149 118 115 79 94 180 87 93 99 83 94 64 76 50 60 73 67 48 61 49
67 56 38 39 51 73 50 55 52 47 82 111 102 118 179 119 45 68 40 64
103 75 81 77 154 183 113 73 139 118 157 127 109 111 199 120 113 214 123 109
222 204 145 101 87 86 134 158 96 58 91 55 67 80 65 64 58 39 45 58
LRH-A10B 100
91 72 127 172 180 182 142 106 157 210 123 160 185 169 170 175 221 155 136 160
161 125 121 77 89 178 81 96 114 77 97 63 75 45 56 80 58 47 47 54
68 42 45 36 52 76 50 56 53 44 84 100 101 121 176 118 44 63 46 63
99 74 75 89 154 179 102 79 141 110 167 131 96 113 205 114 126 221 116 96
224 201 135 102 91 80 148 154 81 63 82 53 77 73 61 64 48 46 52 63
LRH-A11A 55
264 256 169 161 179 180 458 593 401 215 171 281 168 172 167 151 119 323 283 273
282 488 378 306 223 105 91 110 74 126 137 177 103 100 83 109 106 169 191 206
183 313 263 281 244 294 219 192 166 143 116 224 239 256 197
LRH-A11B 55
295 249 165 163 185 182 396 596 377 211 178 260 168 171 167 141 133 323 280 280

320 490 390 303 234 99 101 99 81 122 139 177 123 91 86 102 98 167 189 225
184 287 280 285 247 308 215 203 157 154 115 210 235 220 174
LRH-A12A 54
50 66 104 150 196 197 211 310 268 224 190 189 149 114 82 83 95 91 68 78
104 82 122 136 130 120 81 90 116 111 124 99 94 130 102 129 109 104 79 79
83 73 104 97 65 56 54 57 40 57 76 92 88 133
LRH-A12B 54
55 57 101 159 145 219 230 328 307 219 181 177 145 108 83 80 97 91 73 82
93 98 110 146 124 120 79 90 115 126 105 96 95 134 110 126 96 103 74 87
72 80 100 97 68 60 56 56 39 58 68 96 91 128
LRH-A16A 83
250 370 229 217 217 197 121 93 99 73 76 91 68 79 88 148 180 207 223 208
278 301 292 353 395 441 352 300 233 293 209 202 186 131 182 282 215 233 220 223
210 186 173 221 207 195 269 217 201 221 147 169 183 173 147 169 169 133 112 146
180 150 114 87 67 62 80 69 118 171 118 156 162 134 115 111 64 110 72 63
93 105 145
LRH-A16B 83
241 381 236 225 217 214 121 94 87 72 71 90 65 69 81 136 171 209 205 202
281 318 263 347 404 421 348 297 229 325 209 203 191 134 184 299 213 208 229 226
207 185 174 221 209 191 267 219 197 228 152 165 173 166 160 177 163 134 123 132
187 151 115 87 67 68 65 75 113 173 125 146 171 140 112 102 90 110 68 60
90 98 141
LRH-A17A 58
390 443 611 679 668 802 709 740 651 651 727 615 718 434 467 432 390 342 387 253
251 291 173 167 199 179 194 184 188 136 126 121 78 76 74 105 87 78 80 119
123 119 92 73 81 62 84 107 146 169 95 78 67 94 59 73 66 81
LRH-A17B 58
358 475 588 680 673 804 713 740 641 654 711 589 734 475 451 400 355 336 387 245
252 285 176 162 216 174 208 198 203 146 122 118 77 79 65 122 81 78 82 124
119 122 87 78 71 63 89 106 138 141 104 71 72 88 58 72 67 80
LRH-A18A 77
419 389 321 334 404 379 437 513 305 343 340 229 243 293 259 180 191 168 164 189
161 174 141 150 90 71 66 40 45 44 92 55 59 63 58 61 70 50 45 61
47 42 73 76 86 67 65 112 92 84 91 99 54 72 77 71 59 58 53 58
70 49 44 37 44 59 43 42 35 41 37 45 40 46 56 40 54
LRH-A18B 77
387 393 336 357 366 388 414 497 348 393 329 234 255 275 259 170 194 169 169 190
164 172 143 150 90 71 67 30 57 39 81 60 56 63 61 60 62 55 43 59
46 42 68 66 84 64 62 122 87 83 93 104 52 74 87 73 60 58 53 59
68 53 44 39 42 64 36 45 36 40 39 42 37 49 67 44 49
LRH-A20A 62
162 140 122 95 87 60 76 58 86 92 110 132 160 133 112 112 114 105 61 97
82 102 107 113 105 63 77 69 56 63 81 106 76 104 127 123 101 110 79 62
53 67 105 104 146 123 88 172 202 184 150 119 142 173 224 110 157 131 110 122
106 89
LRH-A20B 62
167 137 122 104 78 64 67 60 82 97 101 141 187 131 109 119 96 92 74 89

82 101 125 122 101 67 86 63 70 62 79 104 77 104 133 108 99 102 71 57
60 63 119 116 154 127 90 143 217 173 137 119 149 173 198 124 165 119 108 107
111 98
LRH-A21A 92
48 78 85 81 93 66 95 97 75 58 73 51 52 76 82 71 68 59 58 51
51 65 62 84 72 61 73 60 68 83 69 76 72 87 58 64 81 76 86 81
85 76 58 55 49 61 69 79 81 81 84 78 78 90 72 67 45 47 78 69
90 57 64 83 85 78 73 81 68 132 64 84 75 103 69 89 99 85 69 72
62 55 78 59 85 86 67 55 57 62 107 75
LRH-A21B 92
60 69 81 75 91 78 101 101 58 60 68 52 51 65 98 58 73 63 46 48
55 55 62 93 71 67 62 61 75 81 69 70 79 80 71 67 66 84 77 85
76 79 41 52 49 71 65 70 78 81 81 72 79 89 69 60 50 45 77 76
61 67 62 88 81 80 77 79 78 125 79 89 77 98 74 79 106 89 70 64
52 54 76 66 68 82 72 65 61 58 85 91
LWH-A22A 85
330 227 309 274 237 212 198 169 186 119 112 97 87 142 147 167 213 231 234 185
238 360 282 335 338 433 381 351 499 365 383 318 293 375 292 290 305 379 334 380
346 248 241 241 229 289 377 291 230 130 284 277 243 231 239 213 196 173 163 171
152 209 188 253 186 182 161 146 144 110 170 237 258 227 244 195 197 211 191 222
221 189 262 245 334
LWH-A22B 85
301 227 293 283 241 217 198 170 187 113 96 89 87 135 148 169 207 228 232 193
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347 248 246 236 229 295 374 281 241 132 286 285 249 241 238 211 188 172 154 168
144 215 180 258 185 188 159 145 143 117 158 229 266 234 235 204 199 205 190 222
201 201 259 235 331
LRH-A24A 62
412 346 365 255 132 220 294 297 186 265 228 229 321 185 211 246 411 259 171 231
291 327 341 311 265 330 258 254 194 328 359 245 169 251 244 281 355 222 298 250
203 130 95 102 141 160 174 163 110 145 156 153 118 114 93 108 93 155 142 184
178 214
LRH-A24B 62
440 337 373 261 128 219 272 313 170 289 215 242 318 182 206 238 421 282 167 230
289 327 331 336 262 319 255 256 220 312 353 246 181 233 237 296 351 224 287 246
223 123 90 117 136 159 156 164 109 138 167 141 113 112 86 100 86 144 156 160
179 209
LRH-A26A 74
19 27 44 73 93 133 106 91 187 122 221 201 162 56 46 44 59 89 130 89
116 118 133 118 79 76 135 181 223 227 209 263 320 188 235 170 210 148 164 134
142 111 91 143 135 85 199 159 137 110 121 130 113 102 100 86 108 184 146 175
191 174 240 239 244 207 286 207 324 153 143 242 253 317
LRH-A26B 74
22 32 42 72 105 129 100 94 189 122 230 204 159 57 49 31 58 91 117 94
102 101 127 118 70 80 135 175 221 227 220 260 317 205 227 175 208 152 161 130
141 106 88 152 126 88 207 144 134 119 119 124 117 96 99 82 112 195 150 159
200 166 236 240 248 209 279 212 322 154 145 235 278 304

LRH-A27A 66
187 274 372 325 319 386 472 264 505 363 251 245 334 229 141 156 115 176 141 136
246 122 103 115 149 110 102 74 70 133 117 97 128 114 122 91 89 62 79 65
67 92 100 128 146 150 151 157 129 110 164 137 107 156 141 145 147 113 118 133
163 179 124 108 161 201
LRH-A27B 66
177 279 364 331 311 397 451 244 478 356 259 254 330 219 141 170 126 169 158 134
255 119 104 112 151 120 90 87 81 119 105 88 135 117 126 91 89 69 78 57
73 94 101 138 141 149 139 156 130 106 147 140 113 155 150 131 150 122 121 116
158 175 119 101 168 206
LRH-A28A 70
222 113 82 92 244 120 190 158 120 75 91 63 94 158 169 179 157 165 178 188
90 142 174 216 220 170 151 133 159 89 114 116 176 161 193 116 103 104 78 155
126 94 119 107 104 82 95 130 94 61 100 61 85 163 123 134 141 109 173 184
148 143 170 109 95 55 69 108 59 136
LRH-A28B 70
236 118 91 119 155 115 186 174 108 70 94 66 97 151 178 168 166 157 185 186
105 133 186 225 218 185 142 122 160 89 132 109 169 158 184 112 113 102 71 158
134 99 140 104 102 84 92 131 88 61 100 66 81 161 120 137 151 101 165 201
158 145 180 101 99 52 67 112 66 120
LRH-A30A 68
291 307 350 371 268 373 443 330 345 325 231 205 308 258 180 211 193 236 157 157
221 121 116 101 154 142 118 96 110 149 103 87 130 138 131 137 123 91 87 74
87 87 111 153 143 127 119 150 116 105 126 96 80 118 100 92 89 87 77 66
83 81 67 58 85 96 85 81
LRH-A30B 68
212 299 350 316 279 365 452 315 354 334 237 196 312 253 167 217 178 271 175 166
216 127 127 113 139 155 123 93 117 143 87 84 127 131 132 131 126 95 79 73
77 96 93 156 144 131 114 129 126 111 130 91 78 118 97 92 96 85 75 71
83 82 58 63 87 94 91 87
LRH-A31A 89
121 78 95 138 117 150 146 123 121 100 96 144 144 129 124 149 154 110 105 165
152 180 129 127 76 93 95 139 180 150 144 109 117 116 135 107 101 106 101 95
101 93 77 83 92 125 142 146 92 89 101 87 70 44 71 106 101 126 137 121
104 86 92 109 104 117 92 73 79 88 91 97 84 94 70 98 74 71 94 110
106 113 109 106 99 87 103 99 117
LRH-A31B 89
136 89 99 122 138 138 151 113 123 103 84 151 153 130 129 151 141 123 117 158
155 163 139 126 69 93 95 155 173 155 151 107 109 125 135 104 115 102 101 89
86 104 76 79 96 122 150 133 100 102 88 88 76 40 79 113 85 130 122 110
91 90 91 97 117 101 109 66 75 91 99 83 107 75 78 98 89 56 113 93
110 120 99 113 94 88 107 107 133

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 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.

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.

Figure 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.

Figure 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.

Figure 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.

Figure 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.

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 Figure 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 Figure 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 some 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 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 phenomenon can be observed in the lower sequence of (a) starting in 1835. In both the widths are also changing rapidly from year to year. The peaks are the wide rings and the troughs are the narrow rings corresponding to good and poor growing seasons, respectively. The two corresponding sequence of Baillie-Pilcher indices are plotted in (b) where the differences in the immature and mature growths have been removed and only the rapidly changing peaks and troughs remain, that are associated with the common climatic signal. This makes cross-matching easier.

t-value/offset Matrix

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

Bar Diagram

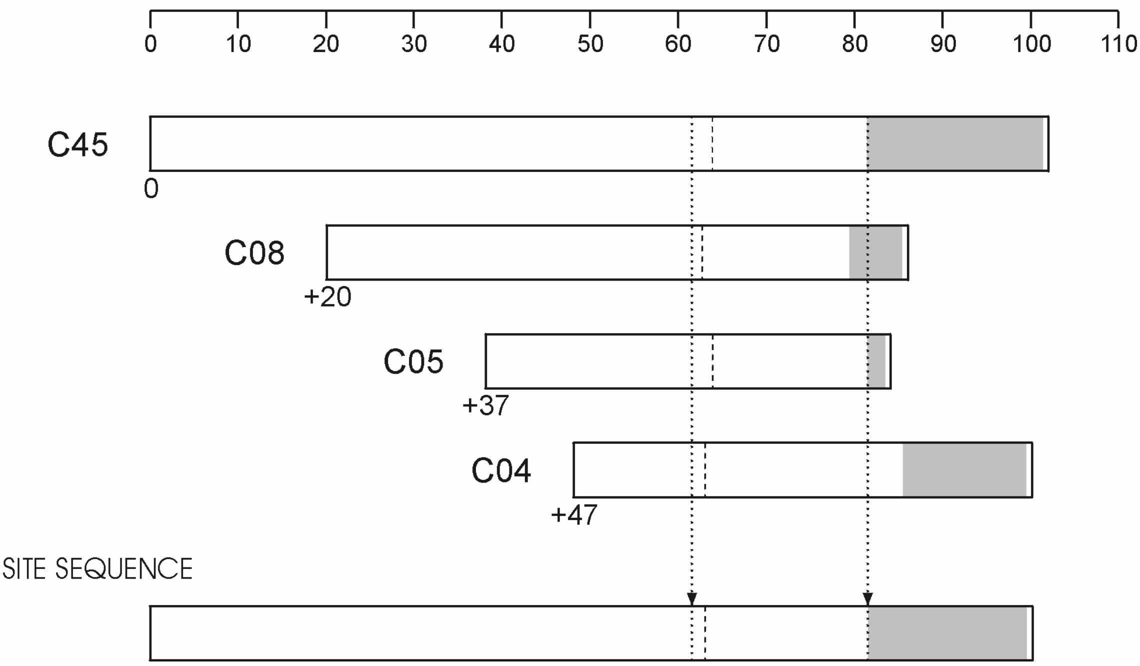


Figure 5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

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.

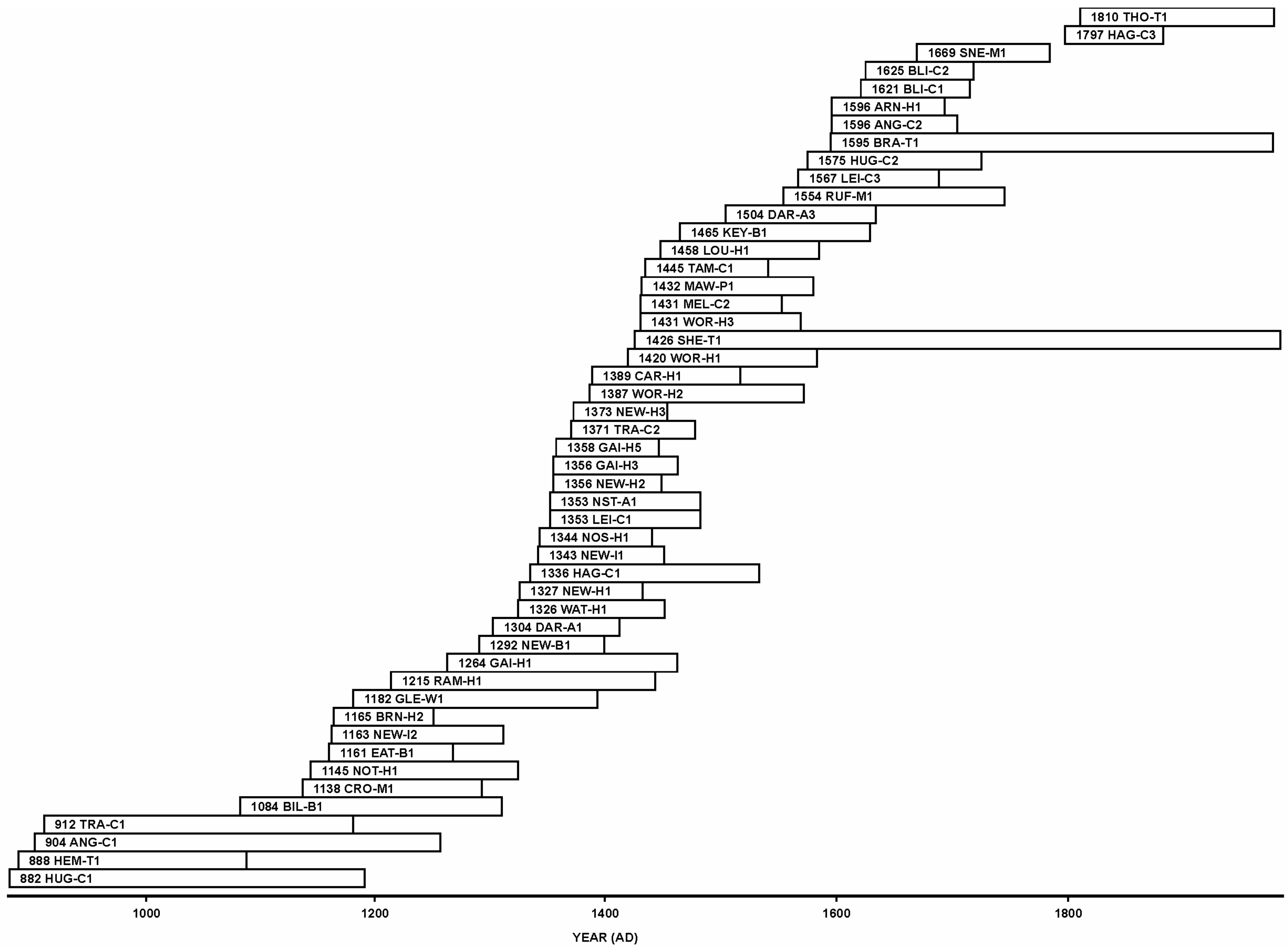
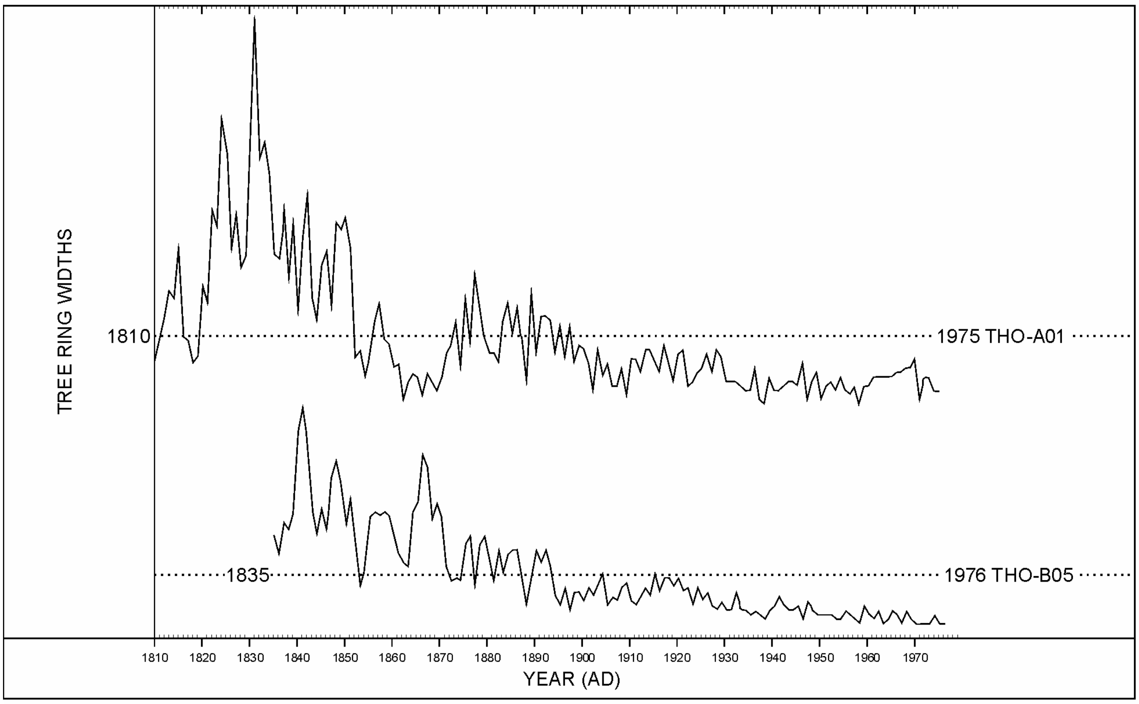


Figure 6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

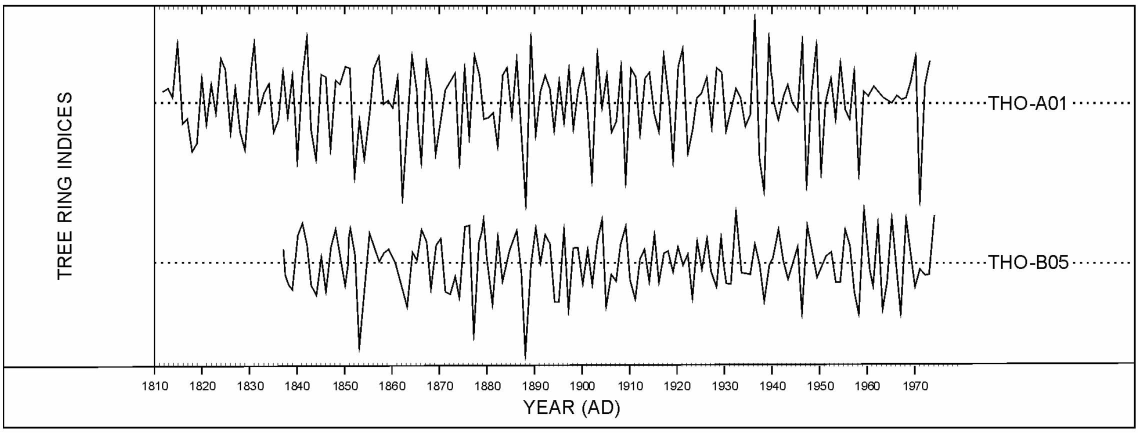


Figure 7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young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

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

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