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YARDE FARMHOUSE, MALBOROUGH, SOUTH HAMS, DEVON
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

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SUMMARY
A number of samples was taken from timbers of various areas at this property, resulting in the construction of five site sequences.
One of these contains 22 samples, taken from the roofs of the North-South and South ranges and from the first- and second-floor joists of the South range, and was found to span the period AD 1432–1603. Interpretation of the sapwood suggests felling of the timbers represented within the range AD 1604–27.
The North-South range was thought to date to the seventeenth century; this has now been supported by the tree-ring results which suggests construction of this part of the building occurred in the first quarter of this century. A quantity of reused timber had been identified within the roof and first-floor joists of the AD 1718 South range. This reused timber has now also been dated to the first quarter of the seventeenth century and is likely to have come from a building contemporary with the North-South range. At least one of the second-floor joists, previously thought to be primary, has been shown to be reused and of the same date as the rest of the timber.
The other four site sequences, comprising a total of nine samples, are undated.

CONTRIBUTORS
Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS
The Laboratory would like to thank the owners of the property for allowing sampling to be undertaken. We would also like to thank John Allan of Exeter Archaeology who kindly arranged access, for his on-site advice and invaluable knowledge of the building, and for providing some of the Figures. Further drawings were produced by Architecton.

ARCHIVE LOCATION
Devon Historic Environment Record
Historic Environment Service
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DATE OF INVESTIGATION
2008–2010

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INTRODUCTION

The former manor house of Yarde Farmhouse is located in Malborough, about 25km south-east of Plymouth (Figs 1–3; SX 7168 4006). The earliest dateable features belong to the late-sixteenth or early seventeenth centuries, although the house may have earlier origins (www.lbonline.english-heritage.org.uk). The original plan of the building is unclear but as seen today, the main part is U-shaped, consisting of a North-South range and two cross-wings that project eastwards: the North range (and eastern extension), and South range (Fig 4). Behind the North-South range is a seventeenth-century two-storey porch, and in the angle between this and the North range is a further, flat-roofed, two-storey porch, thought to date to the twentieth century. To the west of these ranges is a service courtyard, the northern side formed by a western extension to the North range and the western side of the courtyard formed by the kitchen (Fig 4; Thorp 2003).

The present building is mostly the work of the Dyer family, who lived at Yarde Farmhouse between AD 1554 and AD 1765, and illustrates the rising fortunes and social status of the family. No further major building works or refurbishments are thought to have been undertaken after the construction of the South range in the early-eighteenth century (Thorp 2003). Yarde Farmhouse is Grade I listed and a Building at Risk.

South range

This four-storey wing was added in AD 1718 by Richard Dyer after he had inherited the estate from his brother, William. It consists of cellar, two ground-floor reception rooms, a central stair hall, two first-floor bedrooms with closets, and an attic for servants' accommodation.

The roof over this range is of six trusses and five bays, and consists of principal and common rafters, collars, three sets of threaded purlins, and a threaded ridge. However, it is apparent that a large number of the timbers utilised within this roof are reused, with the principal rafters having dovetail-shaped halvings for two lap-jointed collars and two pairs of struts (also lap-jointed), the first down to the lower collar, and the second, presumably down to the tiebeam. The spreader plates on which the trusses rest are cut-up sections of principal rafters. The use of dovetail-shaped lap joints was revived by Cornish carpenters in the late-sixteenth century, spreading to Devon in the early and mid-seventeenth century, suggesting these reused timbers date from this period. Documentary evidence suggests that a sixteenth-century parlour and hall were demolished to provide some of the building materials for the construction of this range (Thorp 2007).

North-South range

This two-storey range is thought to predate the AD 1718 South range and to have originally been the medieval hall. It has a small room at the higher end with a larger heated room beyond it, at the end of which is a through-passage running from the front to the back of the wing (www.lbonline@english-heritage.org.uk). The roof is constructed of a mixture of modern softwood and historic oak timbers. The majority of the oak trusses contain principal rafters which have empty mortices for two sets of through purlins, and would have had halved lap collars, but these are missing (Fig 5). One of the oak trusses (truss 1) can be seen to retain its cranked collar with notched halving joint (Fig 6).

North range

This two-storey range was thought to have been added in the seventeenth century to run parallel to the original parlour range (www.lbonline@english-heritage.org.uk). Although most of the roof is modern, two trusses contain historic timbers. The north principals of these two trusses again have empty mortices, demonstrating they once had through purlins, whilst the southern principals had trenched purlins (Fig 7).

SAMPLING

Tree-ring dating of the timbers at Yarde Farmhouse was requested by Francis Kelly, Historic Buildings Inspector in English Heritage's South-West Office to inform repairs to this Building at Risk. Timbers deemed suitable for sampling were identified within the floors and roof of the South range (reused and apparently primary timbers) and the roofs of the North and North-South ranges, and of the porch.

It was hoped that by providing a date for those reused timbers used in the construction of the roof and the first-floor joists within the South range it would be possible to establish whether they were sixteenth-century and might have come from the same building as other architectural elements reused within this wing. Dating the cellar and attic joists, which appeared to be primary, would hopefully confirm the AD 1718 construction date for this range. It is unclear as to whether the oak roof timbers within the North-South and North ranges are reused or primary and it was hoped that providing dates for these timbers might clarify the situation. Access to the top of a single truss in the porch gave an opportunity to potentially date this roof. Overall, it was hoped that by dating timbers throughout the building, a greater understanding of the development of the building as a whole and the relationship between the various ranges would be obtained.

Although dendrochronological analysis of other areas of the building complex, including the east and west extensions to the North range and the kitchen range, was requested, unfortunately no suitable timbers were found.

In accordance with the brief provided by English Heritage, a total of 46 timbers were sampled. Each sample was given the code YRD-F (for Yarde Farmhouse) and numbered 01–46. Thirty-two of these were taken from the South range, 12 from the reused timbers of the roof (YRD-F01–12), five from the second-floor joists (YRD-F13–17), ten from the timbers of the first-floor joists (YRD-F18–27), and five from the cellar (YRD-F28–32). Two samples were taken from the single accessible truss of the porch roof (YRD-F33 and YRD-F34). Ten samples were taken from the roof of the North-South range (YRD-F35–44) and finally, two samples were taken from the roof of the North range (YRD-F45 and YRD-F46), with the other timbers from this structure being either modern softwood replacements or unsuitable for analysis.

The location of samples was noted at the time of sampling and has been marked on Figures 8–19. Further details relating to the samples can be found in Table 1. Roof trusses, joists, and other timbers have been numbered from east to west or north to south (as appropriate), or follows the numbering system employed by John Allan (Figs 12 and 13).

ANALYSIS AND RESULTS

At this stage it was noticed that eight of the samples (six from the South range and two from the North-South range) had too few rings to make secure dating a possibility. These samples were rejected prior to measurement. The remaining 38 samples were prepared by sanding and polishing and their growth-ring widths measured; the data of these measurements are given at the end of the report. These samples were compared with each other by the Litton/Zainodin grouping procedure (see Appendix), resulting in 31 samples forming five groups.

Firstly, 22 samples matched each other and were combined at the relevant offset positions to form YRDFSQ01, a site sequence of 172 rings (Fig 20). This site sequence was compared against the relevant reference chronologies where it was found to match consistently and securely at a first-ring date of AD 1432 and a last-ring date of AD 1603. The evidence for this dating is given in Table 2.

These samples are taken from timbers of the North-South and South range roofs and the first and second-floor joists of the South range. Eighteen of these samples have the heartwood/sapwood boundary ring, which in all cases is broadly contemporary, ranging by only 15 years, and suggestive of a single felling. The average heartwood/sapwood boundary ring date is AD 1587, allowing an estimated felling date range to be calculated for the 18 timbers represented of AD 1604–27. This takes into account sample YRD-F36 having a last measured ring date of AD 1603 with incomplete sapwood. Further support of contemporary felling is given by the good intra-site matching of samples from different areas seen, consistent with a coherent group of timbers being utilised.

The remaining four samples without the heartwood/sapwood boundary ring have last-measured ring dates ranging from AD 1540 (YRD-F41) to AD 1571 (YRD-F12) which makes it possible that these are also from timbers felled in AD 1604–27.

Three samples, all taken from timbers of the cellar, matched each other and were combined at the relevant offset positions to form YRDFSQ02, a site sequence of 87 rings (Fig 21). Two further samples from the cellar matched each other and were combined to form YRDFSQ03, a site sequence of 59 rings (Fig 22). Two samples taken from principal rafters of the porch roof matched each other and were combined to form YRDFSQ04, a site sequence of 80 rings (Fig 23) and, finally, two samples from the North range roof were combined to form YRDFSQ05, a site sequence of 130 rings (Fig 24). Attempts to date these four site sequences by comparing them against the relevant reference chronologies were unsuccessful and these remain undated.

The remaining ungrouped samples were then individually compared against the reference chronologies and, although some tentative dating was noted, this was not considered secure, and these also to remain undated.

DISCUSSION

Prior to tree-ring analysis being undertaken, Yarde Farmhouse was believed to date to the late sixteenth or early-seventeenth century, although there had been suggestions that it may have had earlier origins. The dated timbers are restricted to the North-South range roof and the South range. These were all felled in the first quarter of the seventeenth century and no evidence of any earlier timbers has been found.

The dendrochronological analysis has successfully dated timbers along the whole length of the roof of the North-South range to a felling of AD 1604–27, demonstrating that this part of the building was probably constructed in the seventeenth century, hence pre-dating the AD 1718 South range as previously suggested, and furthermore narrowing construction to the first quarter of the seventeenth century.

Within the AD 1718 South range added by Richard Dyer, timbers of the roof and the first and second-floor joists have also been dated to AD 1604–27. The roof timbers and first-floor joists were believed to be reused and this supposition has now been confirmed by the dendrochronological analysis. However, although the second-floor joists were not thought to be reused, it has now been shown that at least one of these, a main joist, was also reused. Documentary evidence had suggested a sixteenth-century parlour and hall were demolished to make way for this new South range, providing building materials, including timber. However, with the reused roof and joist timbers all dating to the first quarter of the seventeenth century, this is clearly not the case, unless these sixteenth-century structures had been previously extensively remodelled.

The good intra-site cross-matching seen between the timbers of the North-South range and the reused ones in the South range is suggestive of the trees growing in close proximity to each other. This could perhaps support the hypothesis that the South range roof and floor-framing is constructed utilising timbers from a demolished range on site which was contemporary with the North-South range.

It is unfortunate that none of the other site sequences could be matched against the reference material. Dating these primary timbers would have provided evidence as to the construction dates of the North range roof and the porch and cellar stairs in the South range, and hence potentially provided supporting evidence for the AD 1718 construction of the South range.

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Thorp, J R L, 2007 unpubl *Observations at Yarde, Marlborough (sic), Devon*, Keystone Historic Buildings Consultants, Rep K677/2

TABLES AND FIGURES

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
South Range roof – reused						
YRD-F01	North principal rafter, truss 1	128	h/s	1454	1581	1581
YRD-F02	Collar, truss 1	NM	--	----	----	----
YRD-F03	South principal rafter, truss 2	55	h/s	1533	1587	1587
YRD-F04	Collar, truss 2	50	h/s	1544	1593	1593
YRD-F05	South principal rafter, truss 3	66	h/s	1529	1594	1594
YRD-F06	Collar, truss 3	68	h/s	1527	1594	1594
YRD-F07	South principal rafter, truss 4	59	h/s	1531	1589	1589
YRD-F08	North principal rafter, truss 6	63	h/s	1522	1584	1584
YRD-F09	North principal rafter, truss 2	NM	--	----	----	----
YRD-F10	South principal rafter, truss 5	NM	--	----	----	----
YRD-F11	North upper purlin, truss 5-6	62	h/s	1527	1588	1588
YRD-F12	South upper purlin, truss 5-6	69	--	1503	----	1571
Second-floor/attic joists – presumed primary						
YRD-F13	Main joist	105	h/s	1483	1587	1587
YRD-F14	Joist 2	61	h/s	----	----	----
YRD-F15	Joist 3	55	--	----	----	----
YRD-F16	Joist 4	NM	--	----	----	----
YRD-F17	Joist 7	NM	--	----	----	----
First-floor joists – reused						
YRD-F18	Main north joist	68	h/s	1522	1589	1589
YRD-F19	Main south joist	133	h/s	1453	1585	1585
YRD-F20	Joist 2	103	--	1442	----	1544
YRD-F21	Joist 3	81	--	----	----	----
YRD-F22	Joist 7	103	h/s	1478	1580	1580
YRD-F23	Joist 9	NM	--	----	----	----
YRD-F24	Joist 11	66	h/s	----	----	----
YRD-F25	Joist 20	66	h/s	1530	1595	1595

YRD-F26	Joist 25	118	h/s	1469	1586	1586
YRD-F27	Joist 27	73	h/s	----	----	----
Cellar						
YRD-F28	Base plate	81	h/s	----	----	----
YRD-F29	Understair hanging rail/closing stile	78	h/s	----	----	----
YRD-F30	Understair mid-rail	59	--	----	----	----
YRD-F31	Understair rail 1	53	h/s	----	----	----
YRD-F32	Understair rail 2	59	h/s	----	----	----
Porch						
YRD-F33	North principal rafter	74	h/s	----	----	----
YRD-F34	South principal rafter	59	01	----	----	----
North-South Range roof						
YRD-F35	East principal rafter, truss 1	NM	--	----	----	----
YRD-F36	West principal rafter, truss 1	83	18	1521	1585	1603
YRD-F37	Collar, truss 1	48	14	----	----	----
YRD-F38	West principal rafter, truss 2	54	--	1518		1571
YRD-F39	East principal rafter, truss 4	96	h/s	1492	1587	1587
YRD-F40	West principal rafter, truss 4	78	h/s	----	----	----
YRD-F41	East principal rafter, truss 6	109	--	1432`	----	1540
YRD-F42	West principal rafter, truss 6	NM	--	----	----	----
YRD-F43	East principal rafter, truss 8	80	h/s	1505	1584	1584
YRD-F44	West principal rafter, truss 8	47	h/s	1539	1585	1585
North Range						
YRD-F45	North principal rafter, truss 12	88	h/s	----	----	----
YRD-F46	North principal rafter, truss 14	98	--	----	----	----

*NM = not measured.

**h/s = the heartwood/sapwood boundary ring is the last measured ring on the sample

Table 2: Results of the cross-matching of site sequence YRDFSQ01 and relevant reference chronologies when the first-ring date is AD 1432 and the last-ring date is AD 1603

Reference chronology	*t*-value	Span of chronology	Reference
26 Westgate Street, Gloucester, Glos	9.0	AD 1399–1622	Howard *et al* 1998a
The Guildhall, Worcester, Worcs	8.6	AD 1361–1609	Arnold *et al* 2006
Naas House, Lydney, Glos	8.4	AD 1373–1568	Howard *et al* 1998b
Exeter Quay, Devon	8.4	AD 1407-1606	Mills 1988
Wales and West Midlands	8.3	AD 1341–1636	Siebenlist-Kerner 1978
St Briavel's Castle, Glos	7.9	AD 1362–1636	Howard *et al* 1999
Warleigh House, Tamerton Foliot, Devon	7.7	AD 1367–1539	Howard *et al* 2006

Figure 1: Map to show the general location of Malborough

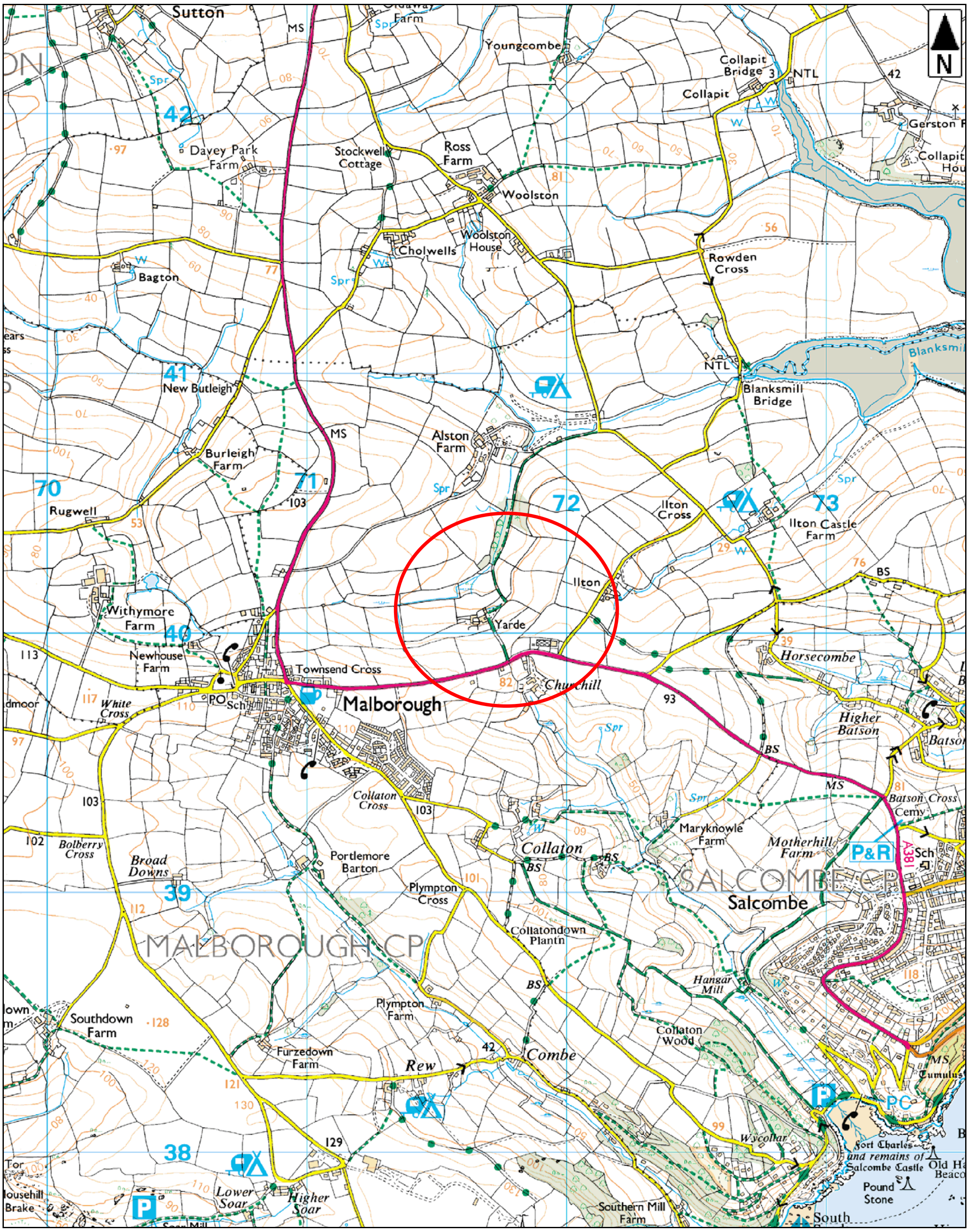


Figure 2: Map to show the location of Yarde Farmhouse

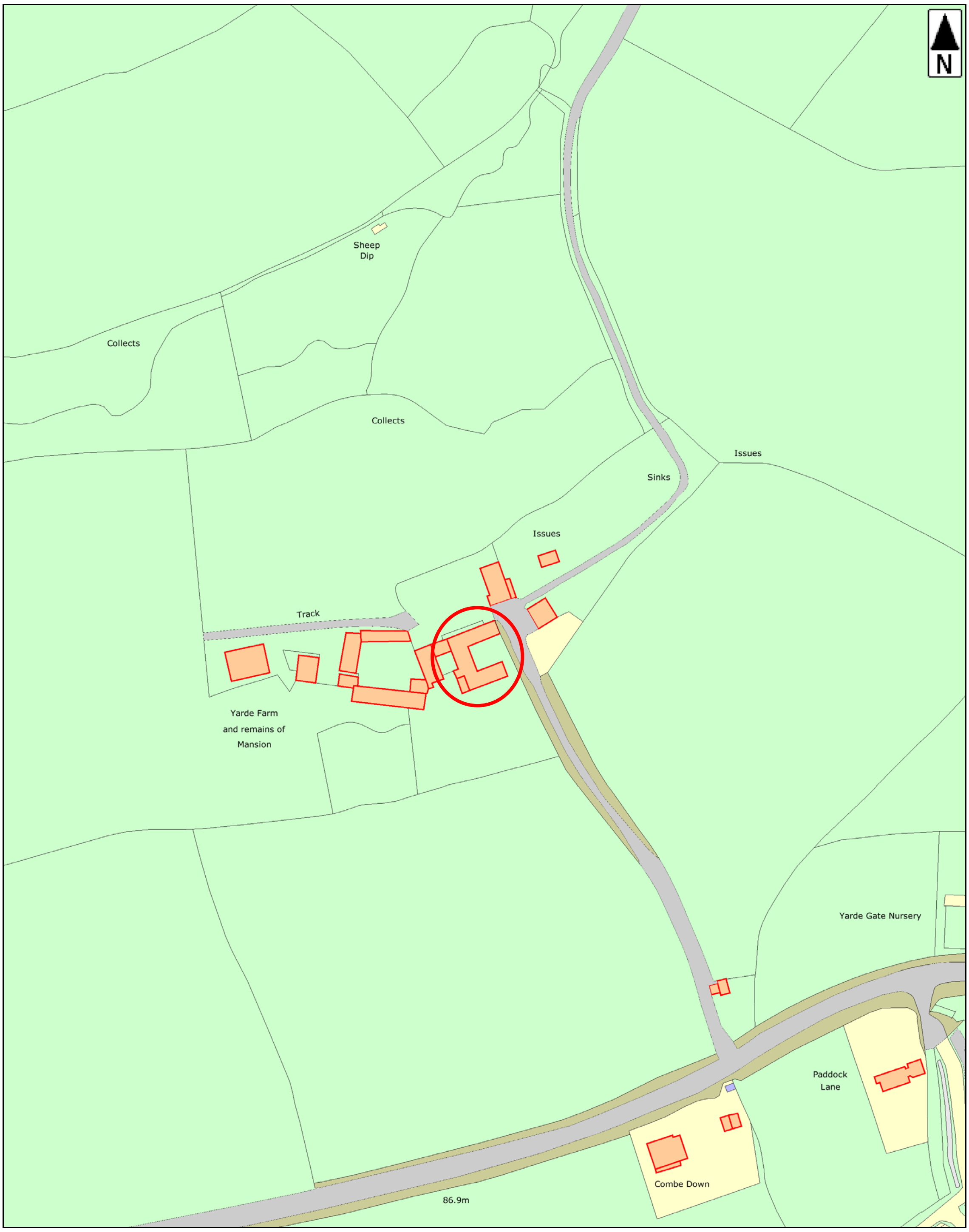


Figure 3: Map to show the location of Yarde Farmhouse

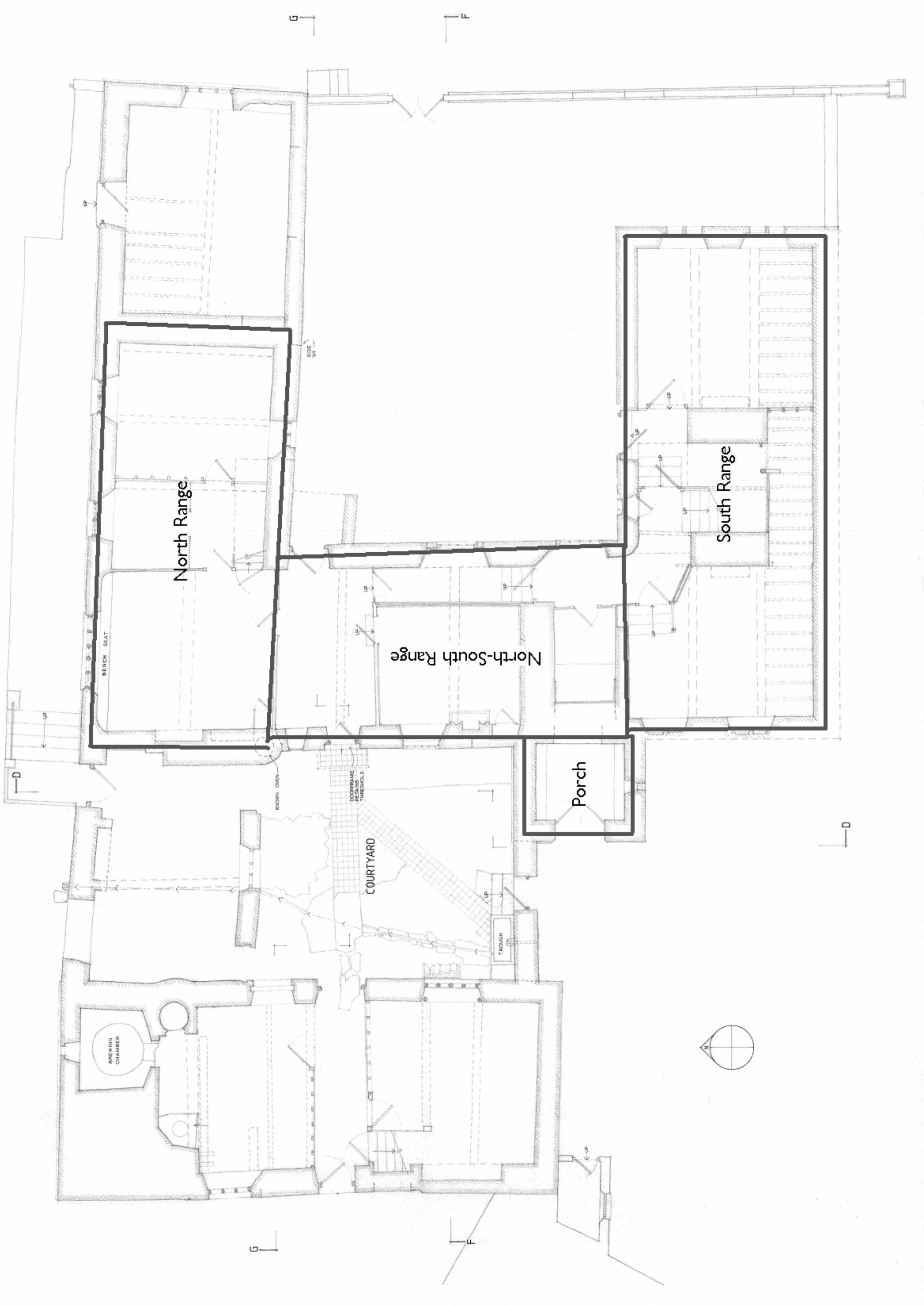


Figure 4: Yarde Farmhouse, at ground-floor and (South range) cellar level, areas under investigation outlined (Architecton)

Figure 5: North-south range, showing the empty mortices for collars and through purlins in the principal rafters, looking north

Figure 6: North-south range; truss 1, taken from the north-east

Figure 7: North range; looking east

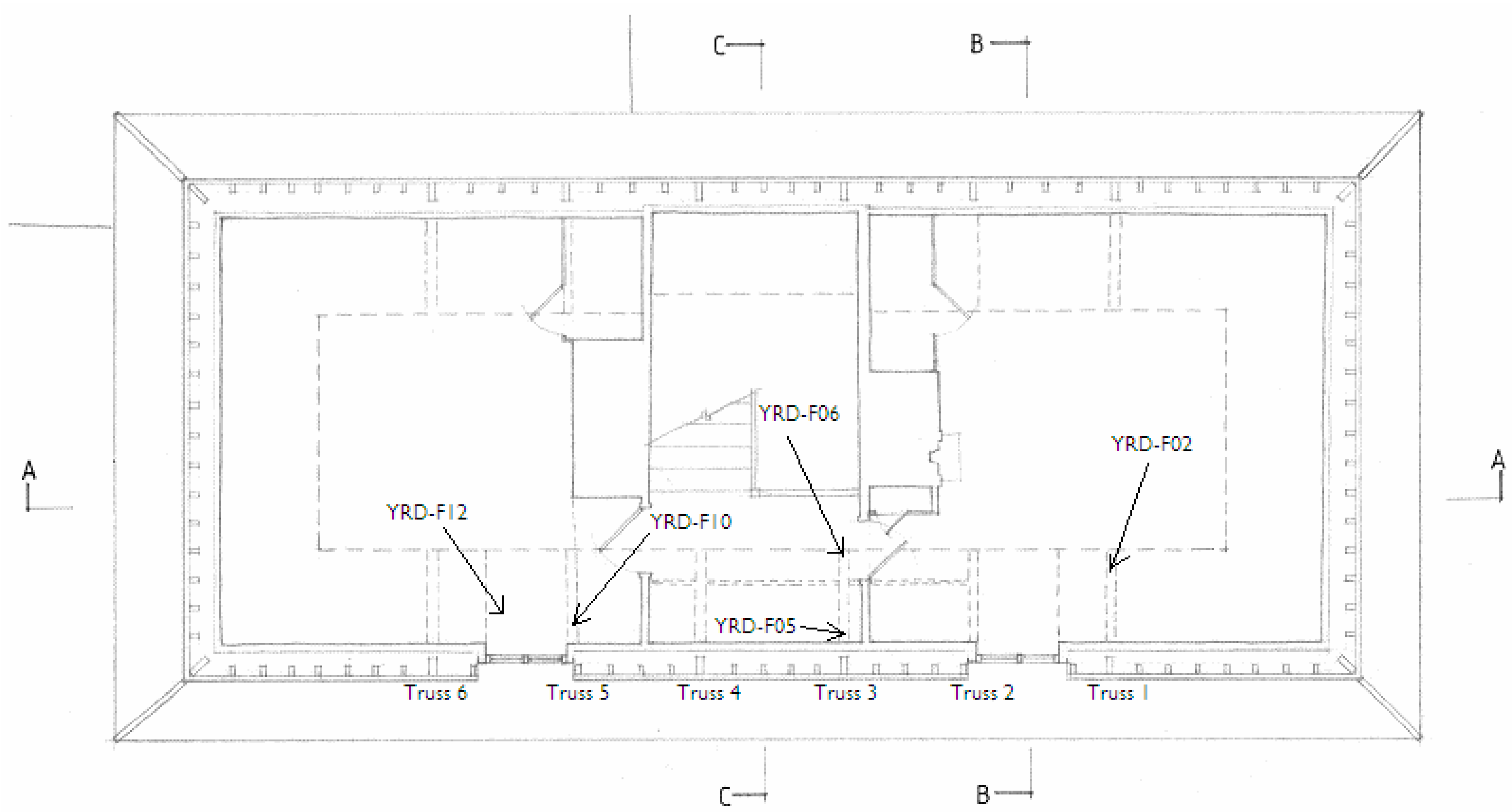


Figure 8: Yarde Farmhouse; South range, second floor plan, showing truss position and the location of samples YRD-F02, YRD-F05–06, YRD-F10, and YRD-F12 (Architecton)

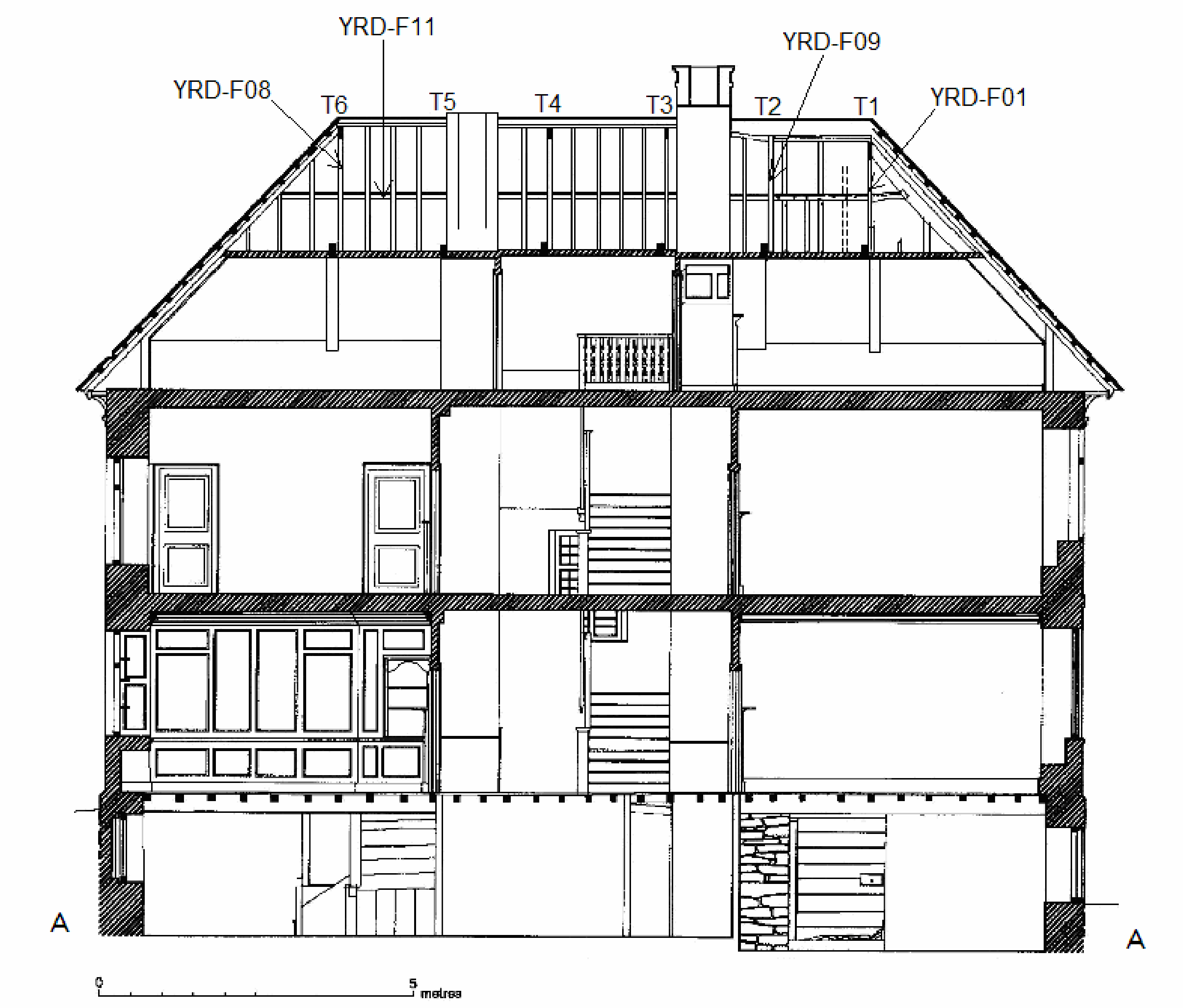


Figure 9: South range; north side A–A, showing the location of samples YRD-F01, YRD-F08–09, and YRD-F11 (John Allan; section position marked on Fig 8)

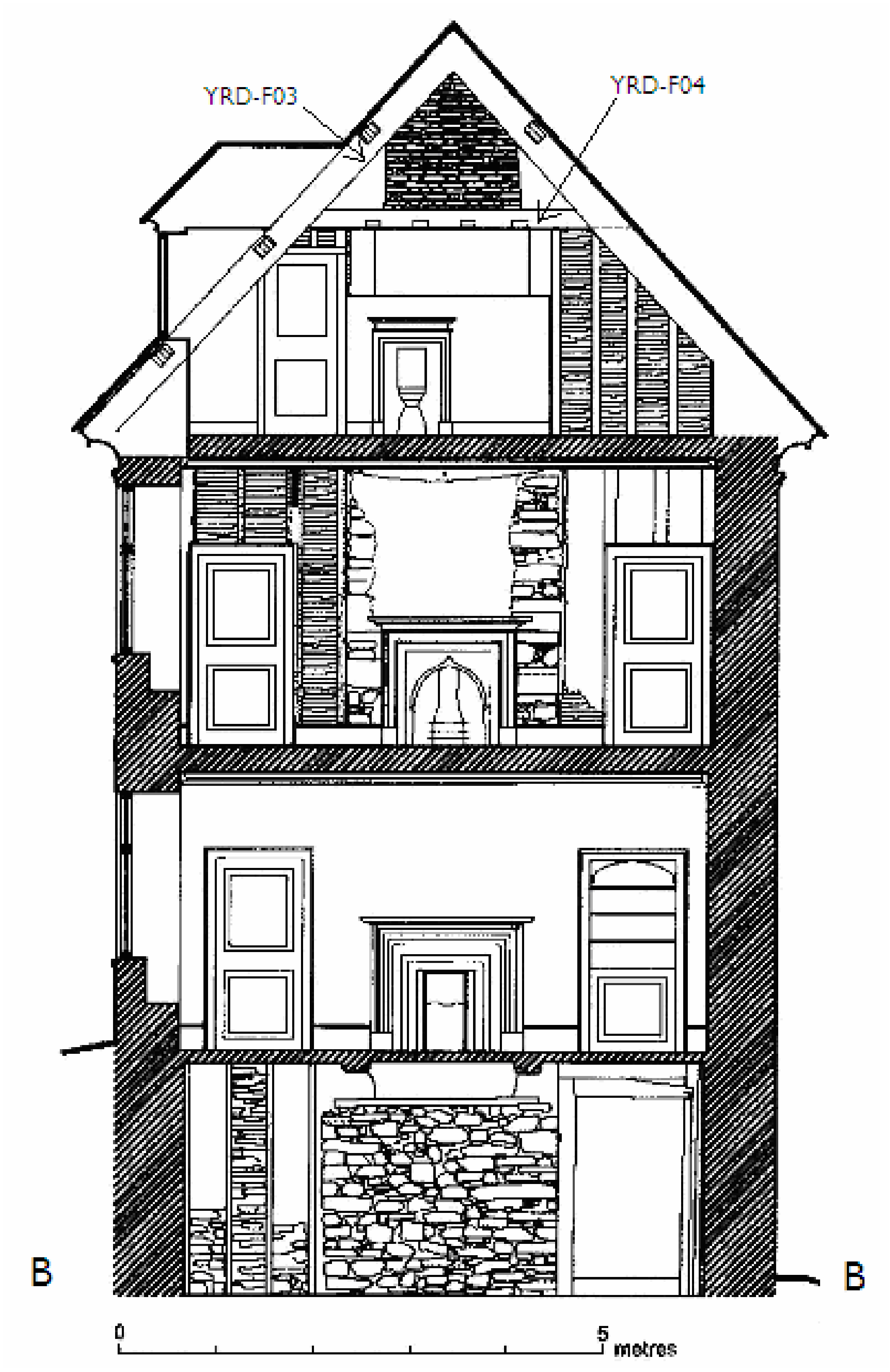


Figure 10: South range; east facing section B–B, showing the location of samples YRD-F03 and YRD-F04 (John Allan, location of section marked on Fig 8)

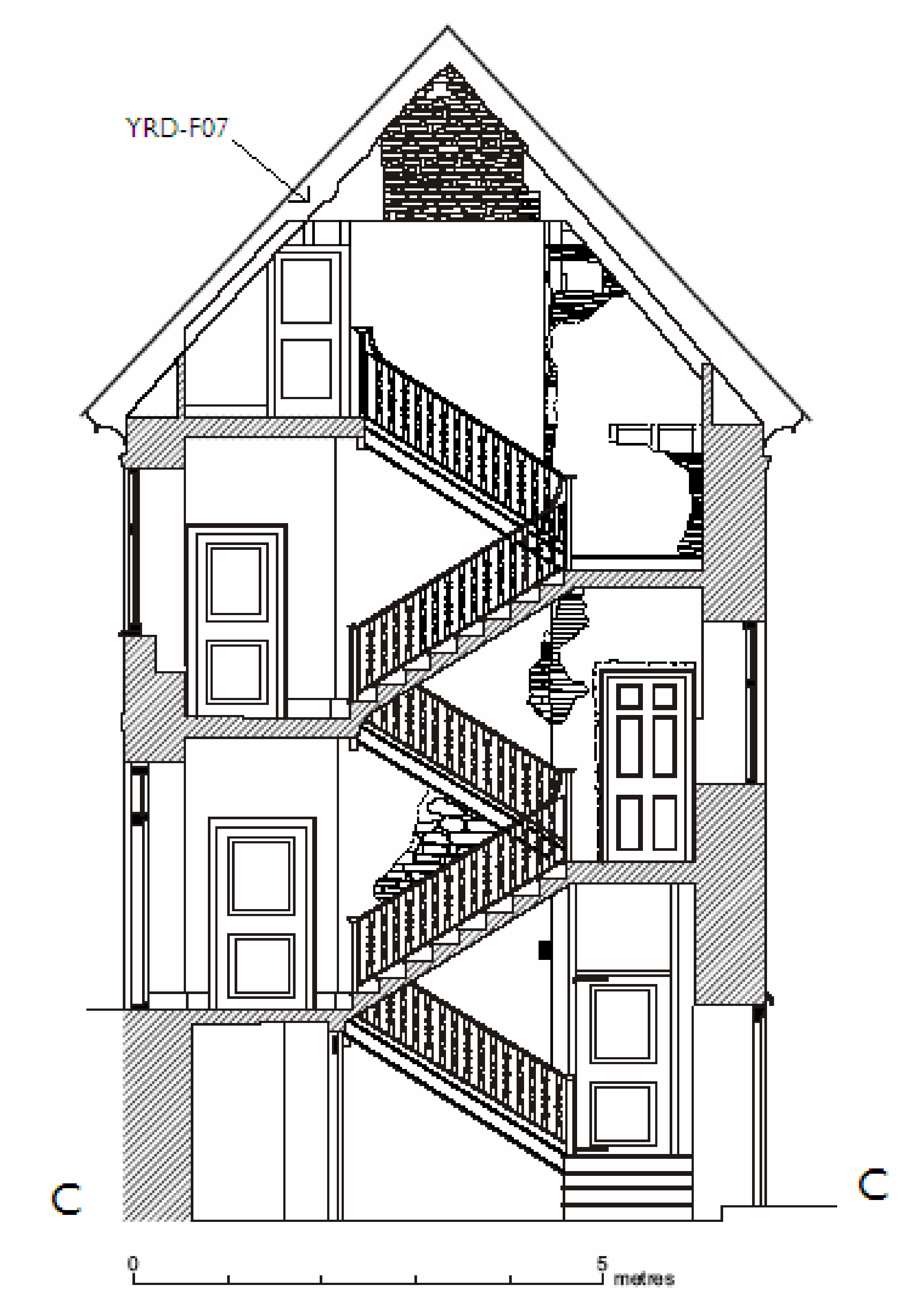


Figure 11: South range; east facing section C–C, showing the location of sample YRD-F07 (John Allan, location of section marked on Fig 8)

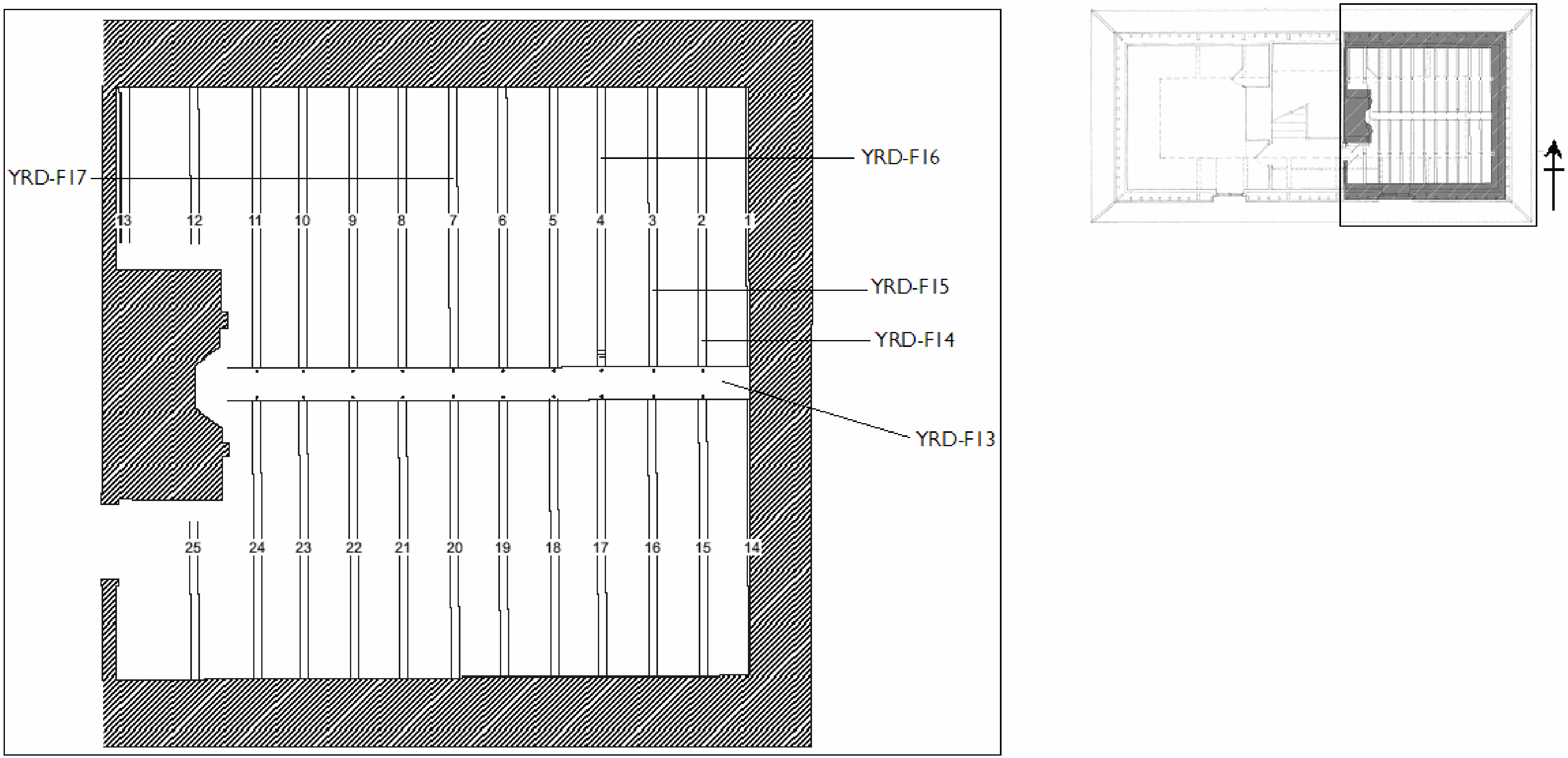


Figure 12: South range; Second floor joists, showing the location of samples YRD-F13–17 (John Allan)

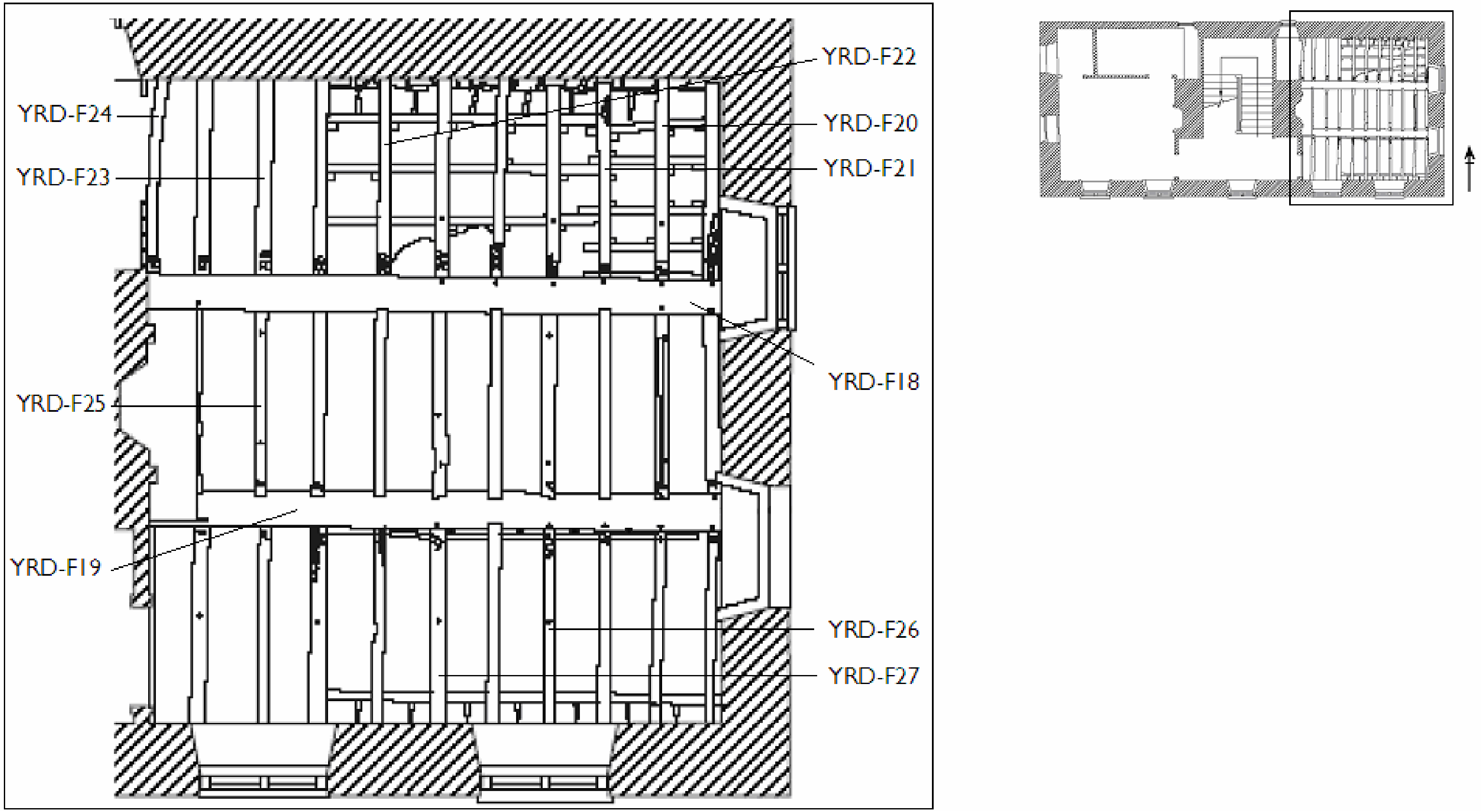
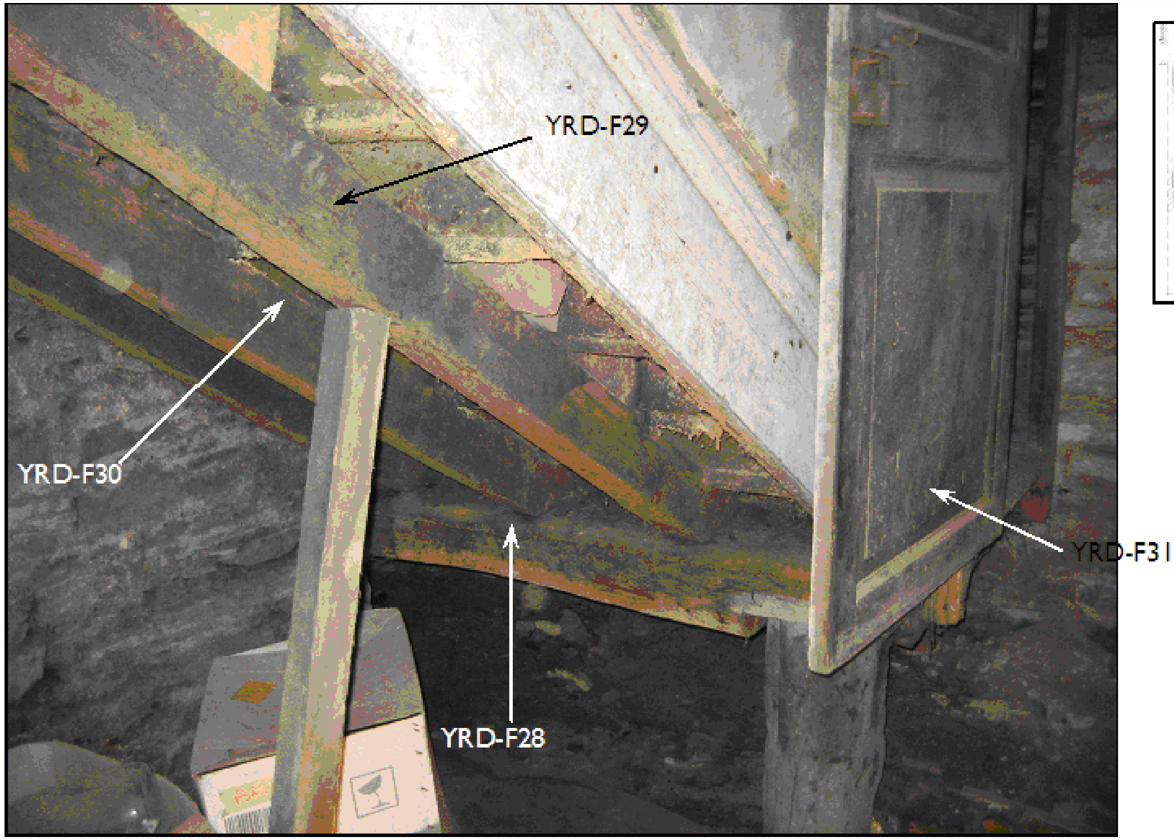
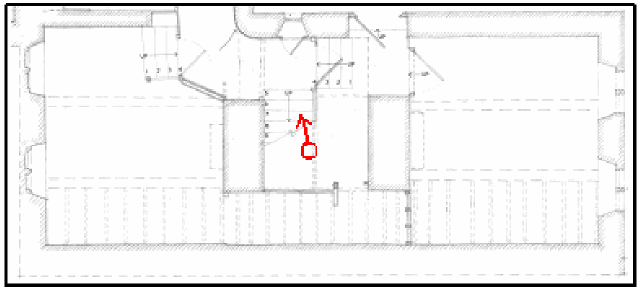


Figure 13: South range: First-floor joists, showing the location of samples YRD-F18–27 (John Allan)





Location and orientation of Fig 14

Figure 14: South range: Cellar, showing the location of samples YRD-F28–31

Figure 15: South range: Cellar, showing the location of sample YRD-F32

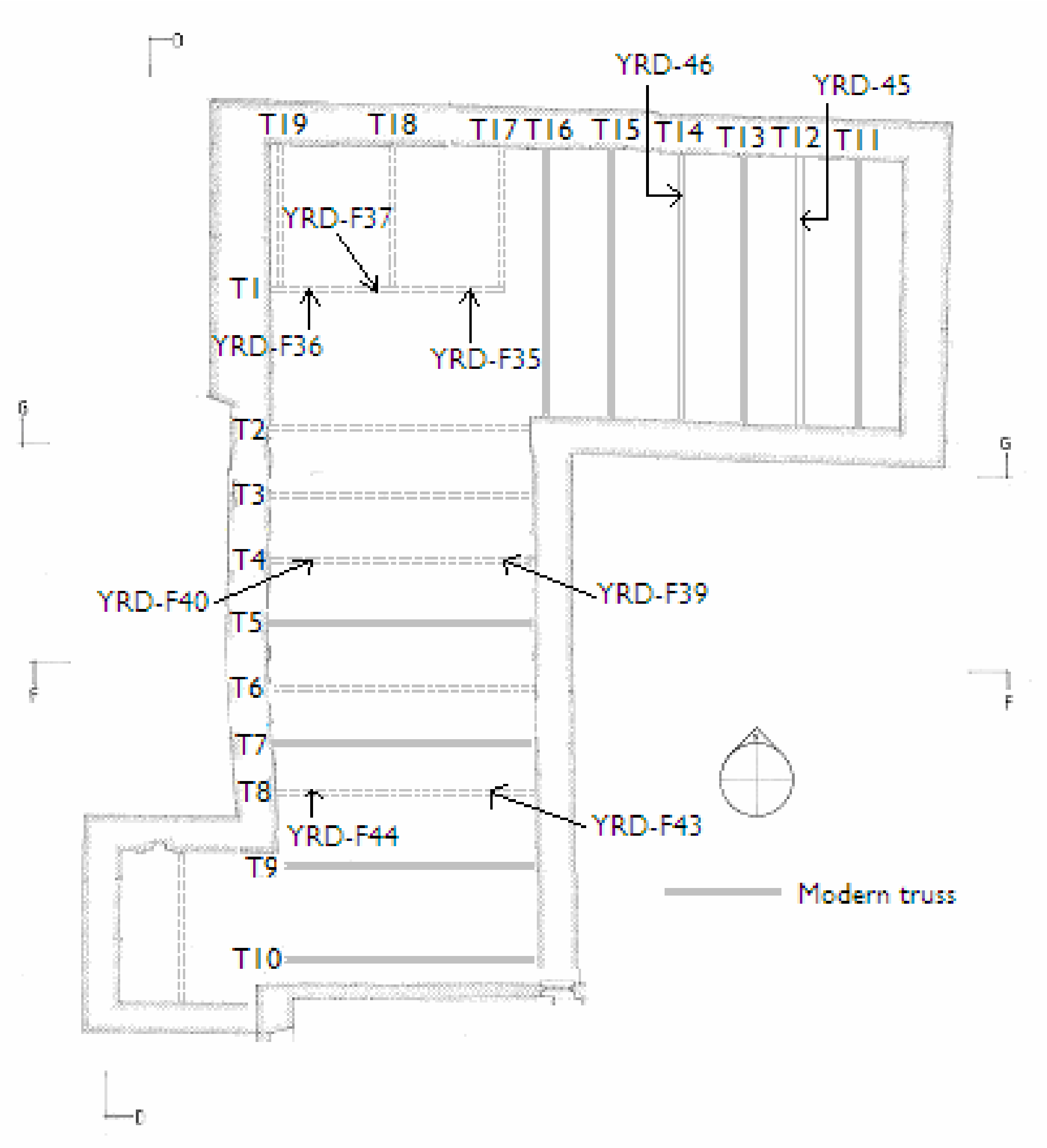


Figure 16: Approximate truss positions in the North-south and North ranges and the Porch, showing the location of samples YRD-F35–37, YRD-F39–40 and YRD-F43–46 (Architecton, amended)

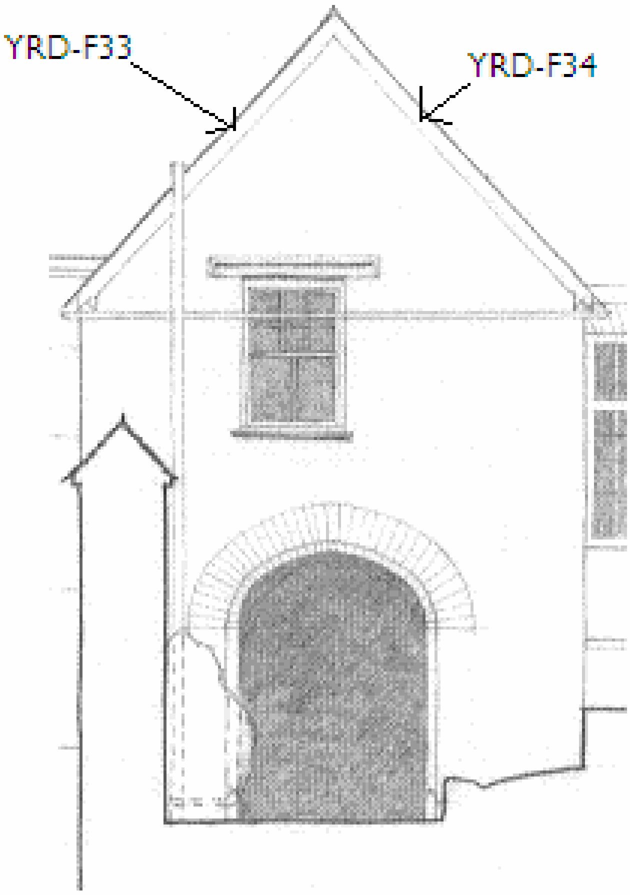


Figure 17: West-facing section D–D through the porch, showing the location of samples YRD-F33 and YRD-F34 (Architecton, position of section shown on Fig 16)

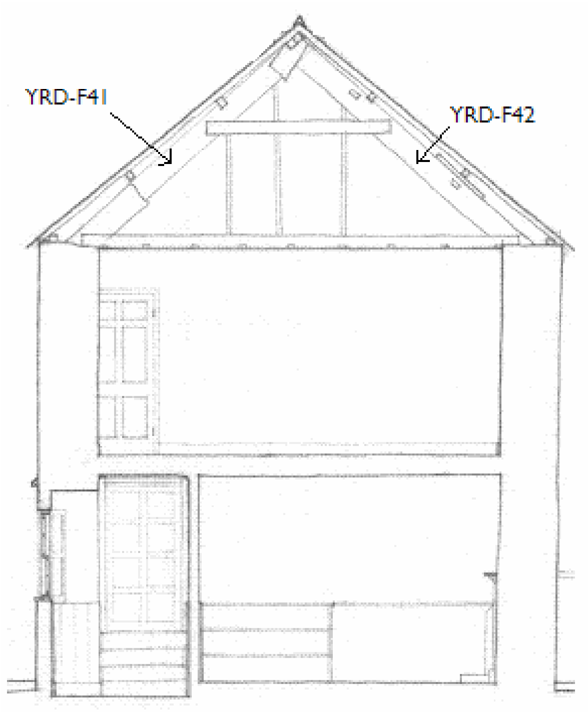


Figure 18: North-facing section through the North-South range, showing truss 6 and the location of samples YRD-F41 and YRD-F42 (Architecton, section position shown on Fig 16)

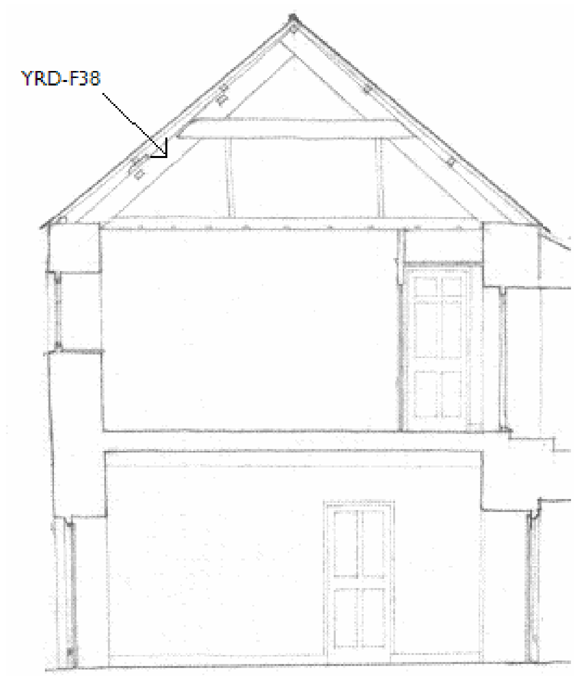


Figure 19: South-facing section through the North-South range, showing truss 2 and the location of sample YRD-F38 (Architecton, section position shown on Fig 16)

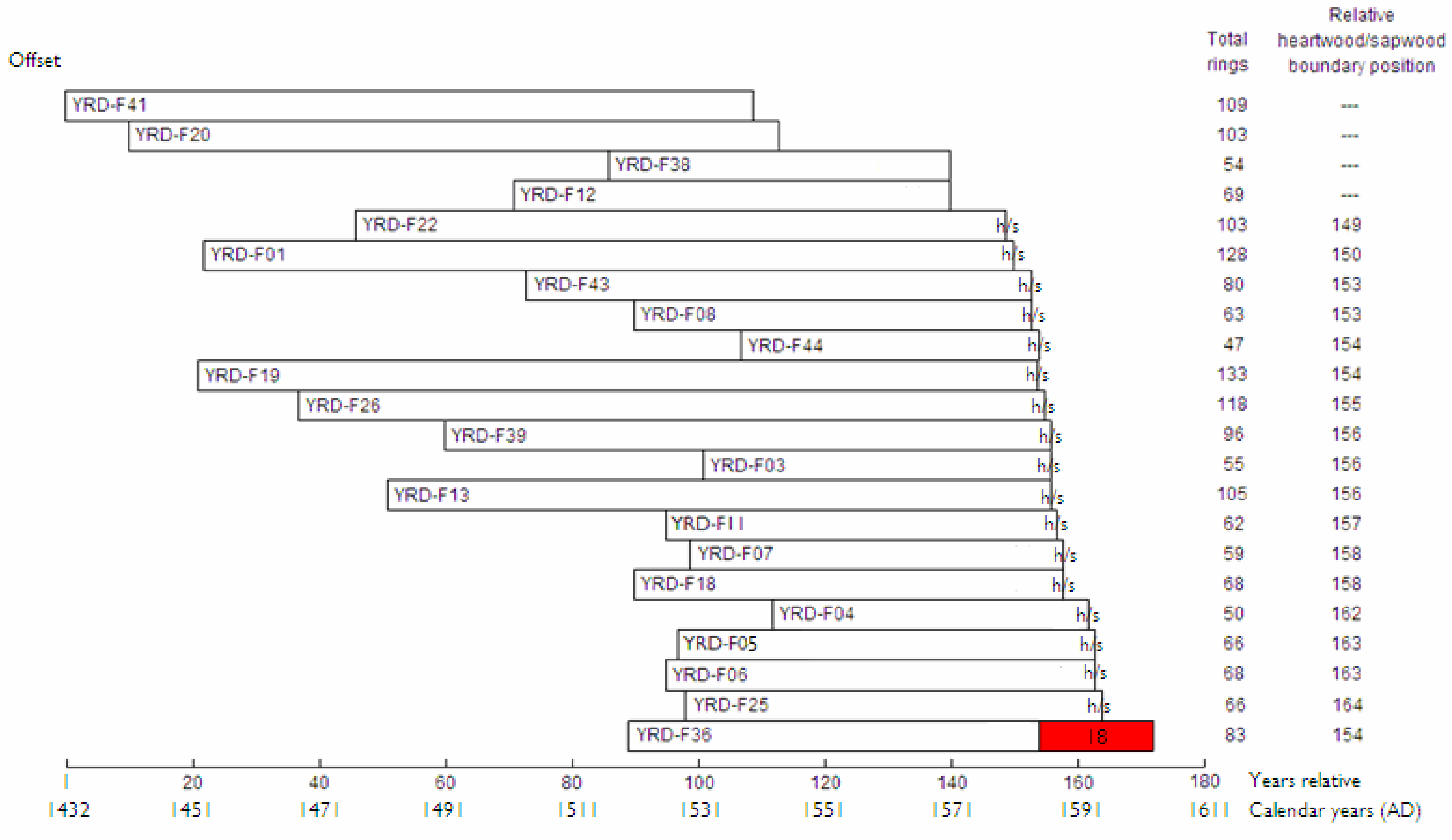


Figure 20: Bar diagram of samples in site sequence YRDFSQ01

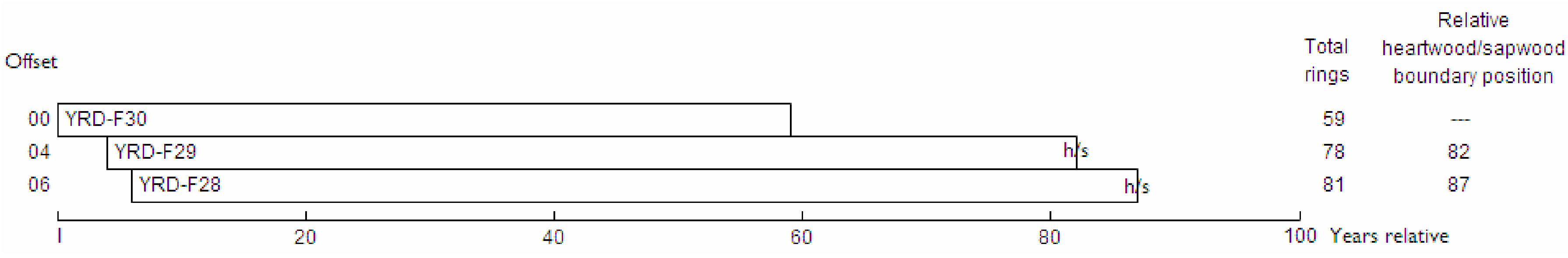


Figure 21: Bar diagram of samples in undated site sequence YRDFSQ02

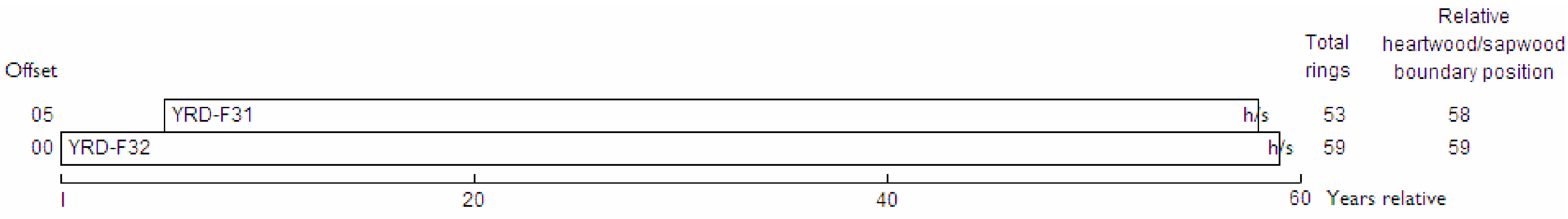


Figure 22: Bar diagram of samples in undated site sequence YRDFSQ03

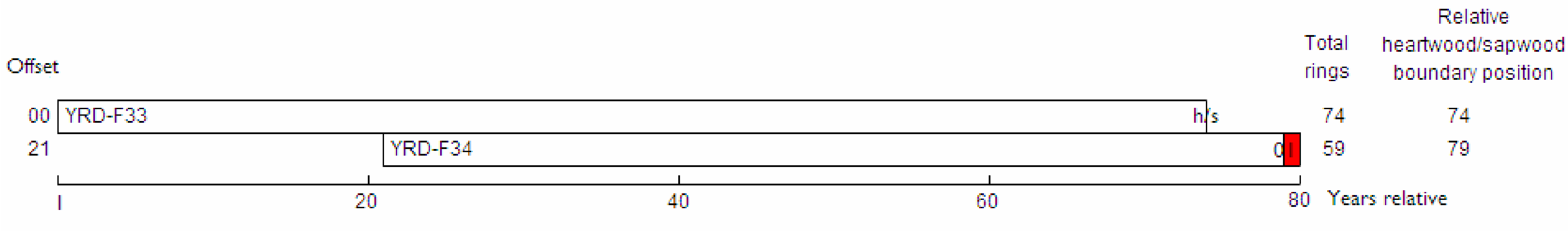


Figure 23: Bar diagram of samples in undated site sequence YRDFSQ04

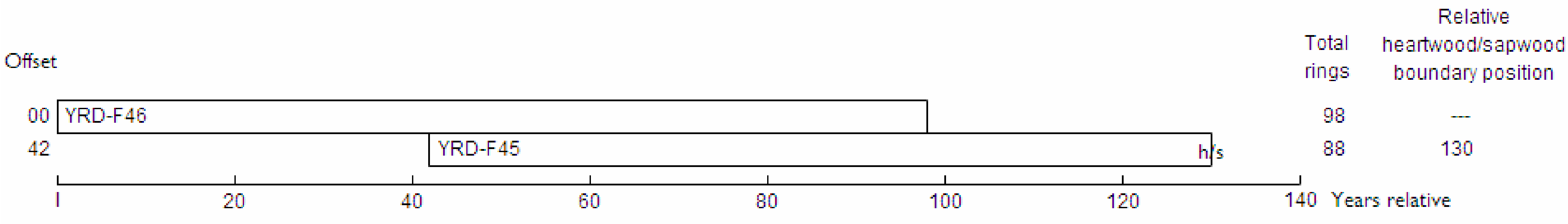


Figure 24: Bar diagram of samples in undated site sequence YRDFSQ05

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

YRD-F01A 128
189 189 183 198 217 245 235 231 131 153 142 158 178 172 131 159 196 164 140 95
132 195 186 119 107 130 111 213 158 142 163 170 200 175 132 171 92 92 84 102
174 127 124 120 73 81 93 76 48 98 99 99 64 47 53 59 43 62 68 74
89 37 42 38 44 45 38 45 94 40 47 33 39 42 42 47 35 58 48 37
34 32 55 66 57 78 102 118 43 109 118 130 75 88 66 59 66 88 80 57
77 88 65 67 48 91 55 86 64 55 91 133 78 53 59 64 62 76 66 64
67 60 49 65 65 64 45 50
YRD-F01B 128
188 179 179 205 211 239 246 222 140 152 145 156 186 178 134 180 199 170 147 89
138 190 193 118 106 138 109 211 155 149 158 179 198 182 142 152 102 86 82 95
172 118 127 126 75 91 83 79 57 91 99 95 69 45 55 50 46 62 61 79
82 39 42 33 43 47 39 50 89 43 45 40 32 44 51 40 24 66 44 42
23 40 56 68 53 58 102 101 48 109 114 121 80 97 74 61 70 101 84 63
76 87 64 67 56 90 67 83 70 67 91 140 65 54 48 67 58 75 64 69
69 52 45 62 56 51 39 53
YRD-F03A 55
160 245 383 229 201 207 266 302 254 209 297 279 243 254 217 239 298 250 301 220
181 189 283 175 188 240 304 237 265 234 154 219 236 222 178 163 193 271 238 162
216 206 185 151 176 176 198 226 147 169 151 223 212 171 161
YRD-F03B 55
171 248 357 224 205 205 260 307 247 211 283 288 241 270 217 239 304 248 283 224
184 190 286 173 187 244 300 235 263 216 145 216 233 221 174 161 195 270 225 165
206 202 183 150 172 178 205 224 147 157 168 221 211 173 149
YRD-F04A 50
114 155 98 98 75 138 100 130 136 123 147 217 108 171 135 147 128 135 143 125
141 177 165 128 97 119 113 108 96 135 121 104 124 109 108 122 123 92 100 83
93 122 117 151 105 153 82 117 105 131
YRD-F04B 50
108 156 98 97 76 133 102 124 168 118 148 219 105 171 140 141 128 135 140 129
140 177 161 127 98 113 119 108 98 134 125 108 125 114 105 125 125 86 98 87
98 120 114 155 103 148 87 116 104 132
YRD-F05A 66
203 209 317 267 249 279 335 259 262 208 284 261 261 175 268 283 218 241 203 188
260 200 302 217 178 186 254 155 216 247 269 242 209 189 125 198 240 212 171 167
197 208 181 157 220 257 198 169 154 141 157 183 103 115 96 137 146 139 247 196
236 141 171 145 158 171
YRD-F05B 66
224 206 318 270 249 282 335 259 257 214 278 269 254 173 270 277 221 237 204 188
265 199 301 218 178 187 250 146 214 246 262 242 202 179 130 196 229 217 168 174
194 206 183 153 220 254 204 163 157 144 151 184 106 109 101 139 136 146 250 193
241 144 167 151 152 170
YRD-F06A 68
231 286 178 195 302 263 192 212 255 262 244 212 246 287 266 204 237 246 259 180
196 148 191 143 163 114 122 110 141 107 92 103 126 102 114 97 88 131 111 117
83 87 95 97 100 100 126 126 117 103 125 95 109 138 101 124 111 113 163 120
150 99 131 93 97 81 99 127

YRD-F06B 68
254 264 177 179 308 249 171 210 257 271 229 197 232 296 250 201 224 250 244 181
198 146 176 152 167 120 122 121 142 100 107 89 122 120 104 102 84 131 116 113
87 86 93 99 101 98 127 122 124 104 124 102 95 126 121 120 116 108 170 131
150 104 139 86 95 85 79 129
YRD-F07A 59
116 160 142 198 257 235 286 316 384 372 454 329 349 393 257 313 318 316 384 391
446 428 270 490 409 217 261 340 439 373 385 370 290 366 295 200 193 201 270 217
254 180 220 280 192 179 172 154 180 211 162 177 180 229 276 313 405 214 260
YRD-F07B 59
138 161 137 198 254 250 285 313 371 376 428 328 348 396 271 316 308 305 379 391
445 416 289 502 396 207 288 325 416 399 382 386 273 346 291 194 191 206 262 221
248 182 223 276 197 179 168 156 179 213 154 179 186 236 270 322 411 227 252
YRD-F08A 63
188 69 48 58 29 34 49 61 53 97 78 76 74 66 78 97 146 183 244 325
253 398 375 244 252 361 298 404 370 451 469 245 370 247 117 187 221 268 244 268
274 229 317 259 155 119 97 161 165 162 126 140 144 106 113 138 139 116 133 95
95 97 156
YRD-F08B 63
189 69 51 51 30 36 57 56 54 94 69 74 66 63 81 94 149 179 239 288
263 396 397 246 247 362 303 400 357 450 473 245 372 248 128 188 215 265 252 259
305 227 319 261 148 108 107 151 167 160 125 138 143 106 112 121 133 109 124 93
98 92 149
YRD-F11A 62
183 230 191 202 368 383 188 239 319 371 300 181 228 231 359 169 368 324 342 184
190 243 303 160 193 184 138 99 105 100 97 83 57 81 128 122 93 100 164 87
69 84 119 89 112 106 99 74 77 54 59 85 144 113 82 76 69 84 94 90
111 66
YRD-F11B 62
172 230 192 198 370 387 178 251 325 389 291 178 238 224 367 177 384 321 350 191
210 232 293 147 188 205 127 107 122 79 125 69 63 83 138 133 94 105 160 86
70 88 118 92 110 107 93 80 79 51 56 83 149 108 81 78 73 79 91 93
111 65
YRD-F12A 69
131 230 193 187 157 179 171 146 234 283 229 268 192 150 242 187 262 256 398 368
327 221 234 213 223 316 238 188 333 241 188 171 212 207 299 200 275 225 268 215
246 181 212 141 184 165 225 150 179 172 131 142 145 92 135 126 135 139 133 145
126 130 142 112 94 111 149 140 166
YRD-F12B 69
129 223 187 179 149 175 162 145 231 275 236 256 198 140 247 187 268 245 399 361
324 219 235 222 221 311 228 205 326 239 183 172 220 205 291 202 277 223 267 201
231 184 205 146 186 158 221 155 178 174 129 160 131 91 134 120 143 131 148 144
121 128 144 110 102 107 144 142 171
YRD-F13A 105
307 427 430 409 419 356 298 309 262 177 246 265 178 277 217 197 159 138 183 220
228 253 180 202 233 217 152 219 292 328 290 333 235 153 192 178 220 220 236 317
66 29 25 26 30 36 33 40 58 45 53 66 67 73 122 65 108 134 118 93
91 80 66 68 107 116 144 111 136 81 73 129 82 68 96 63 71 66 77 57
48 83 73 60 32 32 82 86 86 68 69 66 35 62 49 78 75 73 44 56
58 68 84 107 103

YRD-F13B 105
276 329 434 416 431 383 245 307 262 172 246 263 188 314 227 197 164 139 182 220
227 253 176 202 236 221 154 227 286 324 275 322 234 136 190 160 208 220 230 303
63 26 31 25 32 36 33 38 63 47 53 66 61 78 117 69 109 127 123 88
99 77 66 67 106 113 151 108 133 80 77 127 82 70 91 65 69 71 58 69
51 72 63 46 30 35 85 79 97 63 54 52 36 62 54 73 77 76 64 57
55 81 69 105 111
YRD-F14A 61
415 306 282 402 345 547 489 487 504 401 363 265 436 439 379 352 381 247 294 278
239 219 292 181 207 165 156 134 137 155 137 111 124 119 161 124 119 187 182 101
117 115 105 116 151 165 253 165 279 210 275 188 195 163 211 106 84 98 92 139
116
YRD-F14B 61
421 294 288 384 348 551 481 493 503 396 338 277 429 469 382 355 374 255 289 277
239 217 297 180 202 172 157 144 130 154 138 109 122 122 162 122 123 184 182 99
116 118 105 114 158 159 251 165 288 202 280 184 200 162 211 103 85 99 91 142
105
YRD-F15A 55
533 530 502 737 508 679 468 509 476 605 484 342 451 467 448 401 325 278 216 96
212 172 187 166 187 132 128 134 108 82 75 128 135 114 192 111 163 197 228 61
24 22 30 24 30 43 66 43 74 86 112 96 140 102 96
YRD-F15B 55
536 523 511 679 511 685 465 507 483 604 483 340 462 464 447 423 327 270 199 101
206 172 188 172 172 145 120 140 101 84 81 127 137 109 189 116 171 193 222 56
28 21 33 20 30 43 65 45 75 85 114 85 138 101 104
YRD-F18A 68
284 296 314 404 390 523 519 619 686 600 493 402 346 440 396 327 282 334 332 344
272 301 254 300 207 216 212 294 217 275 289 227 197 260 145 191 167 199 209 196
172 147 197 229 185 151 237 347 267 318 254 309 278 258 224 221 206 176 257 154
198 152 206 237 169 186 173 164
YRD-F18B 68
241 275 301 407 391 529 518 621 692 600 493 403 339 440 392 328 280 331 340 343
297 302 258 304 205 210 224 293 218 271 299 222 205 272 137 185 164 196 216 178
173 147 188 227 192 149 234 357 274 332 248 307 273 254 230 224 203 181 258 152
196 150 206 241 166 196 157 171
YRD-F19A 133
211 164 44 208 230 291 240 177 144 159 277 78 241 337 329 292 449 378 299 402
219 391 370 353 289 170 356 253 285 333 302 331 254 224 219 185 156 130 90 81
126 217 162 175 177 98 103 126 204 202 223 283 197 195 167 117 67 87 153 221
207 170 114 96 130 140 230 335 322 304 212 222 159 147 241 317 251 219 296 206
101 120 278 214 182 134 195 206 132 109 133 131 124 115 178 175 195 119 109 87
95 99 94 55 86 110 239 157 139 174 113 137 111 48 79 61 148 106 119 74
119 68 78 143 116 132 105 112 89 94 89 106 87
YRD-F19B 133
215 162 53 202 236 293 234 183 138 155 276 103 232 340 335 288 445 382 299 410
225 397 355 351 291 171 349 245 289 328 302 357 284 212 217 176 149 133 92 81
122 220 162 167 169 100 113 114 186 213 206 266 192 207 174 145 72 87 144 213
186 170 121 95 143 132 242 330 323 298 207 227 166 148 240 313 255 223 298 205
107 122 281 223 177 135 197 206 128 123 121 145 106 124 176 177 196 121 107 90
96 102 89 50 93 108 234 155 136 174 117 131 111 52 85 62 141 107 116 78
122 63 75 158 107 129 107 113 88 97 82 116 93

YRD-F20A 103
86 108 161 123 171 112 100 157 122 162 98 150 173 112 120 117 120 65 54 49
84 108 65 85 142 177 134 125 94 79 105 79 72 137 112 105 101 139 126 160
131 132 144 179 151 145 120 114 163 208 169 157 266 204 262 136 106 119 165 215
202 251 260 179 83 48 39 49 33 74 166 95 144 83 70 54 59 89 61 107
89 123 97 60 65 80 104 116 83 137 82 79 67 41 90 169 165 272 169 165
79 169 175
YRD-F20B 103
85 107 165 120 177 102 100 163 125 156 105 148 163 116 118 126 118 69 55 54
81 117 58 94 136 179 147 108 85 81 83 85 64 135 122 98 108 142 125 165
125 135 147 182 145 140 125 114 166 220 173 166 252 204 265 137 102 126 161 212
201 253 258 181 85 47 39 50 33 74 164 96 142 94 63 51 57 86 64 110
90 124 92 76 66 88 94 124 78 138 80 84 63 43 91 172 164 260 155 181
79 147 177
YRD-F21A 81
108 133 138 149 115 243 351 142 278 193 188 224 145 265 309 167 122 144 132 149
160 210 125 146 180 206 217 143 96 182 112 145 140 210 131 176 170 123 164 170
168 161 209 156 143 165 269 161 166 140 179 124 188 93 92 63 80 81 75 101
95 122 120 162 162 198 188 124 85 139 196 90 69 72 52 67 103 101 125 120
129
YRD-F21B 81
109 136 138 149 98 259 343 150 270 194 191 223 151 256 317 166 120 144 127 153
164 200 135 146 182 203 208 150 104 177 101 152 141 207 133 177 170 133 152 177
175 148 206 154 145 164 265 168 162 140 179 115 180 88 106 66 75 79 77 103
94 127 116 160 158 207 189 124 87 142 195 87 80 64 53 57 108 92 127 116
129
YRD-F22A 103
80 83 96 113 101 76 90 114 76 91 67 60 74 106 84 79 98 93 130 87
63 53 100 120 121 142 135 141 144 71 95 111 112 131 132 158 129 77 83 98
123 129 132 87 214 101 132 67 93 137 148 116 85 208 125 83 92 110 177 140
135 142 169 146 114 154 118 105 104 106 128 139 114 131 139 122 144 131 110 114
101 96 100 125 102 96 106 116 76 77 76 101 175 119 101 101 71 57 76 80
94 147 109
YRD-F22B 103
81 77 93 104 106 82 78 109 89 79 62 61 95 98 86 61 118 73 132 101
53 50 102 122 116 147 133 145 146 73 86 102 118 117 134 149 139 75 93 89
126 136 131 91 216 110 135 74 97 135 150 116 80 218 121 89 84 112 178 149
135 139 168 150 114 156 118 108 105 108 121 139 115 134 136 126 145 130 112 116
97 118 100 127 99 99 110 115 79 74 86 96 169 110 118 102 77 61 77 77
118 124 90
YRD-F24A 66
201 207 153 110 140 201 91 220 288 273 193 217 255 239 221 197 176 243 220 166
196 293 181 223 180 251 135 219 218 214 174 137 98 128 137 159 182 193 174 135
170 161 115 115 188 196 162 181 276 168 178 191 159 131 121 133 142 148 133 150
156 207 154 114 77 80
YRD-F24B 66
211 210 150 110 137 205 97 214 297 274 188 228 246 240 215 194 178 241 224 161
200 307 168 230 164 247 142 228 224 226 170 136 92 134 131 156 184 190 179 134
175 156 112 116 189 196 158 175 278 160 177 194 149 128 108 133 141 141 131 141
161 199 154 112 97 71

YRD-F25A 66
212 230 163 131 112 164 179 255 188 187 304 237 130 179 136 82 72 76 56 73
63 98 71 105 116 84 107 133 100 120 92 120 103 107 92 99 59 59 94 209
232 267 170 128 117 86 46 64 64 126 197 124 65 88 75 95 157 170 182 266
238 129 88 59 76 99
YRD-F25B 66
201 229 164 143 99 170 180 252 185 187 295 233 132 201 148 83 70 66 69 68
66 93 69 105 111 92 110 139 98 126 71 120 105 103 96 87 62 56 99 198
238 264 178 135 107 78 48 61 63 129 194 132 71 88 82 90 159 174 190 259
239 129 79 57 83 94
YRD-F26A 118
182 124 75 55 44 42 51 30 33 30 28 45 59 50 45 51 47 51 65 47
56 35 31 20 33 31 36 36 40 31 53 59 72 88 91 79 129 136 110 150
78 66 94 103 86 60 53 42 39 38 102 84 118 169 92 105 48 60 78 107
109 46 145 133 140 71 140 74 196 157 215 190 80 56 105 76 108 61 104 87
204 110 155 105 93 150 122 118 89 261 145 137 164 99 106 106 138 85 94 105
154 133 146 127 120 158 122 114 130 93 105 86 92 112 85 134 128 93
YRD-F26B 118
191 128 75 60 37 39 58 36 34 25 26 49 61 47 46 54 44 53 65 48
56 27 24 35 32 29 30 40 47 37 36 74 80 87 94 88 125 145 113 147
77 66 93 108 79 58 61 37 36 37 102 84 131 162 110 104 65 47 92 121
106 48 149 129 147 74 144 73 190 163 213 180 91 55 95 77 103 56 97 79
203 108 156 106 95 150 122 116 87 262 141 144 166 101 94 116 132 79 95 104
146 144 147 126 120 170 123 113 126 97 88 94 86 117 84 132 117 93
YRD-F27A 73
273 190 202 198 212 133 178 110 78 100 93 103 111 149 139 158 128 174 163 187
216 165 105 145 134 86 79 93 66 122 152 142 136 165 171 116 206 96 104 62
117 148 82 112 150 147 138 161 137 138 148 163 146 169 153 180 102 166 171 111
128 129 121 118 63 74 56 83 44 65 87 59 72
YRD-F27B 73
236 197 207 208 217 126 187 96 92 97 93 105 107 157 131 161 135 185 149 197
208 176 97 149 130 91 85 90 80 111 143 143 140 173 181 111 204 92 121 57
127 137 96 125 146 155 133 166 130 133 142 175 138 175 162 174 104 165 166 108
126 128 126 103 66 78 57 79 54 58 76 61 71
YRD-F28A 81
531 421 365 308 91 72 60 137 147 179 247 154 82 65 18 33 37 65 73 87
94 103 41 74 71 65 97 60 168 60 62 48 158 107 130 106 111 96 81 68
64 202 172 171 181 195 428 374 387 201 89 123 157 183 146 168 299 275 261 159
223 263 252 240 328 150 110 134 94 144 100 139 250 90 72 73 54 68 105 107
115
YRD-F28B 81
537 429 376 313 87 67 66 117 156 168 247 163 78 58 25 29 33 64 76 79
97 103 46 71 80 66 96 56 171 66 62 51 155 108 135 108 107 103 84 68
59 193 164 179 184 196 434 377 429 182 90 121 161 186 143 169 304 235 265 166
238 255 251 245 329 155 115 131 98 142 86 146 243 92 70 79 52 66 106 105
115
YRD-F29A 78
230 334 515 484 467 387 80 71 86 168 212 221 321 167 58 51 32 36 40 67
94 83 89 66 48 34 34 39 42 40 75 45 51 43 216 108 242 189 265 163
56 49 73 68 111 101 76 89 126 114 100 97 89 104 141 136 95 99 81 106
114 166 185 218 130 111 135 115 70 102 65 84 66 97 94 68 55 60

YRD-F29B 78
233 347 504 485 475 387 90 72 83 169 214 220 327 173 57 47 31 37 39 64
95 86 87 70 45 37 32 42 42 38 75 46 50 43 199 111 262 186 264 164
45 44 51 59 81 95 75 93 136 113 105 101 85 126 158 102 121 78 82 100
106 156 180 217 127 115 136 113 72 103 64 95 49 107 94 66 56 83
YRD-F30A 59
247 526 557 521 266 354 571 530 528 385 154 82 103 258 274 213 255 163 45 43
32 36 27 64 108 98 90 58 36 51 51 44 61 43 90 41 43 36 72 58
141 98 137 147 64 142 103 187 306 160 162 159 268 186 185 115 58 101 116
YRD-F30B 59
246 502 548 498 266 354 574 531 525 391 155 83 106 255 278 205 256 168 51 38
31 33 29 68 104 99 88 61 33 54 54 44 63 39 87 41 41 44 68 57
146 96 134 152 57 126 110 173 315 161 149 159 258 183 181 113 60 106 113
YRD-F31A 53
273 334 262 374 397 285 177 234 259 240 266 255 295 169 163 250 286 245 290 168
318 187 238 227 333 180 248 223 206 206 163 245 308 262 186 207 248 194 139 117
125 162 122 127 192 163 269 222 206 199 214 182 246
YRD-F31B 53
256 343 259 377 405 274 174 243 255 252 228 282 289 153 167 250 293 241 280 169
329 191 239 236 336 186 243 225 197 221 158 246 312 256 198 212 268 181 135 111
131 172 123 132 190 167 273 231 201 201 243 184 251
YRD-F32A 54
214 222 228 305 220 283 368 228 307 293 162 177 299 278 220 262 168 242 173 178
233 280 186 303 137 210 190 298 194 268 155 266 208 179 212 261 285 251 250 184
192 190 185 124 143 154 210 129 119 177 140 226 226 198
YRD-F32B 41
170 163 215 226 186 231 154 183 144 179 176 299 186 226 190 168 195 198 234 221
211 154 173 169 189 163 156 157 191 145 115 161 116 221 242 190 213 257 199 153
163
YRD-F33A 74
351 372 247 168 244 252 323 325 498 295 170 103 109 153 136 135 149 155 264 180
107 83 44 50 87 150 165 105 92 144 168 163 140 118 131 150 127 158 99 114
86 60 117 144 119 204 128 117 56 53 36 40 56 73 119 150 155 251 246 95
88 135 153 116 112 161 156 116 72 92 142 159 105 177
YRD-F33B 74
342 367 248 167 229 243 316 347 489 298 162 114 108 147 145 139 147 154 252 177
115 76 49 53 79 154 170 102 90 161 159 170 146 108 112 149 118 124 105 125
88 63 113 144 117 203 125 123 61 36 34 46 55 73 123 146 157 250 251 95
89 125 158 113 105 154 167 119 67 90 147 160 106 187
YRD-F34A 48
113 185 147 75 85 92 78 81 51 58 162 120 131 96 112 81 51 106 180 171
178 149 129 56 43 80 89 99 235 275 376 349 495 288 235 200 336 530 296 304
320 312 192 120 115 98 92 66
YRD-F34B 59
61 34 47 47 88 109 93 72 73 86 90 116 73 70 119 91 162 102 97 60
67 148 225 262 313 284 267 125 126 102 134 118 206 283 411 355 493 418 324 165
371 415 335 210 208 206 118 52 92 117 111 76 88 135 59 44 65 68 39
YRD-F36A 83
177 184 79 48 53 58 76 97 124 138 175 204 193 274 194 145 173 230 279 277
244 172 209 151 117 161 219 212 248 229 254 311 193 274 263 132 129 129 199 180
136 150 136 139 172 135 91 112 171 141 206 165 199 197 135 111 92 149 161 189
145 121 102 180 195 146 178 144 117 132 121 149 170 146 141 137 163 153 118 94
88 111 123

YRD-F36B 83
185 179 83 52 52 60 74 105 122 138 153 208 189 273 193 149 176 225 281 275
260 180 219 159 119 147 211 208 242 233 249 319 178 279 262 130 135 121 195 170
152 151 127 134 160 140 96 118 167 148 221 169 200 192 143 99 95 148 158 190
156 127 98 180 185 152 176 139 121 118 125 140 169 150 154 147 171 161 110 89
91 108 118
YRD-F37A 48
449 515 445 318 240 285 250 306 392 424 453 303 351 404 259 342 279 257 326 360
350 347 363 250 246 153 175 178 194 225 154 140 201 220 134 162 224 252 185 228
115 172 185 119 161 125 113 208
YRD-F37B 48
525 517 448 300 234 292 242 311 390 431 501 320 399 415 337 317 342 201 339 362
334 329 374 256 246 157 155 196 182 246 157 171 188 236 125 171 197 239 195 219
122 149 189 123 167 124 110 208
YRD-F38A 54
124 109 149 137 338 309 257 187 155 245 309 172 155 259 224 178 104 138 138 212
214 231 293 173 111 236 208 209 200 191 198 173 181 222 226 225 192 159 164 216
161 186 145 198 137 146 170 191 169 145 124 103 132 224
YRD-F38B 54
121 111 151 143 356 308 248 178 151 241 313 185 152 245 225 176 118 133 136 214
225 228 293 167 112 263 204 226 203 198 213 170 196 212 228 193 175 161 159 220
162 183 150 189 140 125 176 197 173 154 105 101 136 238
YRD-F39A 96
50 48 65 72 71 37 42 52 42 53 56 65 68 68 78 70 79 70 56 116
123 205 204 91 116 110 77 136 105 89 86 75 123 87 132 275 171 108 107 183
124 102 74 80 87 122 75 62 71 52 37 75 83 68 63 48 49 69 76 106
89 83 82 84 67 66 80 73 70 101 122 82 77 120 99 57 95 85 103 114
81 93 77 110 90 117 97 176 173 134 124 140 174 190 193 173
YRD-F39B 96
49 51 70 70 67 39 41 52 47 48 49 68 63 74 83 65 85 61 60 116
135 200 200 99 114 111 84 120 122 79 90 69 128 86 129 237 172 103 105 180
117 104 66 87 85 126 66 61 68 41 37 71 76 66 55 41 60 53 70 125
85 83 84 73 67 73 75 78 66 104 131 66 96 104 89 66 91 92 100 117
80 96 77 104 99 107 99 172 171 132 116 148 177 190 195 170
YRD-F40A 78
340 202 323 248 214 276 445 568 429 366 361 303 243 257 411 285 180 350 339 194
208 240 191 276 244 232 357 108 118 235 124 177 186 225 231 155 184 235 232 137
134 141 172 231 153 260 174 234 110 141 189 225 277 224 123 115 155 192 157 137
195 112 82 130 97 111 93 78 70 146 157 97 125 123 106 161 148 304
YRD-F40B 78
291 219 313 252 213 279 436 576 441 364 369 307 259 259 409 281 185 369 323 209
194 241 195 270 243 238 345 117 104 235 138 166 192 238 207 151 163 266 230 139
134 141 168 232 154 258 165 228 123 152 196 237 262 218 130 115 152 192 159 145
173 112 92 133 88 111 101 78 74 150 163 102 121 105 120 159 152 315
YRD-F41A 109
85 143 188 275 223 194 121 111 128 131 105 117 130 129 161 180 204 209 195 202
177 231 256 151 258 273 300 157 150 146 206 217 179 196 209 263 235 140 204 190
212 131 138 239 208 189 170 217 271 282 269 245 150 152 228 180 167 156 162 125
88 109 150 110 125 64 62 88 109 121 146 146 136 150 126 110 118 102 124 146
165 170 156 71 100 86 110 165 122 164 166 102 120 75 89 136 137 78 82 201
106 143 81 79 110 173 152 164 162

YRD-F41B 109
75 141 189 280 232 193 140 108 133 139 102 117 131 129 142 178 213 197 191 197
198 236 230 188 251 270 293 152 159 149 202 218 177 197 204 264 239 154 201 189
219 121 143 233 210 187 178 221 269 289 258 253 144 166 232 183 175 159 151 126
83 116 139 110 139 64 58 89 105 122 145 149 140 154 119 116 124 103 119 141
158 174 157 68 104 86 116 162 121 163 165 100 131 63 95 131 123 91 89 191
113 144 82 83 111 170 151 166 154
YRD-F43A 80
400 433 466 251 209 194 201 295 257 285 239 180 236 191 220 195 410 312 198 145
126 93 125 148 164 205 280 259 221 240 204 191 248 257 318 325 321 236 268 200
122 125 149 165 205 254 284 292 189 306 271 126 156 181 192 188 177 176 144 157
166 136 114 113 137 162 201 165 177 205 151 146 147 159 165 232 166 134 120 168
YRD-F43B 80
408 452 545 239 209 196 203 279 254 291 236 180 236 196 223 188 406 326 212 134
140 111 113 154 167 213 260 279 221 233 208 199 252 258 316 323 320 229 271 197
124 126 149 167 208 256 282 290 186 310 268 123 156 182 198 182 181 172 142 146
173 136 112 112 141 158 207 180 178 198 141 137 147 159 168 239 165 130 105 167
YRD-F44A 47
179 284 269 210 226 225 156 150 188 188 220 269 280 307 188 295 293 123 143 178
257 220 216 222 170 189 192 141 110 88 135 146 210 169 201 208 122 104 107 146
162 254 184 147 123 183 174
YRD-F44B 47
219 261 289 214 220 248 148 143 194 191 226 253 272 308 186 288 300 127 137 178
250 237 188 224 176 177 192 142 103 102 135 145 215 170 188 206 129 97 118 148
162 250 182 145 130 189 152
YRD-F45A 88
78 116 53 70 57 64 61 117 103 65 82 40 103 121 68 89 185 104 104 61
80 104 155 167 104 76 59 74 51 124 157 90 58 163 154 88 70 239 156 204
137 141 164 128 83 160 111 146 86 102 97 120 100 140 90 59 34 36 24 18
46 24 38 20 26 73 110 65 42 89 176 152 86 46 70 98 91 125 200 273
189 146 267 305 143 256 176 92
YRD-F45B 88
107 111 55 68 58 54 54 122 107 63 79 49 91 125 72 76 156 91 116 62
79 113 157 161 117 67 77 57 58 133 155 92 62 164 152 83 75 246 139 196
133 133 160 135 91 160 111 151 92 108 106 117 100 139 80 70 32 22 18 23
23 47 34 44 39 66 97 61 43 84 176 154 75 50 56 103 88 127 198 302
193 149 258 306 151 242 189 96
YRD-F46A 98
94 166 567 429 374 371 274 207 234 171 128 154 217 295 351 174 165 125 121 139
129 286 271 130 172 89 98 103 120 123 137 117 103 101 130 68 85 93 93 68
58 64 68 57 37 25 28 14 20 40 62 40 37 32 68 80 40 72 156 86
63 39 38 51 72 63 60 55 48 73 102 208 249 123 131 282 201 97 98 181
126 155 99 121 132 76 69 114 74 114 72 78 87 109 82 116 90 62
YRD-F46B 98
97 174 576 386 378 373 280 215 230 167 122 160 179 320 384 200 163 126 121 142
150 280 268 137 167 87 104 104 109 133 124 121 104 99 123 80 94 99 90 73
61 65 69 61 32 31 29 14 17 45 56 44 42 29 71 89 37 76 135 83
63 36 40 50 72 67 56 52 54 74 100 205 252 143 138 281 198 102 94 181
124 161 99 116 137 73 72 113 73 116 69 81 87 100 86 119 88 60

APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

Tree-ring dating, or dendrochronology as it is known, is discussed in some detail in the Laboratory's Monograph, *An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Building* (Laxton and Litton 1988) and *Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates* (English Heritage 1988). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The width of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure A1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths for oaks, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of oak timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring.

If the bark is still on the sample, as in Figure A1, then the date of the last ring will be the date of felling of the oak from which it was cut. There is much evidence that in medieval times oaks cut down for building purposes were used almost immediately, usually within the year or so (Rackham 1976). Hence if bark is present on several main timbers in a building, none of which appear reused or are later insertions, and if they all have the same date for their last ring, then we can be quite confident that this is the date of construction or soon after. If there is no bark on the sample, then we have to make an estimate of the felling date; how this is done is explained below.

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

1. **Inspecting the Building and Sampling the Timbers.** Together with a building historian the timbers in a building are inspected to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can sample *in situ* timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer rings than this, 50 for example, sequences of widths become difficult to match to a unique

position within a master sequence of ring widths and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure A2 has about 120 rings; about 20 of which are sapwood rings – the lighter rings on the outside. Similarly the core has just over 100 rings with a few sapwood rings.

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

Sampling is done by coring into the timber with a hollow corer attached to an electric drill and usually from its outer rings inwards towards where the centre of the tree, the pith, is judged to be. An illustration of a core is shown in Figure A2; it is about 150mm long and 10mm diameter. Great care has to be taken to ensure that as few as possible of the outer rings are lost in coring. This can be difficult as these outer rings are often very soft (see below on sapwood). Each sample is given a code which identifies uniquely which timber it comes from, which building it is from and where the building is located. For example, CRO-A06 is the sixth core taken from the first building (A) sampled by the Laboratory in Cropwell Bishop. Where it came from in that building will be shown in the sampling records and drawings. No structural damage is done to any timbers by coring, nor does it weaken them.

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

All sampling by the Laboratory is undertaken according to current Health and Safety Standards. The Laboratory's dendrochronologists are insured.

Figure A1: A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976

Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

Figure A3: Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measured twice to ensure that an error has not been made. This type of apparatus is needed to process a large number of samples on a regular basis

Figure A4: Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical

2. **Measuring Ring Widths.** Each core is sanded down with a belt sander using medium-grit paper and then finished by hand with flourgrade-grit paper. The rings are then clearly visible and differentiated from each other with a result very much like that shown in Figure A2. The core is then mounted on a movable table below a microscope and the ring-widths measured individually from the innermost ring to the outermost. The widths are automatically recorded in a computer file as they are measured (see Fig A3).

3. **Cross-Matching and Dating the Samples.** Because of the factors besides the local climate which may determine the annual widths of a tree's rings, no two sequences of ring widths from different oaks growing at the same time are exactly alike (Fig A4). Indeed, the sequences may not be exactly alike even when the trees are growing near to each other. Consequently, in the Laboratory we do not attempt to match two sequences of ring widths by eye, or graphically, or by any other subjective method. Instead, it is done objectively (ie statistically) on a computer by a process called cross-matching. The output from the computer tells us the extent of correlation between two sample sequences of widths or, if we are dating, between a sample sequence of widths and the master, at each relative position of one to the other (offsets). The extent of the correlation at an offset is determined by the *t*-value (defined in almost any introductory book on statistics). That offset with the maximum *t*-value among the *t*-values at all the offsets will be the best candidate for dating one sequence relative to the other. If one of these is a master chronology, then this will date the other. Experiments carried out in the past with sequences from oaks of known date suggest that a *t*-value of at least 4.5, and preferably at least 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton and Litton 1988; Laxton *et al* 1988; Howard *et al* 1984–1995).

This is illustrated in Figure A5 with timbers from one of the roofs of Lincoln Cathedral. Here four sequences of ring widths, LIN-C04, 05, 08, and 45, have been cross-matched with each other. The ring widths themselves have been omitted in the bar diagram, as is usual, but the offsets at which they best cross-match each other are shown; eg the sequence of ring widths of C08 matches the sequence of ring widths of C45 best when it is at a position starting 20 rings after the first ring of C45, and similarly for the others. The actual *t*-values between the four at these offsets of best correlations are in the matrix. Thus at the offset of +20 rings, the *t*-value between C45 and C08 is 5.6 and is the maximum found between these two among all the positions of one sequence relative to the other.

It is standard practice in our Laboratory first to cross-match as many as possible of the ring-width sequences of the samples in a building and then to form an average from them. This average is called a site sequence of the building being dated and is illustrated in Figure A5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences of the four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. Thus in Fig A5 if the widths shown are 0.8mm for C45, 0.2mm for C08, 0.7mm for C05, and 0.3mm for C04, then the corresponding width of the site sequence is the average of these, 0.55mm. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

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

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

Quite often some, though not all, of the original outer rings are missing on a timber. The outer rings on an oak, called sapwood rings, are usually lighter than the inner rings, the heartwood, and so are relatively easy to identify. For example, sapwood can be seen in the corner of the rafter and at the outer end of the core in Figure A2, both indicated by arrows. More importantly for dendrochronology, the sapwood is relatively soft and so liable to insect attack and wear and tear. The builder, therefore, may remove some of the sapwood for precisely these reasons. Nevertheless, if at least some of the sapwood rings are left on a sample, we will know that not too many rings have been lost since felling so that the date of the last ring on the sample is only a few years before the date of the original last ring on the tree, and so to the date of felling.

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

Even more precise estimates of the felling date and range can often be obtained using knowledge of a particular case and information gathered at the time of sampling. For example, at the time of sampling the dendrochronologist may have noted that the timber from which the core of Figure A2 was taken still had complete sapwood but that some of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 20mm, a reasonable estimate can be made of the number of sapwood rings lost, say 12 to 15 rings in this case. By adding on 12 to 15 years to the date of the last ring on the sample a good tight estimate for the range of the felling date can be obtained, which is often better than the 15 to 35 years later we would have estimated without this observation. In the example, the felling is now estimated to have taken place between AD 1512 and 1515, which is much more precise than without this extra information.

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

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

6. **Master Chronological Sequences.** Ultimately, to date a sequence of ring widths, or a site sequence, we need a master sequence of dated ring widths with which to cross-match it, a Master Chronology. To construct such a sequence we have to start with a sequence of widths whose dates are known and this means beginning with a sequence from an oak tree whose date of felling is known. In Figure A6 such a sequence is SHE-T, which came from a tree in Sherwood Forest which was blown down in a recent gale. After this other sequences which cross-match with it are added and gradually the sequence is 'pushed back in time' as far as the age of samples will allow. This process is illustrated in Figure A6. We have a master chronological sequence of widths for Nottinghamshire and East Midlands oak for each year from AD 882 to 1981. It is described in great detail in Laxton and Litton (1988), but the components it contains are shown here in the form of a bar diagram. As can be seen, it is well replicated in that for each year in this period there are several sample sequences having widths for that year. The master is the average of these. This master can now be used to date oak from this area and from the surrounding areas where the climate is very similar to that in the East Midlands. The Laboratory has also constructed a master for Kent (Laxton and Litton 1989). The method the Laboratory uses to construct a master sequence, such as the East Midlands and Kent, is completely objective and uses the Litton-Zainodin grouping procedure (Laxton *et al* 1988). Other laboratories and individuals have constructed masters for other areas and have made them available. As well as these masters, local (dated) site chronologies can be used to date other buildings from nearby. The Laboratory has hundreds of these site sequences from many parts of England and Wales covering many short periods.

7. **Ring-Width Indices.** Tree-ring dating can be done by cross-matching the ring widths themselves, as described above. However, it is advantageous to modify the widths first. Because different trees grow at different rates and because a young oak grows in a different way from an older oak, irrespective of the climate, the widths are first standardized before any matching between them is attempted. These standard widths are known as ring-width indices and were first used in dendrochronology by Baillie and Pilcher (1973). The exact form they take is explained in this paper and in the appendix of Laxton and Litton (1988) and is illustrated in the graphs in Figure A7. Here ring-widths are plotted vertically, one for each year of growth. In the upper sequence of (a), the generally large early growth after 1810 is very apparent as is the smaller later growth from about 1900 onwards when the tree is maturing. A similar phenomenon can be observed in the lower sequence of (a) starting in 1835. In both the widths are also changing rapidly from year to year. The peaks are the wide rings and the troughs are the narrow rings corresponding to good and poor growing seasons, respectively. The two corresponding sequence of Baillie-Pilcher indices are plotted in (b) where the differences in the immature and mature growths have been removed and only the rapidly changing peaks and troughs remain, that are associated with the common climatic signal. This makes cross-matching easier.

t-value/offset Matrix

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

Bar Diagram

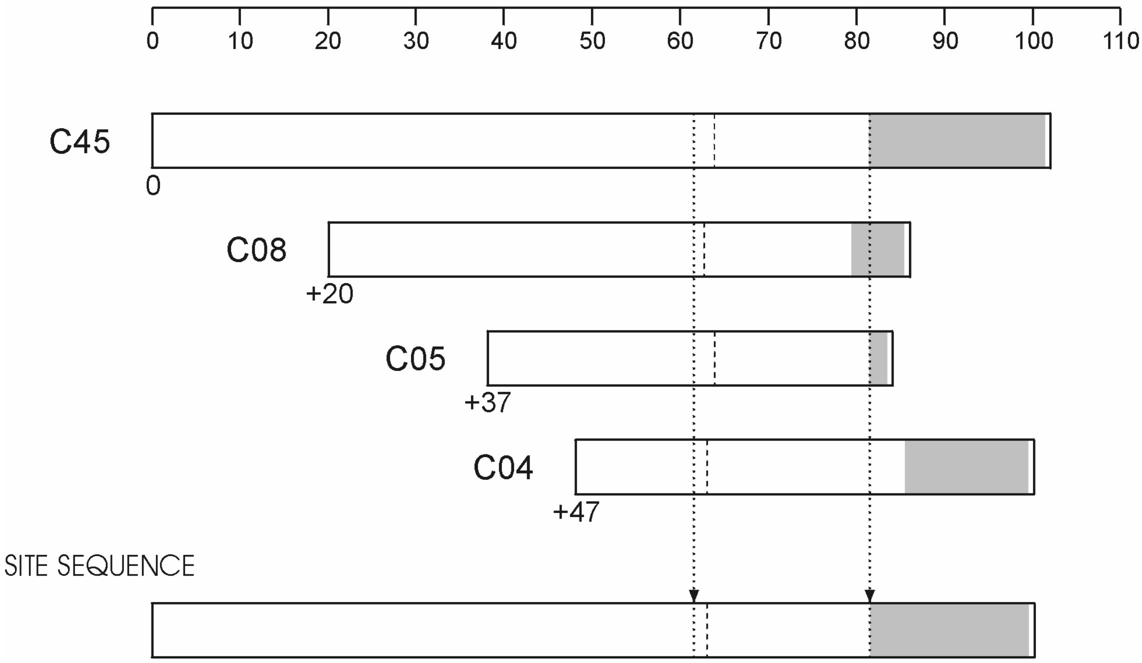


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

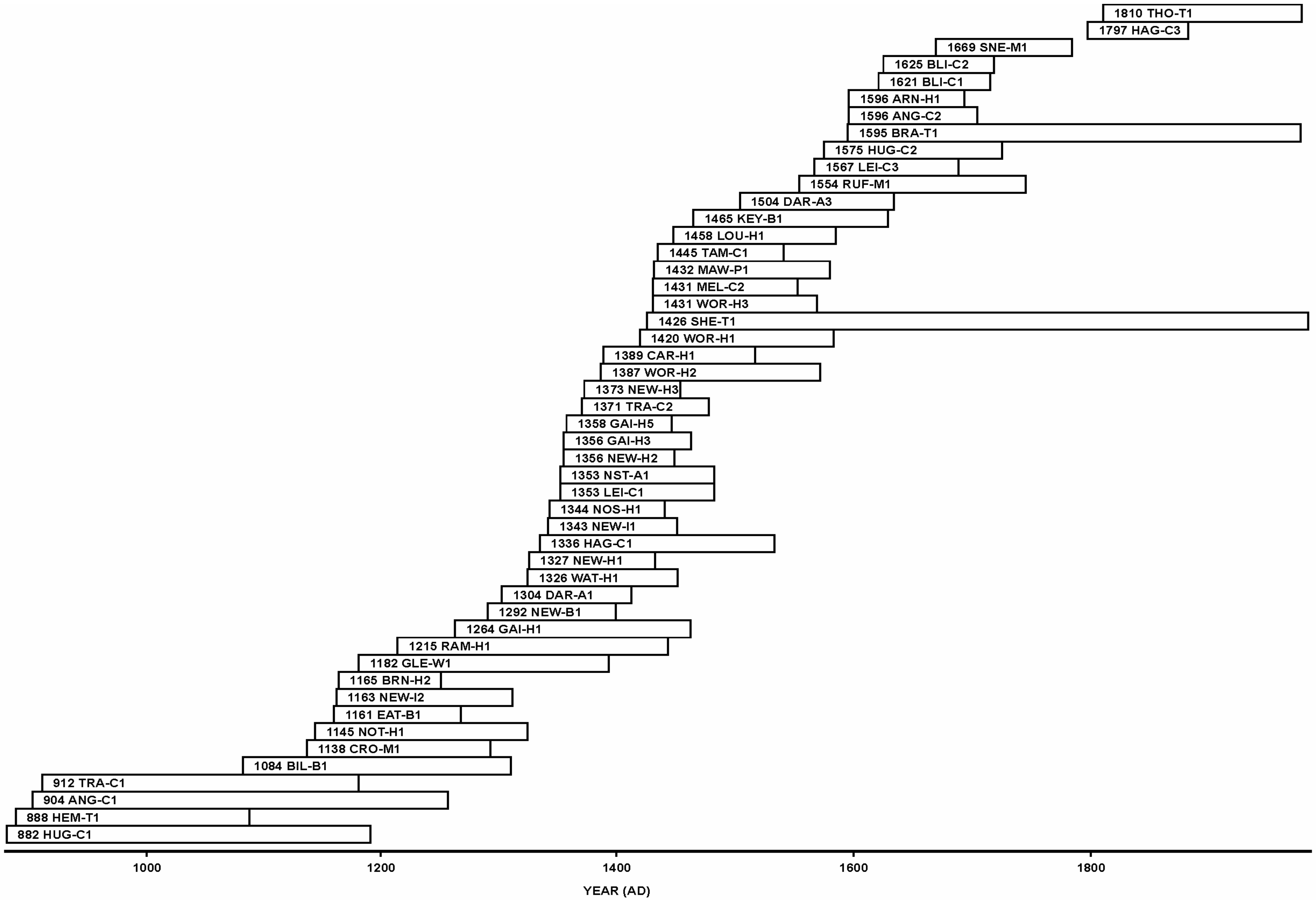
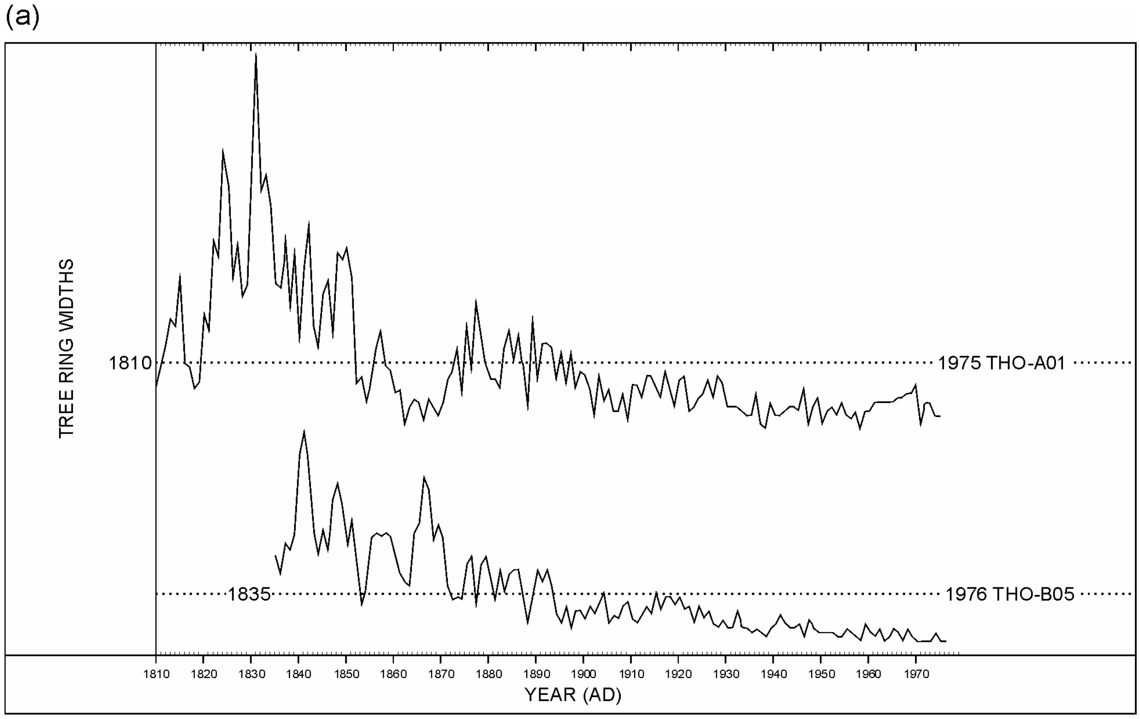


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87



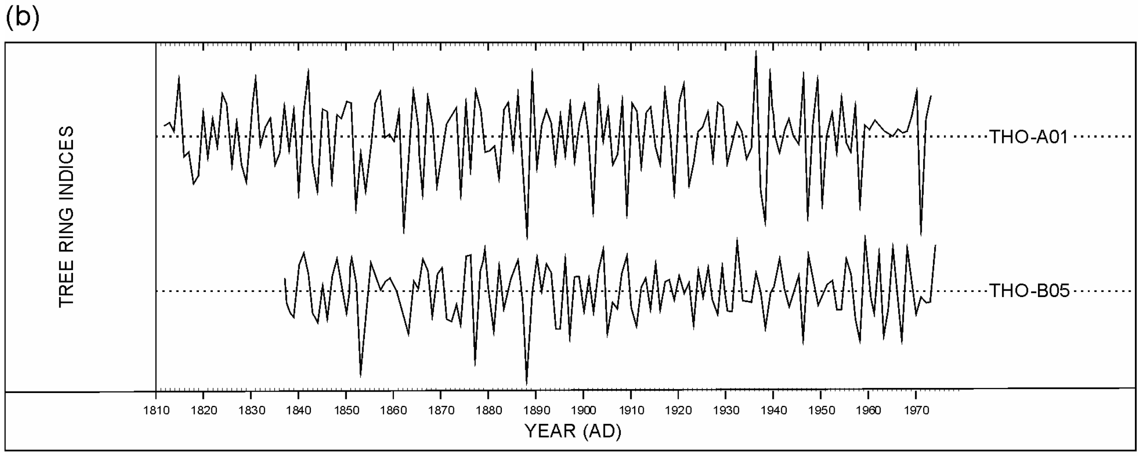


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree are wider than the later ones of the older tree in both sequences

Figure A7 (b): The Baillie-Pilcher indices of the above widths

The growth trends have been removed completely

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