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RESTORMEL MANOR, LOSTWITHIEL, CORNWALL
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

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Restormel Manor, Lostwithiel, Cornwall
Tree-Ring Analysis of Timbers

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Summary

Dendrochronological analysis undertaken on a series of samples from the central and western range roofs of this building has resulted in the construction of four site sequences.

Attempts to date these site sequences were unsuccessful.

Tree-ring analysis has, in this instance, been unable to provide any firm dating evidence for this building.

Keywords

Dendrochronology
Standing Building

Author's Address
Nottingham Tree-Ring Dating Laboratory, 20 Hillcrest Grove, Sherwood, Nottingham, NG5 1FT.
Telephone:0115 9603833. Email:alisonjarnold@hotmail.com, roberthoward10@hotmail.com

Introduction

Restormel Manor house, part of the Restormel estate belonging to the Duchy of Cornwall, is situated to the north of Lostwithiel village, just to the south-east of Restormel Castle and by the River Fowey (Figs 1 and 2; SX10736129).

In its earliest form, this Grade II listed building probably consisted of two rooms with a through passage. The central three-storey embattled porch may be a late-eighteenth century addition, possibly replacing an earlier one or perhaps is the earlier one having undergone substantial alterations. To the east and rear of the passage is the stair tower, into which was inserted a new stair in the mid-eighteenth century. Further extensions in the eighteenth century gave the building a symmetrical façade, with the end two bays to the east and west being slightly advanced. Other additions were a two-storey wing to the rear west and a mid-nineteenth century passageway along the rear east, inside the original external wall, providing access to the service rooms along the rear east (Fig 3).

This building has previously been listed as a mid to late seventeenth-century farmhouse, with later stair tower, refronted and remodelled in the eighteenth century and with nineteenth-century additions to the rear west and rear east. However, recent investigations suggest that the main farmhouse dates to the sixteenth century, with the dates of the extensions being uncertain.

Roofs

The roof over the main central (or principal axis) range, thought to be the earliest surviving part of the building, consists of five original trusses, (with a further two replacements). These trusses have cranked collars (where they survive) with dovetail (or fishtail) joints to the principal rafters. Some of the original purlins survive with pegs for former rafter fastenings. There is a small area west of the porch where the original rafters still survive pegged to the purlin. This roof is thought to date to the late-sixteenth or early-seventeenth century (Fig 4).

To the west of the main range is the western (or service) range. The roof over this has six oak trusses with principal rafters pegged at the apex and with pegged collars. They have heavy pine tiebeams which are visible as part of the ceiling structure in the chamber below. The roof is thought to be of eighteenth-century date (Fig 5) and is said to be similar to the roof structure in the south stable block.

Acknowledgements

The plan of the building (Figs 3, 6, and 12) was provided by the Duchy of Cornwall. Truss drawings on which the location of samples has been marked were provided by Nigel Thomas of the Cornwall County Council Historic Environment Service (Figs 7–11 and 13–15). Nigel Thomas also kindly allowed us access to the draft report commissioned by James Scott of the Duchy of Cornwall, on the Restormel Manor (Berry *et al* forthcoming), some details from which have been used in the above introduction. Thanks are given to Eric Berry for arranging access to the building, for his on-site advice, and continuing enthusiasm. The Laboratory is also very grateful to Cathy Tyers of Sheffield Dendrochronology Laboratory for her invaluable comments and suggestions on an early draft of this report.

Aims and Objectives

Sampling and analysis by tree-ring dating was commissioned and funded by English Heritage. It was requested by Francis Kelly, Historic Buildings Inspector at English Heritage's Bristol Office, to inform statutory advice in advance of an application for Listed Building Consent. It was hoped that successful tree-ring analysis would provide a construction date for the two roofs under investigation.

Sampling

In accordance with the specifications set out in brief, a total of 24 roof timbers was sampled. Each sample was given the code RST-M (for Restormel Manor) and numbered 01–24; those from the western range RST-M01–13 and those from the central range RST-M14–24. The position of samples was noted at the time of sampling and has been marked on Figures 7–15. Further details relating to the samples can be found in Table 1.

Analysis and Results

At this stage it was noticed that seven of the samples (five from the western range roof and two from the central range roof) had too few rings to make secure dating a possibility and these samples was rejected prior to measurement. The remaining 17 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 17 samples were compared with each other by the Litton/Zainodin grouping procedure (see appendix).

At a least value of t=4.5, nine samples had formed four groups. Firstly, two samples from the western range roof matched and were combined at the relevant offset positions to form RSTMSQ01, a site sequence of 98 rings (Fig 16). Two further samples, from the western roof, matched and were combined at the relevant offset positions to form RSTMSQ02, a site sequence of 82 rings (Fig 17). Two samples from the central roof matched and were combined at the relevant offset positions to form RSTMSQ03, a site sequence of 83 rings (Fig 18). Finally, three samples, again from the central roof, matched and were combined at the relevant offset positions to form RSTMSQ04, a site sequence of 79 rings (Fig 19). There was no cross-matching between these four site sequences. Attempts to date these site sequences by comparing them against a large number of relevant reference chronologies for oak were unsuccessful and all remain undated.

Each of the ungrouped samples was then individually compared against the reference chronologies but again no consistent match could be found and these are also undated.

Discussion

Prior to the tree-ring analysis being undertaken, the central range was thought to be the earliest surviving part of this building, dating to the late sixteenth or early-seventeenth century. The range to its west was thought to date to the eighteenth century. It is unfortunate that tree-ring analysis has been unsuccessful in this instance with none of the sampled timbers being dated, thus neither confirming nor refuting these dates. Nor has the analysis been able to establish the relative dates of the two areas under investigation.

There are a number of possible reasons for these disappointing results. Perhaps most significant is the poor intra-site matching of samples seen at Restormel Manor, with analysis producing four separate groups containing only two or three samples each and leaving eight ungrouped samples. As the two roofs investigated were understood to be of different dates, it would not necessarily be expected to see grouping of timbers between the roofs. However, given that all indications pointed to each roof being the result of a single phase of construction, it might be thought likely that more grouping between samples within each phase would occur. This poor intra-site matching of timbers within a phase could suggest that rather than each roof being constructed from a coherent group of trees from a single source, actually a disparate series of trees from several sources have been utilised. Alternatively, it may be that, although each roof is thought to be of one phase of construction, the timbers of these two roofs actually represent multiple felling episodes.

Successful matching would also be inhibited if the trees utilised in these roofs had been subjected to highly localised growing conditions, thereby masking the overall climatic signal necessary for successful matching and dating. However, there does not appear to be anything obviously unusual with regards to the ring patterns of these samples which might have inhibited successful matching with the reference material.

Dendrochronological analysis in the south-west counties of England, notably Devon and Cornwall, has proven problematic, so the production of long, well-replicated site sequences is particularly important for sites such as Restormel Manor. Generally the longer and better replicated a site sequence is, the greater the chance of successful dating. In this case the longest site sequence (RSTMSQ01) is only of 98 rings and the best replicated contains only three samples (RSTMSQ04). As mentioned above one of the roofs in the stable block is very like the roof over the west range in appearance with the suggestion that they are of the same or similar date. There are also a number of other farm buildings on the estate thought to date to the eighteenth century which may potentially lend themselves to sampling and tree-ring analysis. It might be useful, if the opportunity arises at some point in the future, to investigate whether samples can be gained from the timbers of these buildings with the hope that by collecting more data of comparable date the possibility of successfully dating this roof in the future is improved.

A further contributory factor in the lack of dating, although not the lack of intra-site cross-matching, may be that there is a deficit in contemporary regional data with which to compare the data from Restormel Manor. Of the relatively few sites analysed in Cornwall, most date to a 100-year period spanning approximately AD 1450 to AD 1550; consequently, if the roofs were actually of their expected dates, then there is very little relevant regional reference data.

Despite some recent successes, dendrochronological analysis remains challenging in many parts of these two counties, probably due to a preponderance of young trees being utilised in the buildings, combined with the apparent need to establish a more localised network of reference data. The importance of a strong localised network of reference data in certain areas has been highlighted by the research investigation in mid-Devon jointly funded by English Heritage and Devon County Council (Groves 2005). Consequently as further work is undertaken in Cornwall it may become possible to date previously undated sites such as Restormel Manor.

<u>Reference:</u>

Berry, E, Parkes, C, and Thomas, N, forthcoming *Restormel Manor, Lostwithiel, Cornwall, Historic Building Analysis and Landscape Survey*, Historic Environment Service report, Cornwall County Council

Groves, C, 2005 *Dendrochronological Research in Devon: Phase I*, Centre for Archaeol Rep, 56/2005

Table 1: Details of tree-ring samples from Restormel Manor, Lostwithiel, Cornwall

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Western (left) range roof, trusses numbered south-north (18th century?)						
RST-M01	East upper purlin, south-east corner to truss 1	66	h/s	----	----	----
RST-M02	East middle purlin, truss 1-2	77	19	----	----	----
RST-M03	East principal rafter, truss 2	NM	--	----	----	----
RST-M04	East principal rafter, truss 3	73	20C	----	----	----
RST-M05	East upper purlin, truss 3-4	94	16	----	----	----
RST-M06	East principal rafter, truss 4	48	--	----	----	----
RST-M07	West principal rafter, truss 4	60	02	----	----	----
RST-M08	West principal rafter, truss 3	58	17	----	----	----
RST-M09	West principal rafter, truss 2	NM	--	----	----	----
RST-M10	Upper purlin, south hip end	71	07	----	----	----
RST-M11	West upper purlin, truss 1–2	NM	--	----	----	----
RST-M12	West upper purlin, truss 2–3	NM	--	----	----	----
RST-M13	West upper purlin, truss 3–4	NM	--	----	----	----
Central (principal axis) range roof, trusses numbered east-west (16th century?)						
RST-M14	North principal rafter, truss 2	60	h/s	----	----	----
RST-M15	South principal rafter, truss 2	77	--	----	----	----
RST-M16	North principal rafter, truss 3	NM	--	----	----	----
RST-M17	South principal rafter, truss 3	80	--	----	----	----
RST-M18	Collar, truss 3	NM	--	----	----	----
RST-M19	North principal rafter, truss 4	63	h/s	----	----	----
RST-M20	Collar, truss 4	61	h/s	----	----	----
RST-M21	North principal rafter, truss 5	49	--	----	----	----
RST-M22	South principal rafter, truss 5	68	h/s	----	----	----
RST-M23	Collar, truss 5	54	h/s	----	----	----
RST-M24	North principal rafter, truss 6	73	h/s	----	----	----

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

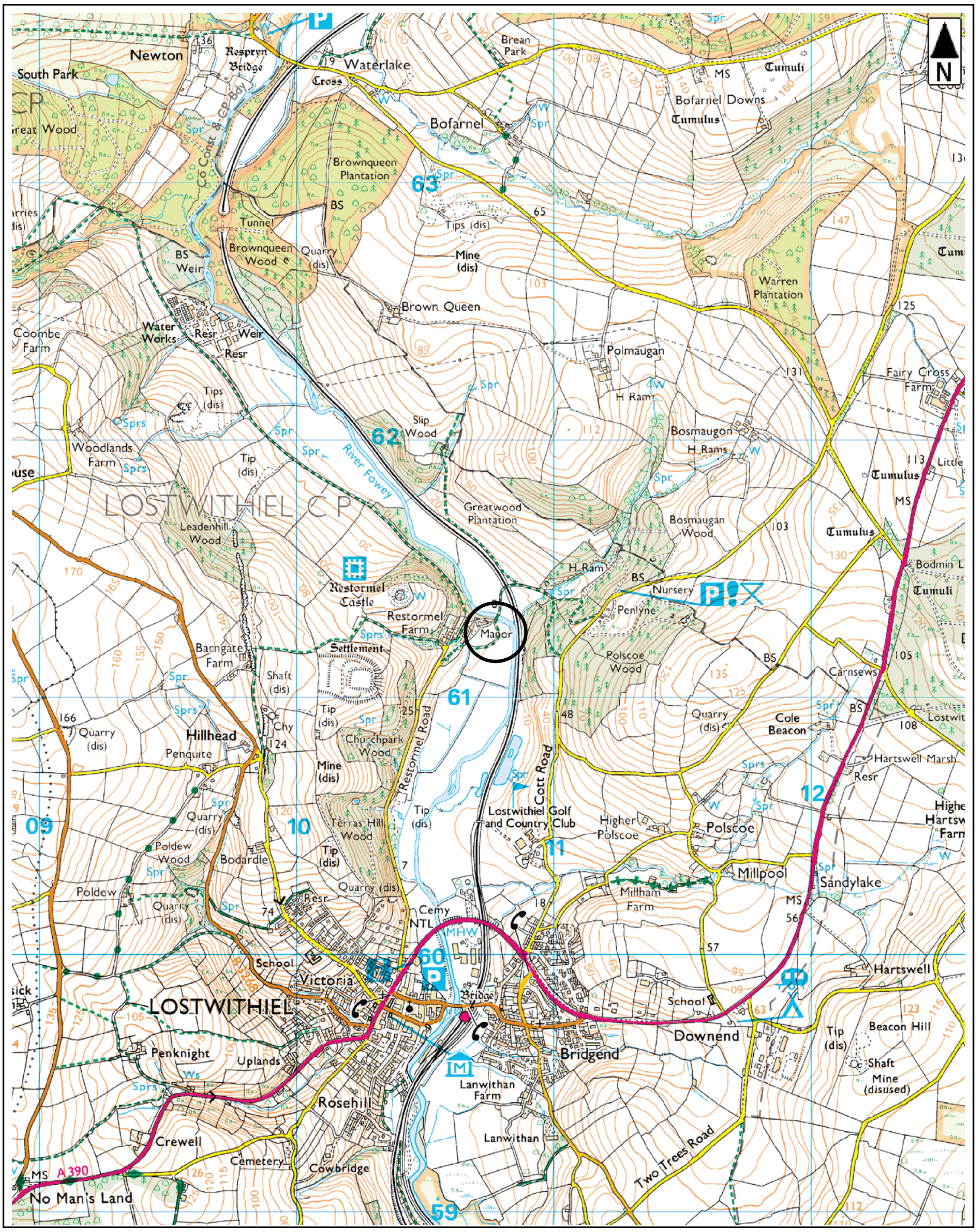


Figure 1: Map to show the general location of Restormel Manor, Lostwithiel, Cornwall

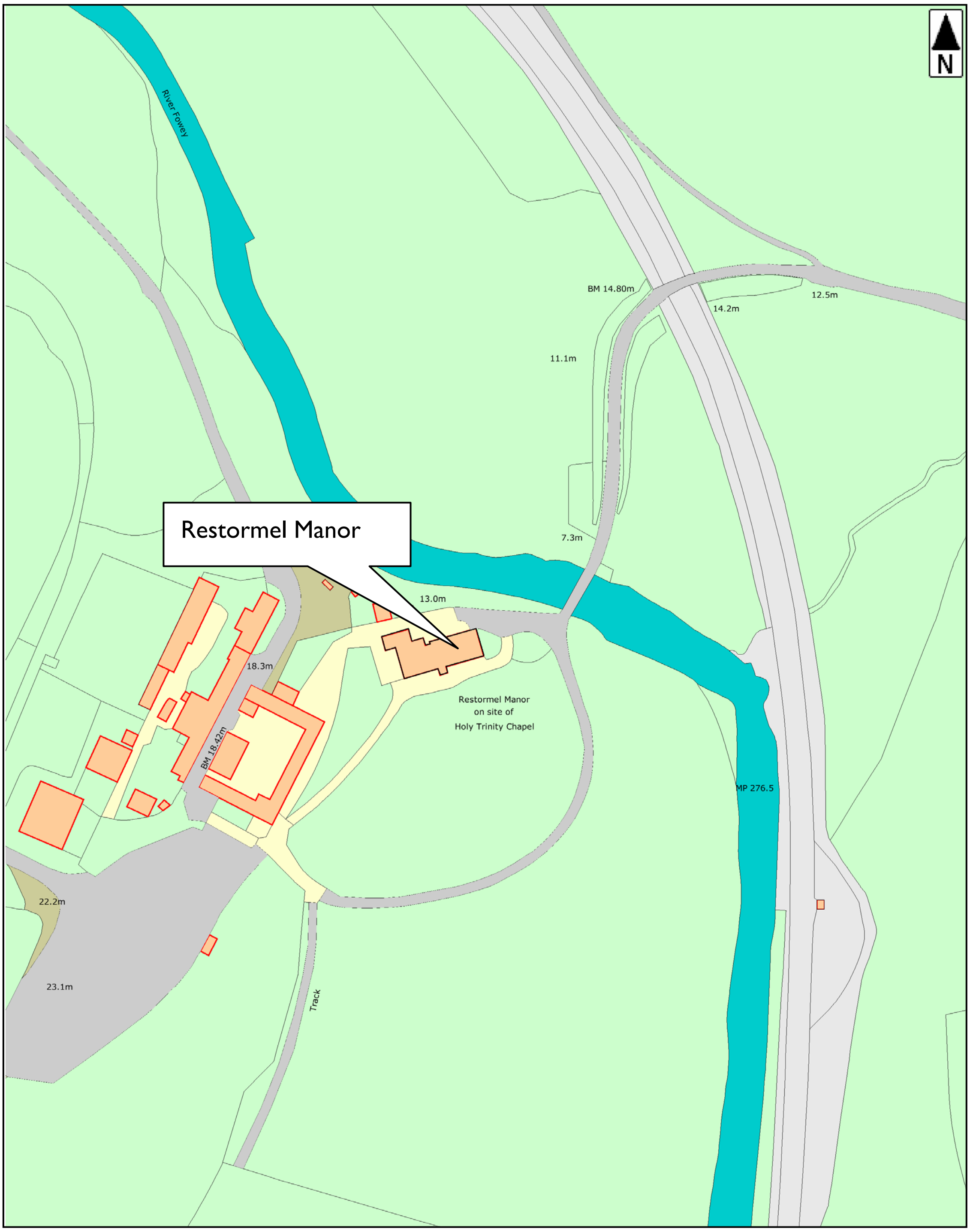


Figure 2: Map to show the location of Restormel Manor

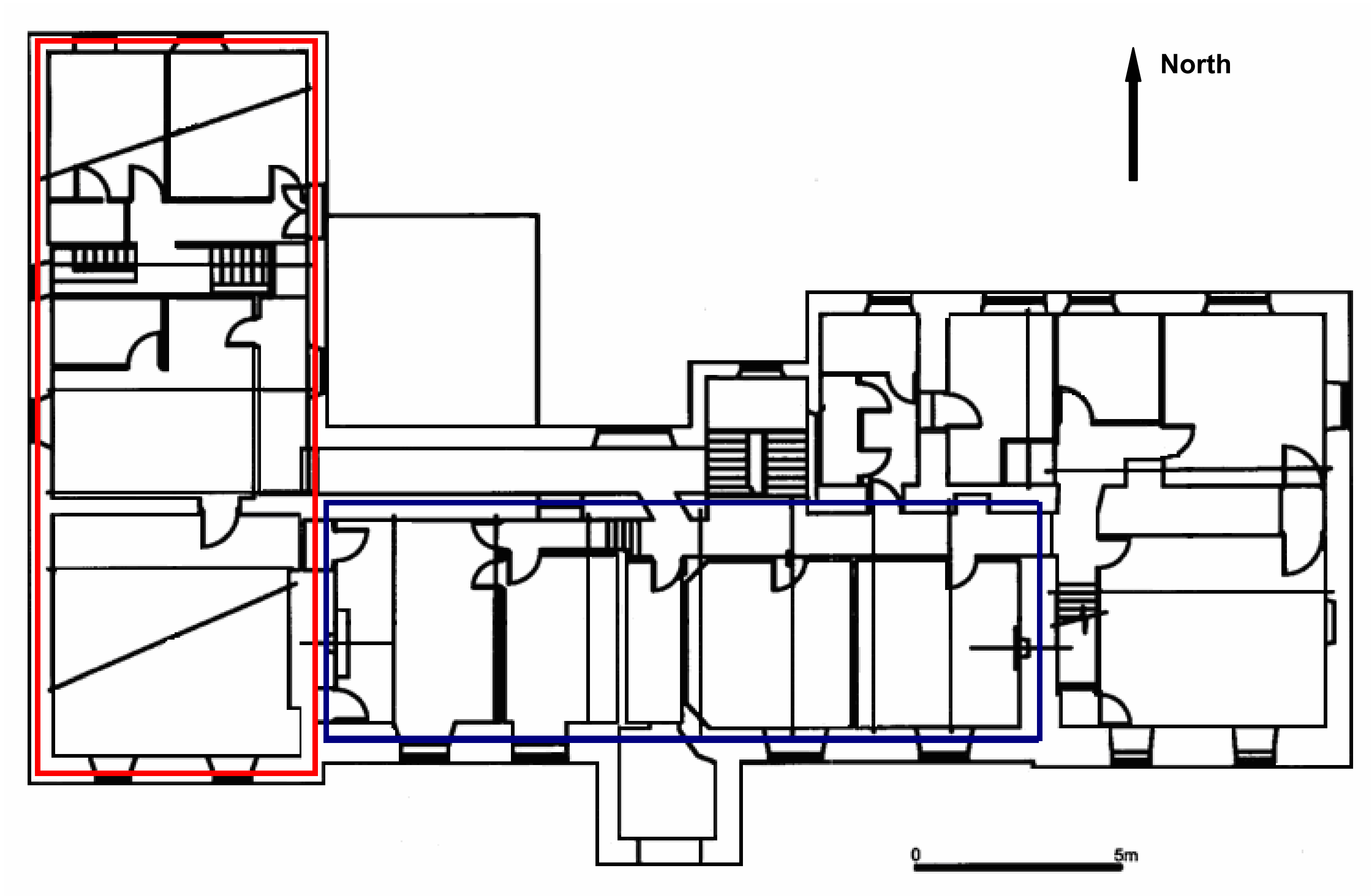


Figure 3: Plan of Restormel Manor House; central range in blue, western range in red (Duchy of Cornwall)

Figure 4: Central range roof; truss 6

Figure 5: Western range roof truss; truss 3 in foreground

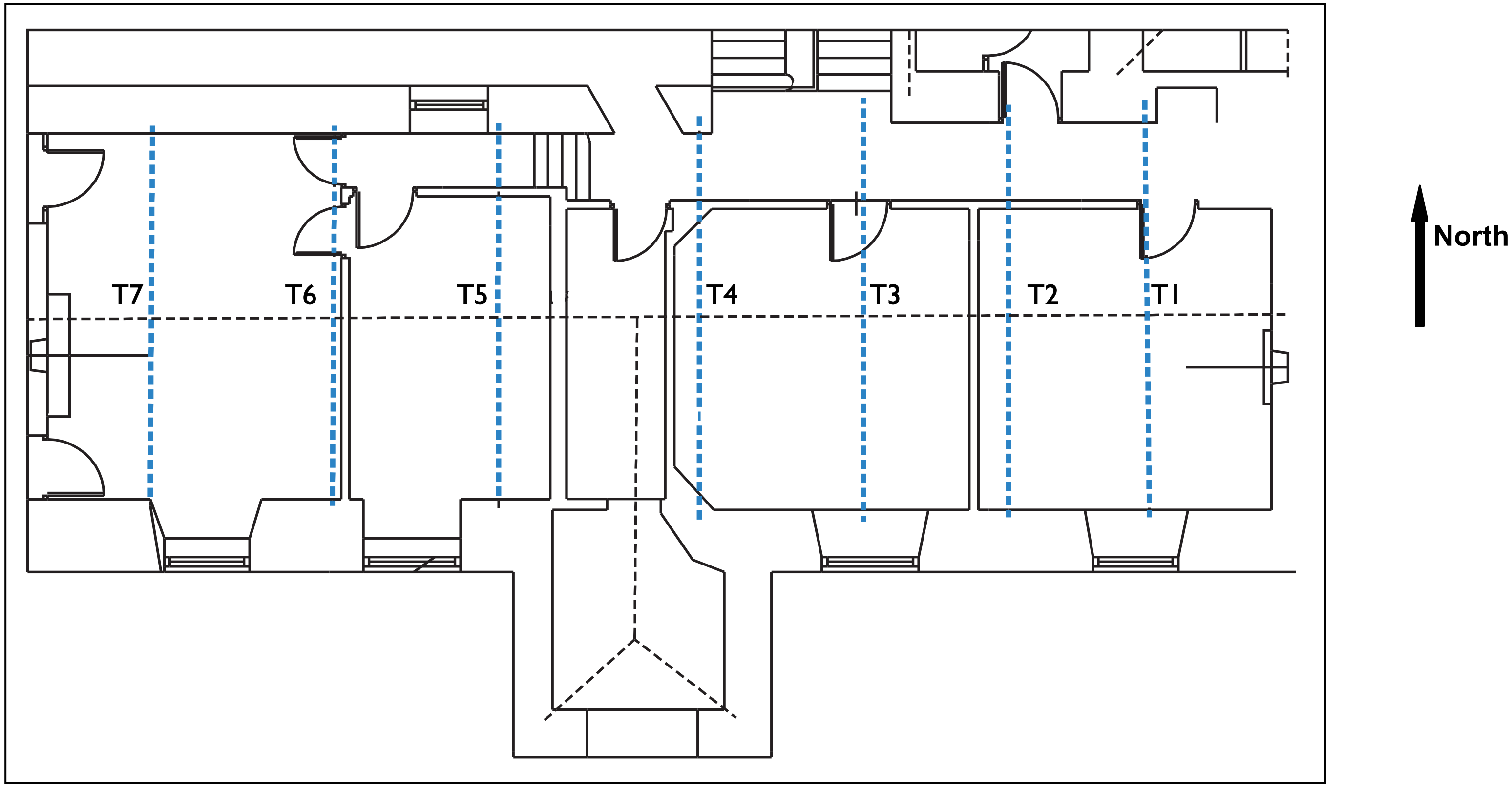


Figure 6: Plan of the central range, trusses shown in blue (Trusses 1 and 7 are replacements) (Duchy of Cornwall)

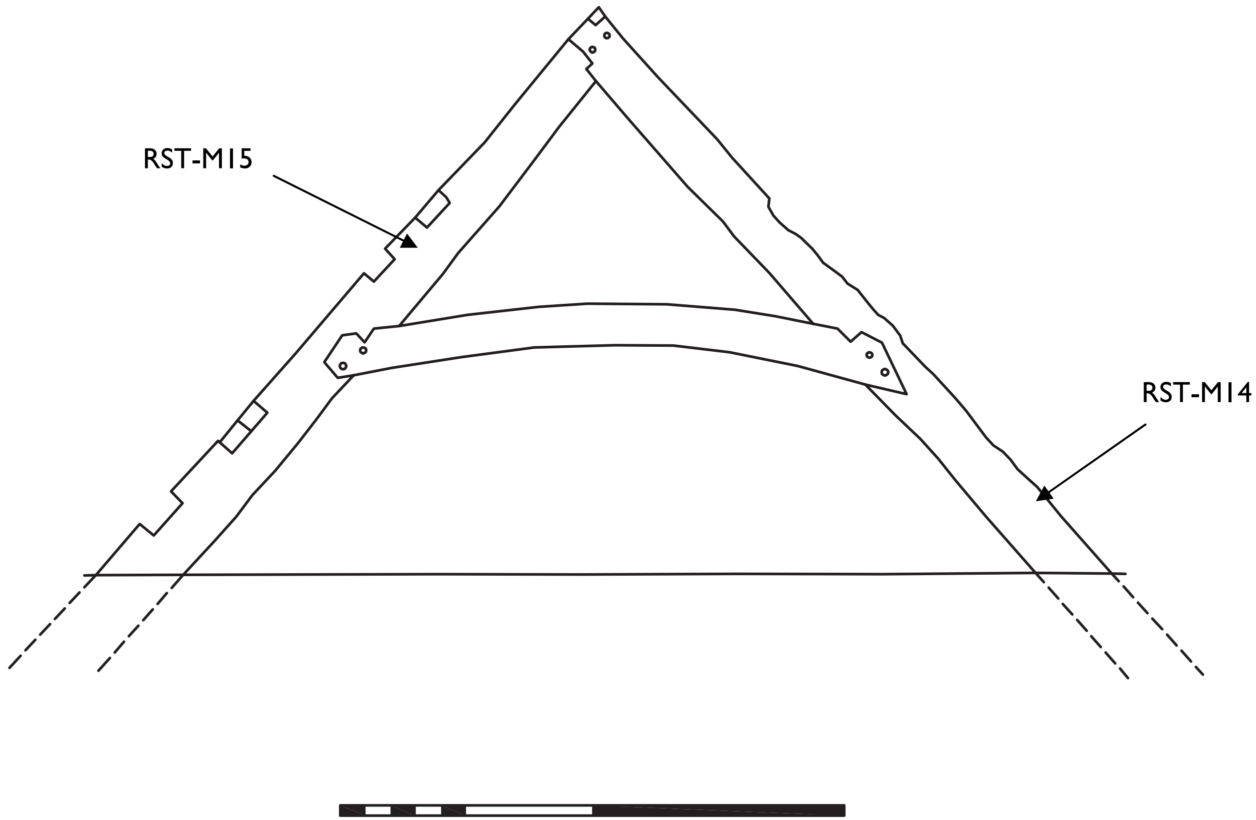


Figure 7: Truss 2, east face (based on drawing of Truss 3), showing the location of sample RST-M14 and RST-M15 (Eric Berry and Nigel Thomas)

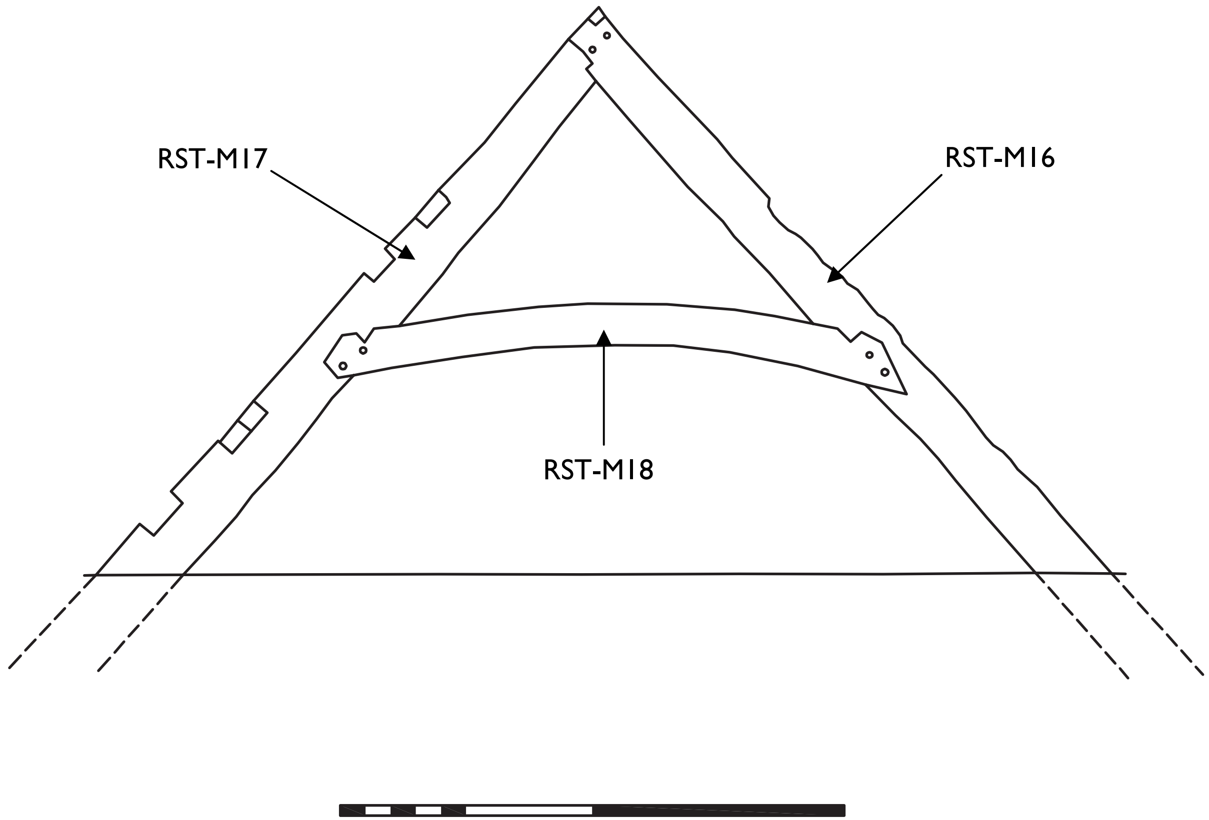


Figure 8: Truss 3, east face, showing the location of sample RST-M16–18 (Eric Berry and Nigel Thomas)

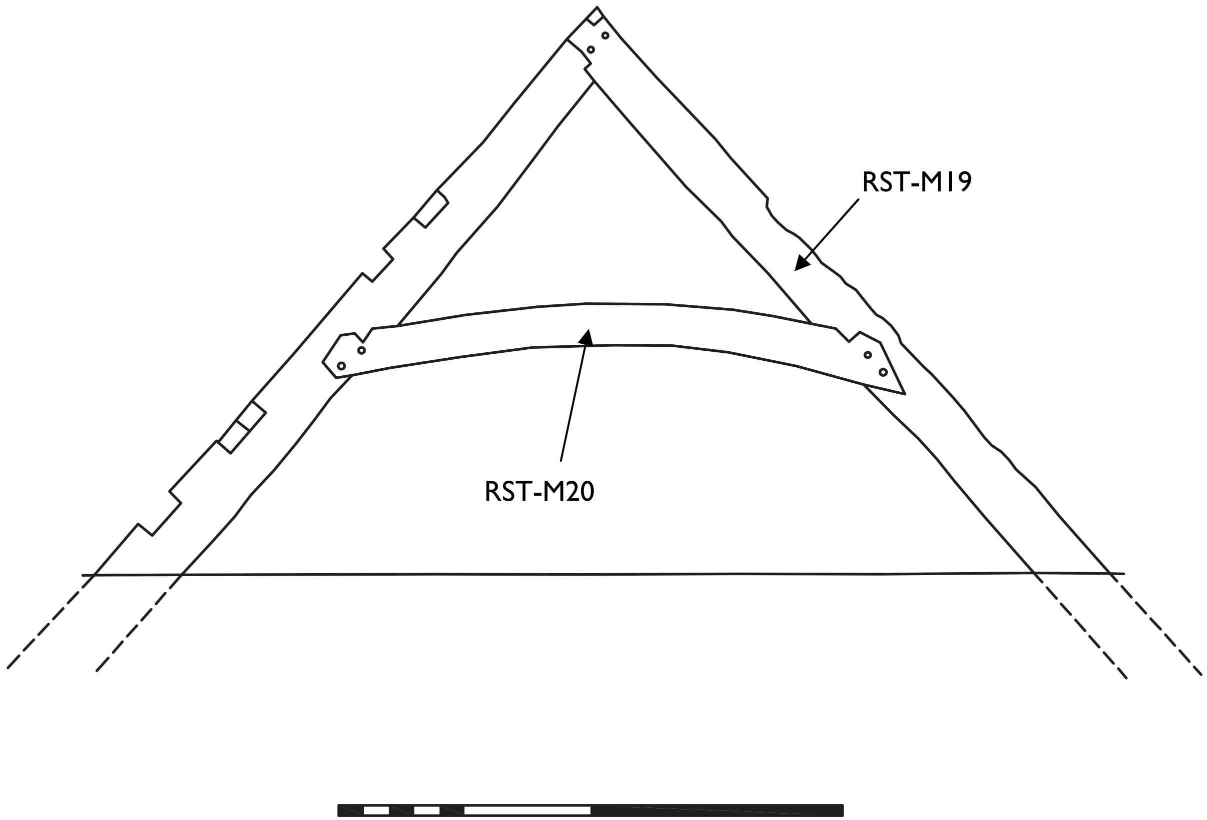


Figure 9: Truss 4, east face (based on drawing of Truss 3), showing the location of sample RST-M19 and RST-M20 (Eric Berry and Nigel Thomas)

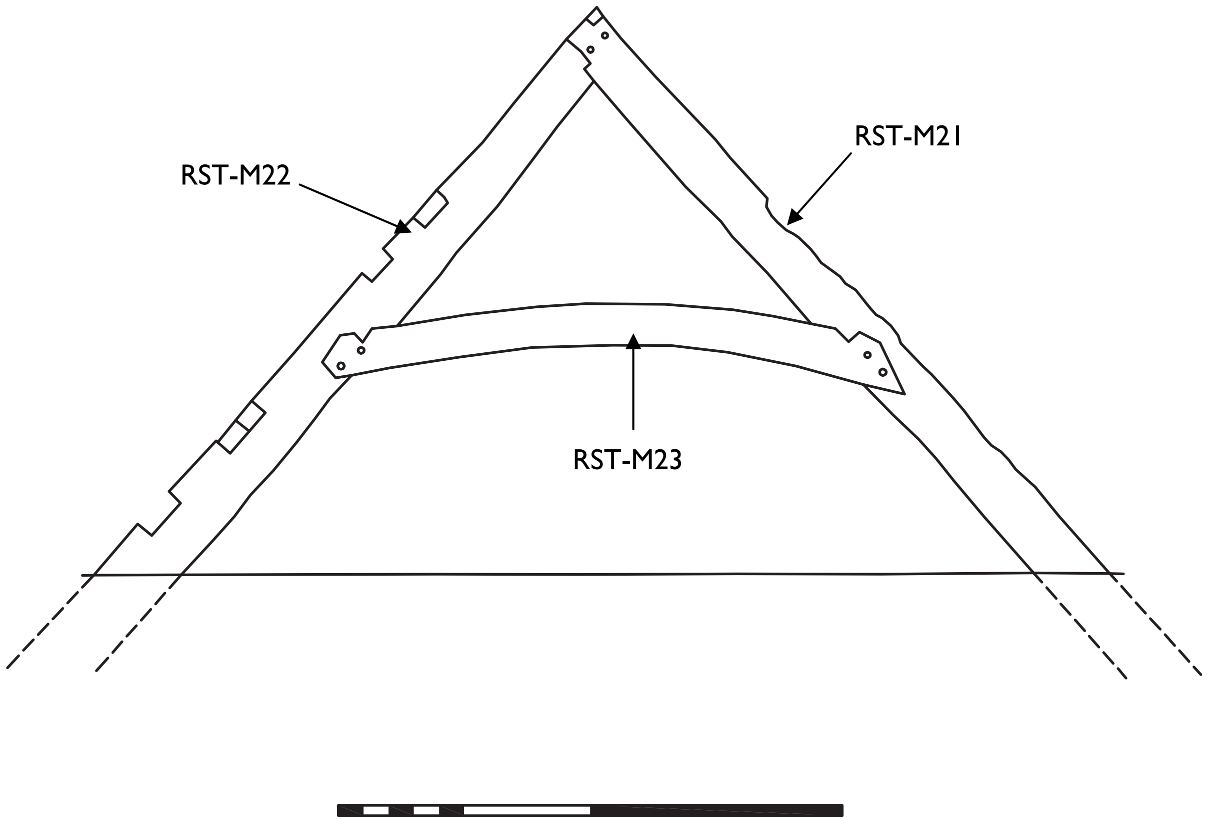


Figure 10: Truss 5, east face (based on drawing of Truss 3), showing the location of sample RST-M21-3 (Eric Berry and Nigel Thomas)

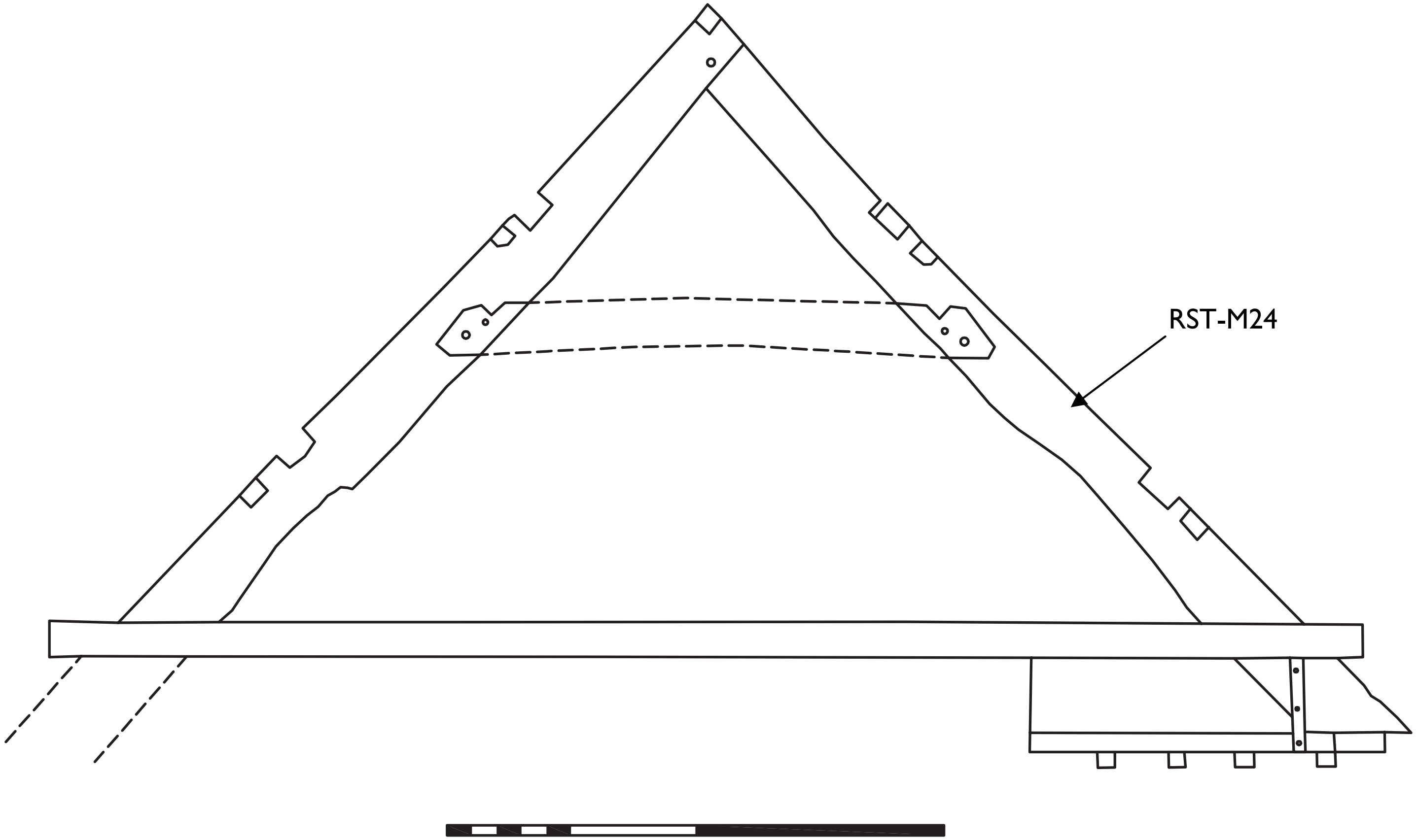


Figure 11: Truss 6 (east face), showing the location of sample RST-M24 (Eric Berry and Nigel Thomas)

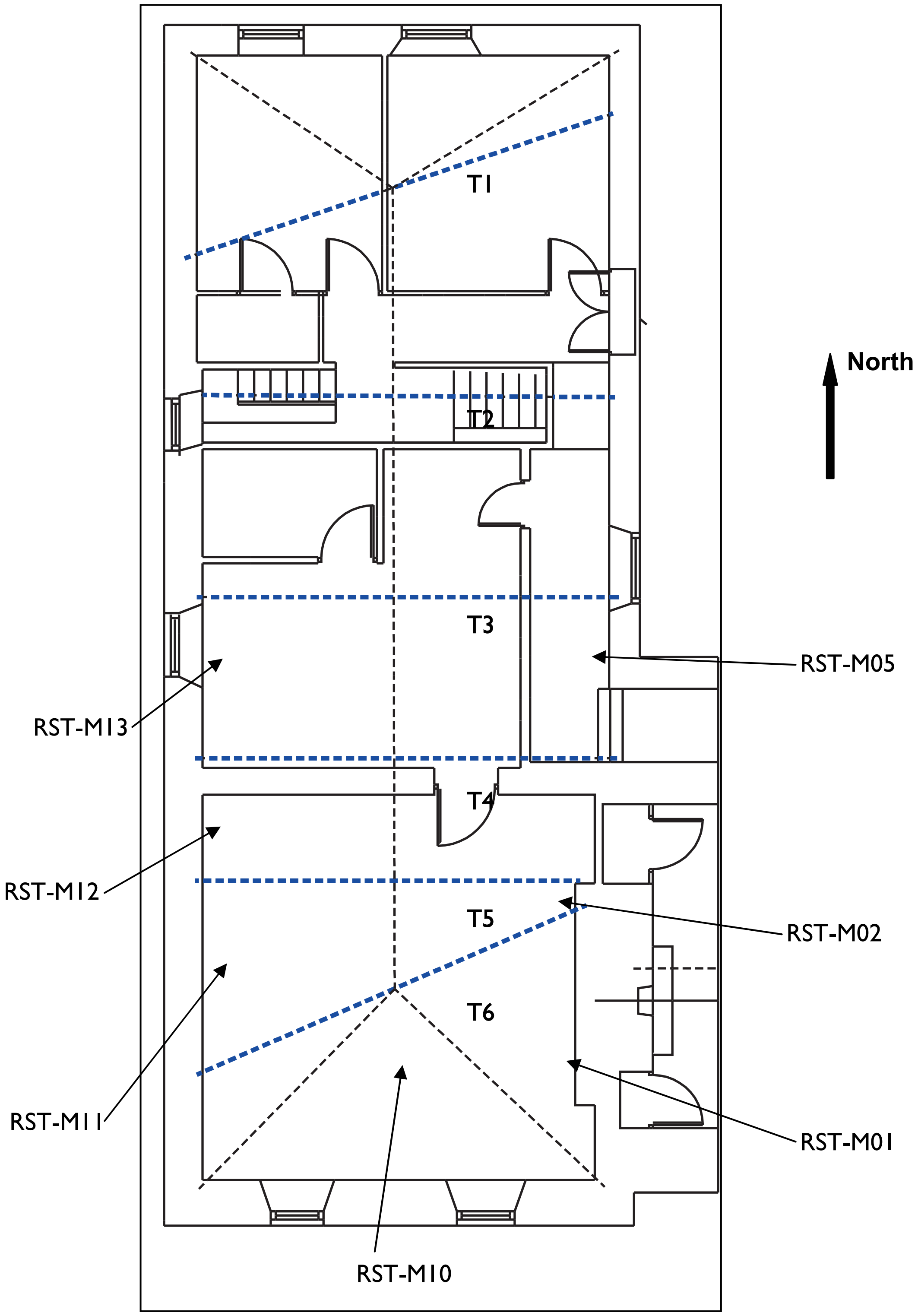


Figure 12: Western range, with trusses marked in blue, showing the location of samples RST-M01, RST-M02, RST-M05, and RST-M10–13

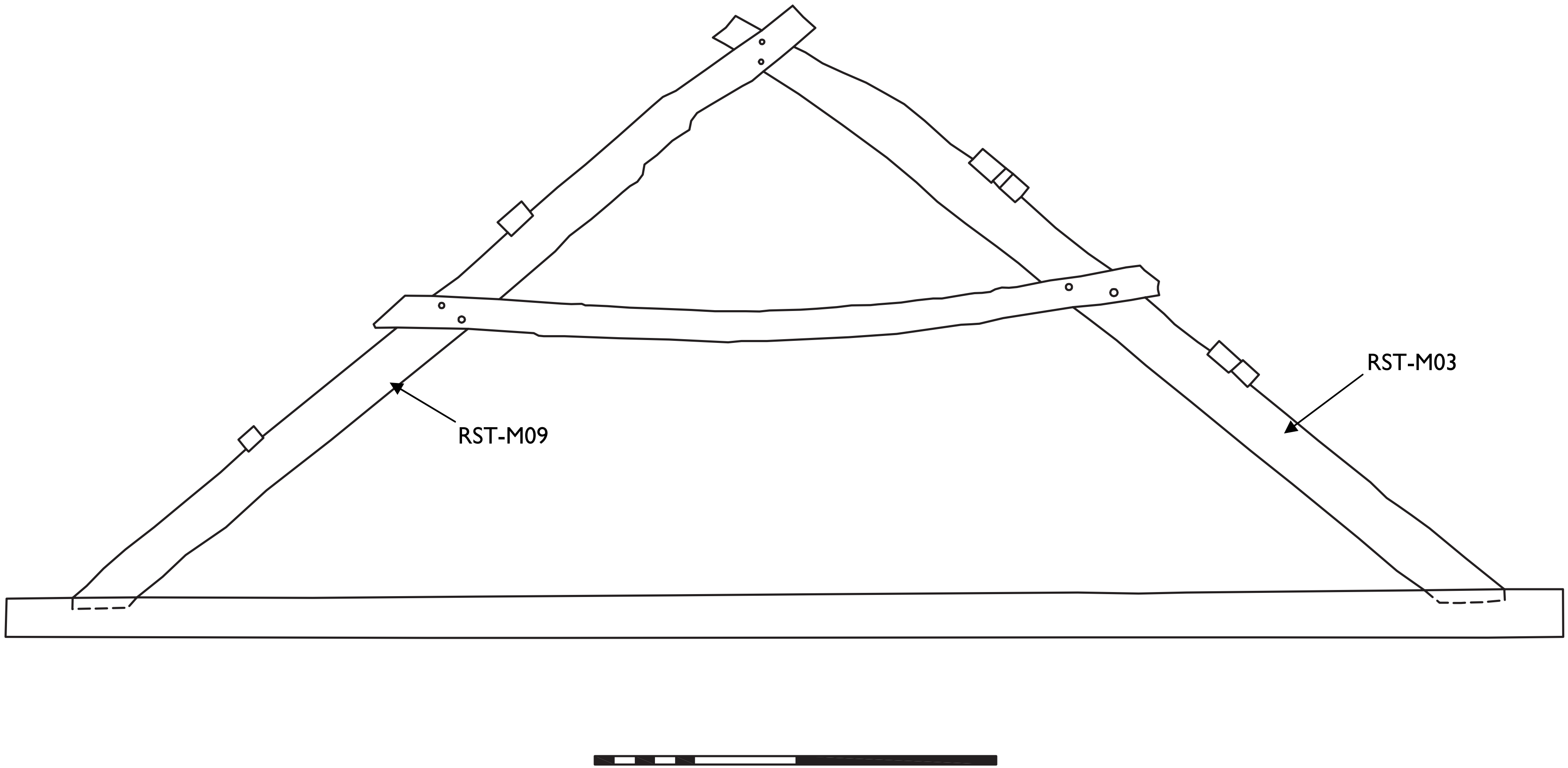


Figure 13: Truss 2 (south face), showing the location of sample RST-M03 (Eric Berry and Nigel Thomas)

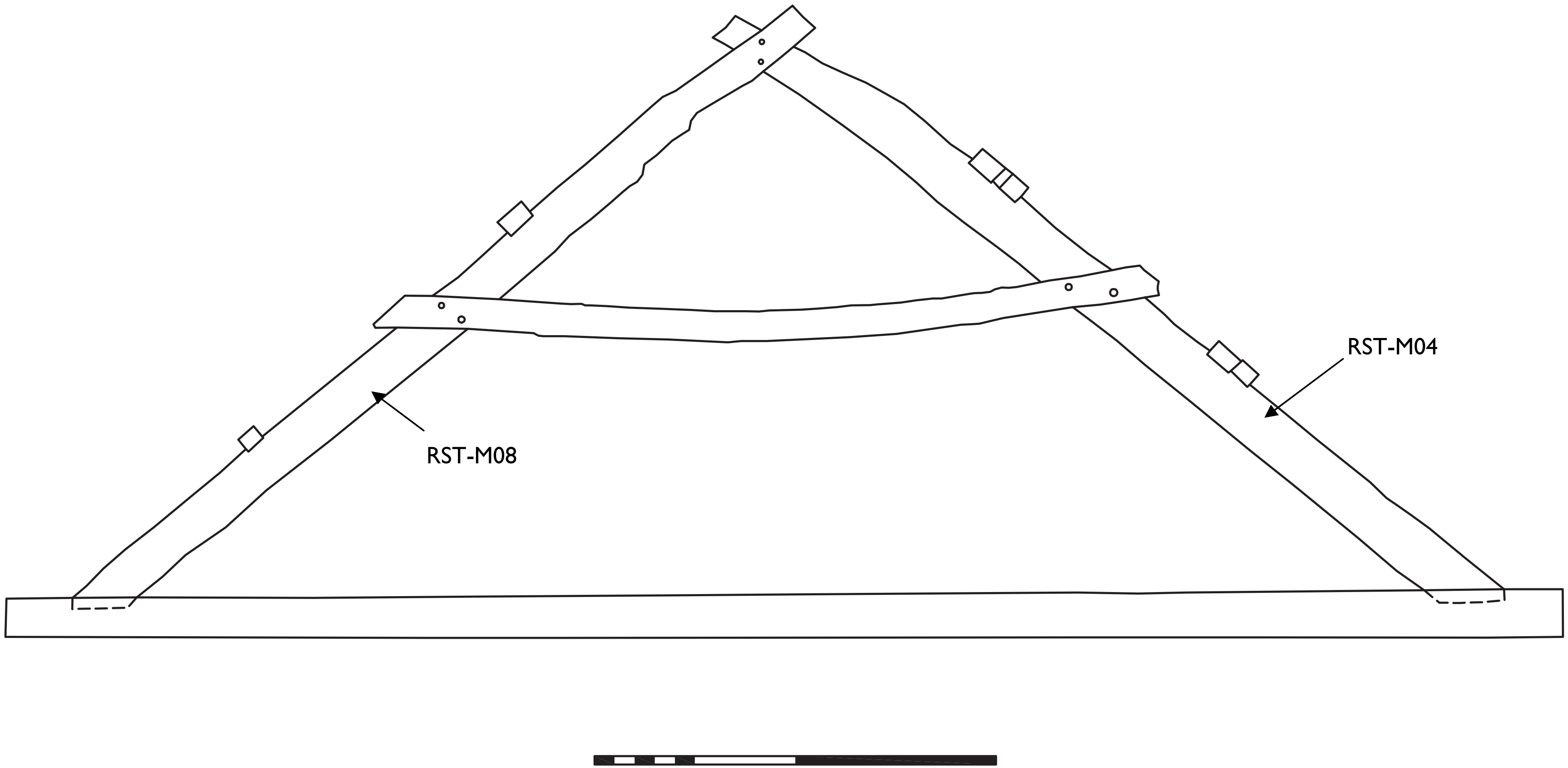


Figure 14: Truss 3 (south face), showing the location of sample RST-M04 and RST-M08 (Eric Berry and Nigel Thomas)

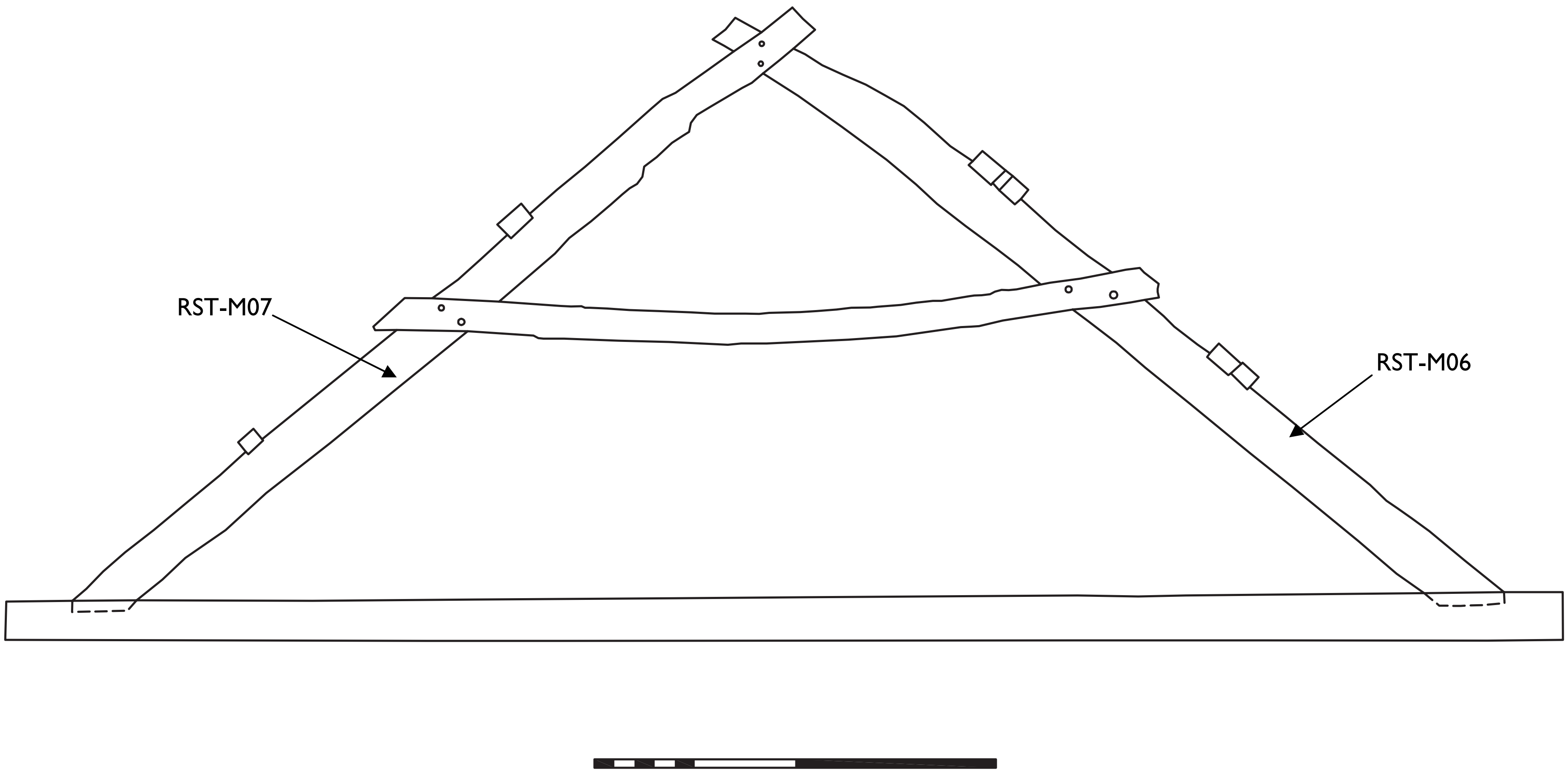


Figure 15: Truss 4 (south face), showing the location of samples RST-M06 and RST-M07 (Eric Berry and Nigel Thomas)

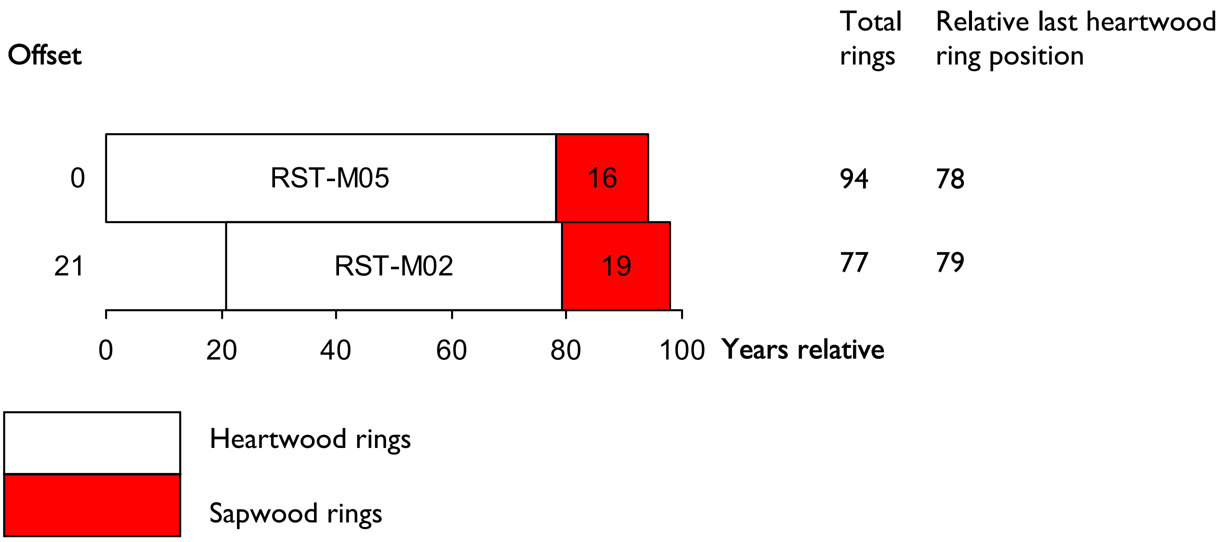
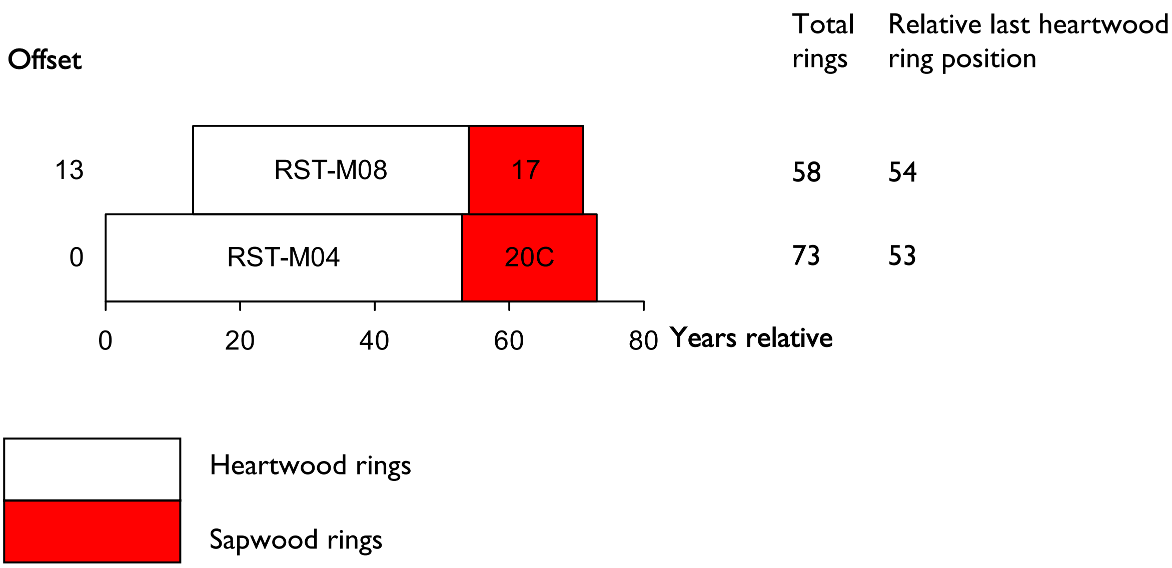


Figure 16: Bar diagram of samples in undated site sequence RSTMSQ01



C = complete sapwood retained on sample, last measured ring is the felling date

Figure 17: Bar diagram of samples in undated site sequence RSTMSQ02

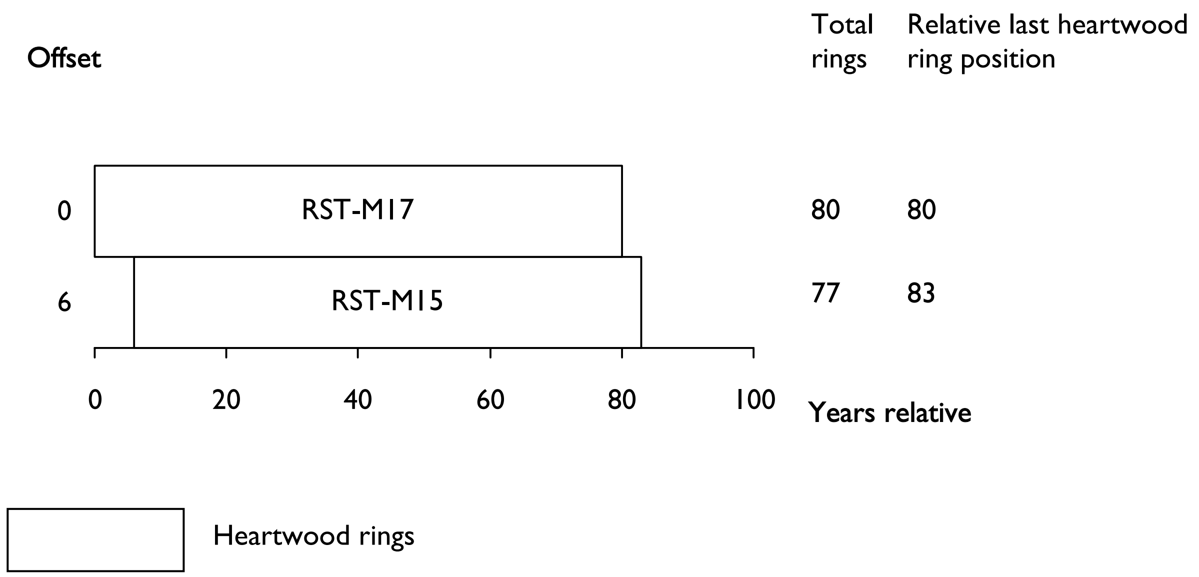
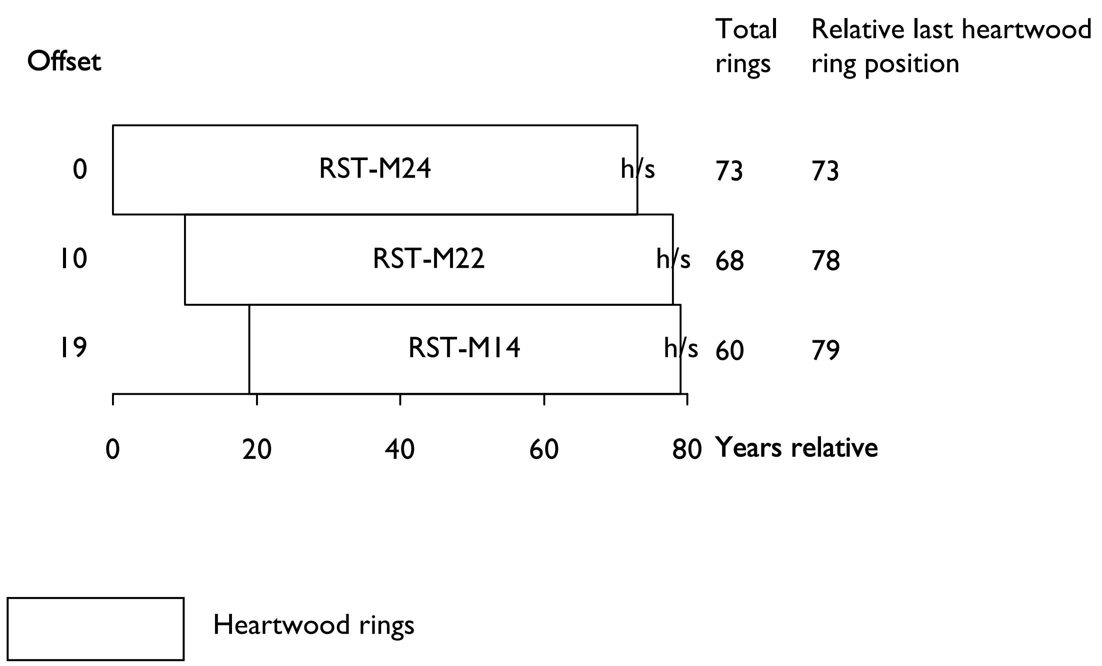


Figure 18: Bar diagram of samples in undated site sequence RSTMSQ03



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

Figure 19: Bar diagram of samples in undated site sequence RSTMSQ04

Data of measured samples – measurements in 0.01mm units

RST-M01A 66
261 266 174 122 248 348 350 306 255 173 328 368 310 332 414 429 290 290 332 322
293 406 441 539 452 244 283 250 140 71 87 95 83 84 108 157 178 86 57 49
54 50 45 41 41 55 74 64 48 49 57 86 141 180 146 142 28 43 45 39
30 39 70 133 127 181
RST-M01B 66
283 257 179 125 250 347 345 307 261 172 337 373 317 313 424 423 295 294 314 324
298 418 435 536 441 245 285 250 140 70 88 97 80 83 112 151 185 74 63 54
43 51 53 50 48 49 68 58 45 62 73 87 140 189 147 137 35 41 44 39
32 37 76 135 131 166
RST-M02A 77
356 199 217 117 212 124 168 223 118 95 85 107 126 95 105 114 162 105 187 122
134 126 125 118 142 81 65 106 95 103 154 96 86 116 148 131 116 84 92 120
80 92 83 54 81 83 87 94 100 78 78 110 109 127 84 78 88 76 92 113
60 75 59 73 69 106 101 135 91 194 164 188 97 123 157 238 418
RST-M02B 77
284 191 211 122 207 130 173 216 124 96 90 105 110 117 95 119 155 112 190 108
143 132 121 110 144 90 69 99 91 121 150 95 89 116 153 115 117 84 85 115
86 68 98 69 74 92 79 100 95 85 69 113 116 113 86 70 98 81 85 105
72 66 58 85 64 105 89 124 96 198 166 187 93 119 155 226 428
RST-M04A 73
284 372 366 280 316 294 141 194 216 246 241 241 281 256 232 343 262 257 184 71
60 59 50 84 74 82 124 135 161 173 167 216 162 161 121 178 167 153 154 159
174 110 145 180 88 73 70 73 86 84 87 103 119 75 55 71 75 85 90 86
84 72 138 138 65 75 77 121 146 129 97 78 99
RST-M04B 73
312 385 366 277 321 305 134 204 210 242 245 240 284 251 236 336 268 256 192 74
54 57 60 79 80 88 140 125 163 173 173 214 165 158 119 175 162 143 160 160
183 114 143 180 100 75 70 68 81 79 108 116 114 73 41 69 73 90 89 87
86 72 136 142 62 73 78 122 155 133 92 75 107
RST-M05A 94
175 323 251 337 222 188 224 222 327 285 284 318 257 269 269 147 130 188 238 181
189 190 161 216 156 308 211 213 225 203 225 167 184 206 226 118 139 212 215 245
184 174 191 154 169 198 153 99 125 171 156 158 115 102 116 118 96 119 62 90
115 105 59 69 85 99 133 81 89 90 50 37 78 70 108 66 64 83 100 86
93 66 90 100 80 60 91 98 167 138 243 260 254 194
RST-M05B 94
215 311 255 331 213 184 228 270 327 276 276 325 244 274 263 147 136 185 234 179
187 195 155 222 157 300 215 222 248 203 231 163 177 207 221 126 138 212 209 245
181 187 162 168 177 200 150 91 128 169 153 157 124 110 121 110 95 114 68 89
120 96 68 63 85 103 103 75 83 88 47 51 76 76 104 72 64 102 81 88
86 82 113 95 64 64 99 97 158 135 213 327 281 197
RST-M06A 48
245 313 258 277 397 361 220 122 144 195 172 228 231 155 163 190 192 132 162 121
166 151 182 182 212 198 325 248 265 307 198 140 154 119 126 175 166 234 209 219
182 139 183 126 206 156 187 209
RST-M06B 48
250 312 263 273 392 361 225 124 151 194 176 216 227 158 160 183 200 132 167 123
162 152 184 180 211 195 333 246 243 263 195 141 159 126 124 173 158 230 207 210
186 130 189 122 212 150 190 150
RST-M07A 60
221 344 186 239 353 437 402 441 399 344 479 388 353 449 364 352 218 256 231 214
292 278 209 249 214 300 200 237 179 175 207 173 176 177 177 211 158 165 168 116
101 148 143 156 170 146 197 201 211 214 98 148 152 182 125 203 212 215 175 140

RST-M07B 60
220 343 181 236 352 428 398 440 401 344 485 404 347 452 379 337 212 256 226 222
282 280 202 243 223 283 207 229 183 173 199 183 167 176 176 204 162 171 174 118
94 150 148 157 169 146 199 193 208 215 103 149 149 187 119 202 218 222 194 122
RST-M08A 58
312 308 329 355 284 212 51 56 43 30 46 75 100 125 142 229 230 262 286 259
263 250 252 260 238 211 207 254 179 217 287 151 104 104 151 153 122 127 175 154
167 101 100 123 148 164 165 126 126 241 205 133 142 150 188 216 169 134
RST-M08B 58
308 307 351 354 275 218 50 44 43 36 49 63 107 123 143 224 224 263 283 272
251 257 241 237 222 198 205 278 184 220 275 136 135 111 144 148 122 129 175 153
171 91 105 112 146 165 169 128 126 231 208 134 143 148 196 206 177 135
RST-M10A 71
380 363 228 238 137 120 90 95 65 185 261 256 306 329 270 250 215 291 277 160
156 102 125 196 208 191 170 119 131 166 163 189 218 167 208 157 171 161 175 236
197 129 136 113 142 106 155 168 143 155 194 249 228 225 177 114 103 94 71 113
123 136 132 335 485 525 404 289 303 190 218
RST-M10B 71
379 360 220 243 136 112 92 81 71 184 263 253 278 333 265 253 225 312 282 160
149 87 147 190 213 218 149 124 130 162 160 191 225 171 195 159 175 162 178 226
202 127 141 101 145 122 144 167 138 163 199 247 223 235 164 116 111 89 72 109
120 146 129 338 476 530 411 294 296 177 192
RST-M14A 60
216 232 207 279 206 233 251 209 227 241 177 160 198 170 179 219 195 148 178 148
158 139 155 101 142 156 99 131 115 105 135 140 131 112 94 78 74 128 128 127
122 152 114 151 148 171 164 148 145 143 160 179 205 172 95 92 108 138 158 221
RST-M14B 60
164 237 228 249 196 232 256 241 234 216 194 160 191 179 180 225 196 153 173 113
167 150 149 126 122 156 101 146 108 96 136 142 130 119 114 74 73 124 127 127
124 152 137 151 149 171 161 146 146 145 164 177 208 168 102 87 109 154 143 230
RST-M15A 77
274 399 335 395 321 356 362 290 414 540 418 437 257 337 364 233 402 284 251 364
285 351 217 354 296 422 435 437 432 392 352 423 318 315 131 107 175 117 209 196
166 181 248 187 146 177 120 93 199 31 22 26 12 18 14 36 37 27 29 35
41 46 104 64 123 129 179 201 213 311 338 194 314 274 372 282 249
RST-M15B 77
322 373 320 391 306 352 346 281 409 539 422 426 263 347 361 227 383 296 238 368
284 354 213 352 282 423 441 421 446 367 347 418 310 296 149 100 164 117 230 206
157 181 247 191 148 172 116 103 189 37 19 14 15 20 14 23 38 34 27 42
34 48 92 64 110 145 173 203 217 333 342 193 313 269 343 280 248
RST-M17A 80
268 297 333 300 328 267 334 379 368 414 471 513 449 372 481 548 412 417 387 366
442 299 329 232 233 253 227 279 240 249 234 274 276 230 294 321 305 305 293 137
118 117 242 135 99 64 84 120 204 193 196 224 194 158 281 52 29 35 51 52
64 54 92 50 46 30 32 28 33 31 34 25 26 36 49 41 54 34 65 167
RST-M17B 80
266 289 293 300 328 270 336 421 364 408 476 522 452 375 478 551 411 425 350 378
442 309 355 236 232 255 235 260 237 240 221 270 289 238 319 313 287 319 284 142
143 105 227 125 79 76 78 109 197 174 193 247 190 170 280 60 24 38 52 58
57 60 80 44 40 37 28 21 35 25 33 30 30 37 38 44 58 32 71 161
RST-M19A 60
108 106 212 141 208 147 185 210 157 201 205 239 227 245 231 276 227 228 284 243
186 201 175 171 146 219 194 177 200 220 218 180 175 167 191 227 134 135 157 147
131 183 123 150 169 132 118 173 188 216 184 214 271 272 257 273 299 187 200 218

RST-M19B 42
196 190 161 137 207 165 158 203 223 220 182 195 159 227 231 131 154 157 199 148
196 122 139 160 126 122 156 191 223 178 219 272 271 272 264 272 194 193 223 383
502 738
RST-M20A 61
282 177 311 306 317 378 477 541 450 398 494 454 484 429 496 664 583 673 490 447
293 315 270 173 204 232 198 143 66 131 242 273 244 232 206 334 332 288 348 210
303 287 195 242 266 201 152 220 168 130 175 395 240 225 208 148 251 332 176 176
114
RST-M20B 61
200 181 302 309 319 375 472 542 446 401 493 451 462 427 492 673 578 669 493 443
293 321 263 167 247 199 206 137 64 143 238 274 247 250 204 314 354 280 337 225
281 291 186 248 274 214 120 229 180 129 182 383 269 240 195 167 231 359 168 172
123
RST-M21A 49
350 568 412 433 257 551 540 460 338 30 43 45 79 143 169 214 304 333 254 248
415 618 657 685 514 583 461 264 414 340 432 317 410 421 413 413 543 523 456 505
362 314 337 414 515 360 339 438 324
RST-M21B 49
368 530 402 442 269 549 544 455 341 35 46 53 68 136 168 201 313 405 258 219
475 601 657 671 521 561 470 268 429 337 437 295 412 426 393 401 544 489 467 507
350 311 329 416 495 359 329 445 327
RST-M22A 68
259 349 404 386 286 206 325 272 311 328 277 225 256 154 220 207 195 293 225 194
199 206 243 259 253 245 167 185 172 155 145 152 122 120 138 104 118 125 100 147
148 159 146 123 93 89 132 163 144 156 153 143 145 144 164 194 159 168 165 164
146 177 175 106 98 113 127 155
RST-M22B 68
218 369 375 380 284 202 297 277 296 328 276 228 255 152 230 201 204 300 225 182
206 189 237 250 246 246 168 170 180 158 147 144 130 126 144 102 121 130 99 154
147 163 145 122 89 94 129 159 147 154 155 132 133 142 168 186 165 167 150 166
156 173 172 107 98 114 121 148
RST-M23A 54
171 271 290 251 262 252 212 333 259 187 281 262 225 159 170 282 368 301 271 289
254 223 364 269 223 235 264 190 210 191 207 249 212 215 147 267 439 425 451 335
418 433 345 367 389 282 359 249 308 352 323 346 300 180
RST-M23B 54
159 288 281 241 278 218 243 319 248 192 273 257 201 162 169 269 348 305 260 267
244 236 366 238 227 246 265 199 200 182 236 248 216 208 152 261 441 407 444 332
404 429 349 363 381 292 356 278 335 338 390 380 299 167
RST-M24A 73
289 314 214 296 300 420 353 264 252 297 351 340 400 327 359 236 268 242 274 266
236 284 214 103 186 168 170 324 283 219 229 193 239 241 247 218 147 133 144 148
137 173 137 95 140 92 118 129 111 150 172 145 119 126 66 37 73 80 68 91
89 110 128 147 191 179 131 152 130 115 156 199 178
RST-M24B 73
318 311 217 339 264 440 331 266 247 277 341 339 376 342 349 236 270 236 277 255
255 273 213 117 183 175 167 306 281 225 223 196 233 254 237 209 168 136 145 129
142 181 145 91 135 96 117 126 121 145 167 152 109 130 68 38 70 75 67 103
87 113 130 143 177 183 145 136 137 123 137 192 179

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 none of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 2 cm, a reasonable estimate can be made of the number of sapwood rings lost, say 12 to 15 rings in this case. By adding on 12 to 15 years to the date of the last ring on the sample a good tight estimate for the range of the felling date can be obtained, which is often better than the 15 to 35 years later we would have estimated without this observation. In the example, the felling is now estimated to 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

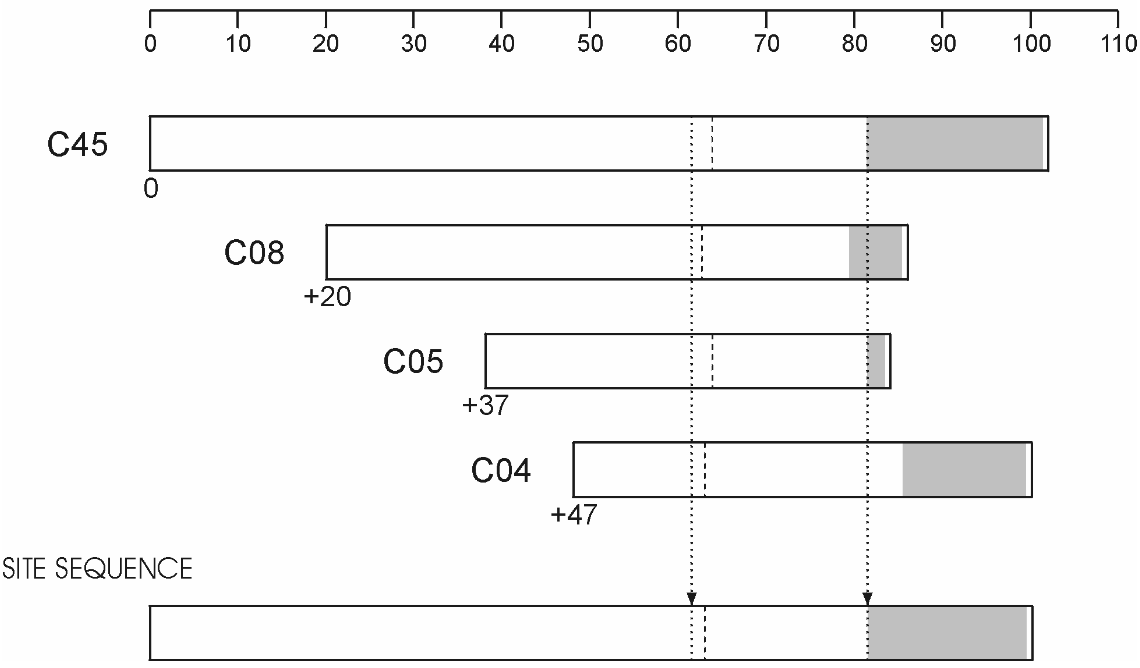


Figure 5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

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.

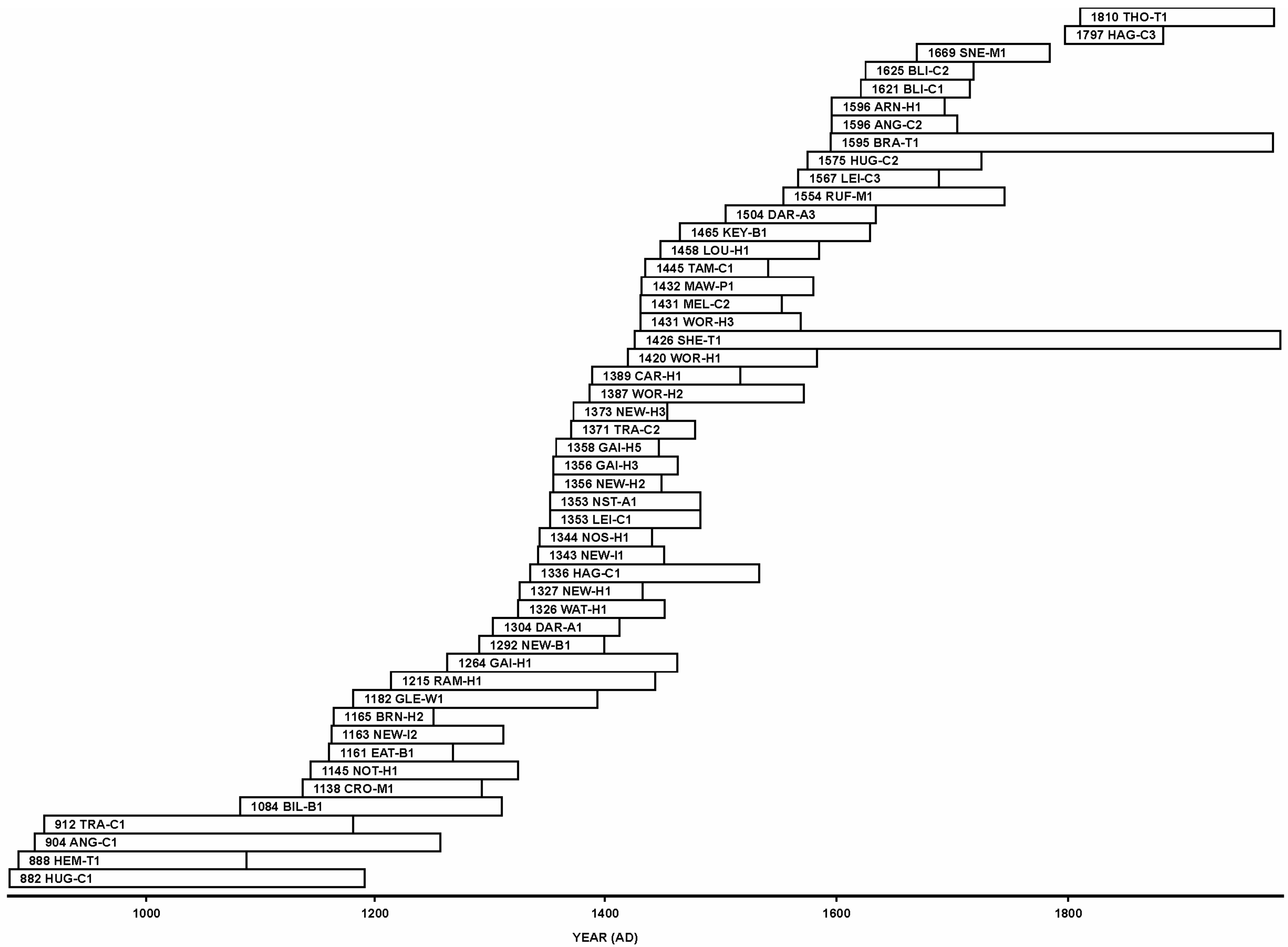
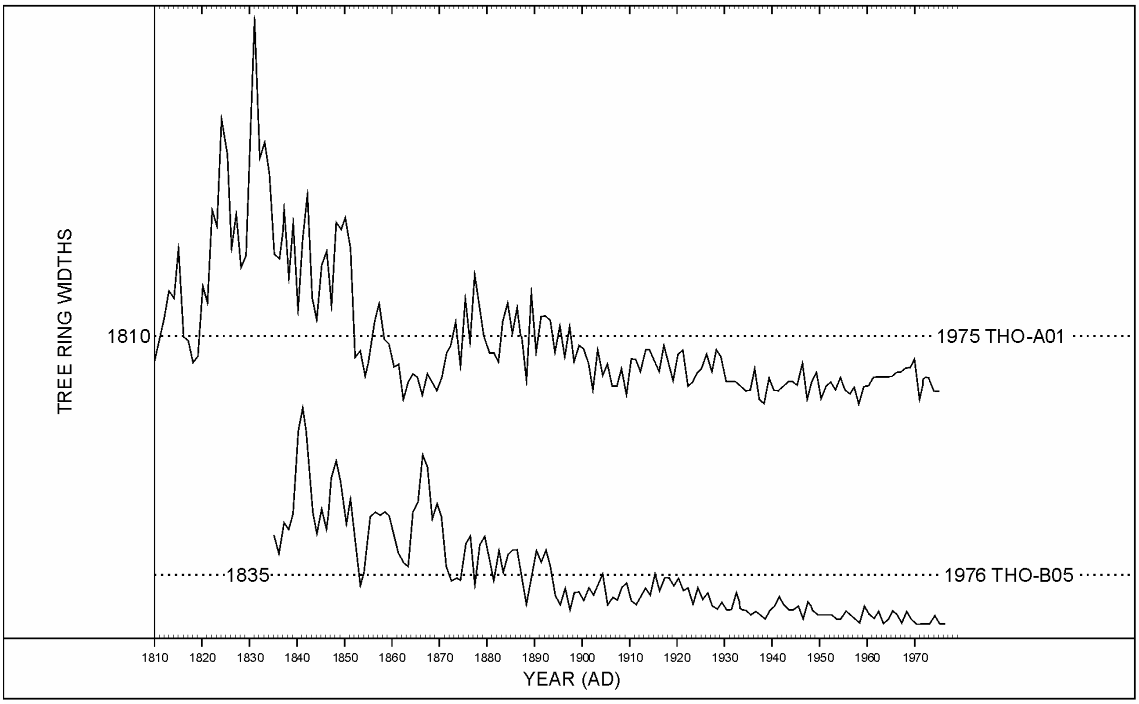


Figure 6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

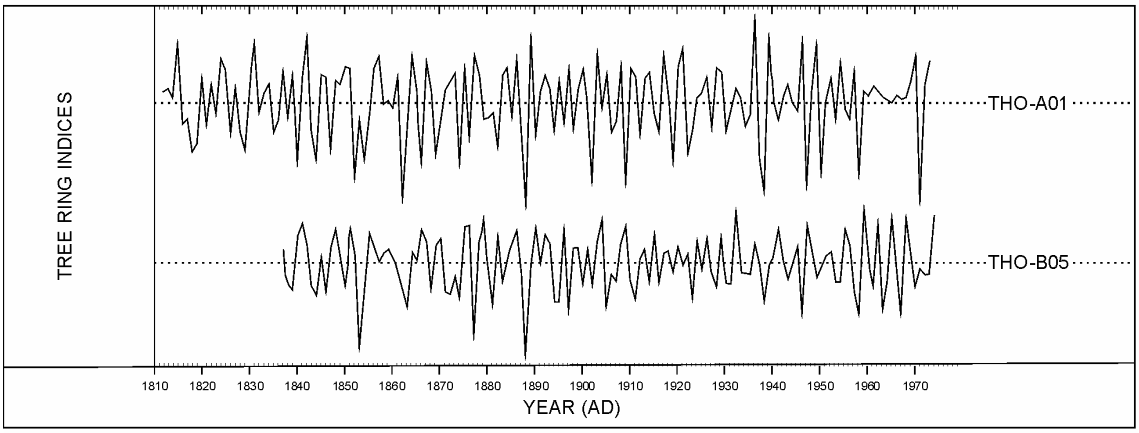


Figure 7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young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