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ST JOHN'S HOSPITAL AND CHANTRY, CIRENCESTER, GLOUCESTERSHIRE
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

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Summary

Dendrochronological analysis undertaken on samples from the roof structure of this building has resulted in the construction and dating of two site sequences.

The first, SJHCSQ01, contains two samples and spans the period AD 1091–1201. Interpretation of the sapwood on these two samples points to them having been felled within the range AD 1202–25. The second site sequence, SJHCSQ02, contains 14 samples and spans the period AD 1254–1436. Three of these samples have complete sapwood and were felled in AD 1436, with the remaining 11 thought to have also been felled at this time.

Prior to tree-ring analysis being undertaken, this roof was believed to be largely of one, early medieval phase, but with some later inserted timber repairs. It is now known that this primary roof structure dates to the second quarter of the fifteenth century, with the majority of dated timbers having been felled in AD 1436, but that it incorporates a number of early twelfth-century, presumably reused, timbers. The few 'inserted' timbers dated were found to have the same felling date as the primary roof timbers. A possible explanation for this is that these 'inserted' timbers are relocated from other parts of the roof or contemporaneous work elsewhere in the building.

Keywords

Dendrochronology
Standing Building

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Introduction

St John's Hospital and Chantry is located on Spitalgate Lane, to the north of Cirencester's medieval abbey precinct (SP02150237; Figs 1 and 2). It was founded by Henry I in about AD 1133 and survived to the present time as an almshouse.

Surviving from the ancient hospital is the main portion of the old infirmary hall, but without its side aisles. It is of roughly coursed limestone rubble, comprising four bays, with arcades of two-centred chamfered arches supported by cylindrical columns with scalloped capitals. The plain, gabled roof has a rubblestone gable at the east end and a later timber truss on top of its west gable. At either side of the wall at the east gable end, at ground-floor level, are blocked openings with semi-circular heads. Presumably primary, these are thought to be windows or hatches rather than doorways. At a level above is another blocked opening with a square head; a tall window or door. The building is a Scheduled Ancient Monument and is on English Heritage's Buildings at Risk register. In May 2006 the roof of St John's Hospital and Chantry was re-tiled, thus giving the opportunity for a survey of the roof itself to be carried out. This was undertaken by Cotswold Archaeology on behalf of Reg Ellis and Associates. The description below, and indeed the general introduction above, is based largely on this survey (Cotswold Archaeology 2006).

The roof

The extant roof structure includes 40 trussed rafter pairs, thought to represent a single phase of construction (Fig 3). Originally each rafter pair would have consisted of rafters, collar, sole-plates, and ashlar pieces, although some have since lost several of these primary elements and one couple is completely missing. There is no ridgepiece, with the rafter couples meeting at halved pegged apex joints. The collars are jointed to the rafters by each end of them being fitted into a slot in the rafter and fixed with a single peg. On the inside of the walls can be seen the ashlar pieces. These are jointed to the rafters in a similar fashion as seen elsewhere within the roof, scarcely a half lap and single pegged. Carpenters' marks were noted on some of the timbers although no discernable sequence could be seen.

In addition to the rafter couples, there are other timbers which are clearly inserted (Fig 4), probably in a bid to strengthen the roof, as there is evidence that it began raking towards the west, possibly after the removal of the masonry west gable end. There is a pair of crude braces fitted to one of the rafter couples and supported on an inserted tiebeam. Other insertions include the introduction of a type of 'aisle purlin' on both sides of the roof at the western end. These are supported by braces which again rise from inserted tiebeams. Additionally, half rafters have been added throughout the roof in a more upright position than those raking rafters next to them. There are also twentieth-century repairs relating to the refurbishment of the building in the AD 1960s.

The form of this building as a whole is typical of an early-medieval hospital, which suggests the primary phase of this building could be early-twelfth century, close in date to the foundation of the hospital *c* AD 1133, making it one of the oldest buildings in Cirencester. Although it was thought very unlikely that the present roof was the original twelfth century one, without known dated parallels with which to compare it, this possibility could not be entirely dismissed.

Sampling and analysis by tree-ring dating was commissioned and funded by English Heritage in order to inform grant-aided repairs, elucidate the historical development of this Scheduled Ancient Monument, and to enhance the understanding of this roof form. It was hoped that the analysis would provide dating evidence for the initial construction of the extant roof and also determine when the roof structure was reinforced by the insertion of additional timbers.

Acknowledgements

The survey upon which the above site description is based was commissioned by Reg Ellis & Associates, on behalf of the Trustees of St John's Hospital and other Almshouse Charities. Thanks are given to all parties for allowing the Laboratory to see a draft of this report. Figures 6–20, upon which are marked the timbers sampled were also taken from this survey. The English Heritage Scientific Dating team and Cathy Tyers of the Sheffield Dendrochronology Laboratory have, as always, provided invaluable support and advice during the production of this report.

Sampling

Two phases of building activity were of interest within this roof: firstly those of the main roof structure, ie, the rafter couples, and secondly the inserted timbers associated with the later strengthening of the roof, ie, some of the tiebeams, nailed-on braces, and the half-rafters. However, once within the roof it could be seen that the timbers of the rafter couples were of varying appearance; some looked rougher-cut, whilst others were squarer and had narrower rings. In order to see if this difference in appearance actually signified a difference in date, when a timber was sampled a note was made as to whether it appeared 'rough-cut' (1), 'squared' (2), or was one of the 'inserted' timbers (3) (Table 1). In all, 27 timbers were sampled. Each sample was given the code SJH-C (for St John's Hospital, Cirencester) and numbered 01–27. The position of samples was noted at the time of sampling and has been marked on Figures 5–20. Further details relating to the samples can be found in Table 1. Rafter couples were numbered 1 to 40 from east to west.

Analysis and Results

At this stage it was noticed that 11 of the samples, nine of them from the 'rough-cut' (1) timbers, had too few rings to make secure dating a possibility and these samples were rejected prior to measurement. The remaining 16 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. All samples were compared with each other by the Litton/Zainodin grouping procedure (see appendix).

At a least value of t=7.0, all samples had grouped into two groups. Firstly, two samples matched and were combined at the relevant offset positions to form SJHCSQ01, a site sequence of 111 rings (Fig 21). This site sequence was then compared with a large number of relevant reference chronologies for oak indicating a consistent match when the date of its first ring is AD 1091 and of its last measured ring is AD 1201. The evidence for this dating is given by the t-values in Table 2.

The other 14 samples matched and were combined at the relevant offset positions to form SJHCSQ02, a site sequence of 183 rings (Fig 22). This site sequence was compared against the reference chronologies where it was found to match at a first-ring date of AD 1254 and a last-ring date of AD 1436. The evidence for this dating is given by the t-values in Table 3.

Interpretation

Analysis of 16 samples taken from the roof timbers of this building has resulted in the construction and dating of two site sequences.

The first, SJHCSQ01, contains two samples and spans the period AD 1091–1201. Both of these samples have the heartwood/sapwood boundary ring, the date of which is suggestive of contemporary felling. The average heartwood/sapwood boundary ring date of these two samples is AD 1185, allowing an estimated felling date to be calculated for the two timbers represented within the range AD 1202–25. This allows for sample SJH-C12 having a last measured ring date of AD 1201 with incomplete sapwood.

The second, SJHCSQ02, contains 14 samples and spans the period AD 1254–1436. Three of the samples within this site sequence have complete sapwood and the last-ring date of AD 1436, the felling date of the timbers represented. Four further samples in this site sequence have the heartwood/sapwood boundary ring, the date of which is suggestive of a single felling. The average of the heartwood/sapwood boundary ring dates of these four samples is AD 1409, which, given that sample SJH-C10 has a last measured ring date of AD 1430 with incomplete sapwood, allows an estimated felling date to be calculated for the four timbers represented to within the range AD 1431–49, consistent with a felling of AD 1436. The remaining seven samples do not have the heartwood/sapwood boundary ring and so an estimated felling date cannot be calculated for them. However, with last measured ring dates ranging from AD 1336 (SJH-C11) to AD 1380 (SJH-C22) it is possible that these samples are also from timbers felled in AD 1436. The high levels of similarity (see below) within this entire group of samples supports this interpretation, and suggests that some of these timbers were more heavily trimmed during conversion.

All felling date ranges have been calculated using the estimate that 95% of mature oak trees from this area have 15–40 sapwood rings.

Discussion

Prior to tree-ring analysis being undertaken, the extant roof was believed to represent a single phase of construction, incorporating some later repairs. On the basis of its design and the primitive jointing used within its construction, Cotswold Archaeology had suggested an early medieval date for the roof. Without similar dated roofs with which to compare it there remained the very slight possibility that the present roof was in fact the original twelfth-century one.

Tree-ring analysis has successfully dated 16 of the timbers; two (both collars) have a felling date within the range AD 1202–25, whereas the other 14 were all probably felled in AD 1436. Given that, apart from the obviously inserted timbers mentioned above, this roof appears to be the product of a single phase of construction, the most likely interpretation of these results is that the present roof structure was built soon after the felling of the timbers in AD 1436, but utilises at least two, and probably more, timbers of the early thirteenth century. Whether these early thirteenth-century timbers were from an earlier roof to this building or a separate but coeval construction is unknown. Tree-ring analysis has not identified any twelfth-century timbers that may have been associated with the initial founding of the Hospital and Chantry. It is unfortunate that many of the 'rough-cut' timbers were unsuitable for analysis, having too few growth rings for secure dating.

Interestingly, one of the half-rafters (SJH-C15) and three nailed-on braces (SJH-C16, SJH-C22, and SJH-C25), identified as inserted, actually date to the same felling as many of the rafter couples. It may be that at the same time that the roof began to rake, other timbers within the roof or elsewhere in the building were being removed and/or replaced and these were used to strengthen it.

At the time of sampling, each timber was allocated a number on the basis of its appearance, (1), (2), or (3), in an effort to identify whether a difference in appearance signified a difference in date. It can be seen that all but one of the 'squarer' cut (2) timbers were dated to the fifteenth century, as were four of the ‘inserted’ (3) timbers. However, with only two of the group (1), ‘rougher’ cut timbers being dated, one to the thirteenth and one to the fifteenth century, this approach has proved inconclusive.

As mentioned above, there are some very high *t*-values between individual samples. Within sequence SJHCSQ02, the samples match at an average of *t*-value of 9.65. Such a high value suggests the timbers represented are from the same woodland, if not the same woodland stand. This very strong matching further supports a contemporary felling for all of the timbers within SJHCSQ02.

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Table 1: Details of tree-ring samples from St John's Hospital and Chantry, Cirencester, Gloucestershire

Sample number	Sample location *	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
SJH-C01	South rafter 4 (1)	NM	--	----	----	----
SJH-C02	North rafter 2 (1)	NM	--	----	----	----
SJH-C03	North rafter 6 (1)	NM	--	----	----	----
SJH-C04	North rafter 18 (1)	NM	--	----	----	----
SJH-C05	Collar 10 (2)	91	14	1335	1411	1425
SJH-C06	Collar 11 (2)	72	h/s	1335	1406	1406
SJH-C07	South rafter 10 (2)	100	--	1270	----	1369
SJH-C08	Collar 13 (2)	85	30C	1352	1406	1436
SJH-C09	North rafter 11 (2)	85	--	1270	----	1354
SJH-C10	North rafter 12 (2)	116	22	1315	1408	1430
SJH-C11	North rafter 26 (2)	83	--	1254	----	1336
SJH-C12	Collar 24 (2)	111	16	1091	1185	1201
SJH-C13	South rafter 12 (1)	136	35C	1301	1401	1436
SJH-C14	Collar 14 (1)	86	16	1115	1184	1200
SJH-C15	South half rafter 18 (3)	81	--	1290	----	1370
SJH-C16	North nailed brace, frame 32–36 (3)	86	--	1273	----	1358
SJH-C17	North rafter 34 (2)	66	--	1285	----	1350
SJH-C18	North rafter 24 (1)	NM	--	----	----	----
SJH-C19	North rafter 28 (1)	NM	--	----	----	----
SJH-C20	South rafter 36 (1)	NM	--	----	----	----
SJH-C21	South strut, frame 21–25 (3)	NM	--	----	----	----
SJH-C22	South lower nailed brace, frame 34–38 (3)	105	--	1276	----	1380
SJH-C23	South rafter 34 (2)	136	35C	1301	1401	1436
SJH-C24	Collar 34 (1)	NM	--	----	----	----
SJH-C25	South lower nailed brace, frame 24–29 (3)	111	h/s	1302	1412	1412
SJH-C26	South ashlar, 33 (1)	NM	--	----	----	----
SJH-C27	Tie 1 (frame 25) (2)	NM	--	----	----	----

*At the time of sampling it was noticed that the timber was of differing appearance. The number in brackets refers to whether the timber sampled appeared (1) = 'rough-cut'; (2) = 'square'; or (3) = 'inserted'.

Table 2: Results of the cross-matching of site sequence SJHCSQ01 and relevant reference chronologies when the first-ring date is AD 1091 and the last-ring date is AD 1201

Reference chronology	*t*-value	Span of chronology	Reference
Southern England	8.6	AD 1083–1981	Bridge 1988
England	6.9	AD 401–1981	Baillie and Pilcher 1982 unpubl
London England	6.1	AD 413–1728	Tyers and Groves 1999 unpubl
Salisbury Cathedral, Wilts	7.2	AD 1119–1241	Howard *et al* 1996
Angel Choir, Lincoln Cathedral, Lincs	6.0	AD 904–1257	Laxton and Litton 1988
Medbourne Manor, Leics	5.8	AD 1068–1287	Howard *et al* 1999a
Hampshire county chronology	5.8	AD 443–1972	Miles 2003
Chap House/Deanery, Brecon Cathedral, Powys, South Wales	5.7	AD 996–1227	Howard *et al* 1994

Table 3: Results of the cross-matching of site sequence SJHCSQ02 and relevant reference chronologies when the first-ring date is AD 1254 and the last-ring date is AD 1436

Reference chronology	*t*-value	Span of chronology	Reference
London England	7.4	AD 413–1728	Tyers and Groves 1999 unpubl
Southern England	5.1	AD 1083–1981	Bridge 1988
Hampshire county chronology	7.3	AD 443–1972	Miles 2003
Kingswood Abbey, Gatehouse, Glos	6.6	AD 1307–1428	Arnold *et al* 2003a
Brockworth Court Barn, Glos	6.0	AD 1352–1456	Howard *et al* 1998
Hulme Hall, Allostock, Cheshire	5.8	AD 1574–1689	Arnold *et al* 2003b
Lodge Park, Aldsworth, Glos	5.8	AD 1324–1587	Howard *et al* 1995
St Mary Magdalene, Cowden, Kent	5.7	AD 1257–1439	Howard *et al* 1999b

Figure 1: Map of Cirencester, with the general location of St John's Hospital and Chantry circled

Figure 2: Map to show the location of St John's Hospital and Chantry

Figure 3: The roof, looking east

Figure 4: North side, showing one of the ‘inserted’ nailed-on braces

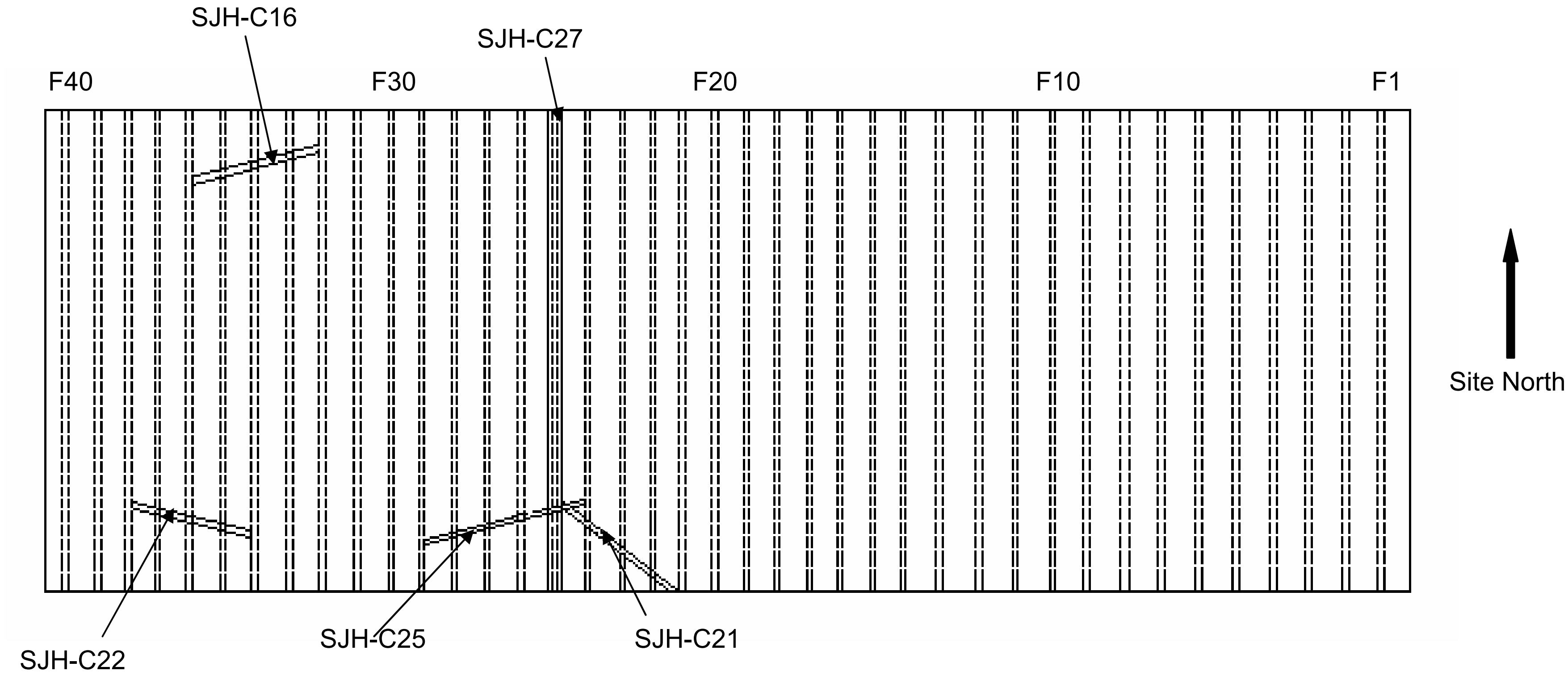


Figure 5: Sketch plan, showing the location of samples SJH-C16, SJH-C21–22, SJH-C25, and SJH-C27

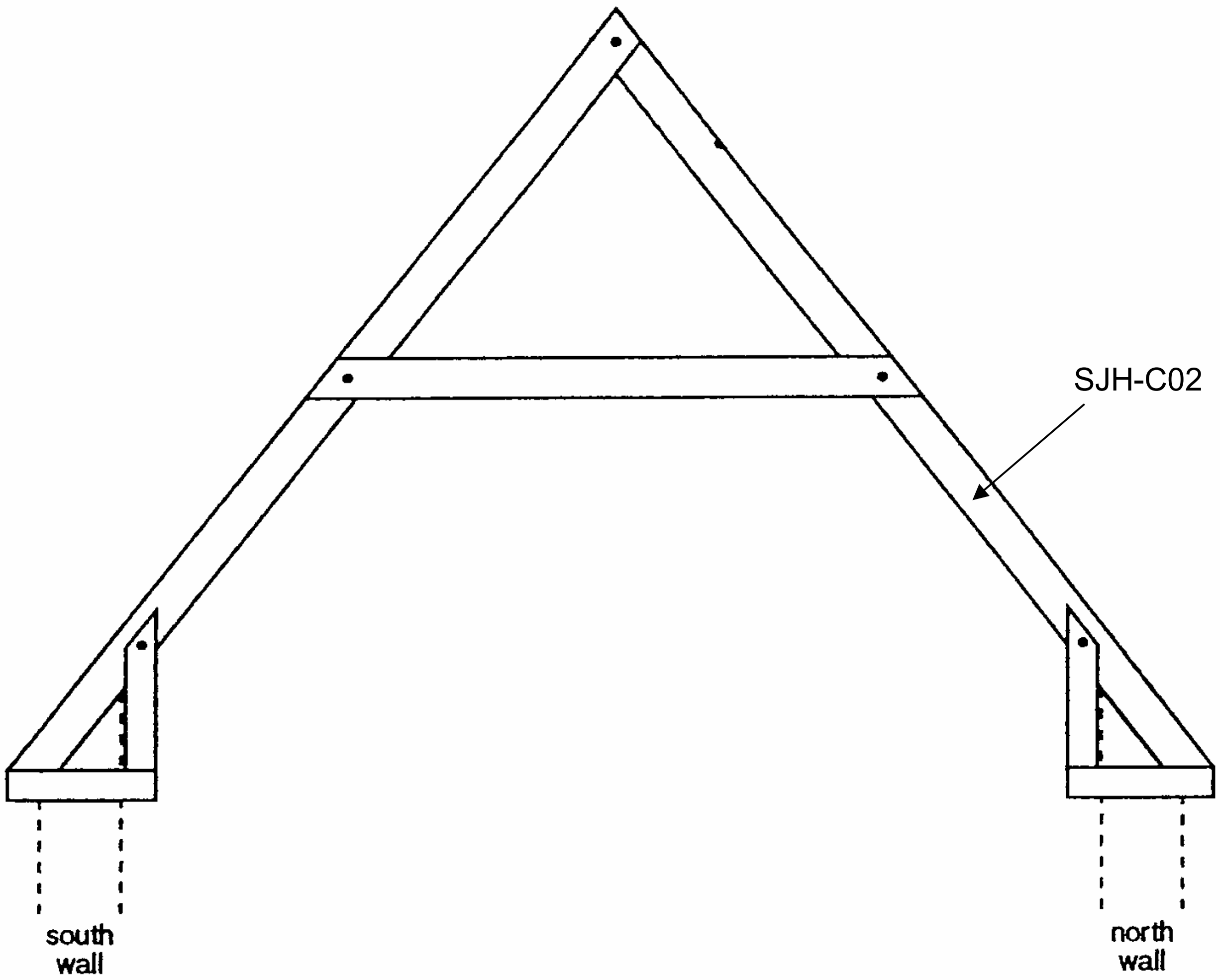


Figure 6: Frame 2, showing the location of sample SJH-C02 (Cotswold Archaeology)

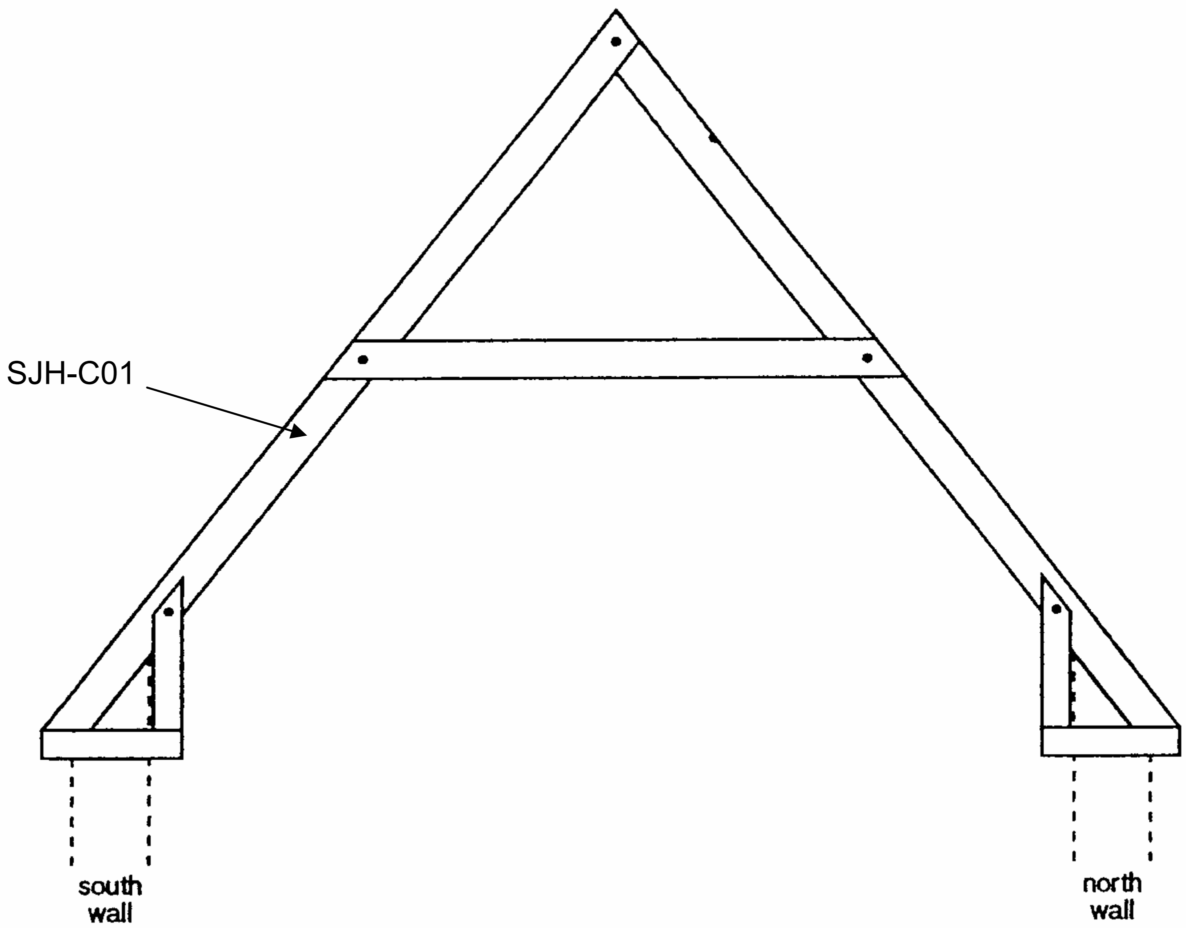


Figure 7: Frame 4, showing the location of sample SJH-C01 (Cotswold Archaeology)

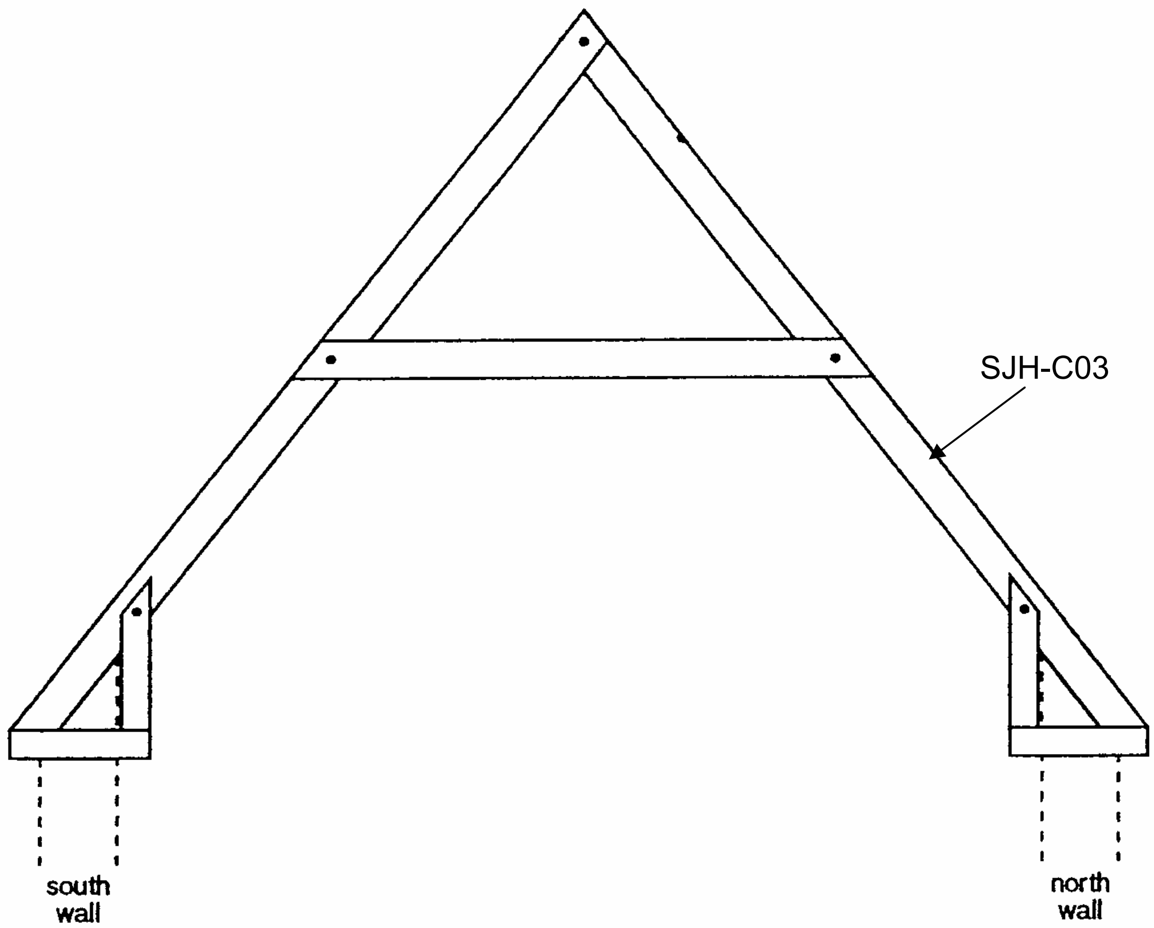


Figure 8: Frame 6, showing the location of sample SJH-C03 (Cotswold Archaeology)

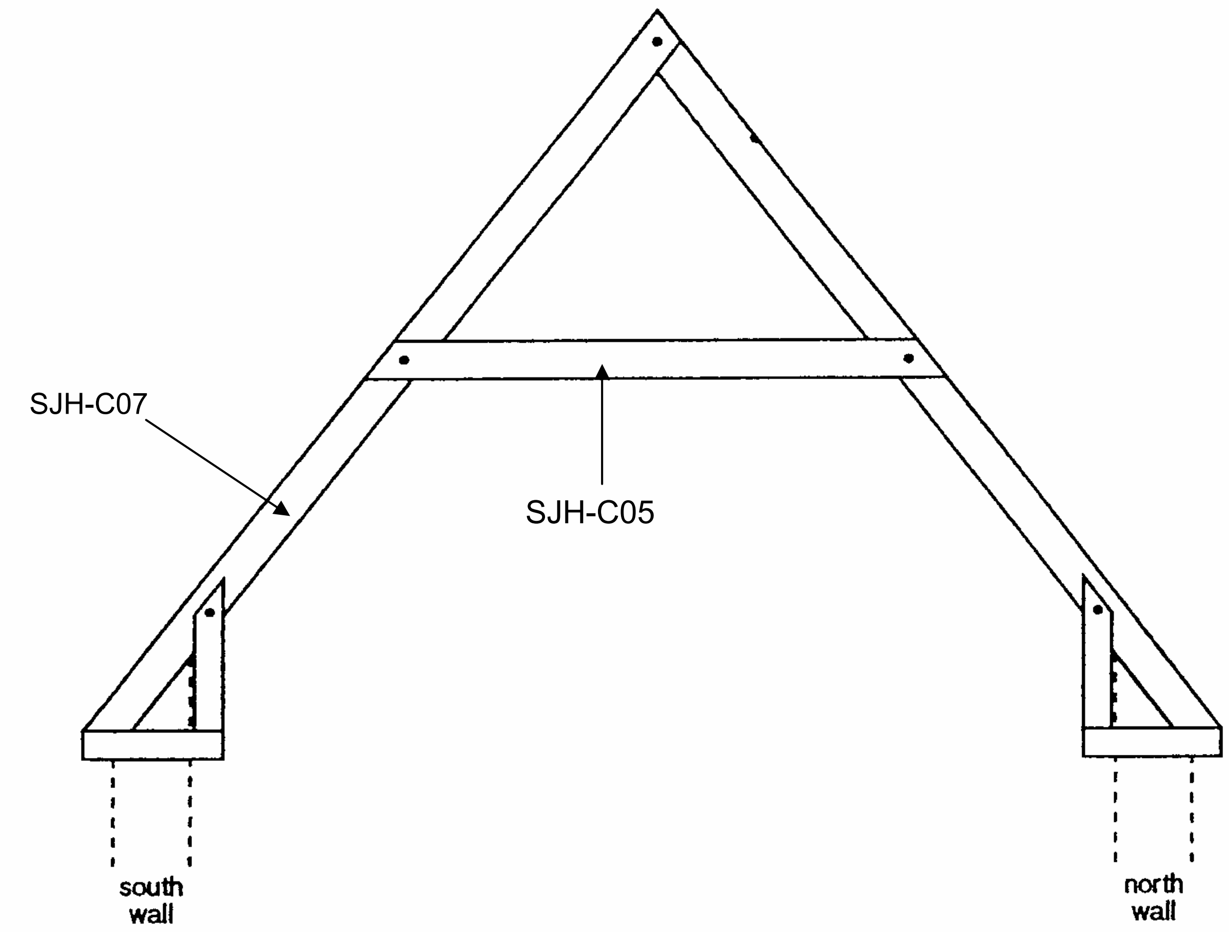


Figure 9: Frame 10, showing the location of samples SJH-C05 and SJH-C07 (Cotswold Archaeology)

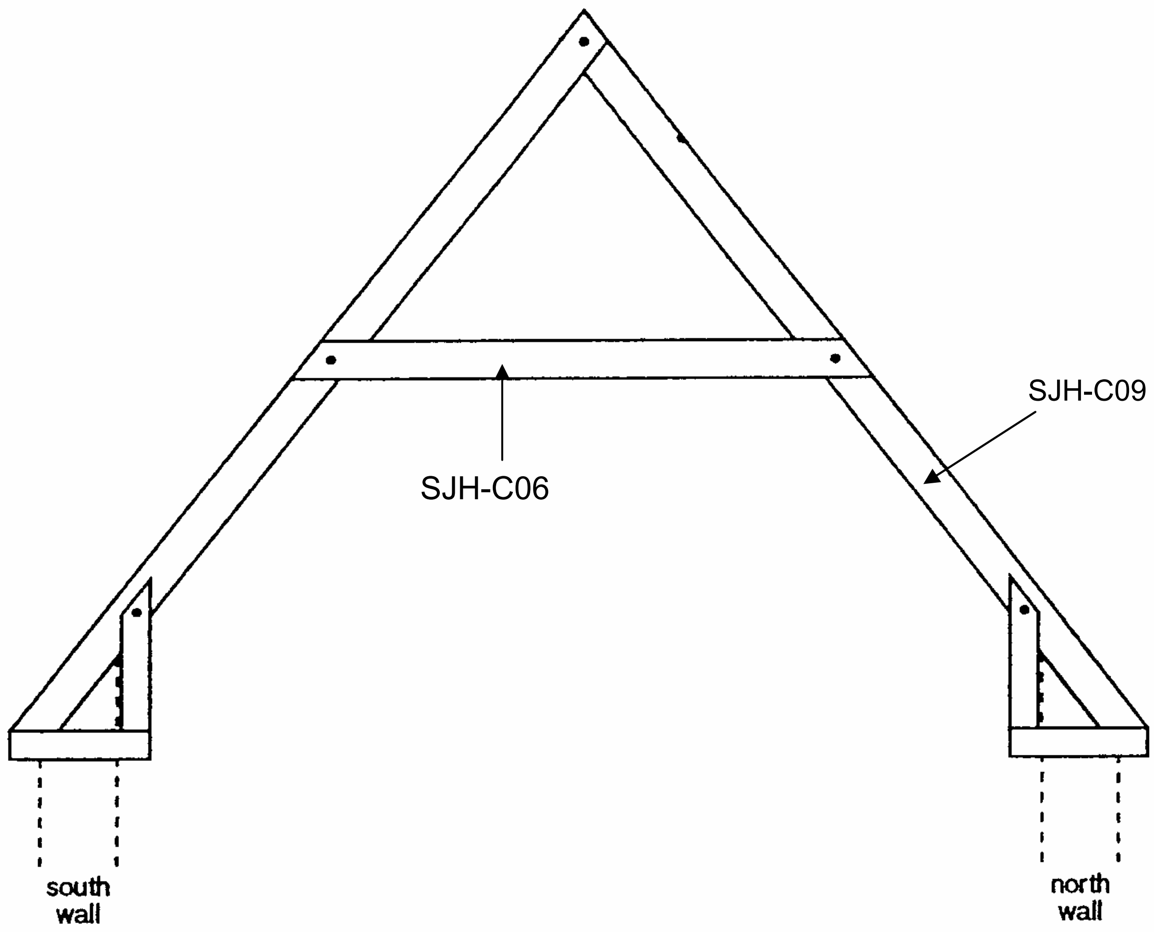


Figure 10: Frame 11, showing the location of samples SJH-C06 and SJH-C09 (Cotswold Archaeology)

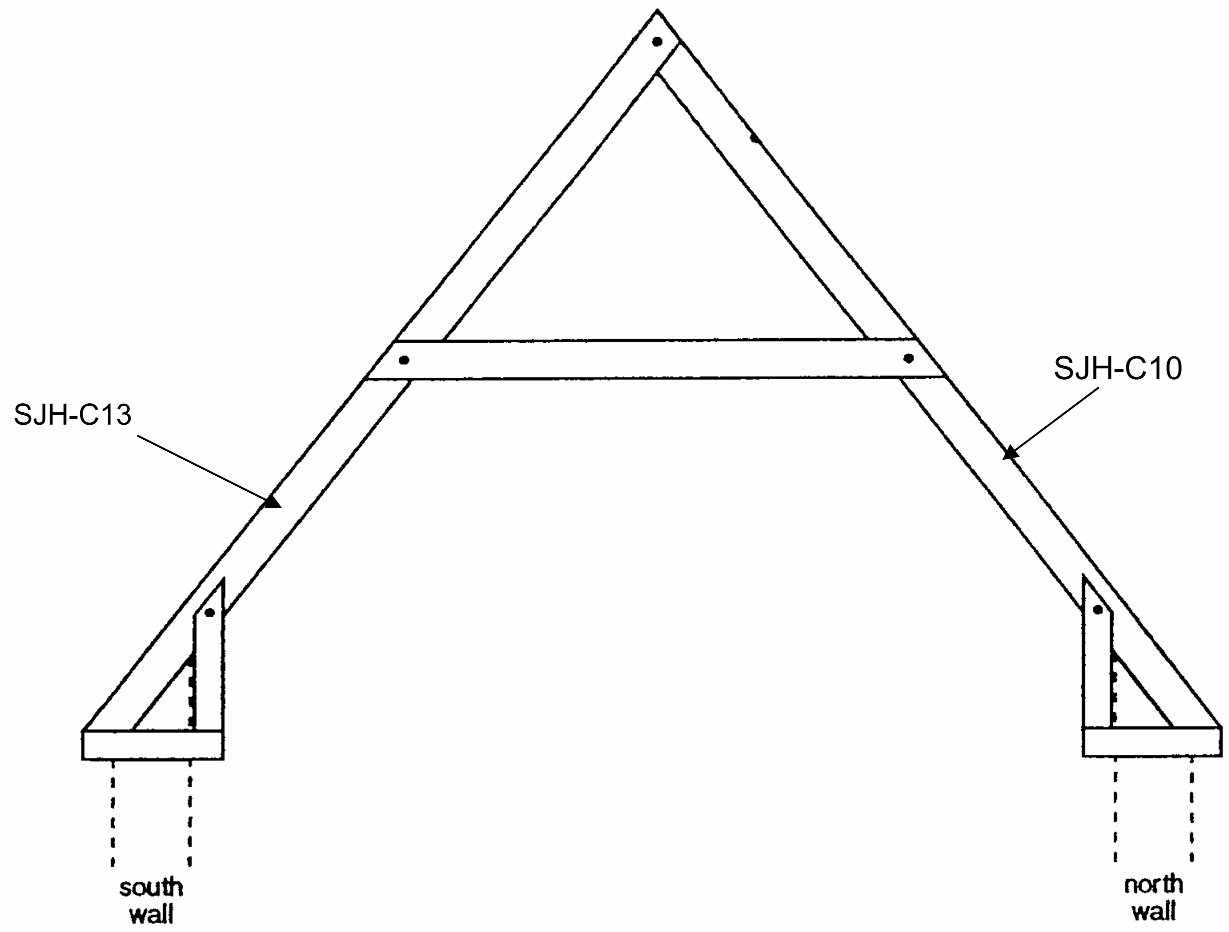


Figure 11: Frame 12, showing the location of samples SJH-C10 and SJH-C13 (Cotswold Archaeology)

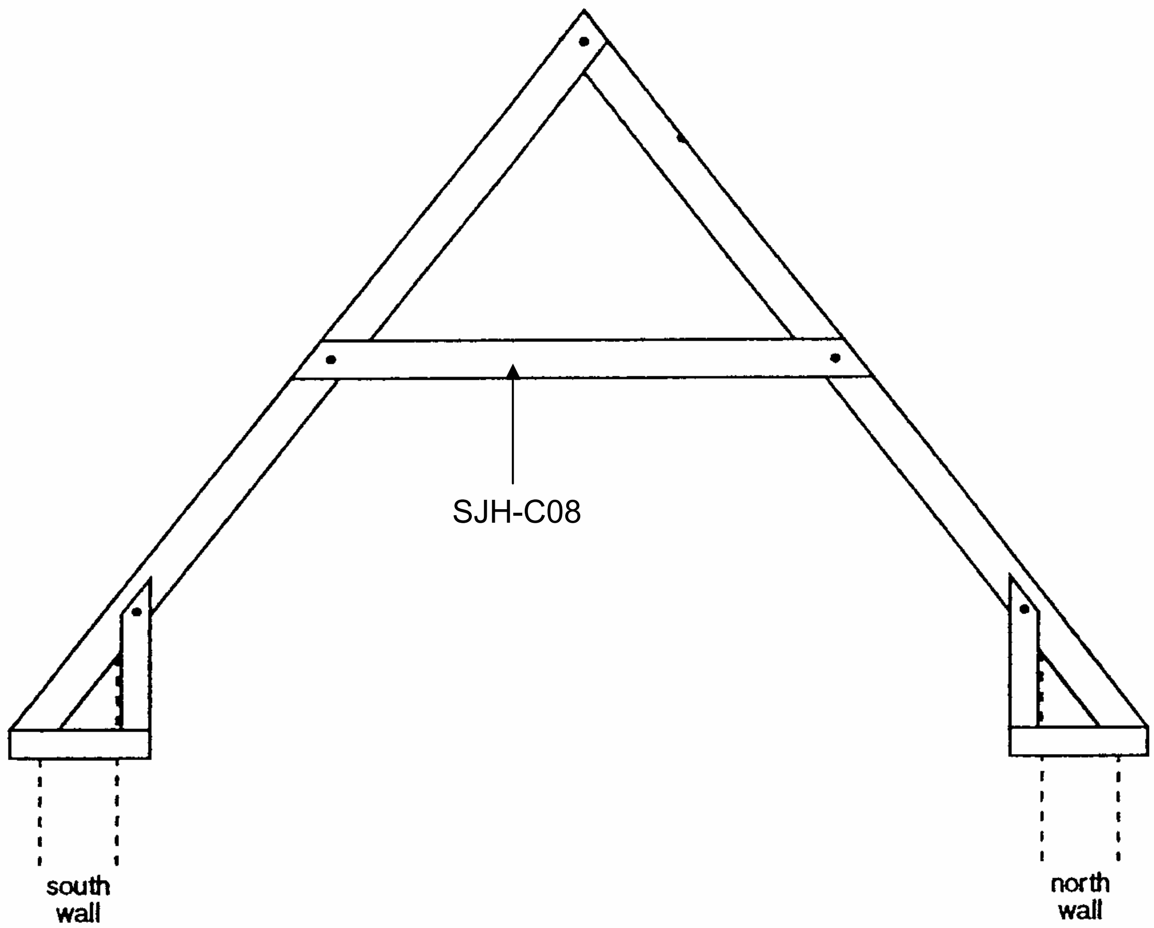


Figure 12: Frame 13, showing the location of sample SJH-C08 (Cotswold Archaeology)

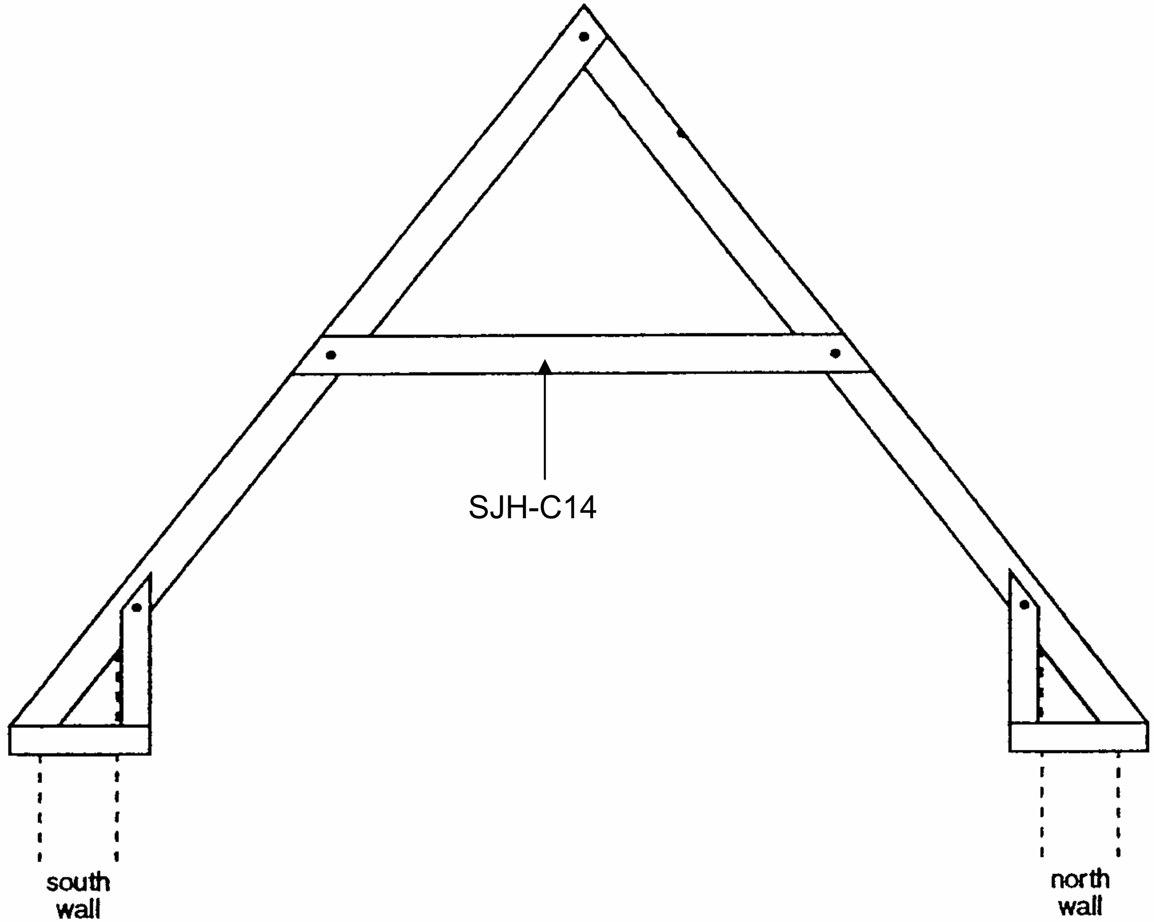


Figure 13: Frame 14, showing the location of sample SJH-C14 (Cotswold Archaeology)

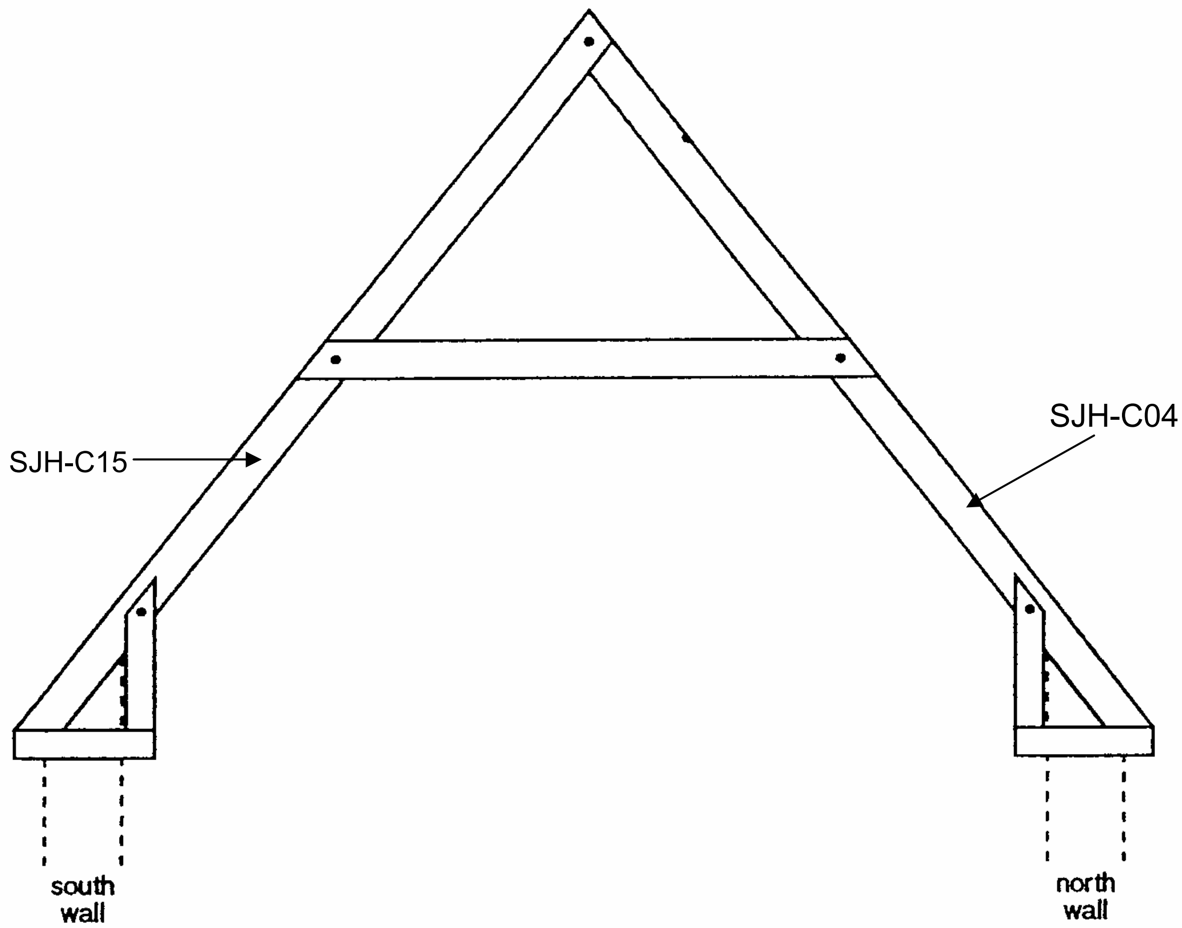


Figure 14: Frame 18, showing the location of samples SJH-C04 and SJH-C15 (Cotswold Archaeology)

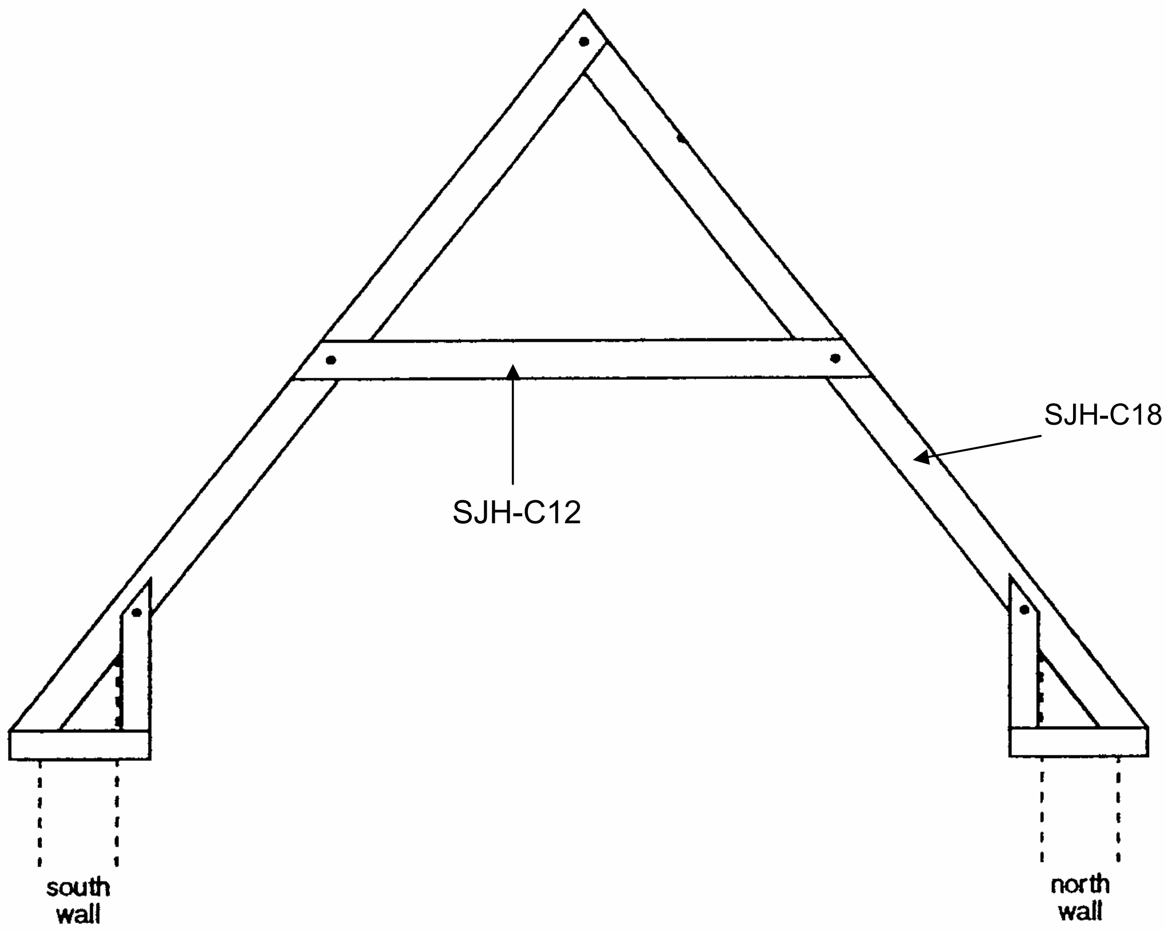


Figure 15: Frame 24, showing the location of samples SJH-C12 and SJH-C18 (Cotswold Archaeology)

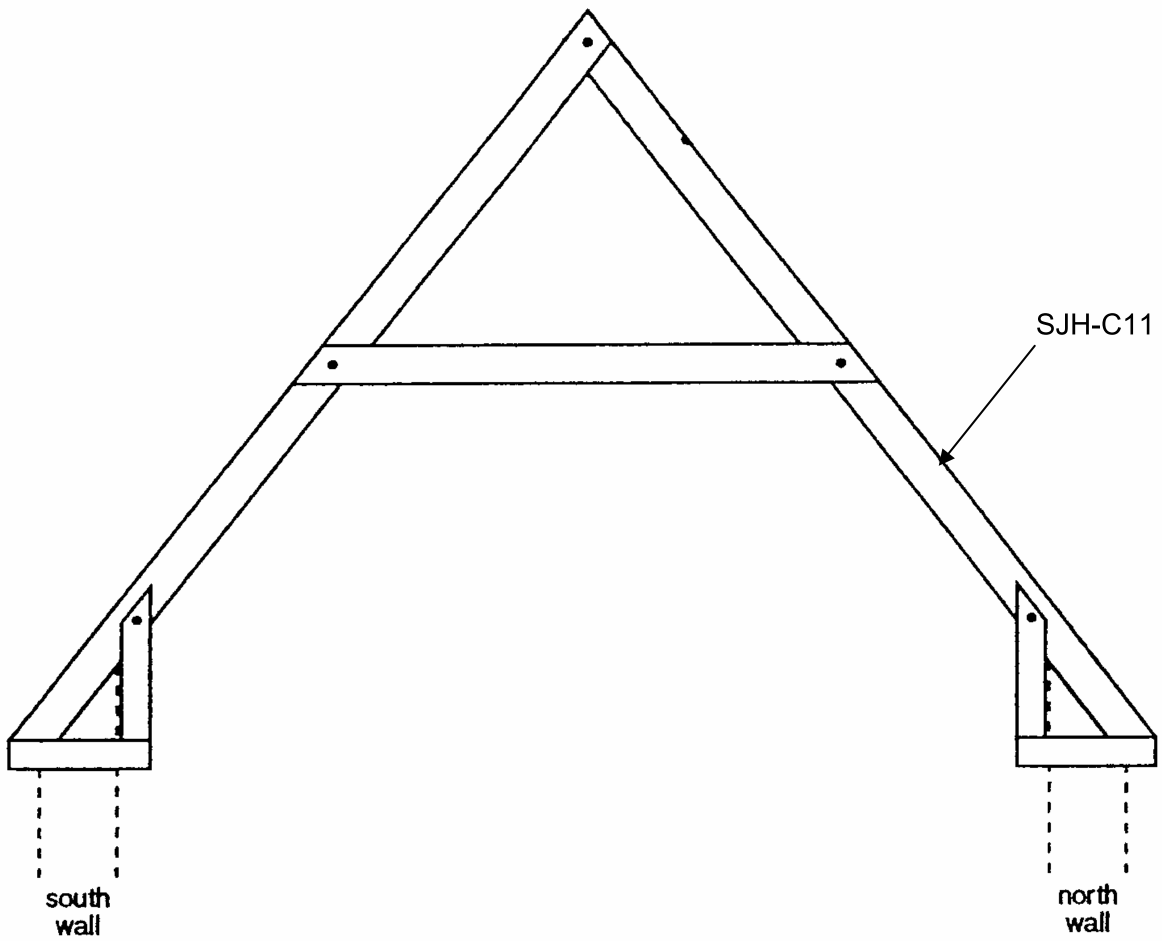


Figure 16: Frame 26, showing the location of sample SJH-C11 (Cotswold Archaeology)

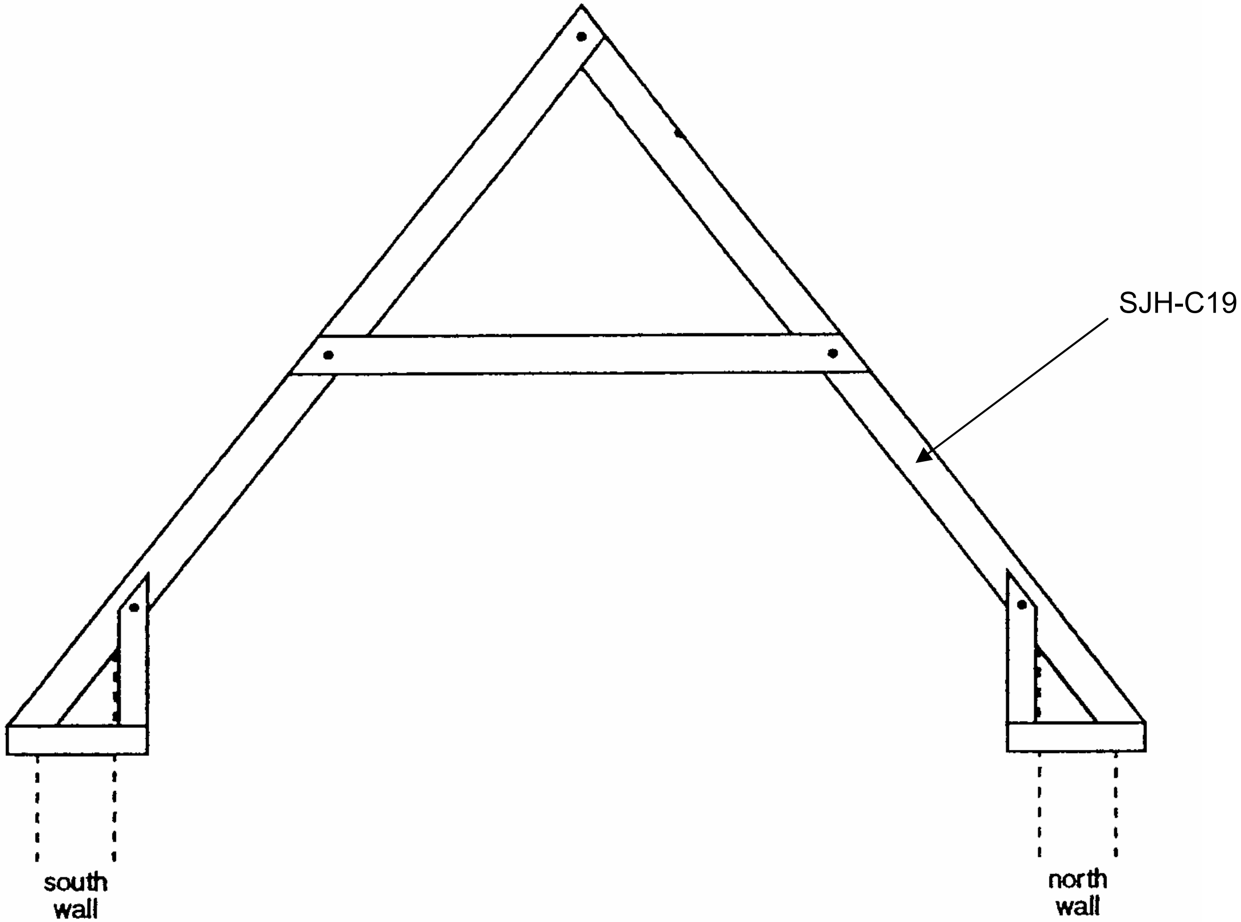


Figure 17: Frame 28, showing the location of sample SJH-C19 (Cotswold Archaeology)

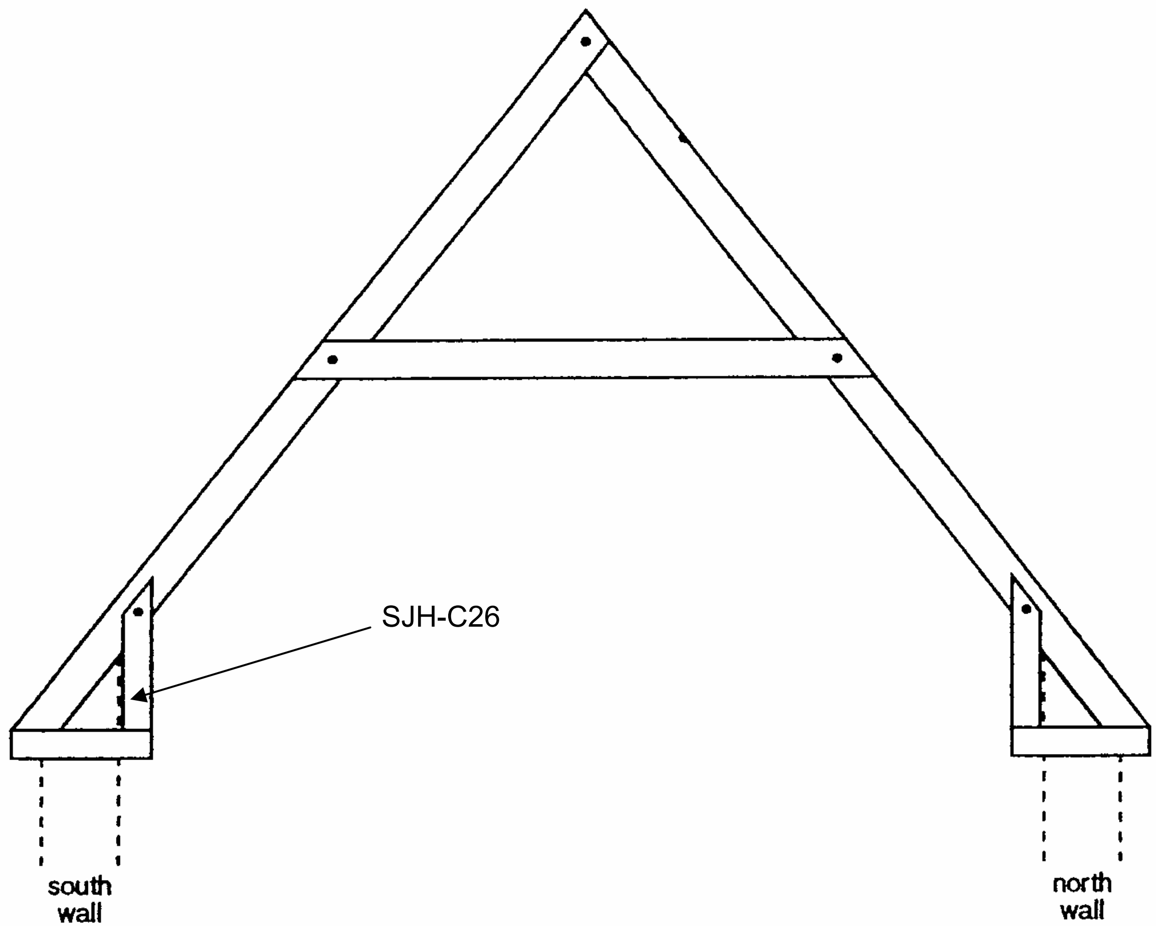


Figure 18: Frame 33, showing the location of sample SJH-C26 (Cotswold Archaeology)

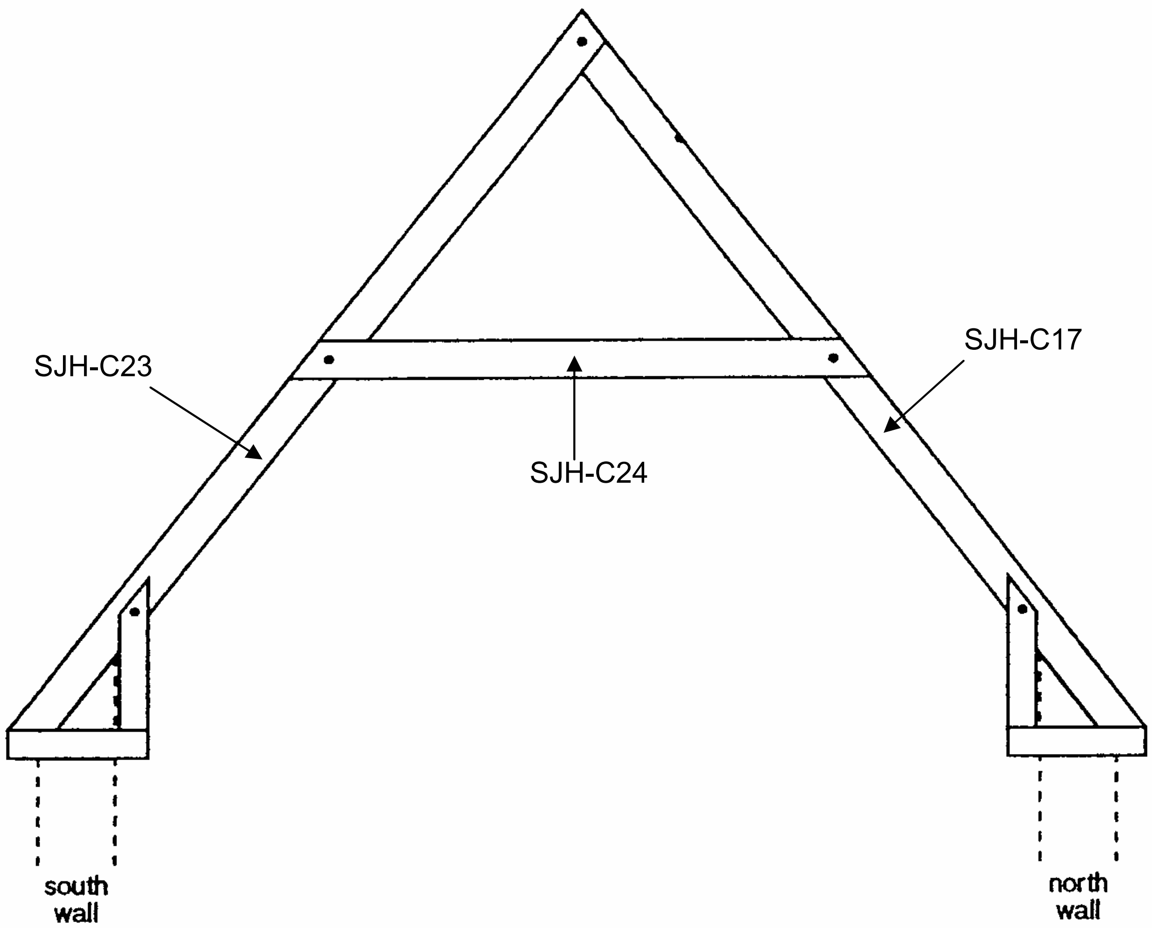


Figure 19: Frame 34, showing the location of samples SJH-C17, SJH-C23, and SJH-C24 (Cotswold Archaeology)

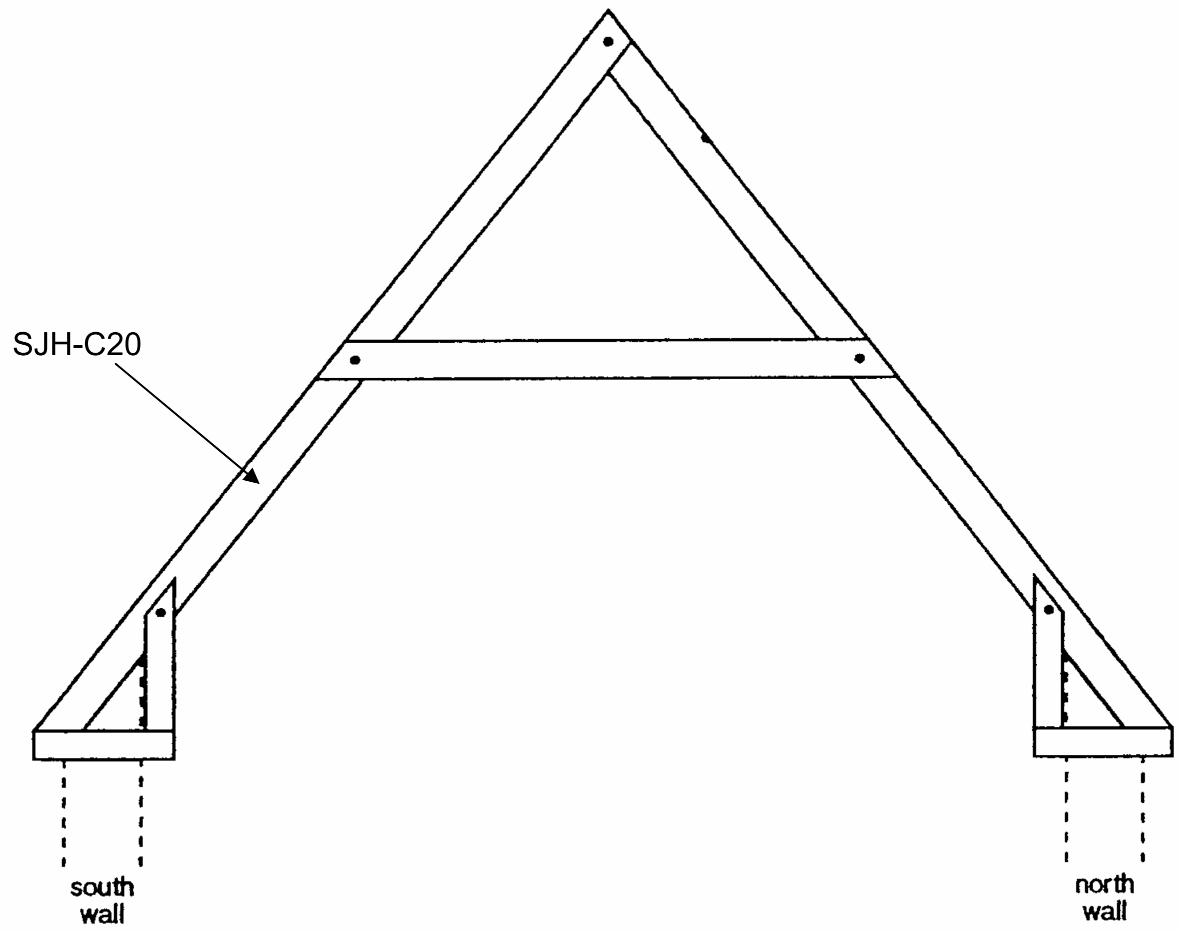


Figure 20: Frame 36, showing the location of sample SJH-C20 (Cotswold Archaeology)

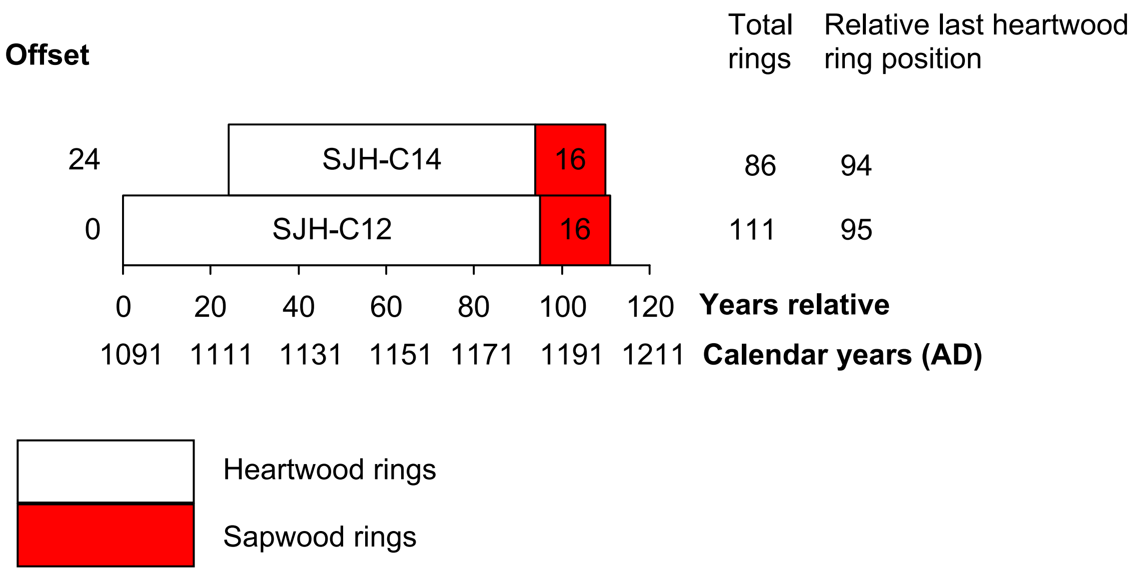
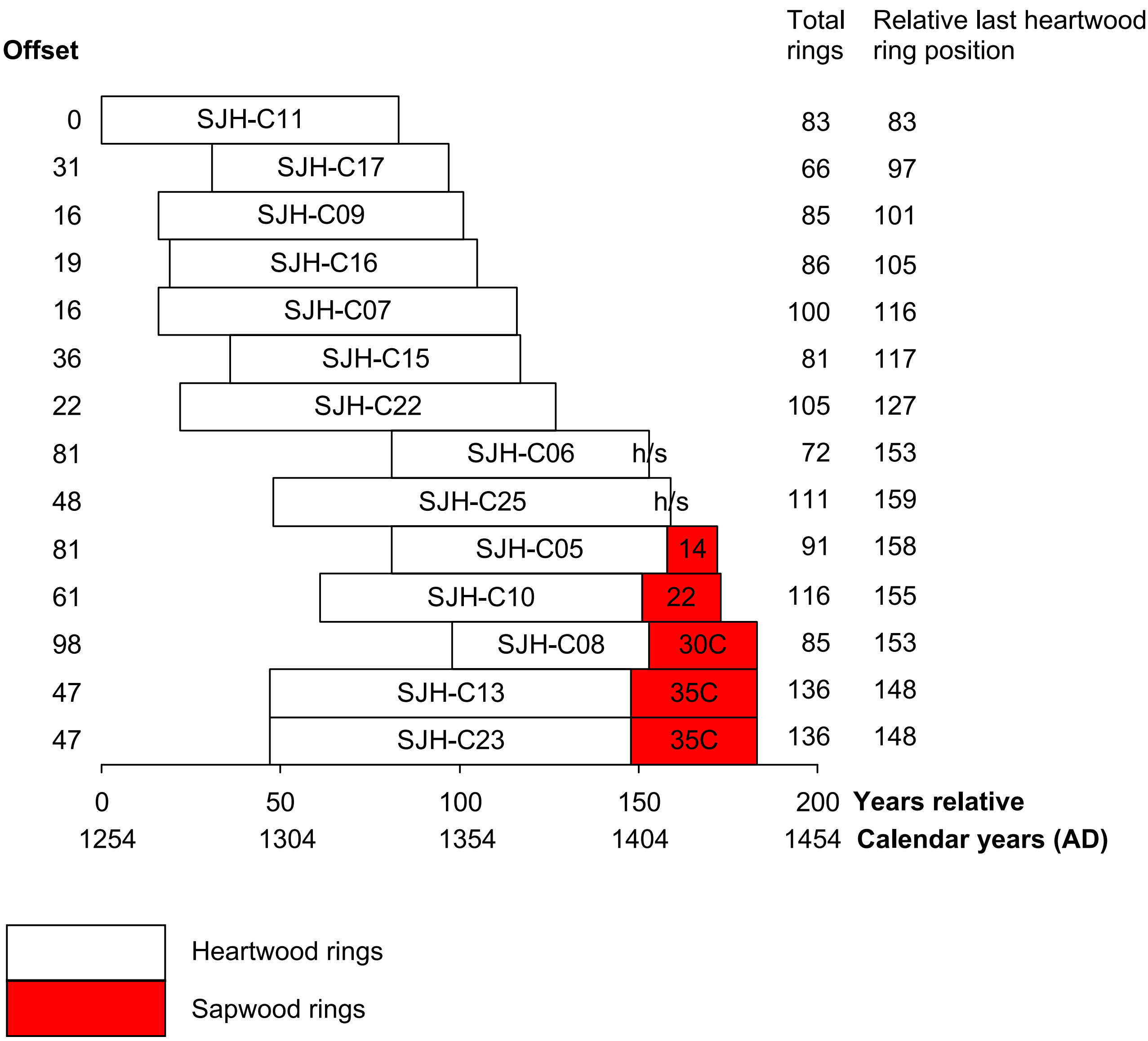


Figure 21: Bar diagram of samples in site sequence SJHCSQ01



h/s = the heartwood/sapwood boundary ring is the last ring on the sample
C = complete sapwood retained on sample, last measured ring is the felling date

Figure 22: Bar diagram of samples in site sequence SJHCSQ02

Data of measured samples – measurements in 0.01mm units

SJH-C05A 91
399 298 306 412 348 213 187 253 297 344 222 109 108 119 112 183 311 186 174 280
269 228 291 194 215 137 137 238 343 348 198 175 139 141 248 270 227 254 172 144
153 200 218 199 232 271 260 346 271 222 202 215 120 122 119 115 102 75 63 52
59 92 90 89 82 77 90 77 72 65 72 155 105 103 104 97 72 58 64 51
34 43 38 35 52 72 81 72 81 56 113
SJH-C05B 91
391 302 303 410 348 215 192 251 297 339 225 118 103 116 113 164 311 186 173 268
259 220 277 203 219 124 134 242 326 346 193 182 131 142 257 263 230 256 179 147
159 193 215 197 229 277 260 344 265 224 205 218 122 115 129 104 110 70 62 54
63 92 88 87 84 82 79 83 63 78 69 153 104 97 120 101 68 59 57 46
35 35 36 42 61 108 102 77 81 83 73
SJH-C06A 72
239 278 356 353 324 211 330 297 347 329 174 65 95 76 86 117 178 133 73 148
262 233 247 201 157 99 146 248 396 493 202 217 119 178 256 222 173 204 181 141
154 160 159 162 190 304 277 286 194 203 195 201 120 102 86 82 74 56 66 52
66 156 107 76 104 106 155 128 103 64 77 128
SJH-C06B 72
245 280 359 364 327 211 336 293 352 329 184 70 94 79 87 116 179 136 77 140
271 235 251 205 150 102 153 249 394 497 167 220 118 175 258 223 180 211 181 147
155 156 161 154 195 316 273 297 190 211 195 201 115 103 89 83 74 62 60 45
71 163 104 74 112 100 154 132 93 62 81 133
SJH-C07A 100
315 252 316 409 253 238 181 179 172 275 214 200 209 267 263 192 202 112 115 190
281 212 242 269 189 99 50 52 90 112 209 242 183 120 80 148 188 208 148 106
80 96 198 70 63 139 187 147 68 140 88 58 68 122 104 66 73 121 80 95
70 24 34 69 79 62 81 112 110 136 85 76 78 75 109 79 30 39 49 44
36 63 40 58 92 99 71 97 62 65 31 51 50 75 79 54 68 53 54 72
SJH-C07B 100
317 256 308 403 241 227 184 184 178 258 208 176 209 285 242 192 189 108 116 196
277 215 242 282 190 93 53 54 82 114 204 243 182 124 82 144 194 227 144 111
75 100 195 67 63 137 190 143 71 136 93 61 64 120 103 67 76 114 80 90
74 23 37 61 82 59 86 113 110 140 81 81 90 91 123 68 27 37 46 38
34 68 43 46 93 99 64 90 66 65 36 44 45 78 78 62 66 50 55 73
SJH-C08A 85
274 254 428 330 335 412 395 304 168 242 333 394 374 193 174 147 127 318 293 241
296 156 139 149 199 243 239 325 315 329 339 182 165 157 193 119 125 104 84 87
70 64 47 53 129 120 107 112 106 143 110 93 83 106 233 124 127 153 129 81
81 61 54 54 46 37 43 68 78 87 60 112 97 67 61 78 79 56 48 46
51 55 61 46 51
SJH-C08B 85
272 250 422 336 334 419 397 297 166 246 337 387 374 190 180 148 126 332 288 244
295 147 138 162 191 256 237 330 302 319 340 186 160 162 190 120 127 100 84 80
77 49 57 60 122 118 112 110 107 146 108 95 72 113 229 132 124 149 135 91
79 61 57 37 39 43 52 72 76 88 74 106 104 61 69 70 85 48 50 57
41 52 61 51 51
SJH-C09A 85
455 334 377 498 300 248 178 222 296 423 321 236 231 332 385 323 256 155 155 219
298 267 277 272 147 70 50 60 61 130 194 255 212 145 86 141 183 206 200 137
96 154 253 108 87 176 225 179 101 158 90 77 72 99 115 66 70 131 95 139
82 25 53 65 86 63 116 113 172 168 106 115 121 113 172 97 42 52 60 48
58 71 41 33 61

SJH-C09B 85
434 328 391 511 303 236 184 212 305 426 332 227 224 351 388 313 272 155 146 220
301 250 272 277 150 75 52 51 65 127 200 259 214 140 86 142 182 206 202 133
101 153 245 112 70 164 219 170 99 168 88 80 66 105 114 65 61 137 97 132
82 23 42 71 82 68 108 118 170 168 106 114 120 113 170 102 37 56 62 44
59 75 41 36 69
SJH-C10A 116
181 232 212 101 176 96 99 80 117 121 82 81 139 85 118 85 38 53 71 104
62 108 125 176 168 115 122 133 110 145 100 47 59 73 60 49 98 46 64 104
116 68 85 84 107 54 63 88 116 130 70 84 60 75 111 114 88 111 61 53
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49 122 68 80 77 60 130 87 57 72 68 99 51 51 51 53 39 37 33 34
36 31 29 62 47 76 89 55 76 76 62 51 68 54 51 58
SJH-C10B 116
175 228 216 106 177 106 108 81 114 122 85 78 150 78 113 87 44 50 76 100
70 97 121 168 169 114 122 131 113 145 107 40 57 88 54 58 88 52 58 104
130 75 90 73 115 49 60 96 112 128 66 87 64 72 116 110 96 115 54 58
73 104 107 63 116 109 88 105 56 58 61 54 46 46 44 44 39 44 58 48
48 117 71 79 84 62 121 85 56 77 67 98 54 56 56 56 38 38 26 39
35 34 31 66 49 85 76 48 90 65 61 52 55 61 54 52
SJH-C11A 83
201 372 305 219 244 304 397 212 305 116 247 266 286 137 196 174 265 212 312 388
164 233 128 179 162 314 209 184 179 280 263 253 193 118 123 179 258 240 223 210
135 51 44 50 63 112 158 249 179 88 44 78 114 174 163 87 68 64 105 51
30 92 94 147 67 190 91 62 70 110 104 61 64 108 69 95 63 26 25 39
65 40 88
SJH-C11B 83
210 390 306 206 254 307 403 247 304 107 239 257 274 134 187 196 250 220 310 422
171 234 125 181 163 308 210 178 203 283 265 251 198 114 111 186 253 240 228 203
135 52 40 51 61 121 161 243 175 104 47 82 110 174 161 92 63 67 100 60
36 85 97 141 66 200 93 66 63 109 101 64 65 106 67 102 59 27 22 45
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SJH-C12A 111
75 123 113 140 101 82 153 166 117 120 107 163 230 177 160 157 135 212 120 86
76 68 67 81 66 71 66 64 67 51 79 74 72 99 73 72 56 72 67 62
86 70 64 58 73 68 44 69 88 125 119 87 84 126 138 101 101 97 105 81
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119 110 122 98 88 161 68 78 69 77 114 69 46 59 102 83 94 42 65 80
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78 65 79 67 78 67 60 82 60 66 72 72 85 87 85 63 59 73 59 73
79 72 72 51 74 64 44 71 81 134 109 83 88 127 139 103 91 113 90 92
48 63 85 52 60 97 109 70 106 120 94 111 69 80 96 85 86 98 107 78
114 114 131 88 87 164 67 71 77 71 114 67 50 59 98 89 88 48 58 87
57 65 80 68 101 106 53 77 90 90 99
SJH-C13A 136
218 188 116 72 97 150 204 173 137 95 127 226 116 44 107 147 163 82 170 90
71 59 74 84 57 49 53 44 56 44 23 28 41 51 50 55 74 75 101 76
66 78 66 94 66 40 43 36 42 48 108 36 37 49 70 53 96 79 56 31
48 67 105 116 66 62 50 78 110 124 92 124 51 83 65 104 85 90 91 121
92 103 73 58 51 66 41 54 34 50 35 38 43 53 45 69 64 57 48 42
91 51 45 48 56 60 45 39 45 50 36 24 24 24 29 30 44 65 30 67
54 34 58 52 40 31 35 44 40 25 39 46 46 36 41 41

SJH-C13B 136
218 188 118 67 101 147 206 174 131 101 121 226 120 46 102 147 162 81 174 91
72 62 70 84 53 52 58 39 59 43 20 25 40 48 57 50 77 73 106 70
67 80 83 95 60 39 33 42 38 44 111 36 33 49 74 47 104 70 61 38
50 61 105 112 71 58 50 77 110 131 90 124 51 84 65 100 80 85 94 121
87 108 65 61 53 62 43 54 31 46 38 43 39 53 41 72 65 55 50 42
93 60 34 55 53 63 46 42 47 46 36 26 23 24 31 29 44 63 35 61
56 37 57 43 45 37 32 43 41 33 48 50 40 40 39 40
SJH-C14A 86
131 144 115 103 136 123 119 139 174 163 147 121 77 165 104 142 122 135 134 129
122 132 79 144 157 250 201 147 97 156 138 111 142 138 152 87 90 63 103 69
85 104 133 95 141 141 113 129 108 96 105 97 80 144 153 83 121 112 107 99
112 180 71 96 98 72 111 92 76 72 126 128 158 54 83 104 84 82 78 63
102 106 59 88 114 70
SJH-C14B 86
111 137 114 110 136 118 114 143 172 161 151 116 86 160 113 118 126 135 129 135
119 132 80 155 147 261 198 141 108 152 147 113 133 160 133 101 84 62 102 76
89 101 129 100 133 156 120 134 102 95 106 102 81 153 150 85 112 118 115 96
111 173 71 100 93 73 113 87 74 75 122 122 166 52 81 107 79 85 77 68
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SJH-C15A 81
262 269 344 269 89 95 76 105 99 104 150 171 149 87 99 119 160 335 250 139
95 170 214 130 124 194 235 164 110 136 117 96 121 198 175 95 93 180 184 155
67 82 98 128 127 109 131 126 150 164 120 101 149 149 172 85 50 66 84 78
75 105 66 83 103 96 70 118 97 76 59 65 86 220 179 86 85 72 114 95
122
SJH-C15B 81
265 264 345 264 82 107 71 113 99 104 156 179 168 103 92 122 164 323 263 117
100 166 212 127 124 189 229 168 110 133 120 101 118 200 179 92 92 178 190 144
74 72 110 122 124 110 131 121 155 169 126 115 146 148 178 92 55 68 92 63
85 120 58 81 100 89 78 111 100 69 67 54 85 214 172 91 81 72 120 101
118
SJH-C16A 86
342 217 223 204 205 185 234 166 140 158 188 158 178 192 129 139 178 222 199 268
243 88 97 57 105 99 99 159 129 113 93 73 92 110 187 145 101 82 77 86
65 65 88 88 73 57 73 60 62 54 85 77 64 69 80 73 66 49 59 45
74 78 57 75 61 75 104 63 89 96 92 93 76 46 69 73 59 65 74 53
80 74 81 48 72 73
SJH-C16B 86
374 213 229 213 202 185 230 194 132 157 192 157 179 189 125 143 182 213 196 292
239 90 80 74 94 86 107 144 132 116 95 74 88 97 170 153 100 84 80 86
58 76 89 81 69 70 61 76 60 45 91 75 53 75 74 70 64 45 42 59
63 73 69 62 70 79 97 65 86 97 92 94 72 55 63 77 55 67 72 57
77 68 88 54 66 59
SJH-C17A 66
275 241 153 172 268 350 298 356 321 142 58 40 45 75 143 290 343 264 152 86
157 218 273 256 178 139 145 230 100 70 193 231 197 101 318 210 175 149 213 193
109 114 187 131 153 147 44 67 109 150 120 149 204 206 202 136 137 142 117 179
106 41 94 86 82 86
SJH-C17B 66
269 261 155 172 285 354 309 355 321 149 52 34 56 62 154 280 335 274 148 83
155 228 270 260 180 137 138 247 93 80 190 227 193 105 289 225 179 137 202 196
104 105 197 139 167 146 46 53 116 144 98 150 205 213 233 132 127 151 123 182
98 52 76 97 75 99

SJH-C22A 105
180 187 169 239 204 158 209 258 288 233 254 156 151 206 288 324 334 262 71 105
75 108 99 114 209 244 203 116 100 152 211 185 162 107 80 102 135 84 110 176
128 97 62 92 61 71 51 102 98 61 75 112 88 74 57 31 66 85 97 63
83 71 82 143 93 87 119 95 115 64 44 63 77 72 61 101 53 61 72 85
69 76 71 52 47 48 81 132 107 66 56 65 63 75 59 51 65 42 43 51
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SJH-C22B 105
174 189 175 232 211 178 216 261 253 218 257 148 149 207 268 333 338 246 80 97
86 102 95 109 194 247 207 110 97 153 207 187 158 107 83 101 137 81 105 179
122 100 72 97 83 68 68 105 94 66 68 106 83 82 42 38 70 88 89 71
87 70 85 131 98 86 121 103 104 68 41 57 85 65 63 102 52 69 65 92
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SJH-C23A 136
238 223 122 82 129 191 231 188 139 107 136 225 72 45 95 135 128 72 185 108
85 75 139 139 90 82 145 84 124 129 39 42 69 96 70 86 145 160 145 107
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33 61 91 97 47 51 39 47 52 71 55 51 29 40 48 63 68 50 55 76
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136 72 43 58 57 79 35 44 50 57 25 21 32 23 29 37 36 63 38 57
45 30 66 42 31 32 51 46 37 31 43 76 38 35 54 44
SJH-C23B 136
243 212 136 68 134 190 233 181 149 100 141 214 80 50 75 133 150 64 195 122
87 81 151 139 88 81 140 87 126 121 40 47 62 97 67 100 143 161 153 114
86 122 107 134 76 25 32 50 51 27 70 41 29 56 110 70 96 69 57 32
38 55 100 85 47 59 38 50 46 79 49 49 39 35 41 70 63 46 62 77
52 58 43 51 44 56 45 27 47 42 42 36 45 42 48 69 50 65 81 56
132 71 37 58 60 72 34 46 52 50 28 28 29 23 27 29 42 68 33 56
56 32 55 47 38 31 37 48 43 30 40 72 42 38 47 41
SJH-C25A 111
145 73 69 74 92 168 174 113 84 76 116 66 67 93 75 73 60 60 68 34
38 83 78 69 70 146 82 82 45 46 56 70 94 80 95 80 93 123 92 72
93 79 96 77 46 57 65 63 61 100 76 70 100 87 74 90 88 66 52 55
87 181 133 83 69 63 76 83 75 50 68 57 48 60 68 89 74 76 65 66
58 63 81 70 72 69 58 68 59 52 49 54 56 43 62 52 46 37 34 38
32 25 37 25 27 27 30 36 37 31 25
SJH-C25B 111
140 76 63 81 85 162 172 111 70 79 104 63 70 91 73 69 56 72 53 48
46 78 86 57 87 142 81 79 50 40 51 84 84 85 92 88 88 121 90 82
80 81 94 81 43 60 68 58 73 91 72 76 93 91 82 89 74 72 46 51
97 186 147 80 64 62 79 86 66 55 66 54 51 60 63 93 69 79 65 65
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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	

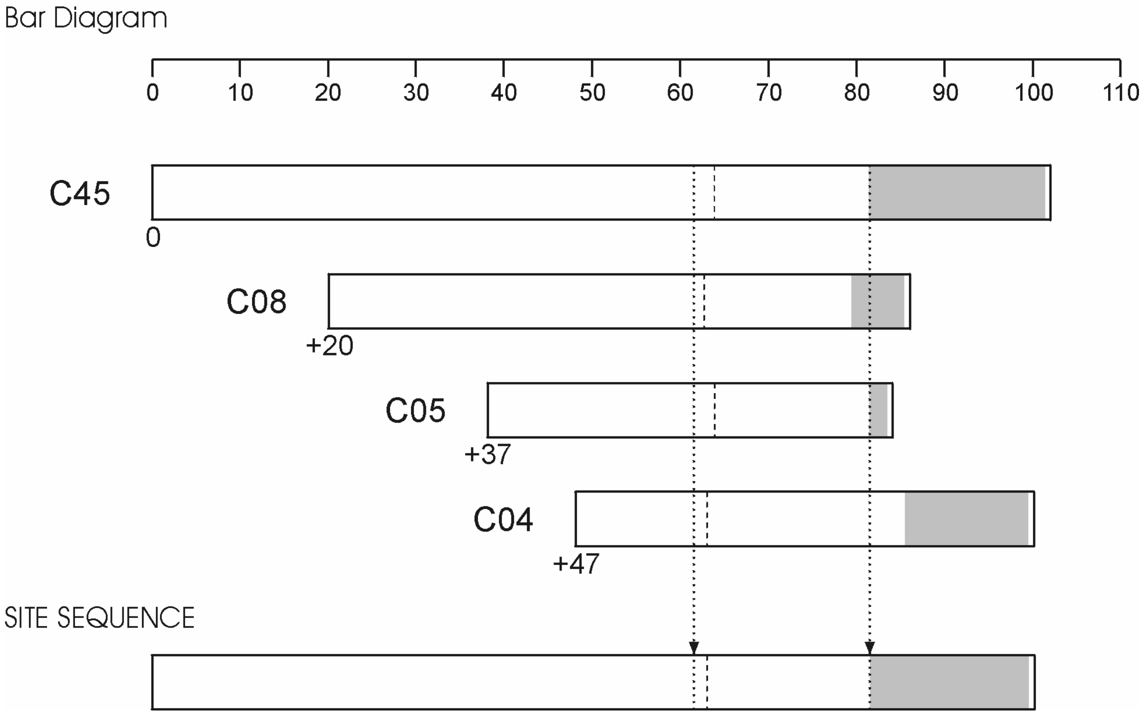


Figure 5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

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.

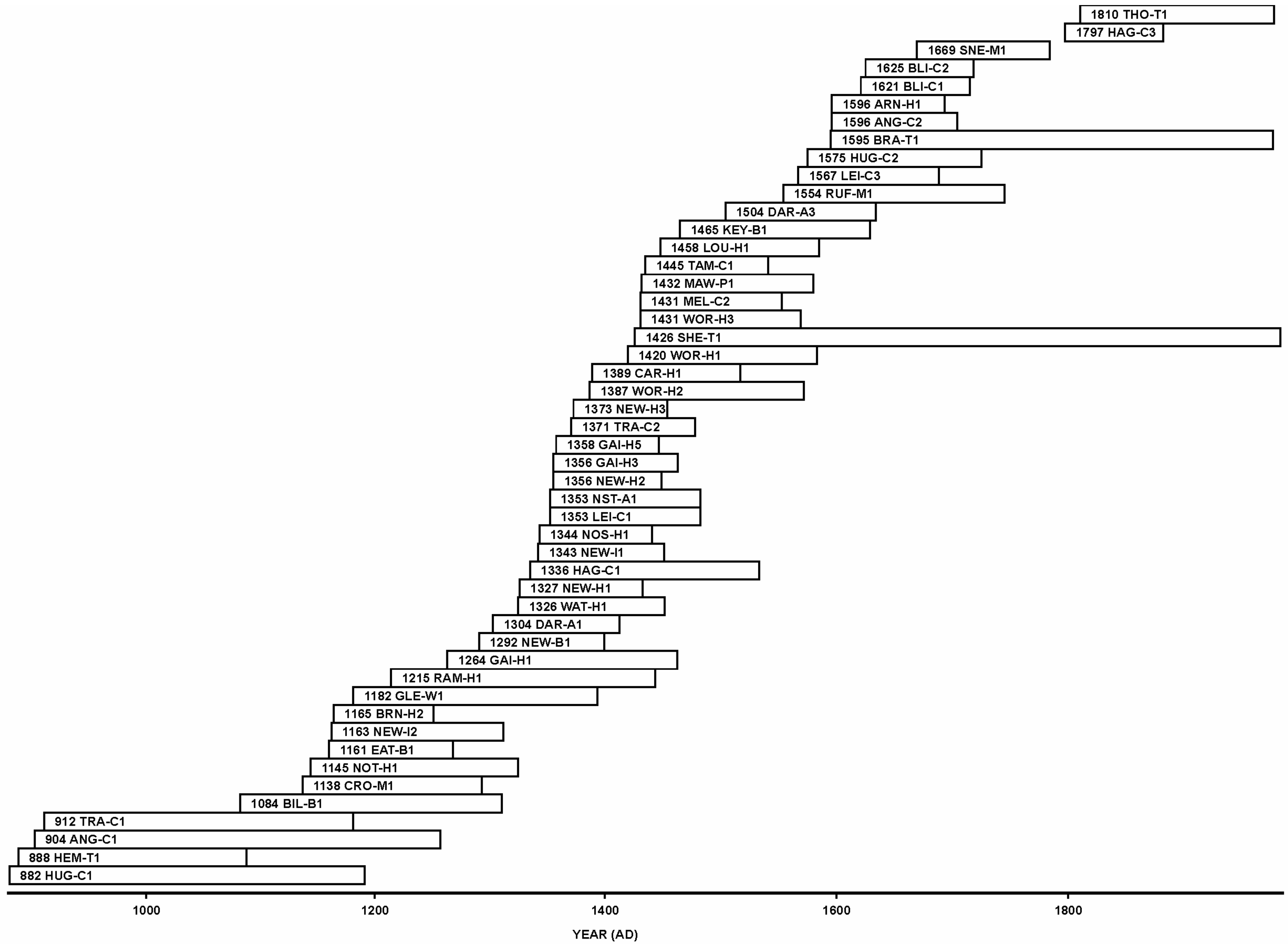
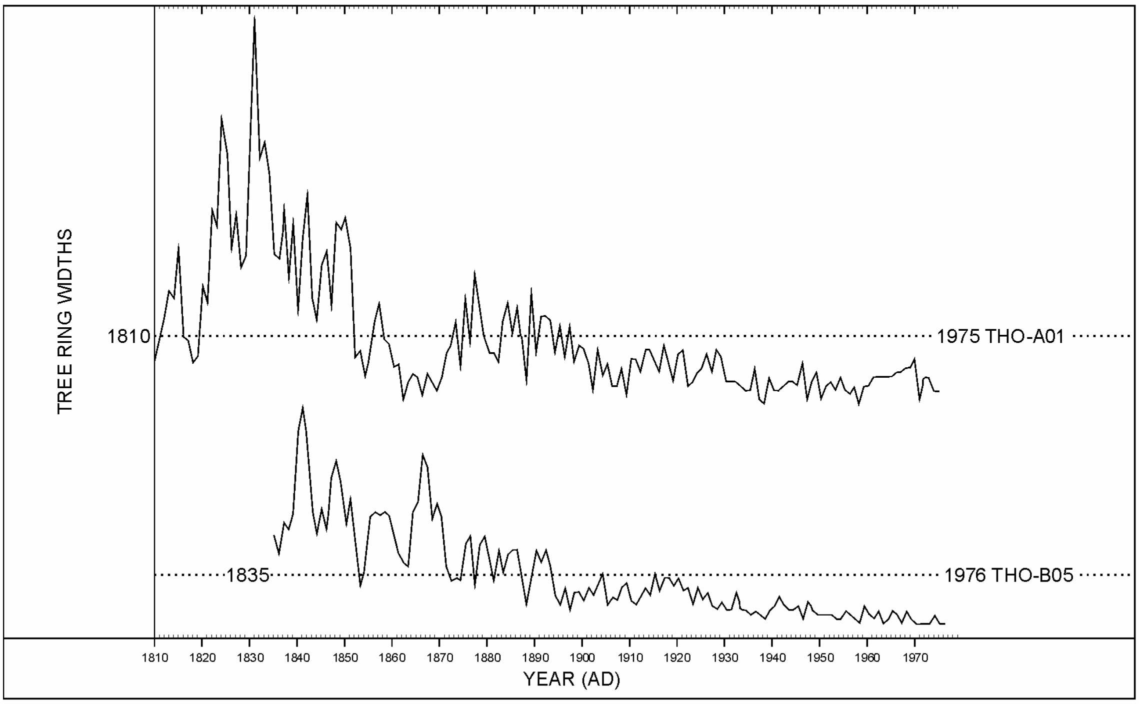


Figure 6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

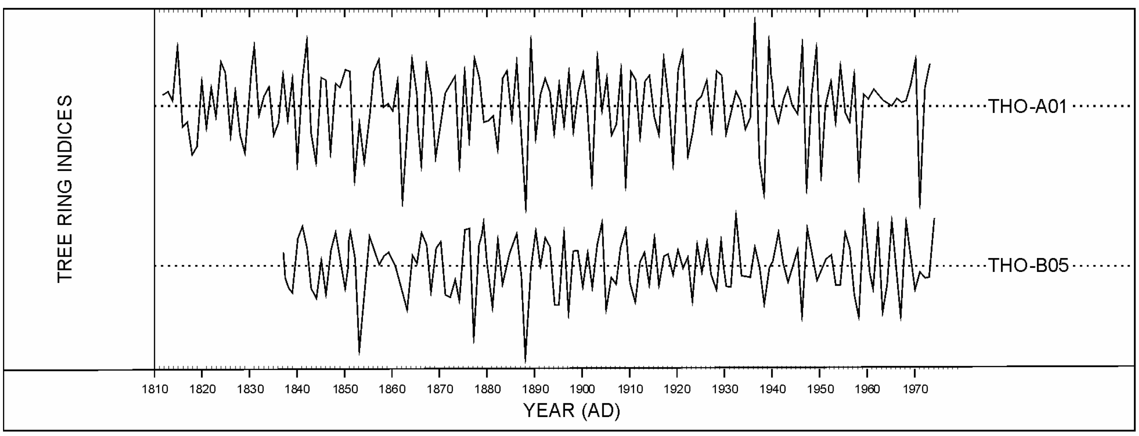


Figure 7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young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