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Summary

Twenty-seven samples from this building at Stanhope, County Durham were analysed by tree-ring dating. This analysis produced two site chronologies. The first, consisting of twenty-three samples and having 207 rings, spans the period AD 1386 – AD 1592.

Interpretation of the sapwood on the dated samples in this first chronology would indicate that the timbers used in the west range were probably all felled in AD 1553; those used in the south range were felled nearer the end of the sixteenth-century, in AD 1592.

The second site chronology consists of two samples and has 113 rings spanning the period AD 1415 - –D 1527. It is not possible to be certain when the timbers represented by these samples were felled, but it is unlikely to be before AD 1542.

Keywords

Dendrochronology

Standing Buildings

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TREE-RING ANALYSIS OF TIMBERS FROM UNTHANK HALL, STANHOPE, CO DURHAM

Introduction

Unthank Hall stands on the south bank of the river Wear opposite and slightly to the west of Stanhope (NY991391; Figs 1 and 2). It is believed that the site has its origins in a medieval moated manor house, possibly dating to the twelfth century. The present house, views of which are provided in Figures 3 and 4, consists of two parts. It is believed that the west range is the earlier. Architectural details here, such as the window surrounds, would suggest a date of between AD 1500 – AD 1570 for this. The roof structure of this west range consists of collar and tiebeam trusses with a somewhat curved profile; such a form is rare, if not unique, in this area and may be indicative of high status for the building. A photograph of the west-range roof is shown in Figure 5. The integral floor structures of this range consist of substantial cross-beams and joists.

The second part of the building, the south range, represents a rebuilding of the medieval hall range, with a two-storey block with attic. Architectural detailing of the south range might suggest a date of between AD 1600 – AD 1700 for this part of the building.

Within these two major parts of the house are to be found evidence of eighteenth- and nineteenth-century alterations; these phases are excluded from the tree-ring sampling brief. A schematic plan showing these phases is provided in Figures 6a/b.

Sampling and analysis by tree-ring dating was commissioned by English Heritage. The purpose of this was to provide information on the historic development of the house prior to proposed renovation and repairs to the building. Furthermore, the dating of Unthank Hall would not only help reassess the significance of this building in its regional context but also help define more accurately the present vague date range for its type. A final purpose of sampling was to help supply additional dendrochronological data for this relatively poorly represented area.

The Laboratory would like to take this opportunity to thank Martin Roberts, English heritage – North East region, for his help in arranging access to the site, for providing such excellent plans and photographs of the building, and for assisting with the introductory paragraph above. The Laboratory would also like to thank Mr Alan Morton, the owner, for allowing the Laboratory to sample and for being so enthusiastic about the history of the site.

Sampling

After discussion with Martin Roberts on the probable phasing of the buildings and the timbers available, a total of twenty-seven core samples was obtained. Each sample was given the code STN-B (for Stanhope, site "B") and numbered 01 – 27.

Eleven samples, STN-B01 – 11, were obtained from the roof timbers of the west range, with a further four samples STN-B12 – 15, being obtained from timbers of the floor structures here; both first- and ground-floor timbers were sampled. Twelve samples, STN-B16 – 27, were obtained only from the roof timbers of the south range, there being no timbers of the floor structure available. Where possible the positions of the samples were recorded on the drawings produced by Martin Roberts and provided by English Heritage. These are reproduced here as Figs 6a/b and Figs 7a – e. The trusses have been numbered from north to south, or from west to east as the case may be. Details of the samples are given in Table 1.

Analysis

Each sample was prepared by sanding and polishing and the growth-ring widths of all twenty-seven were measured; the data of these measurements are given at the end of the report. The growth-ring widths of all the samples were compared with each other by the Litton/Zainodin grouping procedure (see appendix). At a minimum t-value of 4.5 two groups of samples formed. The twenty-three samples of the first group cross-matched with each other at relative positions as shown in the bar diagram Figure 8. In this bar diagram the samples are shown by group according to their location: west range roof timbers, west range floor timbers, south range roof timbers. The growth-ring widths of these twenty-three samples were combined at these relative off-set positions to form STNBSQ01, a site chronology of 207 rings. Site chronology STNBSQ01 was compared with a series of relevant reference chronologies for oak, giving it a first ring date of AD 1386 and a last measured ring date of AD 1592. Evidence for this dating is given in the *t*-values of Table 2.

The two samples of the second group, both of them from the south-range roof, cross-matched with each other at relative positions as shown in the bar diagram Figure 9. The growth-ring widths of these two samples were combined at these relative off-set positions to form STNBSQ02, a site chronology of 113 rings. Site chronology STNBSQ02 was compared with a series of relevant reference chronologies for oak, giving it a first ring date of AD 1415 and a last measured ring date of AD 1527. Evidence for this dating is given in the *t*-values of Table 3.

The two site chronologies thus created, STNBSQ01 and STNBSQ02 were compared with each other. This indicated a cross-match with a maximum t-value of 4.3. This is found when the first ring of site chronology STNBSQ02 (first ring date AD 1415) is at plus 29 rings relative to the first ring of site chronology STNBSQ01 (first ring date AD 1386). This is the relative off-set position as suggested by the independent dating of the two site chronologies. Given the slightly low t-values for the dating of STNBSQ02, its low cross-matching t-value with STNBSQ01, and that fact that doing so does not alter the interpretation of the building, the samples of the two site chronologies were not combined.

Interpretation

West range

Analysis of samples from Unthank Hall has produced two dated site chronologies. The first site chronology, STNBSQ01, has twenty-three samples and includes material from both the west and the south ranges. The second dated site chronology, STNBSQ02, has two samples, both from the south-range roof.

The average last heartwood ring date of the samples from the west range roof only is AD 1529. The usual 95% confidence limit for the amount of sapwood on mature oaks from northern England is in the range 15 – 50 rings. This figure would give the timbers used in the west range roof an estimated felling date in the range AD 1544 – 79. The average last heartwood ring date of the samples from the west range floor only is AD 1531. Using the same sapwood range as above would give these timbers an estimated felling date in the range AD 1546 – 81.

However, one of the samples from the west range floor, STN-B12, retains complete sapwood, with a last ring date of AD 1553. Given that the roof and floor of the west range are integral, and the relative positions of the heartwood/sapwood boundaries on the samples from both areas are highly consistent, it is highly probable that AD 1553 is the felling date for all the timbers used in both areas of the west range.

South range

The roof of the south range provides two samples with complete sapwood, STN-B22 and STN-B23, both having last ring dates of AD 1592. The relative positions of the heartwood/sapwood boundaries on the other dated samples from this part of the building are consistent with AD 1592 being the felling date for all the timbers in the south range.

It is not possible to estimate the felling date of the timbers from the south range roof represented by the two samples, STN-B16 and B17, in site chronology STNBSQ02 (last ring date AD 1527) because neither of them have the heartwood/sapwood transition. The felling date is unlikely, however, to be earlier that AD 1542. There appears to be no noticeable difference between these timbers and the other in the south range roof and it is probable that they are of the same felling date as all the others in this part of the roof.

Conclusion

Analysis by dendrochronology has now been able to provide clear dates for this building. The west range is certainly the earlier and appears to lie well within its expected sixteenth-century date range. The south range is perhaps very slightly earlier than expected, being very late sixteenth century rather than seventeenth century.

Only two of the twenty-seven samples remain undated, STN-B01 and STN-B27. These samples have 80 and 75 rings, respectively. Neither of the samples show particularly stressed or complacent rings that might make cross-matching and dating difficult. There appears to be nothing different or unusual about either of them.

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Table 1: Details of samples from Unthank Hall, Stanhope, Durham

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	West range					
STN-B01	East principal rafter, truss 2	80	no h/s	------	------	------
STN-B02	West principal rafter, truss 2	71	no h/s	AD 1428	------	AD 1498
STN-B03	Upper west purlin, truss 2 – 3	70	3	AD 1464	AD 1530	AD 1533
STN-B04	West common rafter 11, bay 2	76	13	AD 1465	AD 1527	AD 1540
STN-B05	West common rafter 13, bay 2	54	2	AD 1477	AD 1528	AD 1530
STN-B06	East common rafter 13, bay 2	95	no h/s	AD 1411	------	AD 1505
STN-B07	East common rafter 14, bay 3	70	no h/s	AD 1441	------	AD 1510
STN-B08	East principal rafter, truss 4	78	h/s	AD 1454	AD 1531	AD 1531
STN-B09	Upper east purlin, truss 4 – 5	91	5	AD 1445	AD 1530	AD 1535
STN-B10	West principal rafter, truss 5	87	6	AD 1449	AD 1529	AD 1535
STN-B11	West common rafter 12, bay 5	69	no h/s	AD 1443	------	AD 1511
STN-B12	East – west joist 3, first-floor ceiling	130	28C	AD 1424	AD 1525	AD 1553
STN-B13	East – west joist 2, first-floor ceiling	90	no h/s	AD 1421	------	AD 1510
STN-B14	Main east – west joist, ground-floor ceiling	66	h/s	AD 1465	AD 1530	AD 1530
STN-B15	Bottom step, stairs, first-floor to roof	68	h/s	AD 1462	AD 1529	AD 1529

Table 1: Continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	South range					
STN-B16	North principal rafter, truss 4	113	no h/s	AD 1415	------	AD 1527
STN-B17	South principal rafter, truss 4	82	no h/s	AD 1435	------	AD 1516
STN-B18	South common rafter 2, bay 4	70	no h/s	AD 1386	------	AD 1455
STN-B19	North common rafter 2, bay 5	80	no h/s	AD 1432	------	AD 1511
STN-B20	North common rafter 3, bay 5	54	h/s	AD 1521	AD 1574	AD 1574
STN-B21	North common rafter 3, bay 4	114	11	AD 1467	AD 1569	AD 1580
STN-B22	North common rafter 5, bay 4	140	18C	AD 1453	AD 1574	AD 1592
STN-B23	South principal rafter, truss 1	95	27C	AD 1498	AD 1564	AD 1592
STN-B24	South common rafter 4, bay 1	180	10	AD 1408	AD 1577	AD 1587
STN-B25	North principal rafter, truss 1	83	6	AD 1483	AD 1559	AD 1565
STN-B26	East common rafter 6, gable window	158	no h/s	AD 1396	------	AD 1553
STN-B27	West common rafter 4, gable window	75	22	------	------	------

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

Results of the cross-matching of site chronologies and samples with relevant reference chronologies

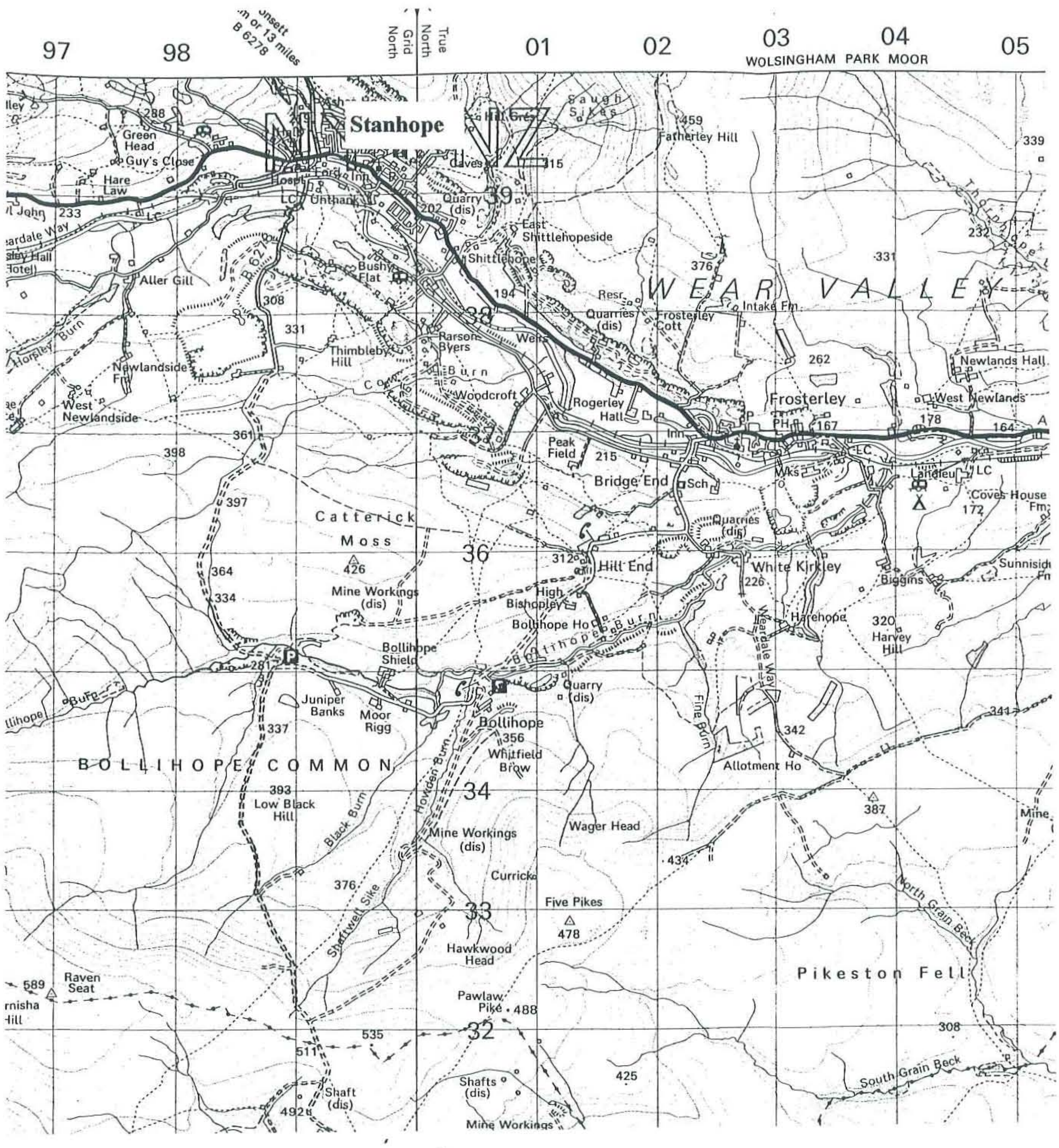
Table 2: Site chronology STNBSQ01when first ring date is AD 1386 and last ring date is AD 1592

Reference chronology	Span of chronology	t-value	
East Midlands	AD 882 – 1981	4.4	(Laxton and Litton 1988)
England	AD 401 – 1981	5.0	(Baillie and Pilcher 1982 unpubl)
Cathedral Precinct, Durham	AD 1364 – 1531	7.4	(Howard *et al* 1992b)
Kepier Hospital, Durham	AD 1304 – 1522	6.1	(Howard *et al* 1996)
Ingleby Greenhow, N Yorks	AD 1429 – 1563	6.7	(Howard *et al* 1993b)
Hornby Hall, Cumbria	AD 1453 – 1549	6.5	(Howard *et al* 1993b)
Unthank Hall, Holmesfield, Derbys	AD 1359 – 1589	6.3	(Howard *et al* 1993a)
Hoyles Farm, Bradfield, Derbys	AD 1448 – 1552	6.2	(Howard *et al* 1993a)

Table 3: Site chronology STNBQ02 when first ring date is AD 1415 and last ring date is AD 1527

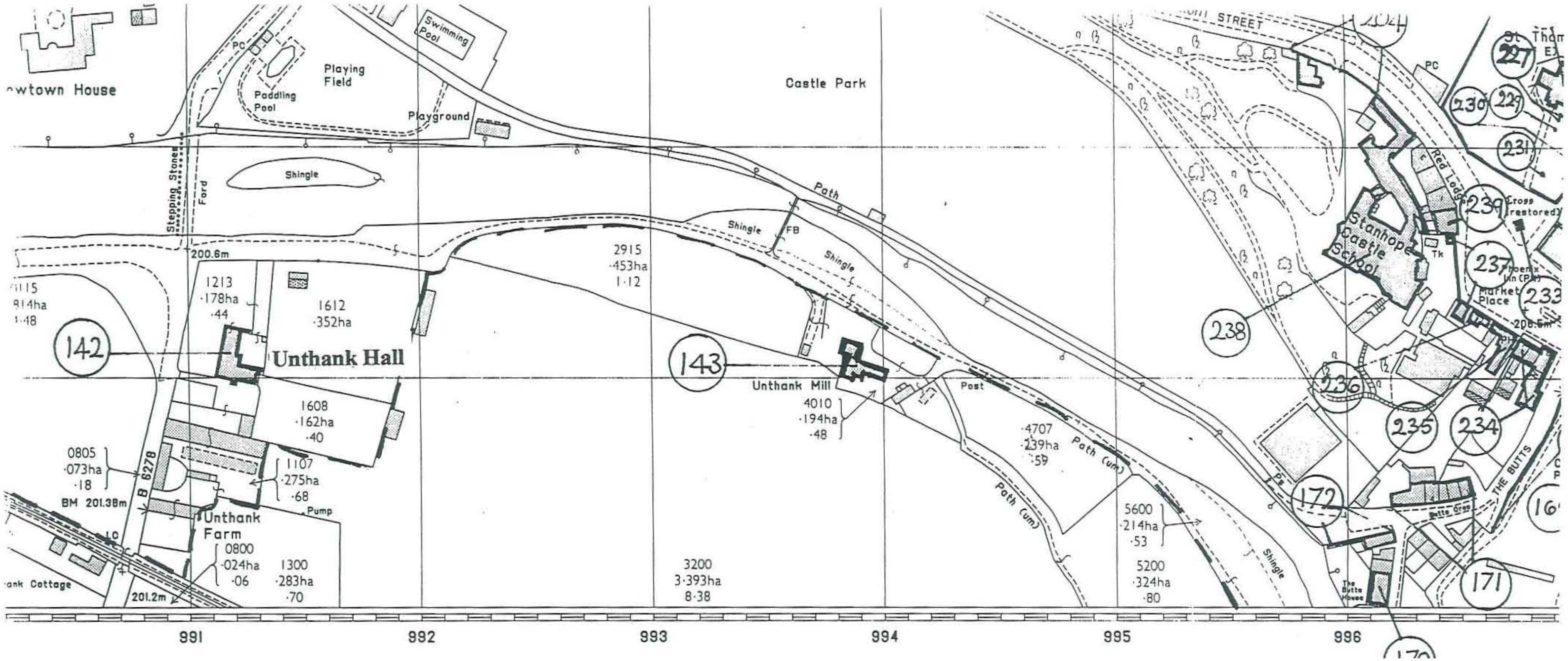
East Midlands	AD 882 – 1981	3.6	(Laxton and Litton 1988)
England	AD 401 – 1981	4.2	(Baillie and Pilcher 1982 unpubl)
Hall Broom Farm, Dungworth, Derbys	AD 1382 – 1495	5.2	(Howard *et al* 1993a)
Kepier Hospital, Durham	AD 1304 – 1522	4.6	(Howard *et al* 1996)
Church Street, Eckington, Derbys	AD 1365 – 1480	4.1	(Howard *et al* 1992a)
Seaton Holme, Easington, Co Durham	AD 1375 – 1489	4.6	(Howard *et al* 1988 unpubl)

Figure 1: Map to show general location of Stanhope



(based upon the Ordnance Survey 1:50000 map with permission of The Controller of Her Majesty's Stationery Office, ©Crown Copyright).

Figure 2: Map to show particular location of Unthank Hall



(based upon the Ordnance Survey 1:10000 map with permission of The Controller of Her Majesty's Stationery Office, ©Crown Copyright).

Figure 3: View of Unthank Hall from the west

Figure 4: View of Unthank Hall from the south

Figure 5: View of the west range roof

Figure 6a: Plan of the ground floor showing phasing, position of trusses, and position of sample STN-B14

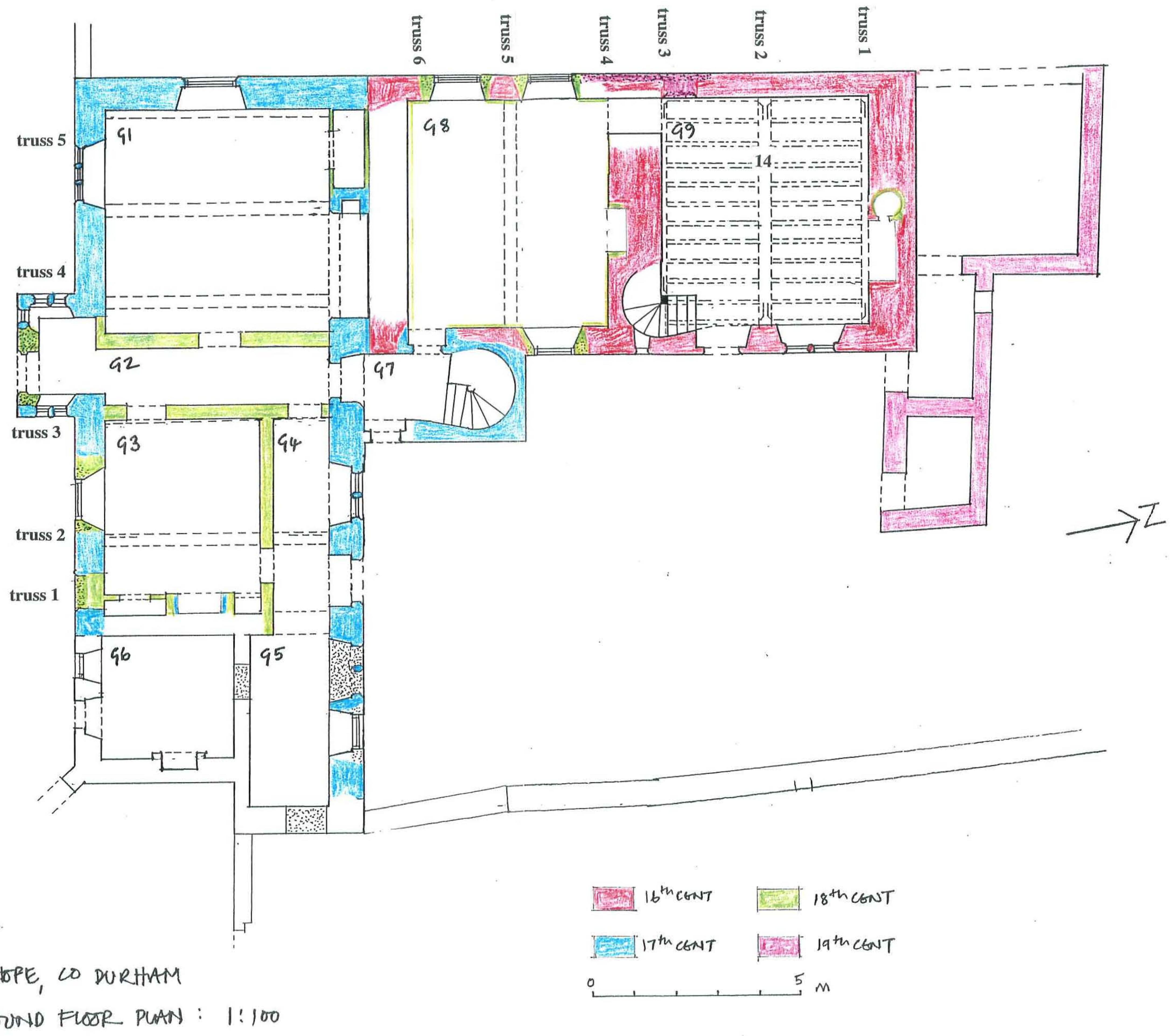


Figure 6b: Plan of the first floor showing phasing, position of trusses, and position of sample STN-B15

Figure 7a: West range roof truss 2 (viewed from the south) to show sample locations

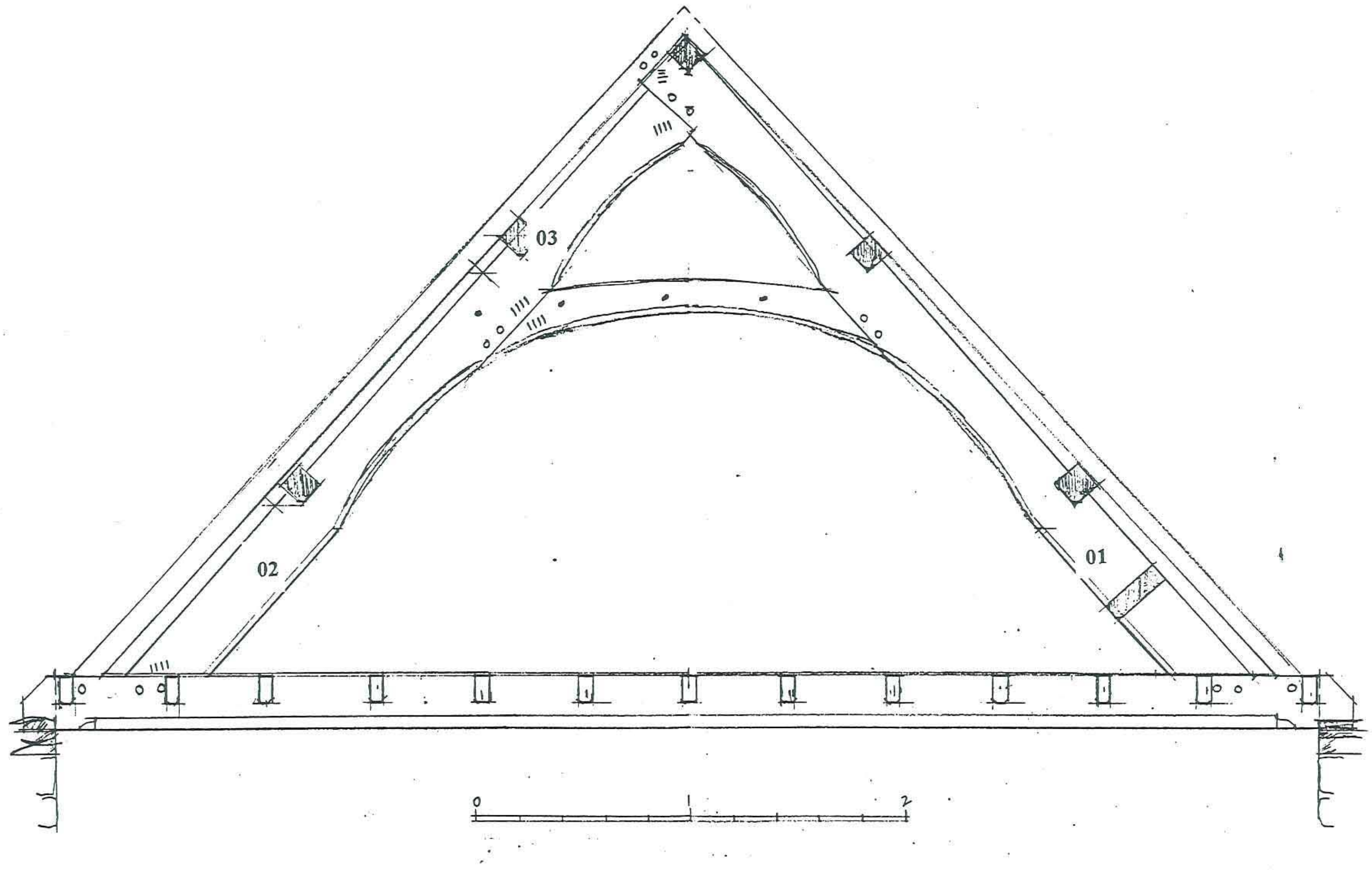


Figure 7b: West range roof truss 4 (viewed from the south) to show sample locations

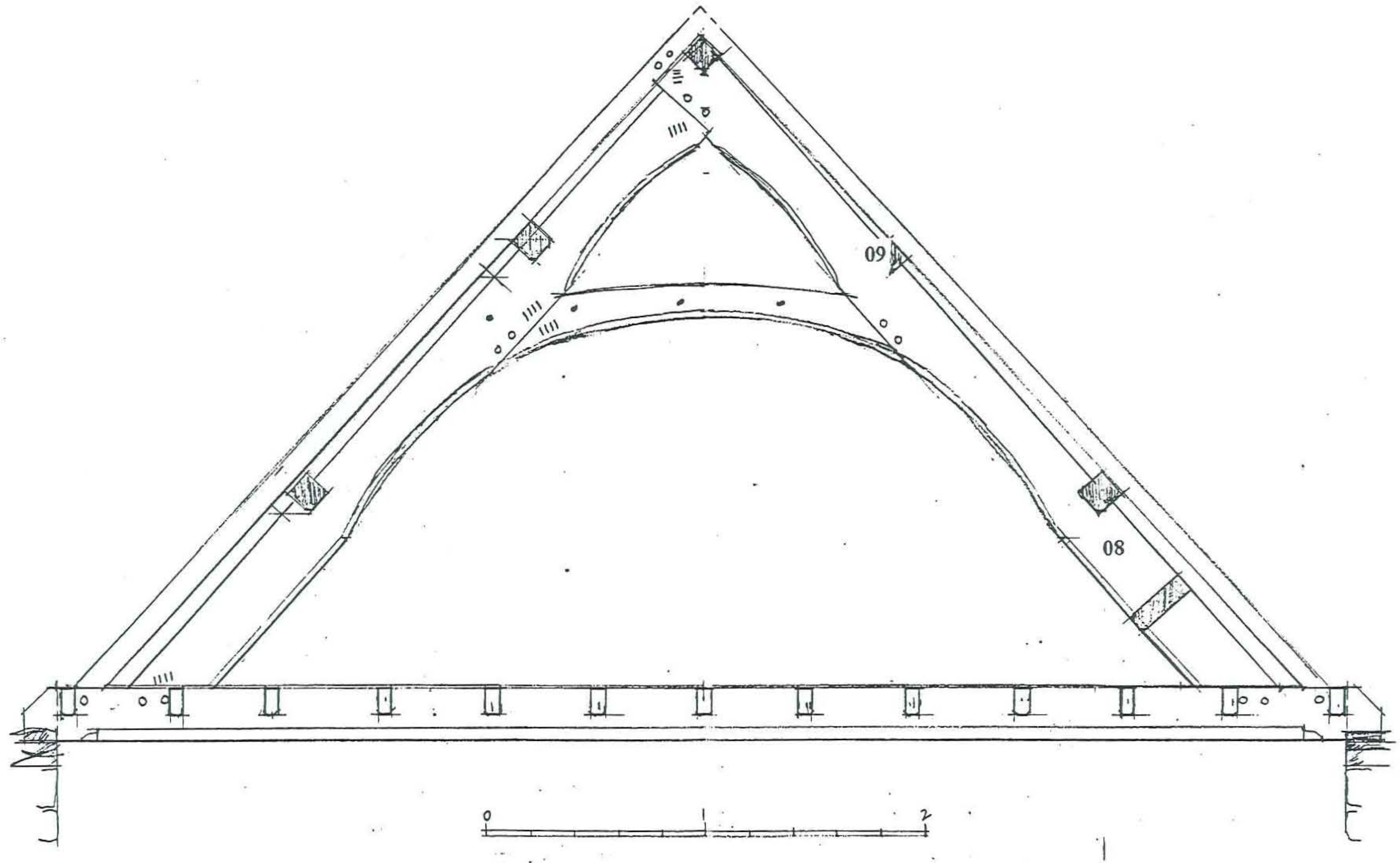


Figure 7c: West range roof truss 5 (viewed from the south) to show sample location

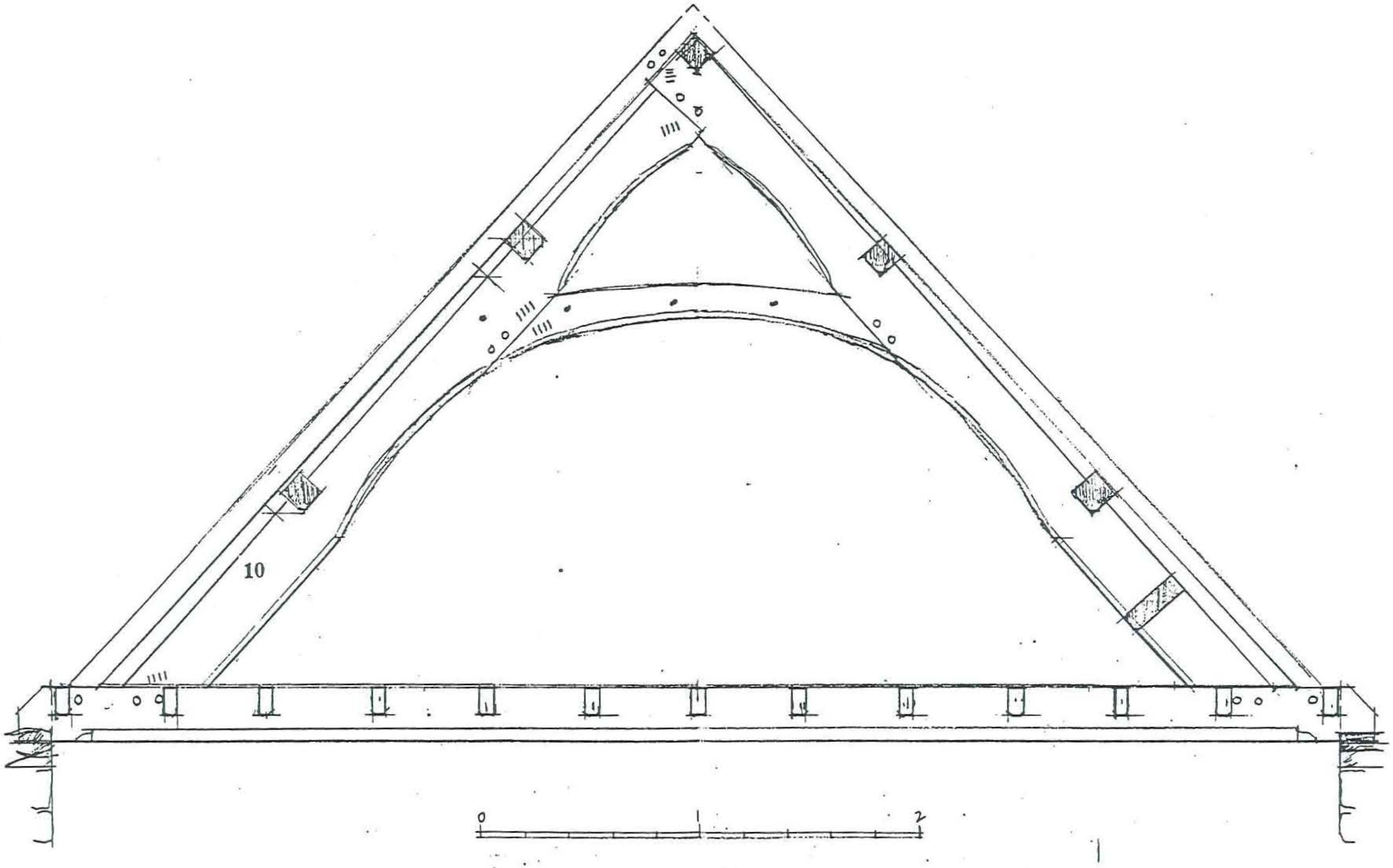
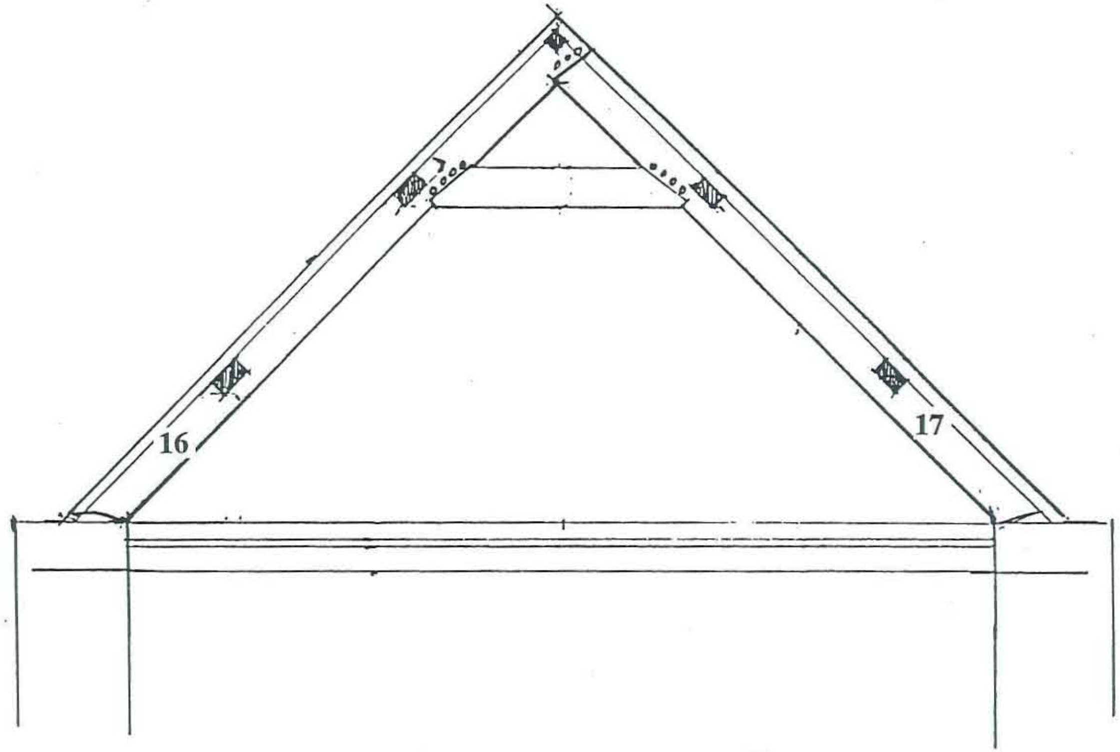
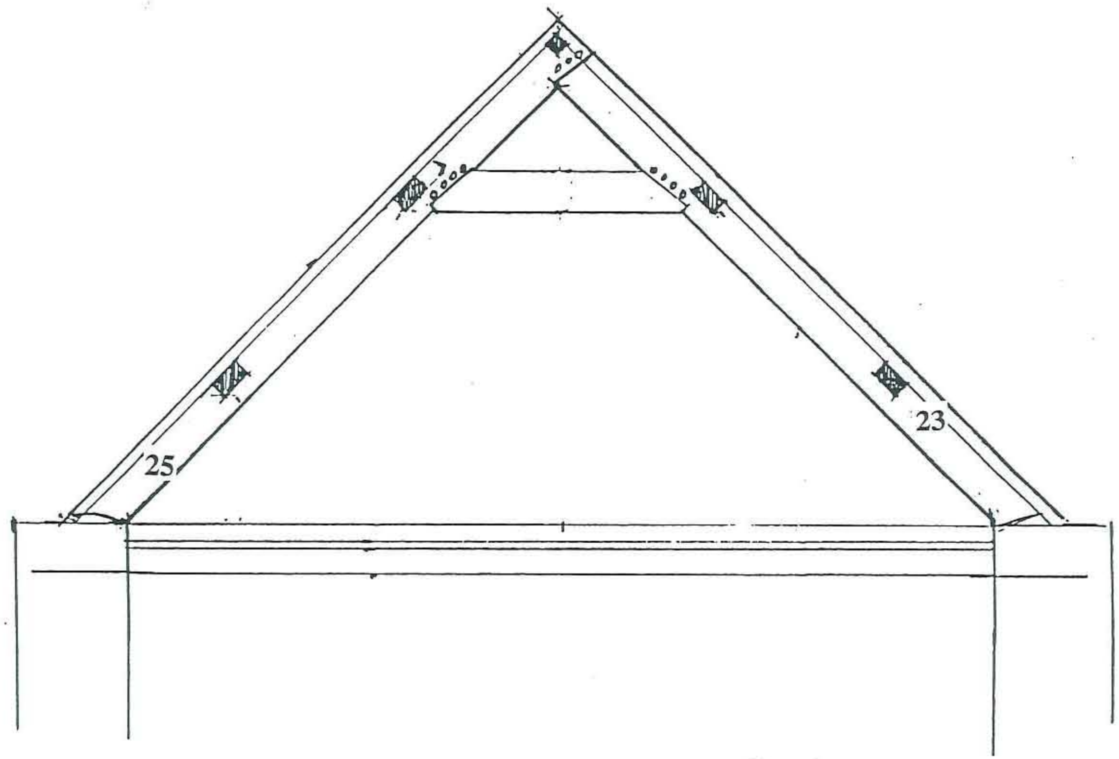


Figure 7d: South range roof truss 4 (viewed from the west) to show sample locations



Scale 1:50

Figure 7e: South range roof truss 1 (viewed from the west) to show sample locations



Scale 1:50

Figure 8: Bar diagram of samples in site chronology STNBSQ01 (grouped by sample location)

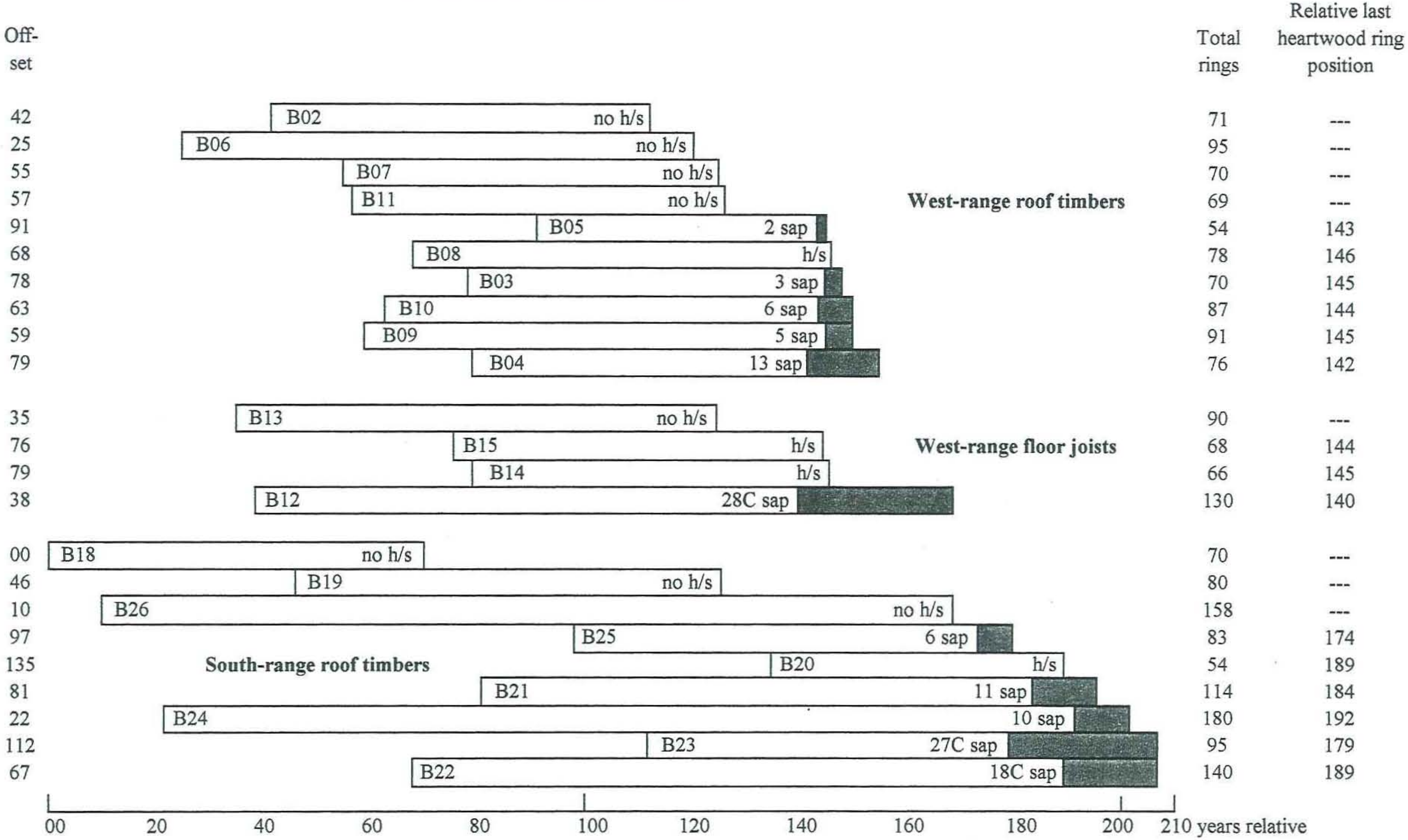
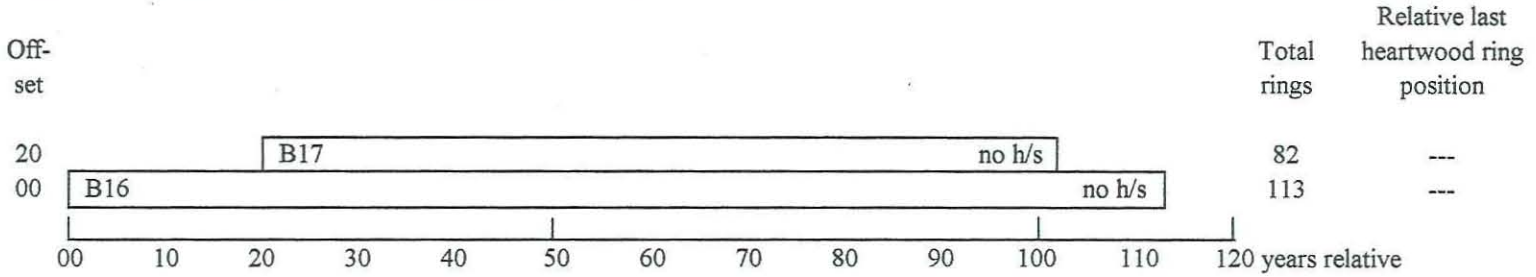


Figure 9: Bar diagram of samples in site chronology STNBSQ02



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

Data of measured samples – measurements in 0.01 mm units

STN-B01A 80
372 319 353 304 407 420 428 380 483 474 392 356 294 335 412 324 416 399 220 277
252 271 233 227 204 261 315 328 327 265 316 309 378 295 356 375 332 271 160 176
138 196 187 176 224 158 275 262 232 294 410 324 298 290 296 276 267 223 181 182
172 243 254 200 150 119 136 231 240 215 207 242 247 237 184 263 158 229 216 240
STN-B01B 80
385 312 345 313 422 411 431 413 466 478 391 368 300 318 435 305 422 400 243 271
247 258 230 252 213 281 268 325 333 262 317 312 366 303 357 360 358 315 169 170
139 185 196 154 212 154 264 281 244 270 408 329 281 292 295 267 234 245 182 180
182 243 240 196 147 145 136 194 216 234 236 238 241 243 181 182 239 255 186 197
STN-B02A 71
215 330 265 253 248 228 346 298 182 218 216 163 204 272 258 222 159 150 160 198
177 203 199 180 237 211 219 156 218 244 232 225 186 186 236 197 227 201 237 259
224 150 129 190 118 139 152 143 165 170 176 182 163 158 54 101 144 146 187 140
135 127 121 134 148 134 128 140 188 151 134
STN-B02B 71
220 319 265 239 259 230 363 298 177 206 209 186 198 281 256 225 164 152 166 182
148 203 212 183 223 213 187 157 185 225 259 204 172 187 250 191 221 184 243 259
214 162 129 186 123 128 157 145 176 170 165 176 166 139 51 101 140 154 173 129
138 129 123 134 151 141 127 145 176 158 136
STN-B03A 70
293 329 394 436 417 399 229 371 252 250 240 223 278 227 312 364 276 319 154 222
276 229 265 202 190 165 170 175 207 109 159 190 222 198 179 279 295 305 364 281
298 314 318 263 354 228 247 252 210 217 217 200 249 208 274 168 119 129 116 77
71 94 135 148 126 143 152 138 110 141
STN-B03B 70
309 337 389 437 411 387 235 376 248 234 242 217 272 218 302 357 281 321 160 233
273 229 256 216 193 162 167 181 194 98 153 191 217 200 176 274 307 311 360 293
291 314 314 253 362 230 240 256 220 216 210 206 255 219 264 167 119 128 125 71
73 93 137 144 130 140 148 142 134 135
STN-B04A 76
224 312 253 233 215 224 281 175 154 112 143 141 114 118 100 111 142 143 133 133
126 153 221 173 157 193 209 184 123 175 166 183 156 119 151 109 72 68 114 145
136 172 123 145 166 160 149 160 154 162 127 153 118 156 124 131 123 132 94 112
127 135 143 106 98 95 83 62 86 78 74 89 88 103 115 145
STN-B04B 76
200 302 258 243 214 220 303 182 154 120 142 140 119 117 105 103 143 149 123 133
141 145 224 182 148 200 209 181 136 157 173 172 172 113 146 108 68 75 109 142
132 174 120 148 173 152 151 164 158 156 120 160 120 149 128 132 126 124 97 110
139 135 128 104 112 73 86 75 82 83 71 91 96 88 131 122
STN-B05A 54
126 91 146 127 137 78 62 76 80 86 149 137 114 127 99 89 57 56 100 138
114 120 100 98 70 78 82 102 105 68 101 93 116 89 63 62 39 47 57 76
77 84 73 60 88 51 49 32 84 81 79 90 73 67

STN-B05B 54
125 101 143 129 137 63 63 65 80 92 125 134 120 122 90 78 62 61 111 156
109 127 94 83 69 73 89 91 118 83 101 101 115 93 63 61 42 40 58 75
72 90 76 67 77 59 42 49 68 94 78 79 68 67
STN-B06A 95
184 149 144 107 131 96 135 86 60 88 61 70 152 116 95 38 43 78 134 121
81 117 156 297 212 205 217 233 147 185 143 130 118 166 139 130 181 153 177 109
151 176 172 150 162 262 201 142 171 141 165 153 106 135 134 151 155 157 71 111
99 75 114 107 74 96 114 115 158 120 126 51 95 107 84 102 69 65 101 83
86 76 55 67 94 105 71 67 84 68 69 63 62 113 91
STN-B06B 95
170 152 146 105 135 96 127 97 63 80 71 69 152 122 93 42 45 58 142 106
91 122 158 289 204 193 222 228 152 167 168 124 105 151 143 138 184 154 184 105
164 168 173 151 156 259 207 132 180 140 155 155 110 139 124 154 153 166 66 90
116 71 117 102 75 99 108 106 171 115 116 57 90 99 93 100 61 76 88 91
76 78 59 76 100 107 65 69 75 78 64 59 73 123 105
STN-B07A 70
325 208 205 277 279 299 352 298 297 160 240 314 218 249 186 280 250 157 190 179
165 163 160 184 164 179 228 248 138 157 184 119 135 143 103 138 159 157 161 123
123 48 106 128 90 124 66 93 100 102 97 89 58 73 99 110 107 96 78 74
58 64 70 93 86 89 72 83 73 86
STN-B07B 70
316 209 203 269 299 274 368 274 299 176 240 329 227 258 190 281 237 159 187 176
156 183 134 187 169 175 239 239 141 152 187 108 144 134 104 137 167 146 158 129
121 48 103 132 94 112 63 100 93 107 111 90 59 71 103 109 105 94 89 55
57 70 70 90 84 84 84 73 89 93
STN-B08A 78
168 163 218 242 163 165 143 154 178 145 195 184 212 239 217 168 204 205 108 165
145 144 164 150 114 168 144 119 44 93 108 91 132 94 121 125 110 121 130 136
148 154 198 150 123 194 155 181 176 127 208 186 142 219 187 174 185 138 142 138
144 135 121 105 122 105 103 109 85 76 101 95 110 105 97 107 127 99
STN-B08B 78
125 163 229 244 163 135 152 159 171 152 175 171 226 265 222 168 203 196 126 184
122 157 151 143 122 174 136 123 36 91 110 103 114 99 121 135 106 108 135 143
152 141 192 157 128 198 166 180 158 144 198 189 144 181 197 169 169 140 138 129
125 129 122 104 121 107 111 112 96 68 89 107 100 124 83 116 118 137
STN-B09A 91
241 191 246 229 225 193 228 252 253 205 159 199 194 171 164 141 162 197 150 150
159 185 241 267 146 188 185 152 129 146 126 137 148 162 234 180 184 75 90 169
202 174 145 135 107 100 122 140 89 87 173 140 133 113 105 108 118 106 79 135
162 206 149 125 157 160 163 108 85 61 80 90 88 99 89 86 105 99 54 82
107 168 146 124 127 127 83 58 67 59 81
STN-B09B 91
194 187 246 212 234 197 204 288 254 216 155 208 192 165 155 141 166 181 145 132
153 187 249 287 167 197 204 145 122 161 131 125 156 163 226 199 185 72 94 163
207 171 139 131 102 113 118 138 90 87 162 147 125 109 112 119 118 101 86 126
158 220 140 137 148 157 164 107 72 67 84 88 82 106 87 87 104 92 55 79
108 184 148 117 132 124 90 58 50 59 72

STN-B10A 87
130 203 239 266 284 307 228 267 292 173 72 98 84 156 121 101 137 175 221 214
164 189 168 93 68 61 80 112 118 76 93 70 66 30 34 41 45 70 81 51
41 51 57 71 47 64 86 128 112 93 91 83 52 30 42 79 123 102 87 76
93 107 93 86 88 116 98 98 88 137 126 124 158 161 78 118 151 109 136 148
113 79 79 72 73 84 99
STN-B10B 87
135 214 237 239 297 307 227 260 304 173 90 87 83 146 125 106 141 172 222 217
162 189 170 96 64 62 78 112 124 78 85 69 65 39 45 39 57 56 77 53
45 62 55 62 43 67 89 115 106 79 98 92 45 38 43 73 114 115 83 77
91 104 93 82 90 110 95 99 95 138 131 121 158 156 85 115 147 122 132 149
142 86 75 64 78 66 107
STN-B11A 69
163 249 244 270 264 196 229 162 193 306 211 222 210 202 211 164 142 169 137 144
133 131 116 147 142 166 143 128 142 78 101 83 84 130 123 151 156 129 122 58
130 109 91 146 75 116 102 98 100 111 78 69 99 126 102 96 92 79 74 76
63 91 86 96 99 137 121 139 100
STN-B11B 69
168 241 258 258 267 200 230 156 194 306 209 229 205 207 210 168 141 174 127 146
155 135 124 154 151 150 136 128 133 75 85 101 75 134 115 153 145 131 133 60
121 120 95 152 78 103 88 113 112 115 62 81 105 124 106 103 99 78 75 77
68 88 91 103 89 119 133 117 99
STN-B12A 130
79 98 111 91 74 64 109 83 95 58 72 102 162 173 123 90 112 144 216 253
253 205 154 211 191 188 185 242 210 172 172 129 177 167 154 102 98 109 139 98
122 108 145 157 161 116 144 109 76 46 53 73 109 100 98 112 103 98 98 82
107 119 103 117 95 73 81 97 93 52 69 97 119 101 86 100 95 59 38 29
72 73 88 92 70 108 87 73 68 66 67 98 79 104 94 105 76 81 55 42
66 71 78 72 75 61 54 56 36 78 62 81 92 70 66 94 100 99 70 78
81 90 106 92 89 82 83 46 68 82
STN-B12B 130
104 100 101 101 65 68 100 89 89 75 75 96 175 174 127 83 122 132 223 246
235 187 169 240 204 166 176 245 215 186 151 124 184 147 135 99 92 105 141 107
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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 Buildings*' (Laxton and Litton 1988b) and, for example, in *Tree-Ring Dating and Archaeology* (Baillie 1982) or *A Slice Through Time* (Baillie 1995). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The *width* of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring..

If the bark is still on the sample, as in Figure 1, then the date of the last ring will be the date of felling of the oak from which it was cut. There is much evidence that in medieval times oaks cut down for building purposes were used almost immediately, usually within the year or so (Rackham 1976). Hence if bark is present on several main timbers in a building, none of which appear reused or are later insertions, and if they all have the same date for their last ring, then we can be quite confident that this is the date of construction. If there is no bark on the sample, then we have to make an estimate of the felling date; how this is done is explained below.

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

1. ***Inspecting the Building and Sampling the Timbers.*** Together with a building historian we inspect the timbers in a building to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can sample *in situ* timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer rings than this, 50 for example, sequences of widths become difficult to match to a unique position within a master sequence of ring widths and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure 2 has about 120 rings; about 20 of which are sapwood rings. Similarly the core has just over 100 rings.

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

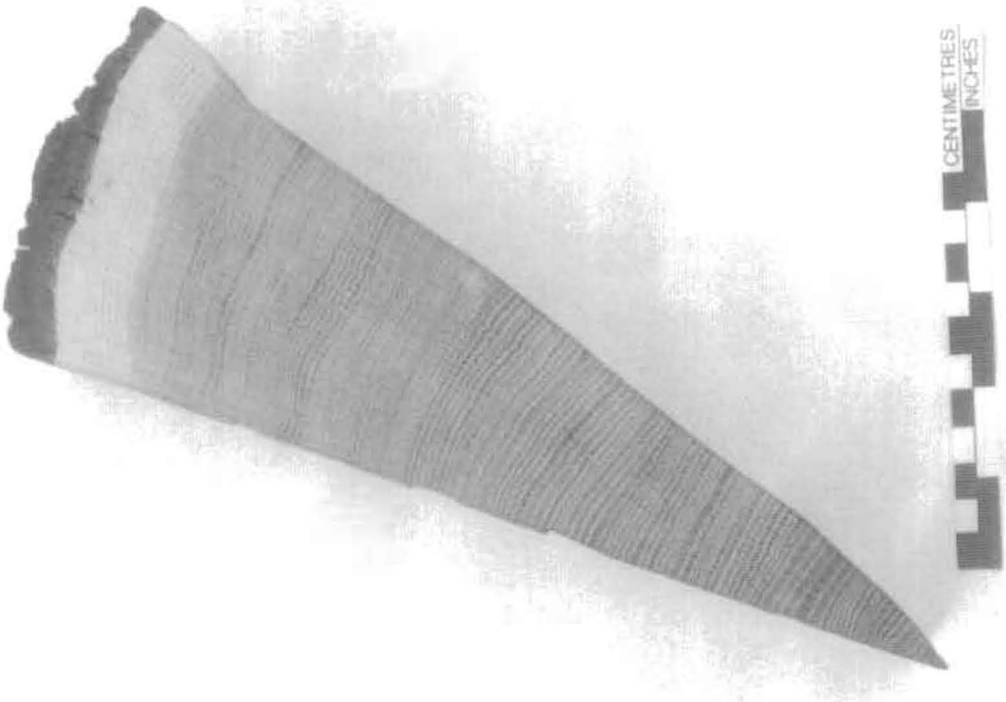

Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

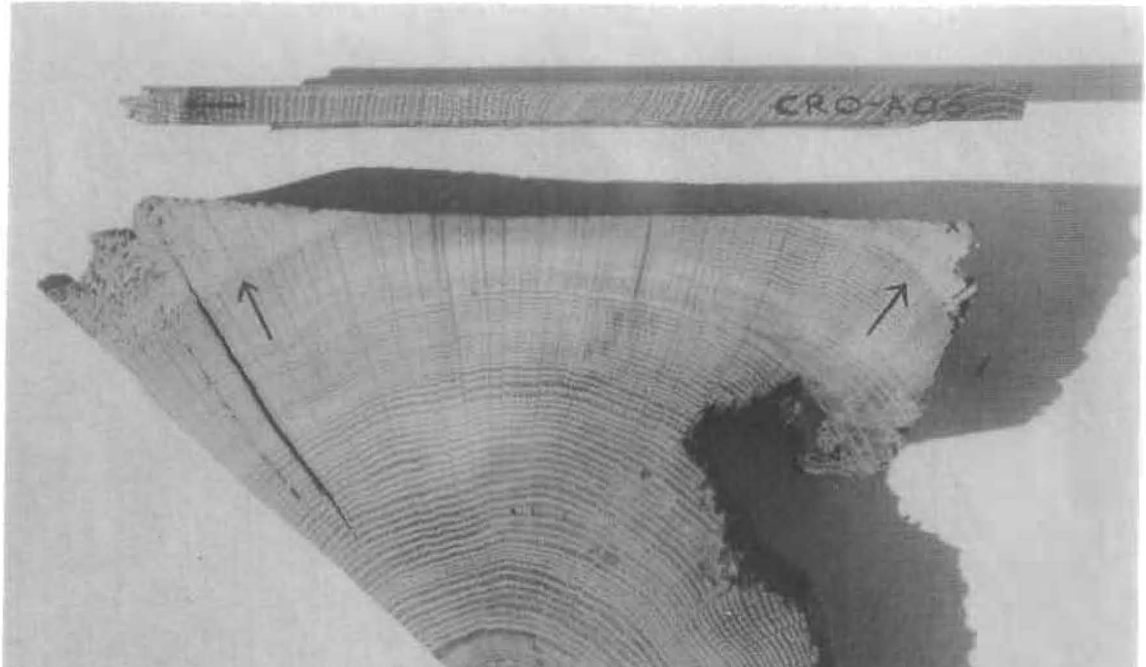

Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

Fig 3. Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measured twice to ensure that an error has not been made. This type of apparatus is needed to process a large number of samples on a regular basis.

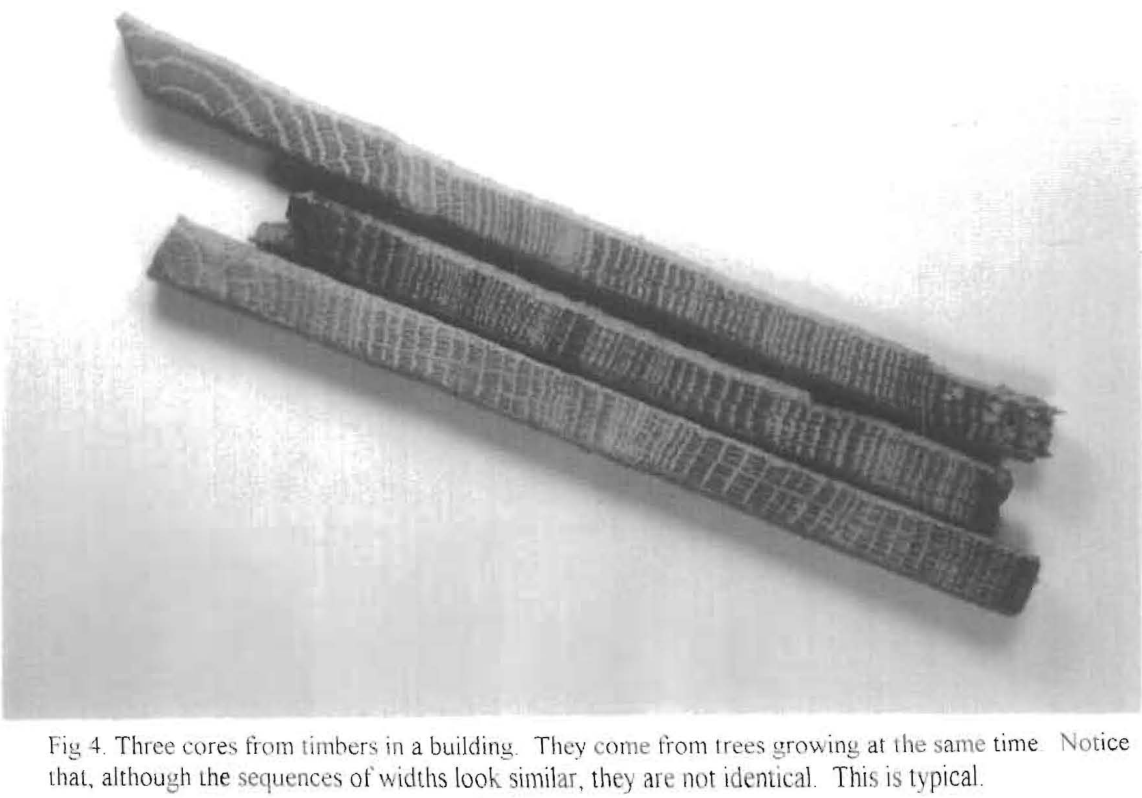

Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

Sampling is done by coring into the timber with a hollow corer attached to an electric drill and usually from its outer rings inwards towards where the centre of the tree, the pith, is judged to be. An illustration of a core is shown in Figure 2; it is about 15cm long and 1cm diameter. Great care has to be taken to ensure that as few as possible of the outer rings are lost This can be difficult as these outer rings are often very soft (see below on sapwood) Each sample is given a code which identifies uniquely which timber it comes from, which building it is from and where the building is located. For example, CRO-A06 is the sixth core taken from the first building (A) sampled by the Laboratory in Cropwell Bishop. Where it came from in that building will be shown in the sampling records and drawings. No structural damage is done to any timbers by coring, nor does it weaken them.

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

All sampling by the Laboratory is undertaken according to current Health and Safety Standards.
The Laboratory is insured with the CBA.

2. ***Measuring Ring Widths.*** Each core is sanded down with a belt sander using medium-grit paper and then finished by hand with flourgrade-grit paper. The rings are then clearly visible and differentiated from each other with a result very much like that shown in Figure 2. The core is then mounted on a movable table below a microscope and the ring-widths measured individually from the innermost ring to the outermost. The widths are automatically recorded in a computer file as they are measured (see Fig 3).

3. ***Cross-matching and Dating the Samples.*** Because of the factors besides the local climate which may determine the annual widths of a tree's rings, no two sequences of ring widths from different oaks growing at the same time are exactly alike (Fig 4). Indeed, the sequences may not be exactly alike even when the trees are growing near to each other. Consequently, in the Laboratory we do not attempt to match two sequences of ring widths by eye, or graphically, or by any other subjective method. Instead, it is done objectively (ie statistically) on a computer by a process called cross-matching. The output from the computer tells us the extent of correlation between two sample sequences of widths or, if we are dating, between a sample sequence of widths and the master, at each relative position of one to the other (offsets). The extent of the correlation at an offset is determined by the *t-value* (defined in almost any introductory book on statistics). That offset with the maximum t-value among the t-values at all the offsets will be the best candidate for dating one sequence relative to the other. If one of these is a master chronology, then this will date the other. Experiments carried out in the past with sequences from oaks of known date suggest that a t-value of at least 4.5, and preferably 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton *et al* 1988a,b; Howard *et al* 1984 - 1995).

This is illustrated in Fig 5 with timbers from one of the roofs of Lincoln Cathedral. Here four sequences of ring widths, LIN- C04, 05, 08, and 45, have been cross-matched with each other. The ring widths themselves have been omitted in the *bar-diagram*, as is usual, but the offsets at which they best cross-match each other are shown; eg. C08 matches C45 best when it is at a position starting 20 rings after the first ring of 45. and similarly for the others. The actual t-values between the four at these offsets of best correlations are in the matrix. Thus at the offset of +20 rings, the t-value between C45 and C08 is 5.6 and is the maximum between these two whatever the position of one sequence relative to the other.

It is standard practice in our Laboratory first to cross-match as many as possible of the sequences of the samples in a building and then to form an average from them. This average is called a site sequence of the building being dated and is illustrated in Fig 5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences from four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

This straightforward method of cross-matching several sample sequences with each other one at a time is called the 'maximal t-value' method. The actual method of cross-matching a group of sequences of ring-widths used in the Laboratory involves grouping and averaging the ring-width sequences and is called the 'Litton-Zainodin Grouping Procedure'. This was developed and tested in the Laboratory and has been published (Litton and Zainodin 1991; Laxton *et al* 1988a). To illustrate the difference between the two approaches with the above example, consider sequences C08 and C05. They are the most similar pair with a t-value of 10.4. Therefore, these two are first averaged with the first ring of C05 at +17 rings relative to C08 (the offset at which they match each other). This average sequence is then used in place of the individual sequences C08 and C05. The cross-matching continues in this way gradually building up averages at each stage eventually to form the site sequence.

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

   Quite often some, though not all, of the original outer rings are missing on a timber. The outer rings on an oak, called sapwood rings, are usually lighter than the inner rings, the heartwood, and so are relatively easy to identify. For example, they can be seen in two upper corners of the rafter and at the outer end of the core in Figure 2. More importantly for dendrochronology, the sapwood is relatively soft and so liable to insect attack and wear and tear. The builder, therefore, may remove some of the sapwood for precisely for these reasons. Nevertheless, if at least some of the sapwood rings are left on a sample, we will know that not too many rings have been lost since felling. Thus in these circumstances the date of the present last ring is at least close to the date of the original last ring on the tree, and so to the date of felling.

   Various estimates have been made for the average number of sapwood rings in a mature oak. One estimate is 30 rings, based on data from living oaks. So, in the case of the core in Figure 2 where 9 sapwood rings remain, this would give an estimate for the felling date of 21 (= 30 - 9) years later than of the date of the last ring on the core. Actually, it is better in these situations to give an estimated range for the felling date. Another estimate is that in 95% of mature oaks there are between 15 and 50 sapwood rings. So in this example this would mean that the felling took place between 6 (= 15 - 9) and 41 (= 50 - 9) years after the date of the last ring on the core and is expected to be right in at least 95% of the cases (Hughes *et al* 1981; see also Hillam *et al* 1987).

   Data from the Laboratory has shown that when sequences are considered together in groups, rather than separately, the estimates for the number of sapwood can be put at between 15 and 40 rings in 95% of the cases with the expected number being 25 rings. We would use these estimates, for example, in calculating the range for the common felling date of the four sequences from Lincoln Cathedral using the average position of the heartwood/sapwood boundary (Fig 5). These new estimates are now used by us in all our publications except for timbers from Kent and Nottinghamshire where 25 and between 15 to 35 sapwood rings, respectively, is used instead (Pearson 1995).

   More precise estimates of the felling date and range can often be obtained using knowledge of a particular case and information gathered at the time of sampling. For example, at the time of sampling the dendrochronologist may have noted that the timber from which the core of Figure 2 was taken still had complete sapwood. Sapwood rings were only lost in coring, because of their softness. By measuring in the timber the depth of sapwood lost, say 2 cm., a reasonable estimate can be made of the number of sapwood rings missing from the core, say 12 to 15 rings in this case. By adding on 12 to 15 years to the date of the last ring on the sample a good tight estimate for the range of the felling date can be obtained, which is often better than the 15 to 40 years later we would have estimated without this observation.

T-value/Offset Matrix

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

Bar Diagram

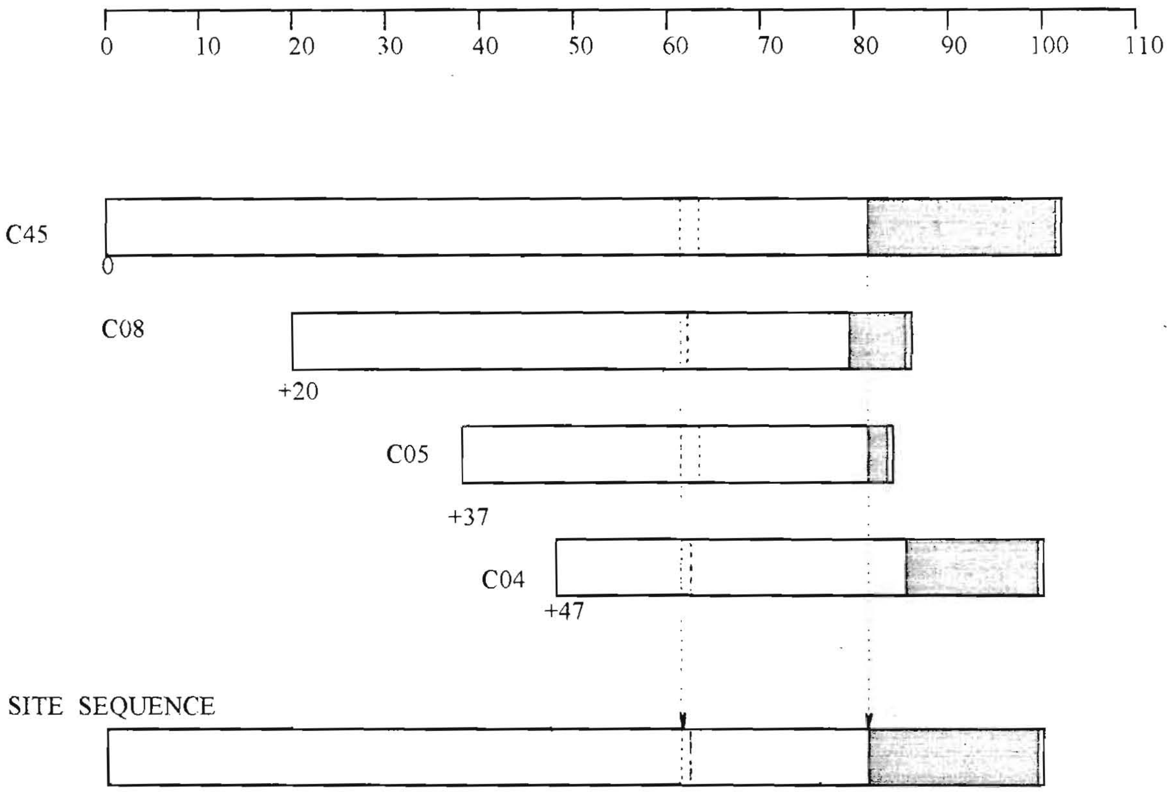

Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.
The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set at relative positions *(offsets)* to each other at which they have maximum correlation as measured by the *t-values*.
The *t-value offset* matrix contains the maximum t-values below the diagonal and the offsets above it.
Thus, the maximum t-value between C08 and C45 occurs at the offset of +20 rings and the t-value is then 5.6.
The *site sequence* is composed of the average of the corresponding widths, as illustrated with one width.

Even if all the sapwood rings are missing on all the timbers sampled, an estimate of the felling date is still possible in certain cases. For provided the original last heartwood ring of the tree, called the heartwood/sapwood boundary (H/S), is still on some of the samples, an estimate for the felling date of the group of trees can be obtained by adding on the full 25 years, or 15 to 40 for the range of felling dates.

If none of the timbers have their heartwood/sapwood boundaries, then only a *post quem* date for felling is possible.

5. ***Estimating the Date of Construction.*** There is a considerable body of evidence in the data collected by the Laboratory that the oak timbers used in vernacular buildings, at least, were used 'green' (see also Rackham (1976)). Hence provided the samples are taken *in situ,* and several dated with the same estimated common felling date, then this felling date will give an estimated date for the construction of the building, or for the phase of construction. If for some reason or other we are rather restricted in what samples we can take, then an estimated common felling date may not be such a precise estimate of the date of construction. More sampling may be needed for this.

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

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

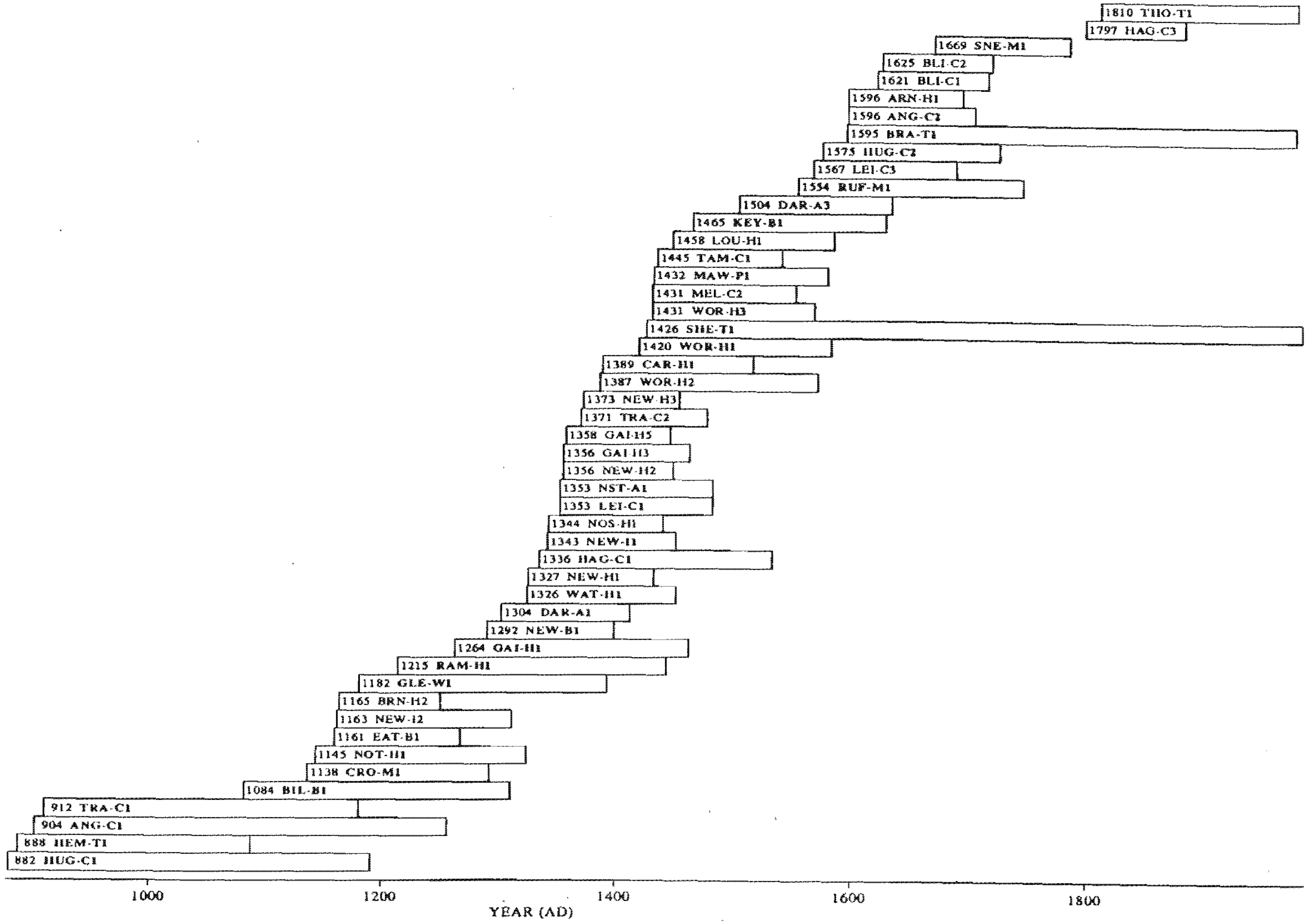

Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

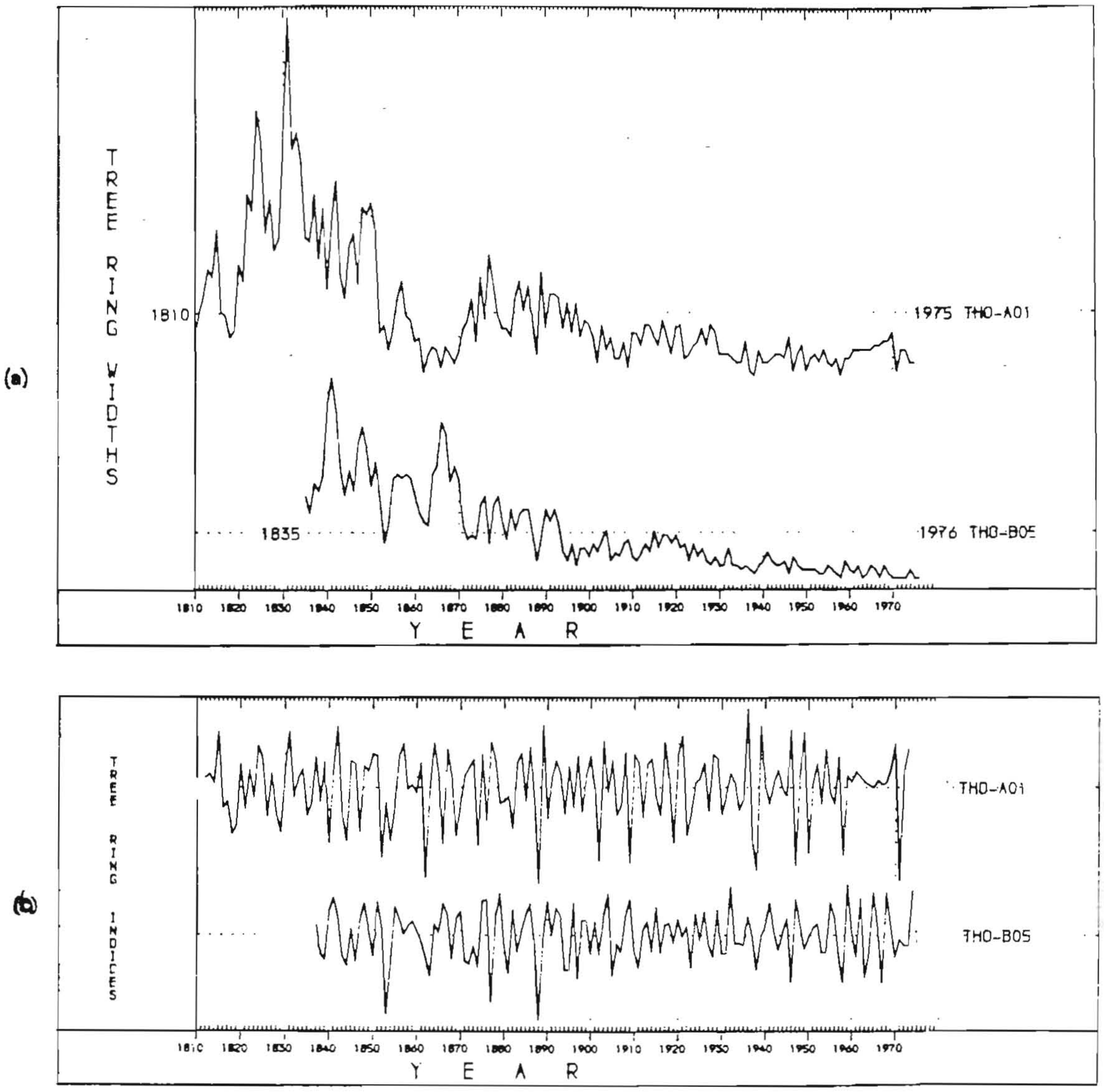

Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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

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

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