RESEARCH DEPARTMENT REPORT SERIES no. 77-2009 ISSN 1749-8775

UPHILL, MAPSTONEHILL, LUSTLEIGH, DEVON
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

ARCHAEOLOGICAL SCIENCE

ENGLISH HERITAGE

Research Department Report Series 77-2009

UPHILL, MAPSTONEHILL, LUSTLEIGH, DEVON

TREE-RING ANALYSIS OF TIMBERS

Alison Arnold and Robert Howard

NGR: SX 783 817

ISSN 1749-8775

SUMMARY

Dendrochronological analysis was undertaken on samples taken from the Solar roof and part of the floor structure at Uphill. A site sequence, of 108 rings, contains six samples from the Solar roof and spans the period AD 1187–1294. Interpretation of the heartwood/sapwood boundary ring date of four samples suggests these timbers were felled in AD 1301–26. The other two dated samples have *termini post quem* felling dates which do not preclude these from also having been felled at this time. The sample taken from the floor structure is undated.
Assessment of the timbers of The Great Hall roof was also undertaken and these were thought suitable for tree-ring dating should the opportunity present itself in the future.

CONTRIBUTORS

Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS

The Laboratory would like to thank Simon Roper, the owner of Uphill, for allowing the work to be undertaken and for his assistance and hospitality throughout its duration. The owner of The Great Hall, Richard Riley, kindly allowed us access to his home in order to make an assessment of the timbers there. Thanks are also given to the English Heritage Scientific Dating Section and Cathy Tyers of Sheffield University Dendrochronology Laboratory for their advice and assistance throughout the production of this report.

ARCHIVE LOCATION

Devon Historic Environment Record
Historic Environment Service
Matford Offices
County Hall
Exeter EX2 4QW

DATE OF INVESTIGATION

2007–9

CONTACT DETAILS

Alison Arnold and Robert Howard
Nottingham Tree-ring Dating Laboratory
20 Hillcrest Grove
Sherwood
Nottingham NG5 1FT
roberthoward@tree-ringdating.co.uk
alisonarnold@tree-ringdating.co.uk

CONTENTS

INTRODUCTION

The Grade-I listed former rectory at Mapstone Hill, Lustleigh (Figs 1–3; SX 783 817), is now divided into three houses: Uphill, The Great Hall, and Oaknurre, with the original medieval house thought to be contained almost entirely within The Great Hall and Uphill (Fig 4). In its earliest form, the building is believed to have been of T-shaped plan, consisting of open hall and two-storey cross-wing. To the south-east side of the cross-wing was added a double range, partly overlapping it, and to the north-west side a single range. The entrance porch and stair hall were inserted in the south-east angle of the hall and cross-wing. It has been suggested that the building was once the manor house and may date back to the fourteenth century. It is known that it underwent substantial restoration and additions at the north-west and south-east end between AD 1833–38 for Samuel Whiddon, curate of Lustleigh, with the hall being further restored in AD 1888.

The roofs

The Great Hall roof (Fig 5) is of eight bays with side-pegged jointed cruck trusses of two alternating designs. One type of truss reduces the width of its principal rafter just below the collar, the other does so just below the top tier of purlins. Each truss has very large, hollow-moulded cusped arch-braces with struts that rise to the collar and principal rafter; the feet of the arch-braces rest alternately on a shaft with moulded cap and base or on a small, inverted five-sided pyramid. There are three sets of purlins; the lowest butts against the principal rafters and is chamfered with step stops. The middle purlin is double hollow-moulded on the underside with pyramid stops; this tier of purlins butts against alternate trusses, but in the others is clasped to the principal rafter by one of the struts rising from the arch-brace. The third, and highest, set of purlins is chamfered with step stops, alternately butting the trusses or clasped to the principals by curved struts rising from the collar. There are chamfered and stopped curved wind-braces running from principal rafter to the middle tier of purlins, the lowest tier of purlins being tenoned to them. There is an angled ridge-piece with triangular strengthening piece beneath it.

The cross-wing, or Solar, roof (Fig 6) is of three bays with gable-trusses and light intermediate trusses. The main trusses have cusped hollow-moulded arch-braces which rise from shafts with moulded caps and straight collars. On these collars stand king-struts which support triangular strengthening-pieces below the angled ridge-piece. Cusped braces rise from the struts to the ridge-piece as if to imitate crown-posts. The intermediate trusses consist of a light collar tenoned to two common rafters and supported by cusped arch-braces; on the collars stand king-struts and cusped arch-braces matching those on the main trusses. There is a single tier of butt purlins and two tiers of cusped, hollow-moulded wind-braces.

The information above is largely based on the Listed Building Description (www.imagesofengland.gov.uk).

Within the ground floor of the cross-wing are some timbers thought to be associated with the original medieval ceiling structure (Figs 4 and 7). These comprise a square-section wood post which carries a long-splayed wood bracket, which is chamfered with convex stops; this in turn supports a chamfered longitudinal beam with stops that are simply vertical cuts. The bracket and beam appear to have been removed on the north-west side of the post.

AIMS AND OBJECTIVES

Sampling and analysis by tree-ring dating was commissioned and funded by English Heritage. It was requested by Francis Kelly, Historic Buildings Inspector at their South-West Regional Office, to inform statutory advice in the context of the current programme of repairs to the cross-wing, or Solar, now part of Uphill. Sampling of the roof structure and the remains of the floor structure was undertaken with the aim of providing a construction date, and hence either confirming or refuting the suggested early-fourteenth century origins.

In addition, an assessment of the adjoining roof in The Great Hall was requested, if access was forthcoming, in order to determine its suitability for dendrochronological analysis, as it has recently been suggested that this part of the building might post-date the Solar.

SAMPLING

Core samples were taken from 12 timbers of the roof and floor structure of the medieval part of Uphill. Additionally, slices were taken from three roof timbers which had been removed during the repairs. Each sample was given the code UPH-L (for Uphill) and numbered 01–15. Samples UPH-L01–07 and UPH-L10–13 are core samples taken from *in-situ* roof timbers, UPH-L08, UPH-L09, and UPH-L14 are sliced samples taken from the *ex-situ* timbers, and UPH-L15 is a core sample taken from a timber of the floor structure. The major components of the roof could be reached from inside but the common rafters were not visible internally. It was possible to reach some of these from outside, but access was restricted to those not yet covered by the new roof felting and battens, ie, northern common rafters of bays 1 and 2. The position of core samples was noted at the time of sampling and has been marked on Figures 7–11. It is unfortunate that, other than their being from two rafters and a wallplate, no other details relating to the sliced samples are known. Further details relating to the core samples can be found in Table 1. Trusses were numbered from west to east.

ANALYSIS, RESULTS, AND INTERPRETATION

At this stage it was noticed that four of the samples had too few rings to make secure dating a possibility. Additionally, sample UPH-L02 had broken during coring and it was not possible to confidently join the two pieces together; neither section contained sufficient numbers of rings to justify analysis. These five samples were rejected prior to measurement. The remaining 10 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 10 samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix).

At a least value of *t*=6, four samples matched each other and were combined at the relevant offset positions to form UPHLSQ01, a site sequence of 100 rings (Fig 12). This site sequence was then compared with a large number of relevant reference chronologies for oak where it was found to match at a first-ring date of AD 1195 and a last-measured ring date of AD 1294. The evidence for this dating is given in Table 2.

Attempts were then made to date the ungrouped samples by individually comparing them against the reference chronologies. This resulted in sample UPH-L09 being matched at a first-ring date of AD 1210 and a last-measured ring date of AD 1281 and sample UPH-L10 being found to span the period AD 1187–1262. The evidence for these dates is given in Tables 3 and 4.

Comparison between the site sequence UPHLSQ01 and the individually dated samples UPH-L09 and UPH-L10 at their expected offset positions produced values of *t*=4.0 and *t*=3.8 respectively. A second site sequence, UPHLSQ02, of 108 rings was then constructed containing all six samples at the relevant offset positions (Fig 13). This site sequence has a first-ring date of AD 1187 and a last-measured ring date of AD 1294. The evidence for this dating is given in Table 5, where it can be seen that the *t*-values are generally higher than for UPHLSQ01.

Four of these dated samples have the heartwood/sapwood boundary ring, the dates of which are broadly contemporary and, therefore, suggestive of a single felling. The average of these dates is AD 1286, which allows an estimated felling date to be calculated for the four timbers represented to within the range AD 1301–26. The other two samples do not have the heartwood/sapwood boundary ring and so estimated felling dates cannot be calculated for these timbers, except to say that with last-measured ring dates of AD 1262 (UPH-L08) and AD 1268 (UPH-L10), this would be AD 1277 and AD 1285 respectively, at the earliest, not inconsistent with both these samples also having been felled in AD 1301–26.

Felling date ranges have been calculated using the estimate that mature oak trees in this area have between 15–40 sapwood rings.

DISCUSSION

Prior to the tree-ring analysis being undertaken, it had been suggested that the building could be fourteenth-century, although it was not certain that the remains as seen today belonged to this early date. This analysis provides strong support for an early fourteenth-century construction date for this part of the original medieval building now within Uphill.

A single sample taken from a timber of the ground-floor structure has not dated and, therefore, it is not possible to confirm whether or not it is contemporary with the roof structure.

The assessment of the roof of The Great Hall indicated that there were timbers potentially suitable for dendrochronological analysis present. Substantial renovations have just been completed on The Great Hall and the owner, Mr Riley, is understandably reluctant for dendrochronological sampling to be undertaken at present. However, as it remains uncertain whether this roof pre- or post-dates that of the solar, it is recommended that dendrochronological analysis is considered if further works are undertaken in the future.

BIBLIOGRAPHY

Arnold, A J and Howard, R E, 2004, *Tree-ring analysis of timbers from the roof of St Catherine's Chapel (south-east transept), Wells Cathedral, Somerset*, Centre for Archaeol Rep, 64, 2004

Bridge, M C, 2002a *Tree-ring analysis of timbers from Muchelney Abbey, Muchelney, Near Langport, Somerset*, Centre for Archaeol Rep, 114/2002

Bridge, M C, 2002b *Tree-ring analysis of timbers from Meare Manor Farmhouse, St Mary's Road, Meare, Somerset*, Centre for Archaeol Rep, 103/2002

Bridge, M C, 2003 *Tree-ring analysis of timbers from Fiddleford Manor, Calf Close Lane, Sturminster Newton, Dorset*, Centre for Archaeol Rep, 13/2003

Miles, D and Worthington, M J, 1997a Tree-ring dates: List 84 – Somerset Dendrochronology project, phase one, *Vernacular Architect*, 28, 172–4

Miles, D and Worthington, M J, 1997b Tree-ring dates: List 82 – General list, *Vernacular Architect*, 28, 164–7

Mills, C M, 1988 Dendrochronology of Exeter and its application, unpubl PhD thesis Sheffield Univ

Groves, C, 1992 *Dendrochronological analysis of oak timbers from the tithe barn, Siddington, nr Cirencester, Gloucestershire, 1990–91*, Anc Mon Lab Rep, 8/1992

Groves, C, 1994 *Tree-ring analysis of Bradford-on-Avon tithe barn, Wiltshire, Anc Mon Lab Rep*, 9/1994

Groves, C, 2005 *Dendrochronological research in Devon: Phase 1*, Centre for Archaeol rep 56/2005

Tyers, I, 2003 *Tree-ring analysis of oak timbers from the south transept and nave roofs of the Church of St John the Baptist, Bradworthy, Devon*, Centre for Archaeol Rep, 2/2003

TABLES

Table 1: Details of tree-ring samples from Uphill, Mapstone Hill, Lustleigh, Devon

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Solar Range – roof						
UPH-L01	North principal rafter, truss 1	67	h/s	1217	1283	1283
UPH-L02	North common rafter 1, bay 1	NM	--	----	----	----
UPH-L03	North common rafter 2, bay 1	61	07	----	----	----
UPH-L04	North common rafter 4, bay 1	NM	--	----	----	----
UPH-L05	North common rafter 5, bay 1	NM	--	----	----	----
UPH-L06	North common rafter 2, bay 2	81	04	1214	1290	1294
UPH-L07	North common rafter 3, bay 2	64	h/s	----	----	----
UPH-L08	Rafter – slice	74	--	1195	----	1268
UPH-L09	Rafter – slice	72	h/s	1210	1281	1281
UPH-L10	South purlin, bay 1	76	--	1187	----	1262
UPH-L11	South purlin, bay 2	NM	--	----	----	----
UPH-L12	East lower windbrace, south principal rafter, truss 2	85	--	----	----	----
UPH-L13	West lower windbrace, south principal rafter, truss 5	NM	--	----	----	----
UPH-L14	Wallplate – slice	63	h/s	1226	1288	1288
Solar Range – floor						
UPH-L15	Post	92	--	----	----	----

*NM = not measured

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

Table 2: Results of the cross-matching of site sequence UPHLSQ01 and relevant reference chronologies when the first-ring date is AD 1195 and the last-ring date is AD 1294

Reference chronology	*t*-value	Span of chronology	Reference
Devon county chronology	6.2	AD 775–1799	Groves and Tyers pers comm
Exeter Cathedral, Devon	7.1	AD 1137–1332	Mills 1988
Bridge Farm, Butleigh, Somerset	6.7	AD 1195–1331	Miles and Worthington 1997a
Long Sutton, Court House, Somerset	5.7	AD 1174–1327	Miles and Worthington 1997a
Muchelney Abbey, Muchelney, near Langport, Somerset	5.6	AD 1148–1498	Bridge 2002a
Meare Manor Farmhouse, Meare, Somerset	5.6	AD 1156–1315	Bridge 2002b
Tithe Barn, Bradford-on-Avon, Wiltshire	5.3	AD 1174–1324	Groves 1994

Table 3: Results of the cross-matching of sample UPH-L09 and relevant reference chronologies when the first-ring date is AD 1210 and the last-ring date is AD 1281

Reference chronology	*t*-value	Span of chronology	Reference
Devon county chronology	5.4	AD 775–1799	Groves and Tyers pers comm
Tithe Barn, Bradford-on-Avon, Wiltshire	7.3	AD 1174–1324	Groves 1994
Fiddleford Manor, Sturminster Newton, Dorset	6.8	AD 1167–1315	Bridge 2003
Exeter Cathedral, Devon	6.2	AD 1137–1332	Mills 1988
Bradworthy Church (nave and south transept), Devon	5.9	AD 1125–1367	Tyers 2003
Long Sutton, Court House, Somerset	5.3	AD 1174–1327	Miles and Worthington 1997a
St Catherine's Chapel, Wells Cathedral, Somerset	5.0	AD 1169–1325	Arnold and Howard 2004

Table 4: Results of the cross-matching of sample UPH-L10 and relevant reference chronologies when the first-ring date is AD 1187 and the last-ring date is AD 1262

Reference chronology	*t*-value	Span of chronology	Reference
Devon county chronology	5.8	AD 775–1799	Groves and Tyers pers comm
Bishops Clyst Barn, Devon	5.6	AD 1145–1386	Miles and Worthington1997b
Exeter Cathedral, Devon	5.3	AD 1137–1332	Mills 1988
Rudge, Morchard Bishop, Devon	5.1	AD 1124–1315	Groves 2005
Bury Barton, Lapford, Devon	5.0	AD 1132–1323	Groves 2005
Tithe Barn, Siddington, near Cirencester, Glos	4.8	AD 1122–1238	Groves 1992
Bridge Farm, Butleigh, Somerset	4.7	AD 1195–1331	Miles and Worthington 1997a

Table 5: Results of the cross-matching of site sequence UPHLSQ02 and relevant reference chronologies when the first-ring date is AD 1187 and the last-ring date is AD 1294

Reference chronology	*t*-value	Span of chronology	Reference
Devon county chronology	7.9	AD 775–1799	Groves and Tyers pers comm
Exeter Cathedral, Devon	8.4	AD 1137–1332	Mills 1988
Bridge Farm, Butleigh, Somerset	7.1	AD 1195–1331	Miles and Worthington 1997a
Bradworthy Church (nave and south transept), Devon	6.6	AD 1125–1367	Tyers 2003
Meare Manor Farmhouse, Meare, Somerset	6.4	AD 1156–1315	Bridge 2002b
Bury Barton, Lapford, Devon	6.2	AD 1132–1323	Groves 2005
Rudge, Morchard Bishop, Devon	6.0	AD 1124–1315	Groves 2005

FIGURES

Figure 1: Map to show the general location of Lustleigh, Devon

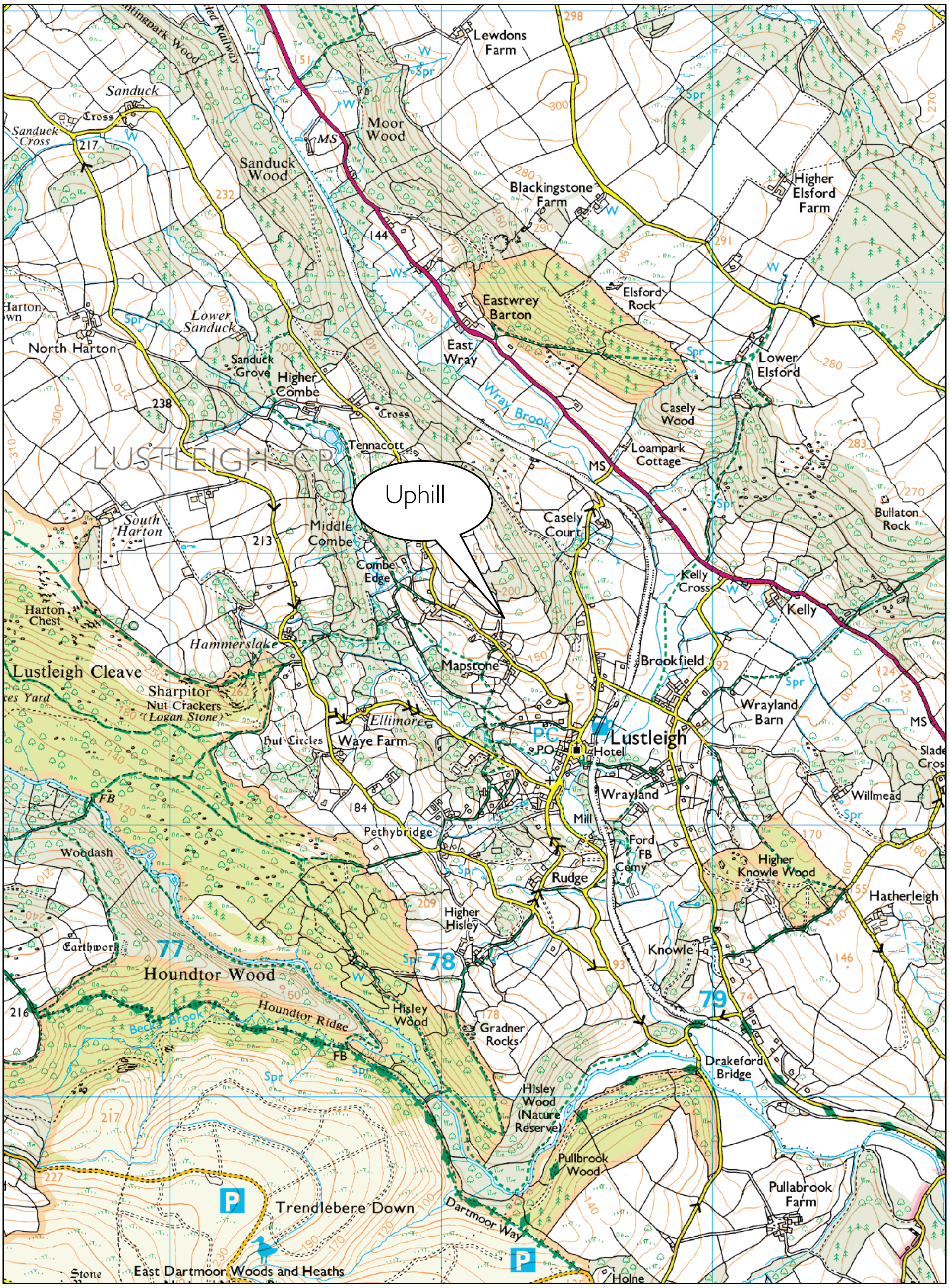


Figure 2: Map to show the location of Uphill

Figure 3: Map to show the site; Uphill outlined in black with the Solar shaded

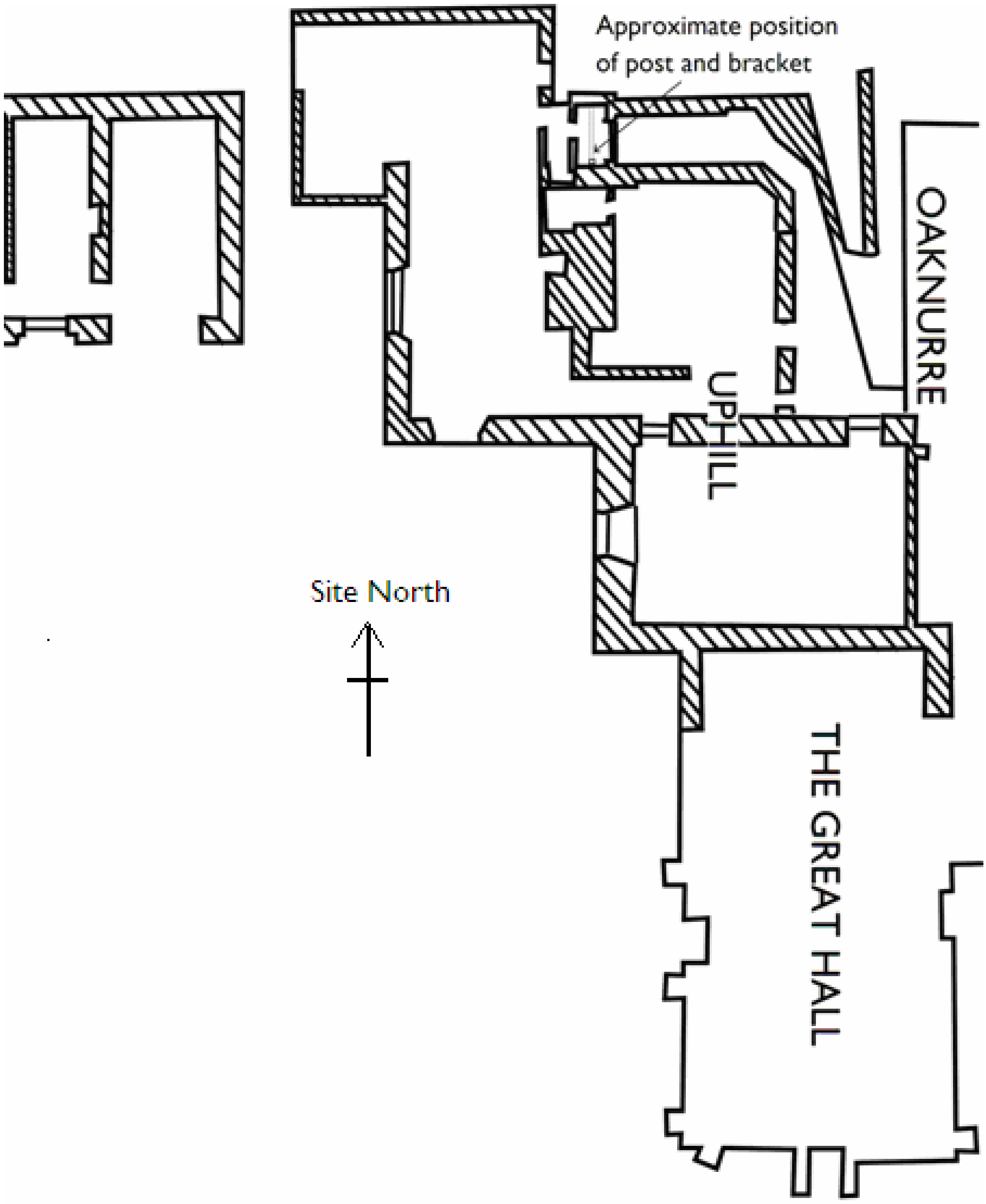


Figure 4: Ground-floor plan, showing the approximate position of the post and bracket structure (after Simon Roper)

Figure 5: The Great Hall, roof, taken from the south

Figure 6: Uphill; the Solar roof, taken from the west

Figure 7: Solar range; floor structure, showing the location of sample UPH-L15, taken from the west

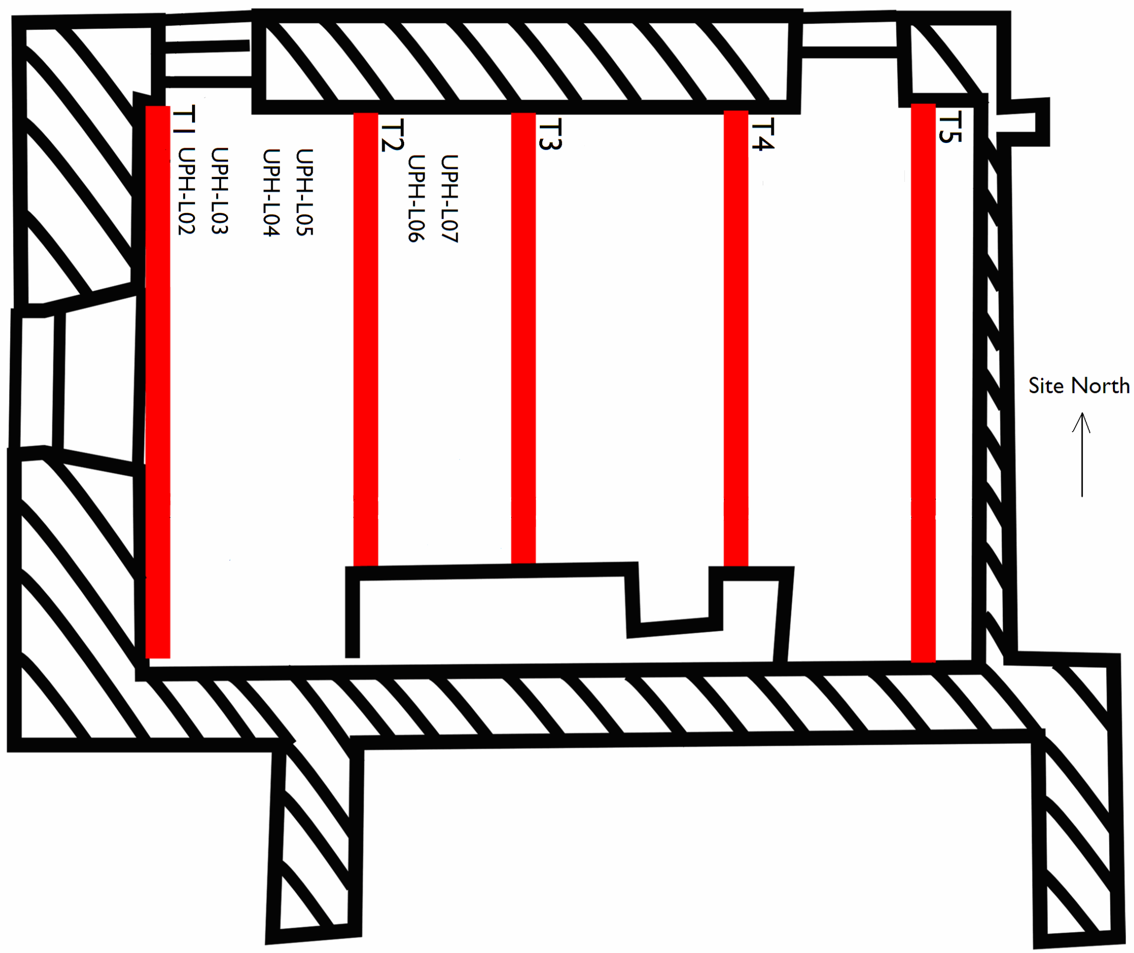


Figure 8: Solar plan, showing approximate truss positions and the location of samples UPH-L02–07

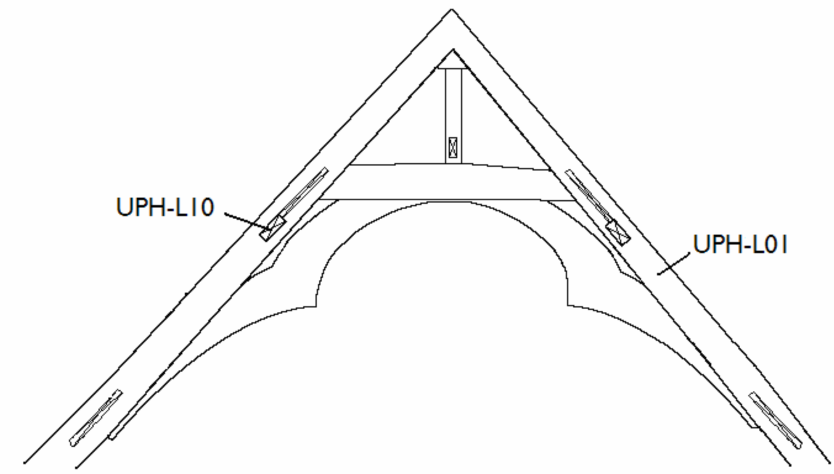


Figure 9: Truss 1 (east face), showing the location of samples UPH-L01 and UPH-L10

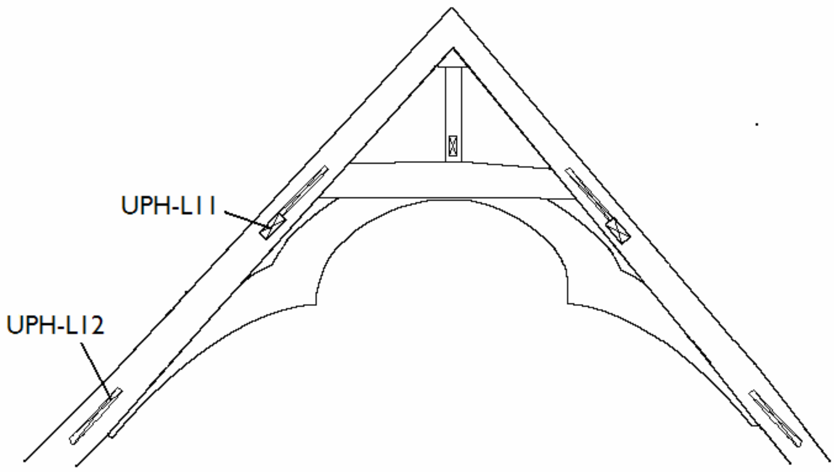


Figure 10: Truss 2 (east face), showing the location of samples UPH-L11 and UPH-L12

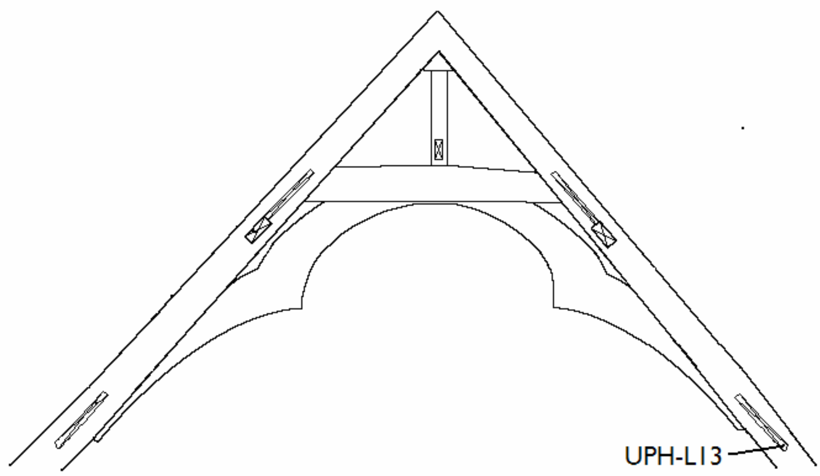
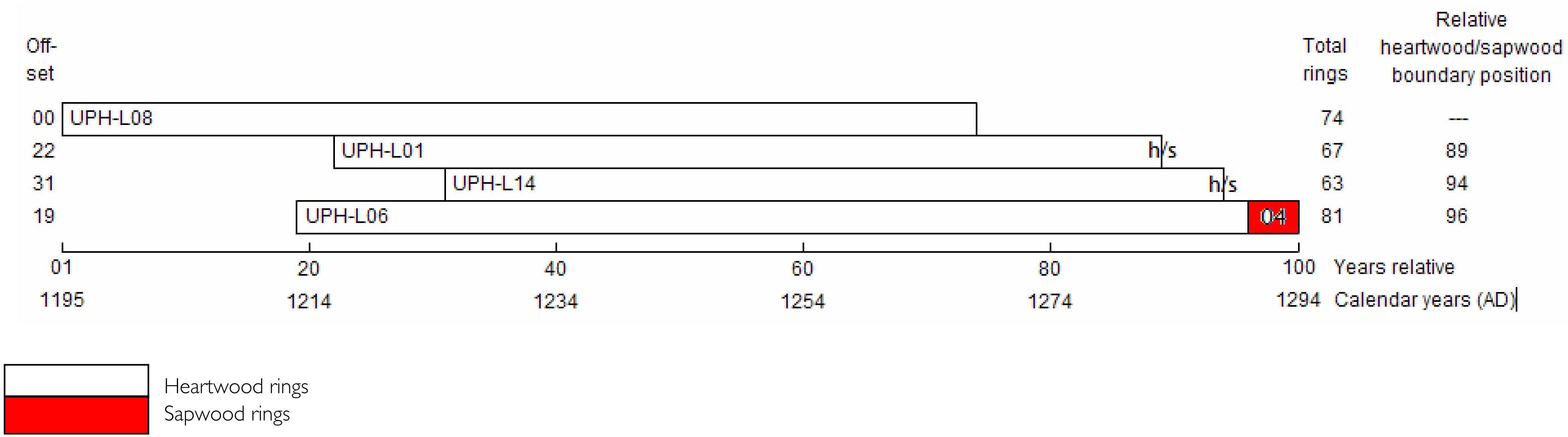
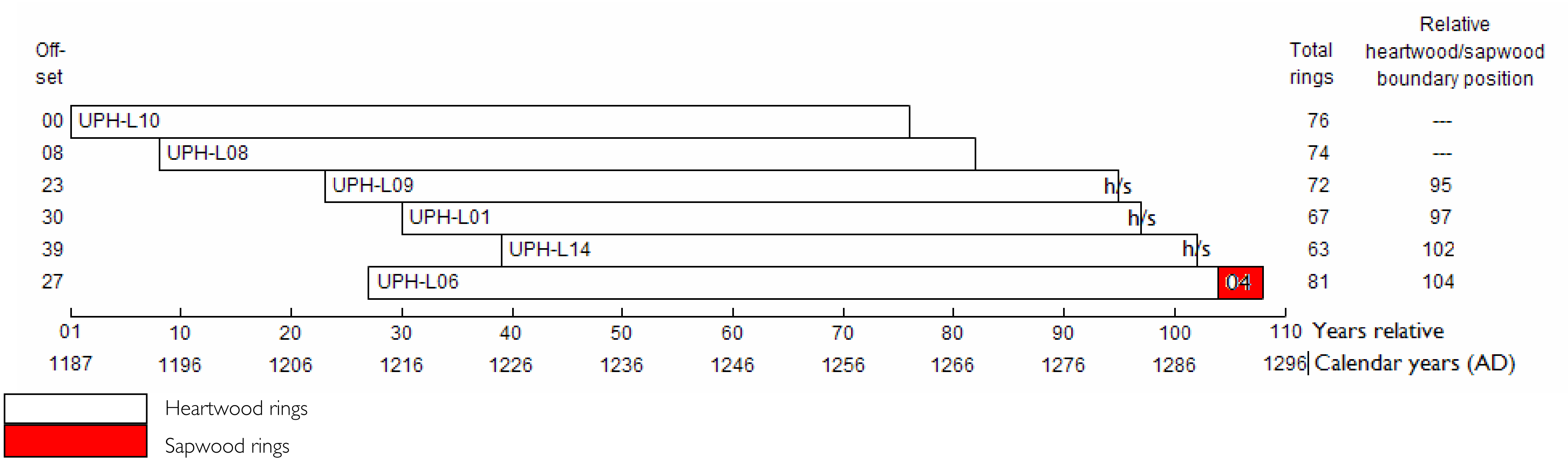


Figure 11: Truss 5 (west face), showing the location of sample UPH-L13



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

Figure 12: Bar diagram of samples in site sequence UPHLSQ01



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

Figure 13: Bar diagram of samples in site sequence UPHLSQ02

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

UPH-L01A 67
254 402 263 288 185 151 76 281 257 332 171 341 291 113 185 203 198 184 167 105
103 154 143 148 113 121 99 161 143 156 101 108 121 97 132 67 85 108 132 117
138 109 88 79 155 143 93 84 96 98 106 102 105 184 162 96 137 104 52 75
81 108 108 108 81 89 72
UPH-L01B 67
278 405 270 295 182 119 82 273 267 331 174 335 294 99 189 189 185 196 167 110
104 151 148 150 111 123 97 148 148 156 103 116 115 101 127 71 91 102 128 123
141 96 84 86 160 132 98 83 94 96 106 106 100 185 157 104 132 104 52 76
81 105 111 109 81 95 82
UPH-L03A 61
203 228 590 682 556 305 387 485 349 244 136 185 234 241 158 229 281 487 605 364
305 204 91 104 180 228 234 182 123 235 153 82 80 70 67 71 62 80 101 166
102 100 64 80 97 120 97 206 246 369 210 256 270 212 205 193 194 144 183 126
157
UPH-L03B 61
158 240 574 679 588 295 342 517 343 246 139 186 239 241 158 228 280 483 615 355
309 197 93 104 183 230 203 154 128 258 143 81 79 70 67 72 62 79 104 167
104 114 58 81 99 132 83 211 249 353 200 257 217 197 173 208 207 150 182 120
146
UPH-L06A 81
112 138 199 262 255 222 260 200 139 154 353 278 132 96 134 84 65 97 70 69
112 135 97 127 133 65 141 95 171 215 229 163 196 136 118 214 120 164 63 165
180 267 198 189 171 132 180 224 198 187 169 244 272 129 134 200 184 190 89 105
126 97 116 195 198 140 177 138 195 164 153 125 191 126 196 227 302 264 237 133
125
UPH-L06B 81
148 136 199 265 243 235 248 189 144 178 335 273 114 78 142 85 60 90 82 66
126 122 95 128 130 69 152 86 175 221 240 170 193 125 129 229 108 152 78 157
186 272 177 174 146 125 186 218 210 177 173 238 286 116 165 172 179 180 93 92
137 85 121 180 205 148 183 140 184 153 156 122 186 130 212 226 293 254 224 157
137
UPH-L07A 64
326 299 237 252 195 192 200 261 260 223 384 326 346 176 257 230 176 170 189 254
183 127 98 136 192 142 126 123 167 99 107 162 178 175 150 142 148 196 182 135
151 233 131 112 102 130 87 225 143 197 156 110 152 63 128 148 180 151 86 105
80 60 52 93
UPH-L07B 64
308 303 239 306 193 190 210 264 241 212 394 326 351 173 246 236 172 169 190 261
188 126 98 135 187 133 114 151 178 108 106 156 178 173 152 151 152 194 186 139
148 239 140 110 101 144 91 198 147 207 168 129 148 78 129 151 168 169 80 103
65 55 50 95
UPH-L08A 74
147 281 149 124 220 211 224 117 93 91 117 81 103 161 162 174 189 126 202 224
268 309 359 274 243 293 184 179 201 323 341 324 288 323 209 136 168 150 170 164
188 137 211 166 116 187 126 204 244 219 232 213 164 195 303 185 181 112 104 113
140 117 109 94 98 120 131 148 131 119 157 168 132 120

UPH-L08B 74
142 276 166 122 209 203 219 126 102 88 100 88 108 164 159 171 190 124 204 220
276 299 361 270 244 292 193 183 174 322 305 317 285 299 175 137 149 156 158 161
175 148 220 171 126 193 134 218 215 236 225 208 180 217 310 188 189 128 132 146
164 150 129 120 86 128 122 158 138 134 149 172 131 108
UPH-L09A 72
152 255 237 151 193 241 217 323 176 266 262 201 148 143 154 175 216 169 295 258
185 118 150 179 231 207 149 209 229 133 119 143 129 163 168 180 200 160 132 226
207 180 187 198 160 314 190 186 188 232 193 232 155 140 120 135 166 131 147 148
205 265 175 178 212 136 79 104 144 154 156 145
UPH-L09B 72
159 256 239 147 192 226 219 287 214 191 256 202 142 112 161 164 224 166 298 244
182 131 136 193 243 209 151 220 228 133 127 128 134 174 179 170 244 120 106 241
206 188 195 222 142 303 164 234 187 228 199 220 144 139 97 161 126 113 151 174
221 329 187 247 192 173 98 143 189 179 180 116
UPH-L10A 76
146 198 170 187 162 141 170 126 256 206 191 172 202 127 166 123 126 128 102 96
81 118 168 225 206 137 165 125 147 167 135 165 152 206 142 125 86 103 186 245
176 255 177 149 165 136 114 101 137 79 134 86 74 75 62 66 90 97 106 97
96 84 98 78 84 71 88 85 109 103 82 91 86 59 122 165
UPH-L10B 76
196 191 177 168 151 150 196 140 268 200 194 152 200 133 138 121 126 118 115 90
77 126 176 226 192 152 159 133 148 157 143 163 162 207 142 137 80 112 185 246
175 256 227 150 173 137 120 110 131 92 129 90 74 82 65 64 86 91 98 113
82 92 93 86 92 81 84 84 119 102 83 102 74 66 127 152
UPH-L12A 85
150 192 143 127 178 211 234 106 140 184 173 193 199 152 112 128 79 58 96 103
52 105 166 173 90 137 126 75 80 233 387 368 148 160 140 109 138 187 256 279
309 288 171 189 187 186 125 238 242 194 261 182 152 132 100 289 367 256 309 297
229 179 177 184 213 297 207 159 268 212 224 231 342 410 500 216 258 152 135 185
216 240 288 284 223
UPH-L12B 85
169 182 124 126 181 205 241 94 148 180 173 183 192 153 115 127 81 71 92 93
58 103 163 167 100 132 126 104 85 236 386 380 144 144 117 131 140 192 247 271
298 271 166 212 180 174 137 257 279 171 244 185 151 126 106 317 363 270 319 297
221 180 162 192 212 298 202 166 269 213 221 225 350 405 482 217 239 179 127 183
217 239 290 279 229
UPH-L14A 63
928 396 519 339 167 216 230 348 286 349 203 252 206 167 243 130 188 159 147 125
94 88 75 116 63 84 51 82 102 135 106 106 82 81 139 128 115 103 99 113
143 142 115 139 202 174 81 100 111 69 83 108 121 153 154 165 170 165 146 117
100 132 107
UPH-L14B 63
929 399 505 349 178 226 225 338 292 358 194 266 191 174 239 124 196 154 143 118
102 90 73 100 85 82 47 83 106 133 107 110 86 84 126 141 109 97 103 109
138 141 119 132 205 171 80 104 111 72 80 106 119 149 160 163 168 164 150 98
129 139 116

UPH-L15A 92
198 310 298 356 392 299 165 168 155 217 152 149 262 318 350 373 199 236 180 120
132 163 252 250 243 171 94 94 116 96 122 153 108 84 54 47 71 64 70 119
98 77 76 90 73 100 85 166 126 130 160 134 108 83 83 60 66 66 63 83
70 57 60 51 79 54 69 75 74 71 64 97 76 82 73 66 94 99 85 95
130 85 69 79 85 76 79 83 88 54 83 80
UPH-L15B 92
166 300 289 362 391 305 158 171 143 216 161 158 271 295 375 364 206 241 181 125
123 164 229 275 240 173 82 100 122 95 125 142 108 77 73 45 63 64 74 118
95 86 73 81 84 97 88 158 126 137 160 118 115 80 80 69 71 56 65 78
76 54 55 51 77 54 69 75 72 67 70 105 71 91 74 59 91 96 90 97
129 87 56 85 81 72 73 90 91 70 81 73

APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

t-value/offset Matrix

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

Bar Diagram

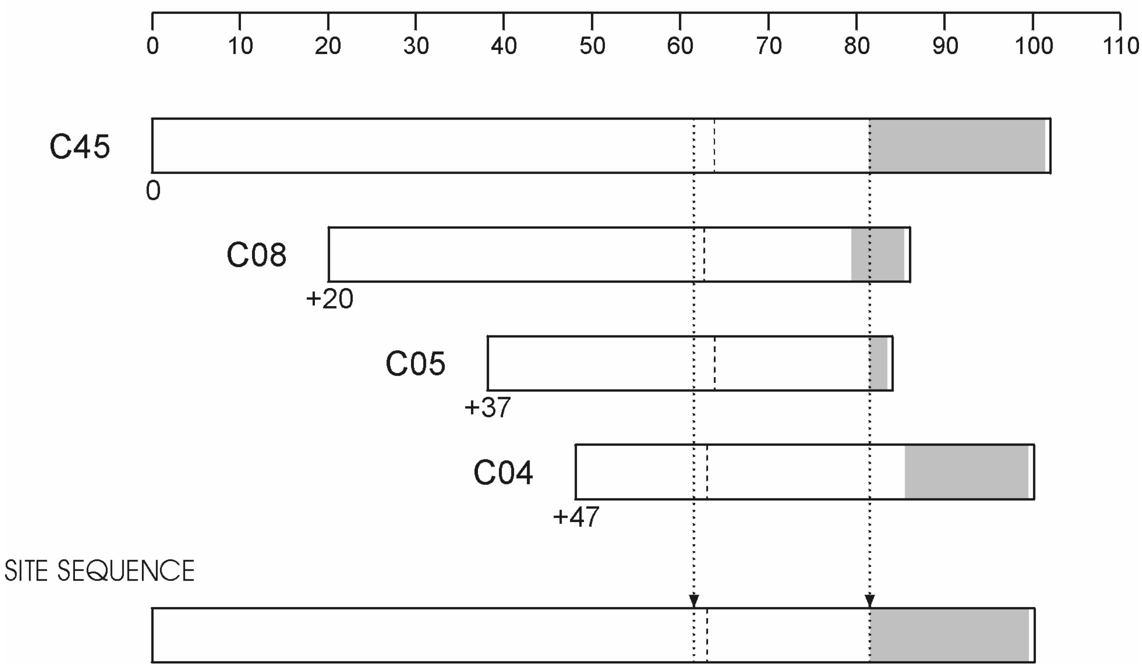


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

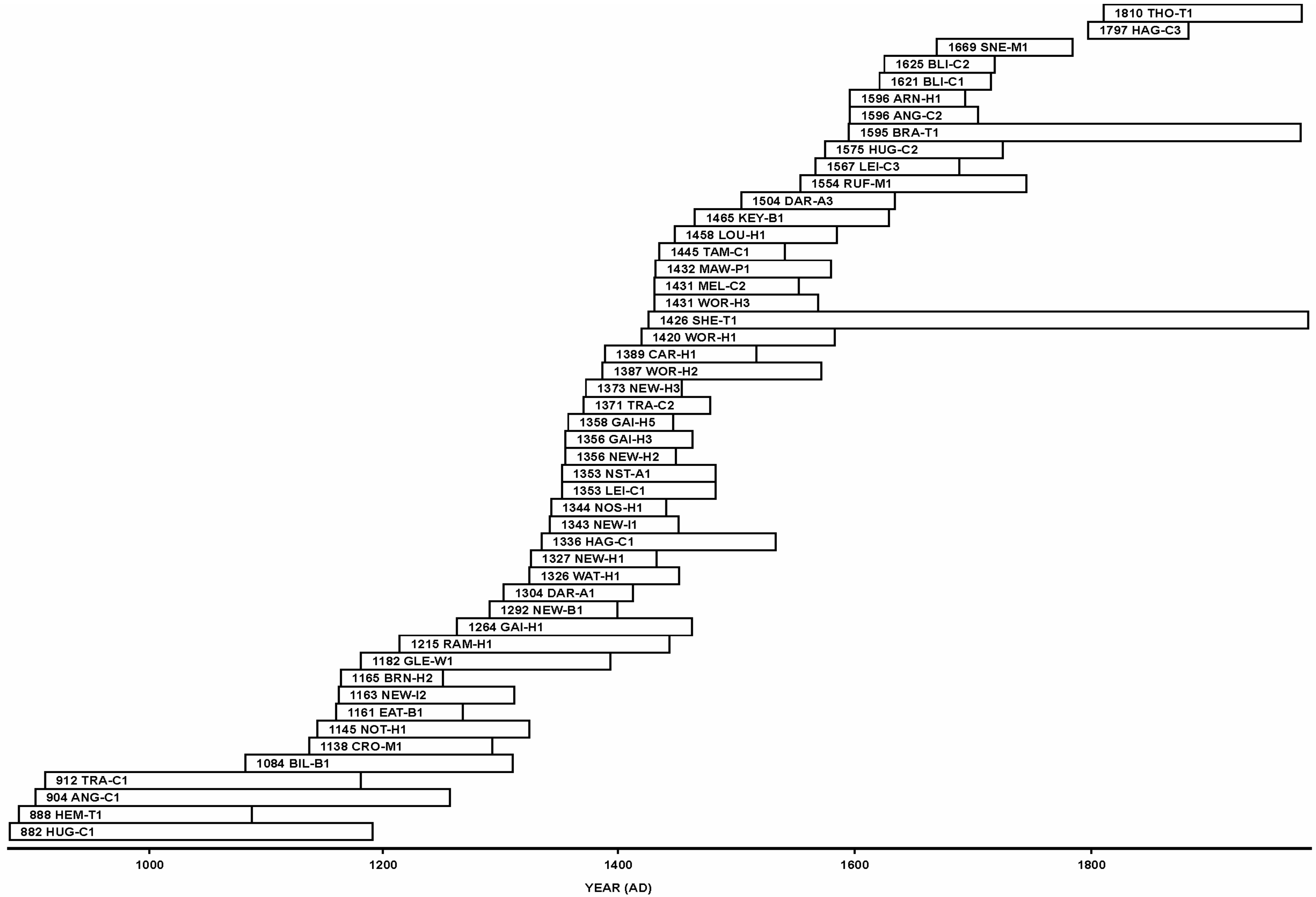
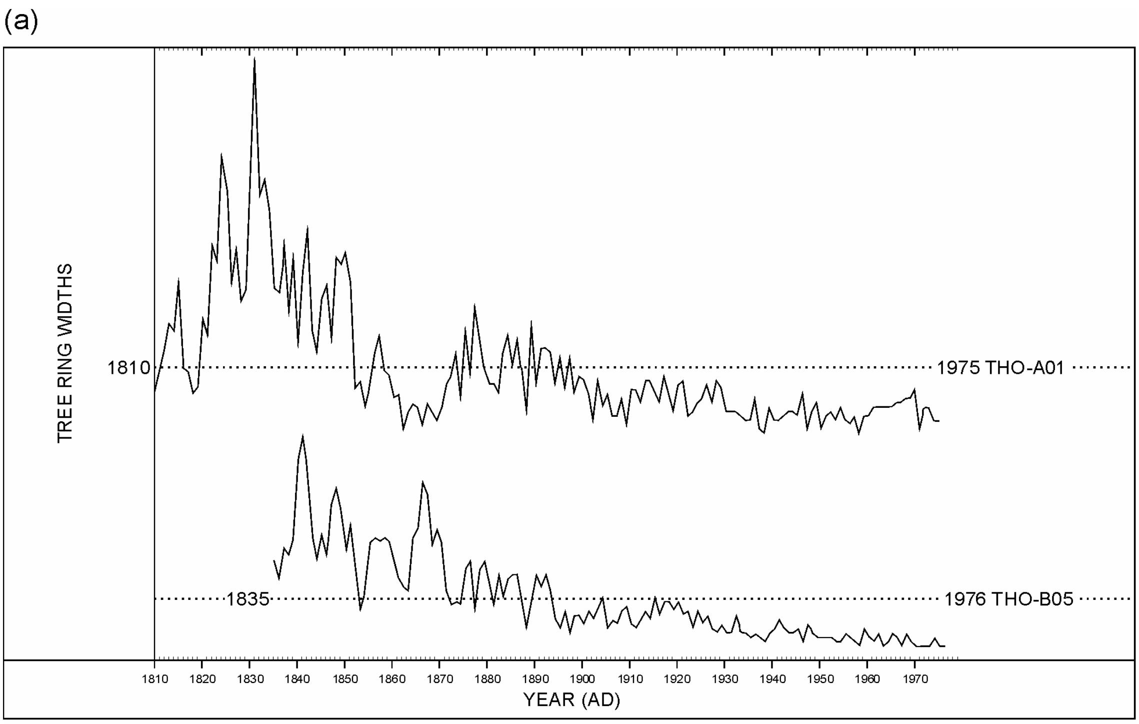


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87



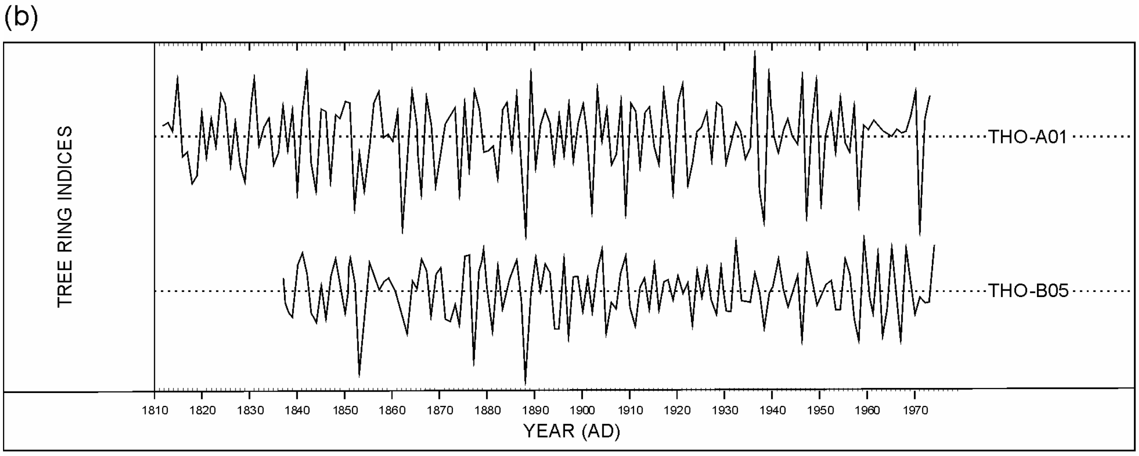


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

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

The growth trends have been removed completely

References

Baillie, M G L, and Pilcher, J R, 1973 A simple cross-dating program for tree-ring research, *Tree-Ring Bull*, 33, 7–14

English Heritage, 1998 *Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates*, London

Hillam, J, Morgan, R A, and Tyers, I, 1987 Sapwood estimates and the dating of short ring sequences, *Applications of tree-ring studies*, BAR Int Ser, 3, 165–85

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1984–95 Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect*, 15–26

Hughes, M K, Milson, S J, and Legett, P A, 1981 Sapwood estimates in the interpretation of tree-ring dates, *J Archaeol Sci*, 8, 381–90

Laxon, R R, Litton, C D, and Zainodin, H J, 1988 An objective method for forming a master ring-width sequence, *P A C T*, 22, 25–35

Laxton, R R, and Litton, C D, 1988 *An East Midlands Master Chronology and its use for dating vernacular buildings*, University of Nottingham, Department of Archaeology Publication, Monograph Series III

Laxton, R R, and Litton, C D, 1989 Construction of a Kent master dendrochronological sequence for oak, AD 1158 to 1540, *Medieval Archaeol*, 33, 90–8

Laxton, R R, Litton, C D, and Howard, R E, 2001 *Timber: Dendrochronology of Roof Timbers at Lincoln Cathedral*, Engl Heritage Res Trans, 7

Litton, C D, and Zainodin, H J, 1991 Statistical models of dendrochronology, *J Archaeol Sci*¸18, 29–40

Miles, D W H, 1997 The interpretation, presentation and use of tree-ring dates, *Vernacular Architect*, 28, 40–56

Pearson, S, 1995 *The Medieval Houses of Kent, an Historical Analysis*, London

Rackham, O, 1976 *Trees and Woodland in the British Landscape*, London