RESEARCH DEPARTMENT REPORT SERIES no. 102-2010 ISSN 1749-8775

APSHILL HOUSE, LOWER CHICKSGROVE, WILTSHIRE
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Matt Hurford, Cathy Tyers and Robert Howard

ARCHAEOLOGICAL SCIENCE

ENGLISH HERITAGE

Research Department Report Series 102-2010

APSHILL HOUSE, LOWER CHICKSGROVE, WILTSHIRE

TREE-RING ANALYSIS OF TIMBERS

M Hurford, C Tyers, and R E Howard

NGR: ST976294

ISSN 1749-8775

The Research Department Report Series incorporates reports from all the specialist teams within the English Heritage Research Department: Archaeological Science; Archaeological Archives; Historic Interiors Research and Conservation; Archaeological Projects; Aerial Survey and Investigation; Archaeological Survey and Investigation; Architectural Investigation; Imaging, Graphics and Survey, and the Survey of London. It replaces the former Centre for Archaeology Reports Series, the Archaeological Investigation Report Series and the Architectural Investigation Report Series.
Many of these are interim reports which make available the results of specialist investigations in advance of full publication. They are not usually subject to external refereeing, and their conclusions may sometimes have to be modified in the light of information not available at the time of the investigation. Where no final project report is available, readers must consult the author before citing these reports in any publication. Opinions expressed in Research Department reports are those of the author(s) and are not necessarily those of English Heritage.

Requests for further hard copies, after the initial print run, can be made by emailing:
Res.reports@english-heritage.org.uk
or by writing to:
English Heritage, Fort Cumberland, Fort Cumberland Road, Eastney, Portsmouth PO4 9LD
Please note that a charge will be made to cover printing and postage.

SUMMARY

Dendrochronological analysis was undertaken on 13 of the 14 samples taken from timbers associated with the former open-hall roof at Apshill House. This resulted in the production of two site chronologies, LCAHSQ01 and LCAHSQ02, incorporating a total of 11 samples. These site chronologies can be dated as spanning the years AD 1080–1332 and AD 1220–1310 respectively.

One timber retained its final sapwood ring immediately below the bark, which dated to AD 1332. It was not possible to determine the season of felling for this timber, however, due to the narrow nature of the growth rings. The analysis suggests that all 11 of the dated timbers used in the construction of the roof probably represent a single programme of felling. Construction of this roof therefore appears likely to have taken place, shortly after felling, in the early AD 1330s.

CONTRIBUTORS

Matt Hurford, Cathy Tyers, and Robert Howard

ACKNOWLEDGEMENTS

The Laboratories would like to thank Colonel Vigors for giving permission to undertake the work and for his enthusiastic support. Thanks are also due to Avis Lloyd for arranging access and for supplying additional background material on the building and to Clive Carter of the Wiltshire Buildings Record for providing the drawings. The work was funded by English Heritage and co-ordinated by Peter Marshall from the English Heritage Scientific Dating Team.

ARCHIVE LOCATION

Wiltshire Archaeological Service
The Wiltshire and Swindon History Centre
Cocklebury Road
Chippenham SN15 3QN

DATE OF INVESTIGATION

2009–10

CONTACT DETAILS

Matt Hurford and Cathy Tyers
Dendrochronology Laboratory
Graduate School of Archaeology
West Court, 2 Mappin Street
Sheffield S1 4DT
Tel: 0114 276 3146
Email: m.hurford@sheffield.ac.uk, c.m.tyers@sheffield.ac.uk

Robert Howard
Nottingham Tree-Ring Dating Laboratory
20 Hillcrest Grove
Sherwood
Nottingham NG5 1FT
Tel: 0115 9603833
Email:roberthoward@tree-ringdating.co.uk

CONTENTS

Introduction 1
Apshill House 1
Sampling 2
Analysis and Results 2
Interpretation 3
Discussion and Conclusion 4
Bibliography 6
Tables 8
Figures 10
Data of Measured Samples 19
Appendix: Tree-Ring Dating 24
The Principles of Tree-Ring Dating 24
The Practice of Tree-Ring Dating at the Nottingham Tree-Ring Dating Laboratory 24
1. Inspecting the Building and Sampling the Timbers. 24
2. Measuring Ring Widths. 29
3. Cross-Matching and Dating the Samples. 29
4. Estimating the Felling Date. 30
5. Estimating the Date of Construction. 31
6. Master Chronological Sequences. 32
7. Ring-Width Indices. 32
References 36

INTRODUCTION

In 2009 the Wiltshire Buildings Record successfully obtained support through the English Heritage Historic Environment Enabling Programme for their project 'Wiltshire cruck buildings and other archaic roof types'. The detailed aims and objectives of the project are set out in the Project Design (Lloyd 2009). The overall aim is to establish a typological chronology of archaic roof types and hence elucidate the development of carpentry techniques in the county. This will then facilitate detailed comparison with other counties allowing Wiltshire to be placed in a regional context. Investigation of these late-medieval buildings (*c* AD 1200 – *c* AD 1550) will combine building survey, historical research, and dendrochronological analysis.

A series of buildings identified by the Wiltshire Buildings Record as having the potential to contribute to the aims and objectives of the project were assessed for dendrochronological suitability during 2009. In order to maximise the potential, these detailed dendrochronological assessments and the WBR's assessments of the significance of the buildings within the project informed the selection of the buildings subsequently subjected to detailed study.

A single final report produced by the Wiltshire Buildings Record (forthcoming a) will summarise the overall results from the project. However, each building included in the project will have an associated individual report produced by the WBR (forthcoming b), whilst the primary archive of the dendrochronological analysis is the English Heritage Research Department Report Series.

A brief introduction to dendrochronology can be found in the Appendix. Further details can be found in the guidelines published by English Heritage (1998), which are also available on the English Heritage website (http://www.english-heritage.org.uk/publications/dendrochronology-guidelines/).

Apshill House

Apshill House lies just to the east of the small settlement of Chicksgrove and about 0.75 km south-east of Lower Chicksgrove, Wiltshire (ST976294; Figs 1 and 2). This L-plan grade II listed property (Figs 3 and 4) incorporates a medieval open hall house, which was owned by Shaftesbury Abbey (Crowley 1987).

The details given below are summarised from the Wiltshire Buildings Record report (forthcoming b) on Apshill House. The original building appears to have been a timber-framed, thatched, raised-cruck open-hall house, comprising a two-bay open hall with a room to the south and probably a cross-passage and service room at the north end. Stylistically this open-hall house appears likely to have been built during the first half of the fourteenth century, prior to the Black Death in AD 1347–8. The seventeenth century saw various successive alterations, including the insertion of a smoke bay in the open hall, the replacement of the external timber framing with stone walls, followed by the flooring over of the open hall, and the construction of the cross-wing which appears to have replaced the service room and forced the relocation of the cross-passage into the hall area. The eighteenth century saw the rebuilding of the south parlour end and alterations to the cross-wing, including some reroofing. Further alterations appear to have been carried out during the nineteenth and twentieth centuries.

The focus of this investigation is the remains of the former open hall. This comprises two trusses and associated roof elements in two bays (Fig 3). The original central open truss, Truss B (Fig 5), and the northern truss, Truss C (Fig 6), are of raised-cruck construction, both with collars and saddles. Truss B is notable for its ogee-cusped arch bracing. There are two rows of purlins and also, in the east side of bay 2, a pair of windbraces between the two cruck blades beneath the lower purlin (Fig 7). In addition there is an extant common rafter that has been sawn through when the stone chimney stack was inserted.

SAMPLING

Sampling and analysis by tree-ring dating of the timbers associated with the roof of the former open hall at Apshill House was commissioned by English Heritage. It was hoped to provide independent dating evidence for the construction of this roof associated with the original construction of Apshill House and hence inform the overall objectives of the *Wiltshire Cruck Buildings and other archaic roof types* project. The dendrochronological study also formed part of the English Heritage-funded training programme for the first author.

A total of 14 timbers associated with the extant remains of the open hall was sampled by coring. Each sample was given the code LCA-H (for Lower Chicksgrove, Apshill House) and numbered 01–14. The sampling strategy encompassed as wide a range of elements as possible whilst focusing on those timbers with the best dendrochronological potential. However the ogee-cusped arch braces were deliberately excluded on aesthetic grounds, as any core taken would have compromised the decorative faces.

The location of samples was noted at the time of coring and marked on the drawings provided by the Wiltshire Building Record, these being reproduced here as Figures 8–10. Further details relating to the samples can be found in Table 1. In this table the timbers have been located and numbered following the scheme on the drawings provided.

ANALYSIS AND RESULTS

Each of the 14 samples obtained was prepared by sanding and polishing. It was seen at this point that one sample, LCA-H01, had an insufficient number of rings ie a minimum of 50, for reliable dating, and so was rejected from this programme of analysis. The annual growth rings of the remaining 13 samples were measured, the data of these measurements being given at the end of this report. The data of these 13 samples were then compared with each other by the Litton/Zainodin grouping procedure (see

Appendix) allowing two groups to be formed at a minimum value of *t*=4.5, the samples of each group cross-matching with each other as shown in the bar diagram (Fig 11). The analytical process was also aided by the use of software written by Tyers (2004).

Both site chronologies, LCAHSQ01 and LCAHSQ02, were compared to an extensive range of reference chronologies for oak, this indicating repeated cross-matches and dates for both of them. The evidence for this dating is given in Tables 2 and 3.

Each site chronology was also compared with the remaining two ungrouped samples but there was no further satisfactory cross-matching. The two ungrouped samples were then compared individually with the reference chronologies, but again there was no satisfactory cross-matching and these samples must, therefore remain undated.

This analysis can be summarised as follows:

Site chronology	Number of samples	Number of rings	Date span (where dated)
LCAHSQ01	9	253	AD 1080–1332
LCAHSQ02	2	91	AD 1220–1310
	2	---	undated
	1	---	unmeasured

INTERPRETATION

The former two-bay open-hall roof is represented by 11 dated samples, nine in site chronology LCAHSQ01 and two in site chronology LCAHSQ02 (Fig 11).

Site chronology LCAHSQ01 includes a single sample, LCA-H14, which retained complete sapwood. Its final sapwood ring immediately below the bark dates to AD 1332. It is not possible to determine what season this timber was felled, however, due to the narrow nature of the growth rings. It could have been felled over a period of several months ranging from as early as summer AD 1332 to as late as early spring AD 1333. None of the remaining eight samples in site chronology LCAHSQ01 has complete sapwood, and it is thus not possible to calculate a precise felling date for the timbers represented. However, three did retain their heartwood/sapwood boundary ring, the average date for this being AD 1301. Using the 95% confidence limit of 15–40 sapwood rings appropriate for mature oaks in this part of England, an estimated felling date in the range AD 1316–41 can be calculated for these timbers. This encompasses the precise felling date produced. The overall variation of the heartwood/sapwood boundary date of all four samples on which it is present is 15 years, which suggests that these timbers probably represent a single programme of felling.

The remaining five dated samples in site chronology LCAHSQ01 have no trace of sapwood and thus it is not possible to calculate their likely felling date ranges. However the dates of their last measured rings vary from AD 1258 to AD 1282 which, combined with the very high level of cross-matching (see below), implies that all dated timbers form a coherent group and are part of the same felling programme, for which a single precise felling date in the early AD 1330s has been obtained. Furthermore, they appear integral to the roof structure with no evidence of insertion or reuse.

Neither of the two samples in site chronology LCAHSQ02 retained complete sapwood, so a precise felling date for the timbers represented cannot be calculated. The heartwood/sapwood boundary ring, dated to AD 1308, was however present on sample LCA-H04, allowing an estimated felling date of AD 1323–48 to be calculated. The second sample, LCA-H03, did not retain its heartwood/sapwood boundary ring, but with a last measured ring of AD 1308, and a potential same-tree match with LCA-H04 (see below), it is likely that they were felled at the same time.

The estimated felling date for the two timbers represented in site chronology LCAHSQ02 encompasses the precise felling date in the AD 1330s obtained above. The low, but nevertheless significant, level of cross-matching of t=4.0 between the two site chronologies, combined with the similarity in the heartwood/sapwood boundary dates, suggests that these two timbers are also likely to be part of the same felling programme as the rest of the dated timbers. Furthermore these two timbers, along with the others dated from the former open hall, also have no evidence for insertion or reuse, suggesting that all 11 dated timbers represent a single building phase.

DISCUSSION AND CONCLUSION

The dated timbers come from throughout the extant remains of the two-bay open hall. Whilst they appear to potentially represent two slightly different woodland sources, the analysis suggests that they are all probably coeval and hence that the original open hall house was likely to have been constructed shortly after felling in the early AD 1330s. It is unfortunate that neither of the cruck blades from truss C was successfully dated, but other elements associated with this truss were dated. The dendrochronological dating evidence supports the stylistic dating evidence, although it should be noted that the early AD 1330s date indicated is based on only one sample with bark edge present.

The high overall level of cross-matching between the individuals in site sequence LCAHSQ01, with the majority of t-values in excess of 6.0, suggests that these timbers probably originated from the same woodland source. Particularly high t-values in excess of 10.0 can be found between a series of samples, suggesting the possibility that samples LCA-H02, LCA-H11, LCA-H12, LCA-H13, and LCA-H14 could be derived from either the same tree, or trees located in very close proximity to each other. Thus there may well only be a few trees represented by these nine dated timbers in LCAHSQ01. In addition, the t-value of 12.2 between the two samples in site chronology LCAHSQ02 suggests that they may also be derived from the same tree.

The two site chronologies from Apshill House generally produce the highest *t*-values, and thus show the greatest degree of similarity, with reference chronologies from the south-west region (Tables 2 and 3). This suggests that it is likely that the timbers were derived from relatively local woodland sources. The higher *t* values produced by site chronology LCAHSQ01 are probably due to it being a much longer and better-replicated site chronology than LCAHSQ02.

It is noticeable that the timbers represented in the two site sequences are very different in character. The majority of timbers analysed are likely to be derived from relatively slow-grown trees in excess of approximately 150 years old when felled, and in some cases likely to be in the region of 250 years old. However there are three exceptions to this, including both samples in site sequence LCAHSQ02. These two sequences are derived from the cruck blades of Truss B and, along with the west cruck blade from Truss C, have noticeably wider average ring widths and are amongst the shortest ring sequences analysed. These three timbers appear likely to have been derived from faster-grown trees under approximately 150 years old when felled. They are also the timbers of largest scantling, suggesting that they could have been specifically selected from a slightly different source with a more open canopy, as would be found towards the edge of woodland or even parkland or hedgerow-type environments.

BIBLIOGRAPHY

Arnold, A J, Howard, R E, Laxton, R R, and Litton, C D, 2003 unpubl composite working mean of tree-ring analysis of timbers from Salisbury Cathedral, Wiltshire – Nottingham Tree-Ring Dating Laboratory unpubl computer file SALCSQ01

Bridge, M C, 2001 *Tree-ring analysis of timbers from the Abbey Barn, Glastonbury, Somerset*, Centre for Archaeol Rep, 39/2001

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

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

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

Crowley, D A, 1987 *The Victoria History of the Counties of England: A History of Wiltshire, Volume XIII, South-West Wiltshire – Chalke and Dunworth Hundreds,* Oxford

English Heritage, 1998 *Dendrochronology: guidelines on producing and interpreting dendrochronological dates*, London

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

Howard, R E, Laxton, R R, and Litton, C D, 2001 *Tree-ring analysis of timbers from Exeter Cathedral, Exeter, Devon, Part I*, Centre for Archaeol Rep, 47/2001

Hurford, M, Tyers, C, and Howard, R 2010 *Bremhill Court, Bremhill, Wiltshire: tree-ring analysis of timbers,* EH Res Dep Rep Ser, 77/2010

Lloyd, A, 2009 *Wiltshire cruck buildings and other archaic roof types: An archaeological and dendrochronological analysis of medieval timber construction in the country* English Heritage Historic Environment Enabling Programme No. 5104

Miles, D, Worthington, M J, and Dallimore, J, 1997 Tree-ring dates for Somerset 1: List 84, *Vernacular Architect*, 28, 172–4

Tyers, I, 1999 *Tree-ring analysis of oak timbers from the Manor Barn, Avebury, Wiltshire*, ARCUS Rep, 524

Tyers, I, 2002 *Dendrochronological analysis of timbers from Manor Farm, Tredington, Gloucestershire*, ARCUS Rep, 574v

Tyers, I, 2004 *Dendro for Windows program guide 3rd edn*, ARCUS Rep, 500b

Tyers, C, Hurford, M, Arnold, A, and Howard, R forthcoming *Dendrochronological Research in Devon: Phase 2*, EH Res Dep Rep Ser

Wiltshire Buildings Record forthcoming a *Wiltshire cruck buildings and other archaic roof types: an archaeological analysis of medieval timber construction in the county,* WBR report

Wiltshire Buildings Record forthcoming b *Apshill House, Lower Chicksgrove*, WBR report

TABLES

Table 1: Details of tree-ring samples from Apshill House, Lower Chicksgrove, Wiltshire

Sample number	Sample location	Total rings	Sapwood rings	Average ring width (mm)	Cross-section dimensions (mm)	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
LCA-H01	Bay 1 west common rafter	nm	--	--	90x100	--	--	--
LCA-H02	Bay 1 east upper purlin	160	h/s	0.83	not recorded	1150	1309	1309
LCA-H03	Truss B west cruck blade	70	no h/s	2.66	510x130	1239	--	1308
LCA-H04	Truss B east cruck blade	91	2	2.03	520x140	1220	1308	1310
LCA-H05	Truss B saddle	128	9	0.49	80x130	1178	1296	1305
LCA-H06	Truss C west cruck blade	79	2	3.18	280x160	--	--	--
LCA-H07	Truss C east cruck blade	104	h/s	1.33	320x140	--	--	--
LCA-H08	Truss C saddle	94	h/s	0.96	170x250	1204	1297	1297
LCA-H09	Bay 2 east windbrace from truss B to lower purlin	115	no h/s	1.22	70x170	1166	--	1280
LCA-H10	Bay 2 east windbrace from truss C to lower purlin	152	no h/s	0.97	70x170	1131	--	1282
LCA-H11	Bay 2 west lower purlin	143	no h/s	1.23	180x200	1116	--	1258
LCA-H12	Bay 1 east lower purlin	187	no h/s	1.34	170x170	1080	--	1266
LCA-H13	Bay 2 east lower purlin	166	no h/s	1.27	170x200	1111	--	1276
LCA-H14	Truss C collar	207	21C	0.71	150x300	1126	1311	1332

nm = not measured

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

C=complete sapwood is retained on core

Table 2: Results of the cross-matching of site sequence LCAHSQ01 and relevant reference chronologies when the first-ring date is AD 1080 and the last-ring date is AD 1332

Reference chronology	*t*-value	Span of chronology	Reference
Salisbury Cathedral, Wiltshire	9.7	AD 1067–1241	(Arnold *et al* 2003 unpubl)
Glastonbury Abbey Barn, Glastonbury, Somerset	9.3	AD 1095–1334	(Bridge 2001)
Bremhill Court, Bremhill, Wiltshire	8.3	AD 1111–1323	(Hurford *et al* 2010)
Fiddleford Manor, Sturminster Newton, Dorset	8.0	AD 1167–1315	(Bridge 2003)
Exeter Cathedral, Exeter, Devon	7.5	AD 1132–1315	(Howard *et al* 2001)
Bridge Farm, Butleigh Somerset	6.3	AD 1136–1304	(Miles *et al* 1997)
Manor Farmhouse, Meare, Somerset	6.1	AD 1156–1315	(Bridge 2002a)
The Manor Barn, Avebury, Wiltshire	6.0	AD 1072–1278	(Tyers 1999)

Table 3: Results of the cross-matching of site sequence LCAHSQ02 and relevant reference chronologies when the first-ring date is AD 1220 and the last-ring date is AD 1310

Reference chronology	*t*-value	Span of chronology	Reference
England: south-west regional chronology	5.9	AD 770–1872	(Tyers pers comm)
Exeter Cathedral, Exeter, Devon	5.6	AD 1132–1315	(Howard *et al* 2001)
Muchelney Abbey, Somerset	5.5	AD 1148–1498	(Bridge 2002b)
Rudge, Morchard Bishop, Devon	5.3	AD 1124–1315	(Groves 2005)
Manor Farm, Tredington, Gloucestershire	5.1	AD 1218–1356	(Tyers 2002)
Glastonbury Abbey Barn, Glastonbury, Somerset	5.0	AD 1095–1334	(Bridge 2001)
Old Rectory, Bridford, Devon	5.0	AD 1220–1278	(Tyers *et al* forthcoming)
Thorne, Clannaborough, Devon	4.9	AD 1200–1319	(Groves 2005)

FIGURES

Figure 1: Map to show the location of Apshill House, Lower Chicksgrove, Tisbury, Wiltshire (based on the Ordnance Survey map with permission of the Controller of Her Majesty's Stationery Office, © Crown Copyright)

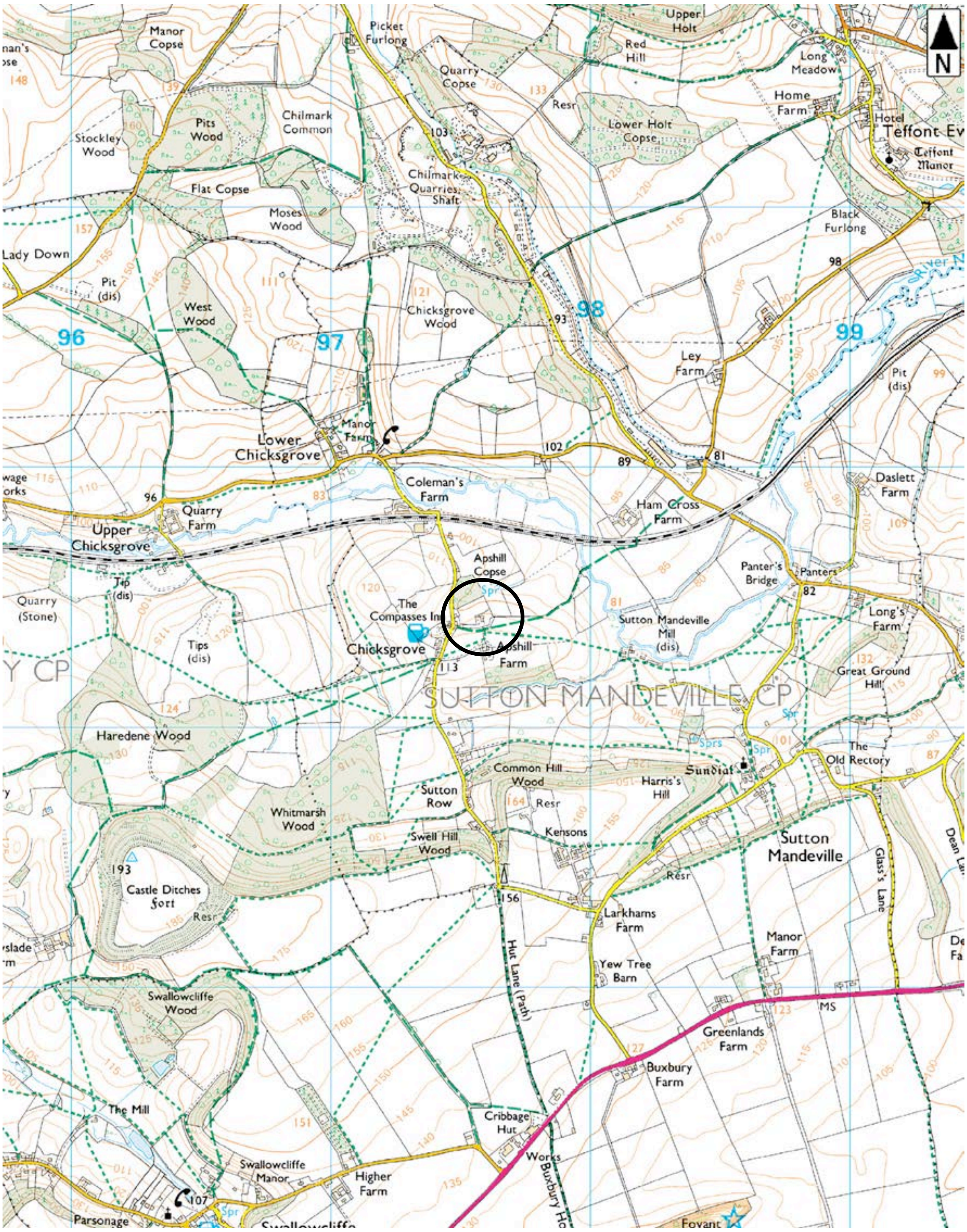


Figure 2: Map to show the location Apshill House (based on the Ordnance Survey map with permission of the Controller of Her Majesty's Stationery Office, © Crown Copyright)

Figure 3: East elevation of Apshill House

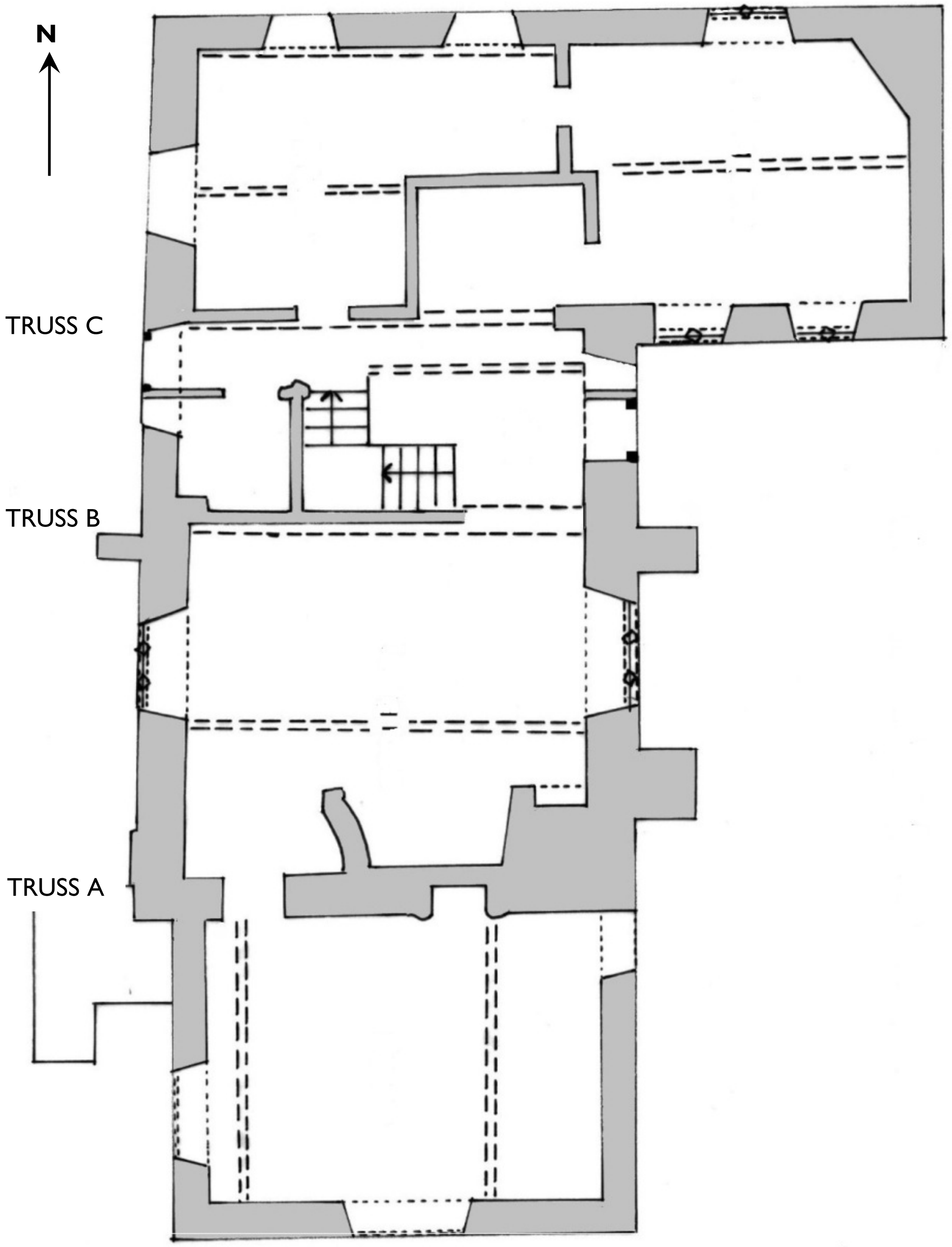


Figure 4: Ground-floor plan of Apshill House below (based on a drawing by Clive Carter of the Wiltshire Building Record)

Figure 5: Truss B north face

Figure 6: Truss C south face

Figure 7: East windbraces in bay 2

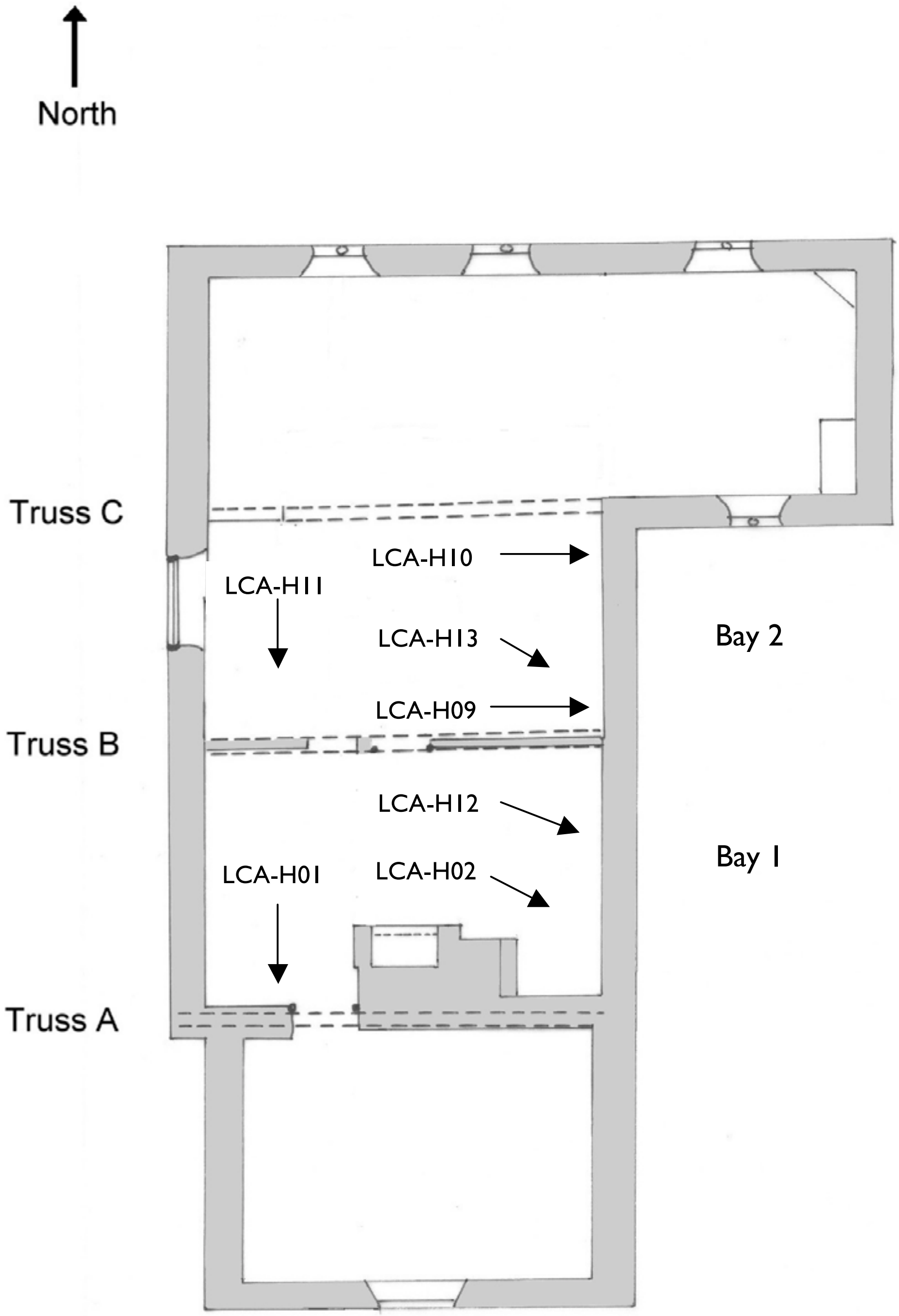


Figure 8: Plan showing the approximate locations of the samples taken from the roof and first floor not shown on the sections below (based on a drawing by Clive Carter of the Wiltshire Buildings Record)

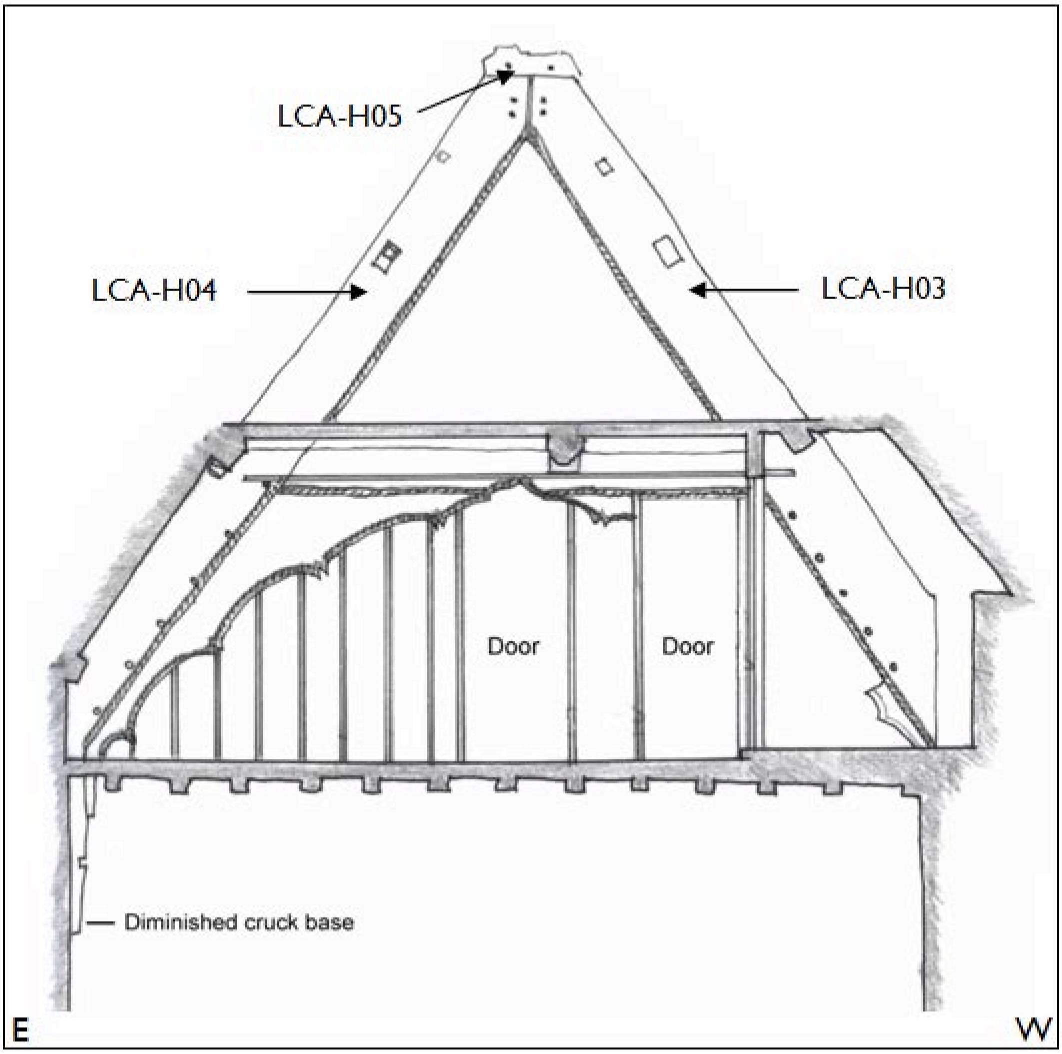


Figure 9: Sample locations from Truss B (based on a drawing by Clive Carter of the Wiltshire Buildings Record)

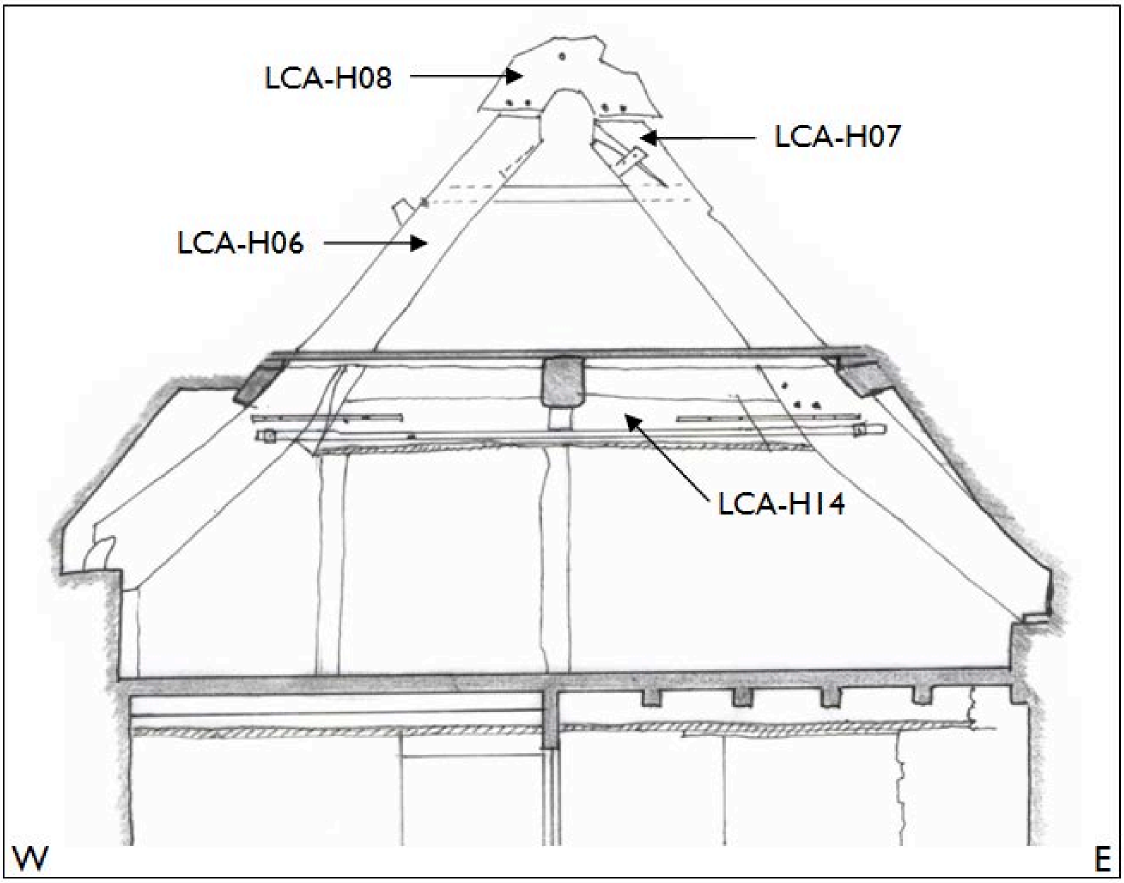
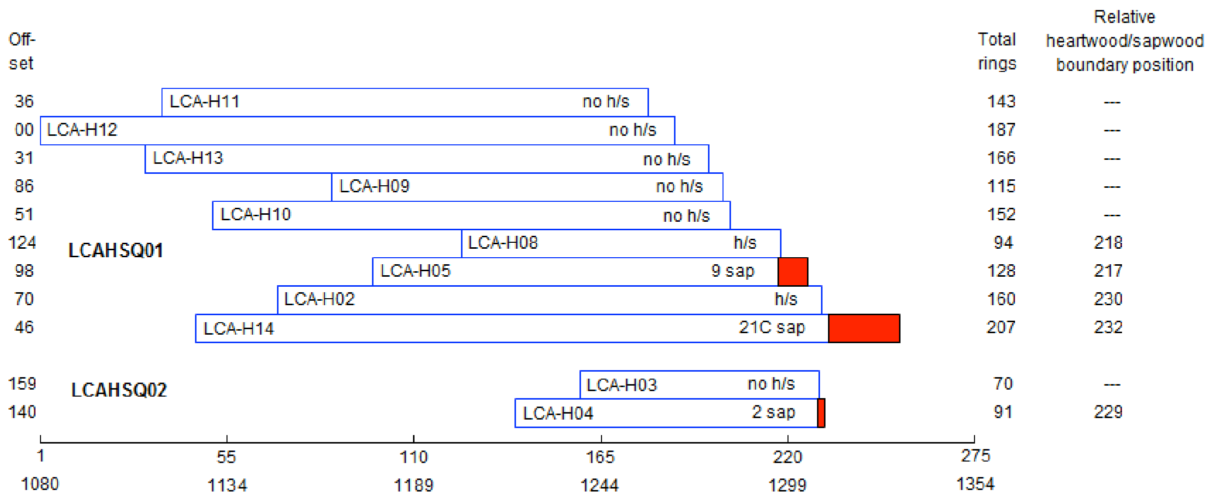


Figure 10: Sample locations from Truss C (based on a drawing by Clive Carter of the Wiltshire Buildings Record)



white bars [ ] = heartwood rings;
filled bars [ ] = sapwood rings
h/s = the last ring of the sample is at the heartwood/sapwood boundary
C= complete sapwood is retained on the sample

Figure 11: Bar diagram of the samples in site chronologies LCAHSQ01 and LCAHSQ02

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

LCA-H02A 160
161 224 168 256 182 155 161 181 139 196 196 182 150 177 181 141 123 92 86 92
105 101 63 70 110 125 151 107 137 139 87 108 99 87 77 60 93 139 94 122
110 112 85 114 131 119 151 164 82 80 91 92 71 90 66 86 79 58 74 74
99 58 68 63 69 66 56 56 66 79 75 93 71 50 50 41 45 36 47 57
40 46 57 47 50 60 44 64 58 69 93 71 68 70 66 54 56 63 67 67
70 59 66 55 62 110 60 56 51 50 72 75 93 67 58 54 74 53 50 67
57 93 68 51 39 93 72 89 73 70 89 73 71 49 37 31 46 57 62 79
79 50 63 50 45 57 42 42 72 40 44 96 57 60 26 41 41 41 48 36
LCA-H02B 160
156 228 168 258 180 156 155 187 130 194 199 181 152 176 189 132 120 92 82 105
108 98 59 73 108 124 155 108 143 130 84 108 110 79 76 54 99 138 92 132
106 109 82 119 128 109 158 160 82 71 93 91 75 87 68 86 81 54 76 77
100 60 61 66 62 71 59 52 66 82 73 95 73 48 46 45 47 47 56 54
41 35 60 50 34 52 58 66 61 83 88 76 64 70 65 54 56 65 67 68
65 61 66 53 64 108 56 57 47 47 72 75 97 71 64 53 70 53 55 69
51 93 65 52 41 91 66 87 78 70 88 77 71 45 42 30 43 59 62 79
70 49 67 50 41 57 44 41 68 38 45 55 59 59 24 41 38 42 44 39
LCA-H03A 70
382 375 248 237 269 270 403 360 306 339 379 311 389 219 446 240 398 316 168 340
327 229 318 282 226 361 342 353 240 320 347 401 424 187 335 442 344 166 253 241
208 263 201 287 247 181 187 168 151 155 194 255 163 224 264 231 208 195 161 173
178 235 235 224 221 158 135 159 175 252
LCA-H03B 70
380 395 254 244 279 288 408 362 301 341 385 306 374 214 459 198 367 325 177 307
331 231 318 276 209 338 330 347 239 338 336 392 429 195 354 452 341 197 232 237
210 257 197 287 251 184 189 172 154 157 195 251 158 226 265 231 202 185 165 175
178 252 222 217 221 158 138 159 172 251
LCA-H04A 91
223 259 183 209 151 120 183 186 214 222 234 172 233 221 184 266 145 377 323 387
340 219 207 279 241 322 377 340 418 340 230 262 177 290 175 353 274 167 232 243
211 278 243 207 243 223 227 183 213 227 304 288 150 173 213 187 163 181 160 142
152 135 191 181 119 103 105 74 96 123 165 108 164 196 132 131 151 132 136 145
201 176 156 140 94 96 125 165 158 107 100
LCA-H04B 91
225 271 171 208 147 117 179 177 211 222 249 169 234 209 184 262 137 374 330 386
350 224 203 284 258 325 379 338 450 354 227 266 172 295 170 350 281 155 232 225
213 280 256 198 237 218 233 176 215 228 303 295 145 164 201 185 156 178 146 143
150 136 193 180 124 104 95 85 88 125 163 108 164 197 129 131 157 135 134 135
209 181 151 140 89 105 120 167 159 103 101
LCA-H05A 128
87 79 66 94 89 57 45 34 50 95 64 74 84 88 53 80 90 97 136 79
73 65 55 71 66 61 42 44 58 34 49 67 59 35 41 35 35 31 36 35
24 49 33 37 32 28 27 33 35 37 35 36 27 23 22 18 30 38 30 41
39 65 44 39 36 48 37 41 39 35 32 37 43 35 28 30 30 52 41 31
33 28 35 53 54 43 51 39 38 33 48 34 33 47 27 29 31 43 52 74
39 69 60 57 47 47 58 40 48 50 53 55 61 45 67 56 51 50 49 61
57 65 57 65 81 70 54 60

LCA-H05B 128
93 78 72 91 81 68 45 31 46 99 66 73 80 83 53 82 87 100 128 81
76 61 53 72 67 62 41 48 53 36 53 66 52 34 40 37 36 34 40 37
26 47 27 36 30 27 25 32 36 38 35 36 27 24 24 17 28 41 27 38
45 58 43 36 33 50 37 39 37 34 32 38 46 35 27 33 32 53 35 27
25 29 33 54 55 47 51 37 36 31 50 36 35 41 29 35 39 48 61 77
37 66 53 56 46 48 58 42 47 49 51 53 63 43 57 54 50 52 51 59
58 68 59 65 77 66 53 57
LCA-H06A 79
391 333 301 258 264 383 398 320 237 307 276 242 262 295 327 304 226 335 393 237
316 334 470 439 367 402 347 236 256 247 311 302 315 247 305 276 333 320 339 342
311 320 326 354 362 412 303 306 289 299 220 264 348 400 417 440 471 338 447 263
407 291 307 379 362 387 300 339 262 155 317 322 328 261 244 234 262 254 264
LCA-H06B 79
389 333 308 268 255 376 390 321 239 305 286 239 263 294 317 307 224 327 377 248
319 323 464 459 338 408 355 233 256 255 300 308 310 249 292 282 335 324 338 346
303 304 307 357 402 405 300 310 292 289 219 259 355 397 415 447 474 331 453 269
409 281 301 373 367 383 308 332 279 152 300 326 332 270 243 242 255 232 286
LCA-H07A 104
100 64 52 49 87 152 91 117 147 164 141 207 262 242 243 274 206 152 223 179
96 85 83 106 144 120 213 159 221 104 107 102 83 121 91 102 125 119 95 98
80 121 122 151 175 135 127 166 164 163 130 114 146 157 185 192 152 149 124 194
115 82 67 102 132 157 174 130 108 97 121 88 91 90 98 141 96 121 64 94
159 106 99 97 176 113 103 105 110 69 69 82 76 79 91 145 149 196 208 211
210 173 152 176
LCA-H07B 104
101 64 55 42 87 150 91 117 143 168 135 201 248 260 240 277 232 154 236 178
99 88 83 105 147 118 213 161 223 95 94 103 78 132 89 107 129 116 92 101
78 125 119 151 172 138 129 167 158 150 139 116 143 148 184 192 166 155 128 194
102 69 72 103 125 152 180 132 108 96 119 93 88 88 102 140 97 118 60 90
158 114 96 100 177 115 96 112 99 75 65 84 74 78 102 136 142 190 212 207
206 185 143 171
LCA-H08A 94
209 278 85 86 182 185 144 140 112 63 90 95 116 81 62 92 137 180 146 123
66 104 166 111 95 192 98 148 134 109 79 76 56 102 122 121 106 97 104 86
91 81 108 86 105 97 112 106 91 111 87 94 62 66 75 75 86 87 88 74
114 66 90 63 84 100 62 75 46 60 36 62 49 48 45 45 70 80 111 68
65 63 70 89 68 81 86 81 98 87 68 60 79 58
LCA-H08B 94
206 263 89 87 180 177 145 137 107 58 84 102 116 72 65 96 131 167 145 116
78 92 159 106 101 192 100 156 137 105 81 71 63 108 114 126 100 100 93 105
81 86 101 90 96 98 115 102 94 101 90 96 71 59 80 74 79 85 85 80
110 62 83 62 89 99 57 81 51 54 34 66 52 50 41 50 62 76 109 67
66 60 74 83 67 84 90 79 101 84 76 65 76 58
LCA-H09A 115
149 114 112 145 91 119 125 113 147 156 198 126 157 153 91 140 170 135 89 57
105 152 93 95 100 114 104 150 149 192 237 217 187 120 99 134 191 174 135 118
133 90 124 145 155 132 134 138 131 141 122 89 92 140 129 161 116 96 64 91
125 123 101 174 94 77 84 61 105 126 86 123 158 192 171 121 126 164 155 132
112 104 118 160 169 133 103 126 116 185 78 60 59 88 102 127 129 98 104 79
85 58 109 83 47 109 86 64 93 90 118 149 104 113 117
LCA-H09B 115
153 113 116 142 89 120 123 118 144 159 198 116 165 146 94 153 168 133 89 52

108 154 93 96 97 118 98 148 145 198 238 220 201 126 99 135 184 179 134 123
136 91 119 144 153 139 143 142 136 128 124 90 91 142 128 158 112 96 66 89
123 125 101 174 86 79 87 61 103 123 85 125 156 198 174 118 132 162 151 134
110 106 116 159 165 131 107 126 115 186 79 53 64 91 103 135 126 91 105 78
85 54 104 70 60 100 85 64 89 96 118 148 108 108 117

LCA-H10A 152

35 110 172 88 98 157 176 135 133 113 80 45 56 70 65 50 72 73 83 71
95 97 89 61 62 87 102 77 114 174 125 163 155 162 175 131 113 91 124 98
120 85 101 129 183 174 115 171 140 98 116 98 70 59 45 95 121 62 84 71
96 71 130 119 133 186 214 177 109 75 110 144 109 78 72 79 52 86 103 105
76 72 69 72 79 76 79 54 84 80 114 88 71 49 56 69 70 77 91 60
51 53 46 77 81 53 88 108 116 135 93 90 113 126 105 73 65 67 92 114
91 86 74 73 122 78 64 53 60 69 100 109 97 102 78 81 57 96 87 48
140 107 75 72 93 136 148 137 143 126 96 107

LCA-H10B 152

29 102 169 90 99 154 178 139 130 116 79 46 56 70 58 47 75 76 89 61
99 94 96 59 69 82 106 74 115 169 130 163 149 161 174 138 117 96 125 98
104 109 92 135 173 171 119 176 137 95 120 93 76 59 36 99 122 61 81 72
96 73 131 122 128 191 215 174 106 78 112 142 106 82 71 81 49 88 104 107
71 75 70 67 84 76 83 49 84 80 110 84 80 51 52 69 70 68 91 60
46 57 42 74 82 51 90 105 126 127 90 91 113 125 104 72 56 74 89 107
99 93 64 84 124 82 68 53 61 64 94 109 95 113 74 83 60 94 73 62
124 112 63 69 86 137 151 139 138 126 97 107

LCA-H11A 143

242 209 262 281 319 173 271 330 255 288 163 137 159 114 102 79 90 150 107 136
137 134 169 149 270 274 150 137 147 165 141 153 145 147 112 183 122 151 99 86
88 130 63 117 183 177 152 192 177 233 133 125 137 148 158 153 90 101 144 140
232 115 145 136 58 89 160 109 75 70 80 166 108 130 128 174 90 194 115 105
118 156 77 76 79 92 140 107 78 118 98 64 105 91 159 108 85 88 105 82
75 72 86 143 118 204 99 89 72 51 68 55 68 85 52 51 60 49 69 63
61 71 94 103 124 73 70 84 56 75 65 67 65 64 103 87 85 56 50 128
68 51 44

LCA-H11B 143

246 224 275 220 326 175 255 334 286 289 163 144 159 109 101 92 81 152 107 137
136 134 169 149 269 263 149 143 133 156 131 151 145 148 111 189 125 152 106 82
88 118 69 105 182 199 148 192 176 236 130 129 124 149 160 149 91 107 139 140
243 104 159 131 66 101 153 114 79 62 83 170 111 125 127 172 95 184 117 102
122 150 78 72 82 90 142 105 79 119 98 62 103 96 159 103 89 83 108 86
66 67 86 138 131 199 104 82 78 43 67 65 65 83 53 52 62 56 52 66
58 75 93 99 127 77 73 79 52 80 64 69 65 63 104 89 85 52 53 131
66 55 41

LCA-H12A 187

210 116 258 277 262 422 397 325 470 415 322 246 299 278 262 218 244 267 212 197
204 192 154 171 191 210 205 257 275 211 205 213 170 213 164 229 176 144 129 144
135 71 106 171 170 203 159 126 153 98 81 73 104 142 95 102 120 102 179 164
293 285 193 172 195 138 99 118 145 141 128 212 124 205 130 91 95 103 69 87
103 124 94 134 117 127 93 91 75 100 138 123 75 85 125 160 191 102 109 103
62 96 128 97 69 57 88 154 84 129 105 118 71 130 115 111 132 186 90 97
70 90 112 92 65 97 80 55 74 66 114 71 67 57 74 71 66 61 69 110
91 144 89 88 58 61 73 64 67 82 51 54 68 61 69 71 63 97 109 98
140 89 77 88 78 79 76 81 80 93 101 85 91 75 91 150 79 64 70 56
87 132 125 102 73 59 79

LCA-H12B 187

218 116 260 278 268 422 396 312 468 424 305 234 296 256 255 217 242 273 214 192
213 193 156 170 193 209 206 258 288 191 195 206 159 205 160 221 176 147 131 152
137 71 103 170 160 211 164 126 155 88 85 72 105 140 93 107 118 103 182 164
294 285 196 175 199 131 103 120 146 140 131 206 131 210 129 91 99 97 62 86
111 119 91 130 121 124 94 87 73 98 133 117 77 80 127 162 183 108 124 108
67 96 129 95 68 60 87 153 86 131 101 118 76 128 114 111 130 183 94 84
73 88 119 90 63 95 81 62 70 65 121 73 61 62 74 77 64 58 69 113
95 142 89 82 64 66 69 63 60 87 58 54 70 60 63 70 70 97 106 104
142 87 80 84 84 71 83 76 75 95 106 78 93 68 101 148 87 65 69 57
84 130 124 97 78 58 74
LCA-H13A 166
310 259 372 281 288 237 198 208 154 154 121 175 248 225 237 159 132 158 101 104
91 111 174 132 126 150 136 195 129 250 176 124 105 124 86 86 93 88 98 88
140 104 162 151 96 138 157 101 173 187 228 196 189 226 186 165 137 149 186 167
179 112 120 158 150 256 128 177 170 96 167 165 134 81 67 87 221 126 159 183
201 132 192 173 166 165 161 109 103 101 101 129 135 90 128 116 70 86 102 141
90 85 71 71 80 69 72 76 146 117 147 85 71 59 52 62 54 62 66 50
54 66 69 54 63 59 91 84 142 136 83 87 89 67 89 70 65 74 97 100
101 84 86 70 127 110 76 66 51 91 151 109 99 82 77 98 68 90 112 103
123 91 79 76 117 120
LCA-H13B 166
309 259 367 283 289 248 200 211 149 156 123 179 268 213 256 186 132 148 104 91
88 115 175 125 134 136 142 184 129 251 183 120 109 122 92 84 89 90 105 80
141 111 157 148 93 144 156 97 193 180 233 194 196 233 194 179 131 134 164 169
186 123 119 166 149 247 124 177 167 98 165 161 134 92 71 86 212 136 148 182
198 133 192 178 158 168 160 114 110 106 96 125 131 86 133 102 82 87 104 144
94 87 78 70 81 64 78 72 146 123 156 85 82 48 55 58 61 53 74 45
56 57 75 54 66 54 88 89 143 140 91 86 83 67 89 64 70 75 93 108
97 90 80 69 147 101 84 64 52 95 149 123 93 88 70 96 65 95 117 98
118 92 85 82 113 122
LCA-H14A 207
108 110 73 45 72 37 50 83 80 66 67 83 184 134 264 149 122 112 106 49
49 64 66 90 80 107 77 112 70 72 124 130 93 102 107 110 104 126 138 109
107 83 74 92 82 71 57 59 70 79 114 80 108 107 75 78 75 64 56 41
69 85 67 82 68 67 50 81 86 85 99 88 54 56 57 81 67 60 49 85
61 54 69 69 104 60 61 63 56 57 62 52 72 77 66 91 64 48 58 55
57 54 56 63 49 37 48 46 48 57 45 71 66 93 88 58 68 81 74 67
51 72 60 69 73 75 74 76 91 96 68 70 66 70 77 109 103 80 76 64
67 55 67 76 57 84 65 77 85 96 70 91 91 69 86 70 65 50 37 39
59 56 53 79 60 47 62 58 58 43 43 49 51 39 56 69 59 56 38 43
42 53 58 42 41 52 49 58 58 48 49 59 47 47 41 49 59 46 43 41
27 36 47 43 38 22 39
LCA-H14B 207
105 108 71 44 79 35 47 91 75 62 74 81 188 132 272 139 123 122 105 49
47 64 66 85 89 103 80 112 72 68 125 134 86 110 106 106 106 126 133 115
103 86 71 95 76 82 49 60 76 78 117 80 107 111 68 82 76 61 62 44
59 93 64 80 67 67 51 77 93 82 104 85 58 55 55 82 68 57 56 75
67 58 61 80 93 68 64 59 60 60 52 58 70 77 68 88 64 53 55 61
56 53 57 65 39 41 54 45 47 59 45 64 71 86 91 62 63 81 73 69
66 61 63 69 75 82 71 74 93 102 76 81 66 71 80 115 99 88 74 68
63 55 73 72 60 77 63 71 80 115 70 95 80 69 82 71 71 45 39 40
57 57 49 81 59 52 61 48 62 49 50 38 50 38 53 70 58 59 34 47
39 52 43 34 31 63 48 63 54 53 56 55 39 45 43 51 55 56 32 38

35 40 44 37 26 27 25

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	

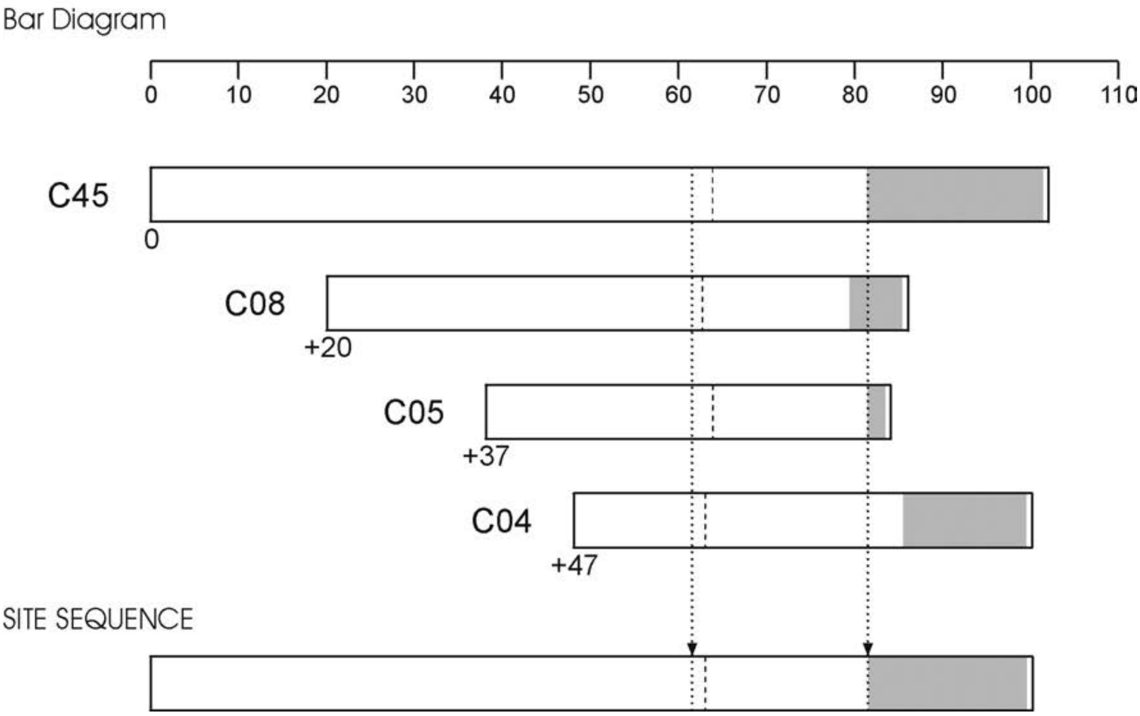


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

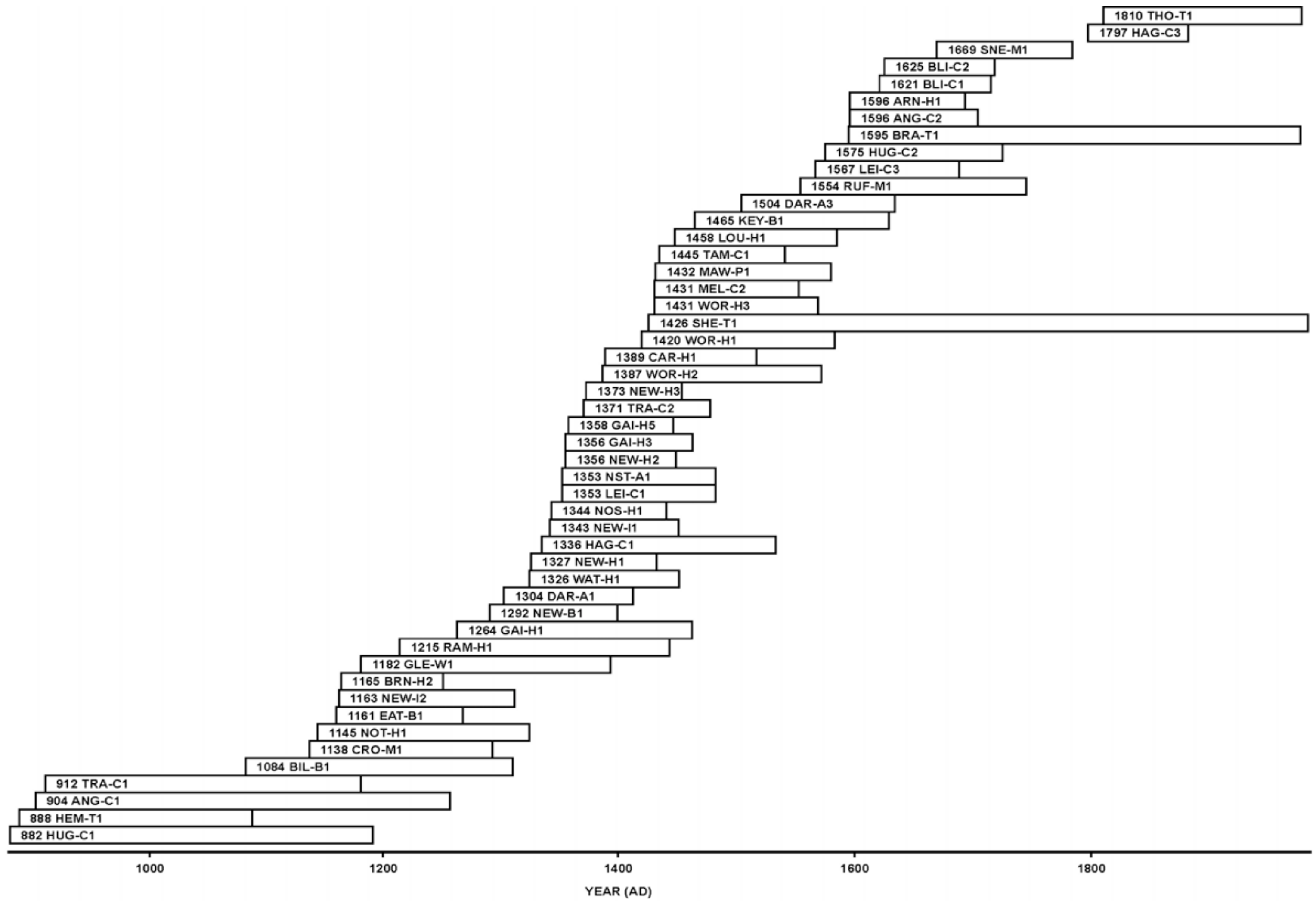
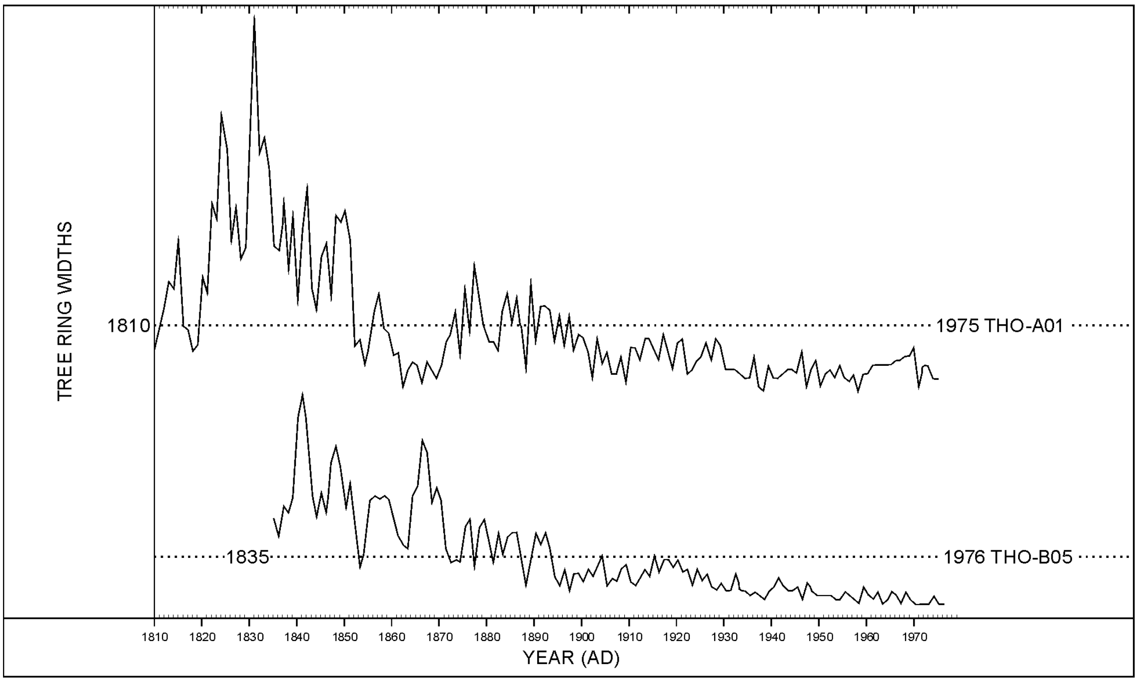


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

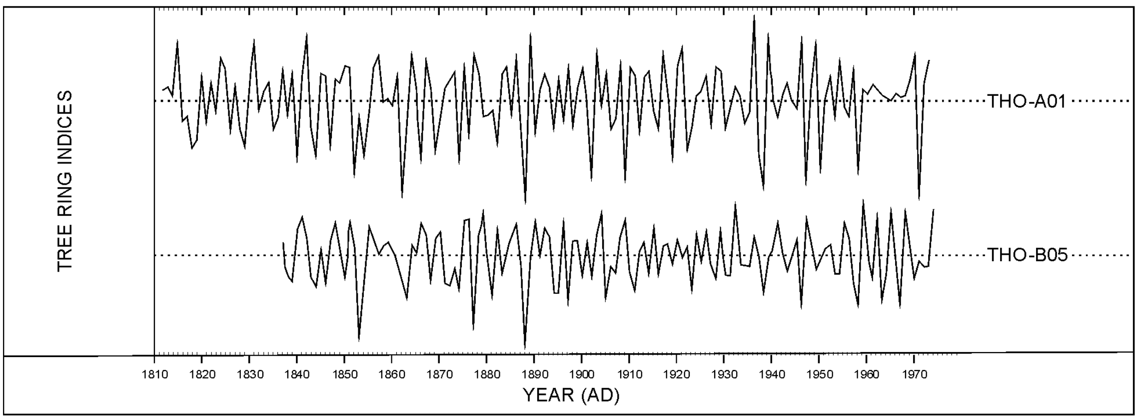


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

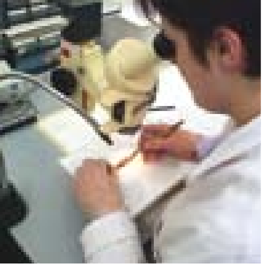
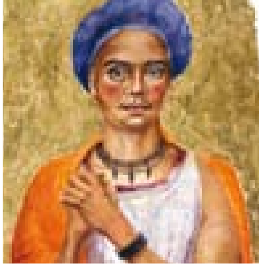
Laxton, R R, Litton, C D, and Howard, R E, 2001 *Timber: Dendrochronology of Roof Timbers at Lincoln Cathedral*, Engl Heritage Res Trans, 7

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



ENGLISH HERITAGE RESEARCH DEPARTMENT

English Heritage undertakes and commissions research into the historic environment, and the issues that affect its condition and survival, in order to provide the understanding necessary for informed policy and decision making, for sustainable management, and to promote the widest access, appreciation and enjoyment of our heritage.

The Research Department provides English Heritage with this capacity in the fields of buildings history, archaeology, and landscape history. It brings together seven teams with complementary investigative and analytical skills to provide integrated research expertise across the range of the historic environment. These are:

* *Aerial Survey and Investigation*
* *Archaeological Projects (excavation)*
* *Archaeological Science*
* *Archaeological Survey and Investigation (landscape analysis)*
* *Architectural Investigation*
* *Imaging, Graphics and Survey (including measured and metric survey, and photography)*
* *Survey of London*

The Research Department undertakes a wide range of investigative and analytical projects, and provides quality assurance and management support for externally-commissioned research. We aim for innovative work of the highest quality which will set agendas and standards for the historic environment sector. In support of this, and to build capacity and promote best practice in the sector, we also publish guidance and provide advice and training. We support outreach and education activities and build these in to our projects and programmes wherever possible.

We make the results of our work available through the Research Department Report Series, and through journal publications and monographs. Our publication Research News, which appears three times a year, aims to keep our partners within and outside English Heritage up-to-date with our projects and activities. A full list of Research Department Reports, with abstracts and information on how to obtain copies, may be found on www.english-heritage.org.uk/researchreports

For further information visit www.english-heritage.org.uk

ENGLISH HERITAGE