RESEARCH DEPARTMENT REPORT SERIES no. 77-2010 ISSN 1749-8775

# BREMHILL COURT
# BREMHILL, WILTSHIRE
# TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Matt Hurford, Robert Howard and Cathy Tyers

ARCHAEOLOGICAL SCIENCE

ENGLISH HERITAGE

Research Department Report Series 77-2010

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M Hurford, R E Howard, and C Tyers

NGR: ST980730



ISSN 1749-8775

## SUMMARY

Dendrochronological analysis was undertaken on 11 of the 12 timbers sampled in the medieval core of Bremhill Court. This resulted in the production of a single site chronology, BHBCSQ01. This comprises series from seven timbers and can be dated as spanning the years AD 1111–1323.

The results identified that the dated timbers used in the construction of the original medieval hall house are of fourteenth-century date and may represent a single programme of felling in the mid-AD 1320s.

## CONTRIBUTORS

Matt Hurford, Cathy Tyers, and Robert Howard

## ACKNOWLEDGEMENTS

The Laboratories would like to thank Mr and Mrs Ellis for giving permission to undertake the work. Thanks are also due to Avis Lloyd for arranging access and for providing additional background material on the building and to Clive Carter of the Wiltshire Building Record for providing the drawings. The Wiltshire Buildings Record project work was supported by the English Heritage Historic Environment Enabling Programme. The dendrochronological work was funded by English Heritage and co-ordinated by Peter Marshall from the English Heritage Scientific Dating Section.

## 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
University of Sheffield
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

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# 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 was 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 Building 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. However, 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/).

## Bremhill Court

Bremhill Court, which has in the relatively recent past been known as The Old Vicarage, is located to the south-east of St Mary's Church in Bremhill, Wiltshire. It is aligned on a north-east to south-west axis (ST980730; Figs 1 and 2) but for ease of reference within this report the building has been described so that the front north-west facing elevation is described as the north elevation. This grade II listed property (Fig 3) contains a medieval core, comprising a base-cruck hall house. This was enlarged in the seventeenth century by gable extensions to the north and south. A two-storey projection was built on to the north front in AD 1820 and the general façade refaced and elaborated. The north elevation had its west end extended and alterations made to the fenestration after AD 1825. The service range to the east was also altered in the nineteenth century with the addition of a projecting gable and two-storey extension dated to AD 1820 (http://lbonline.english-heritage.org.uk).

The focus of this investigation is on the remaining elements of the base-cruck hall house, details of which are given below, based on information provided in the Wiltshire Buildings Record report (forthcoming) on Bremhill Court. It is thought that this hall house probably originally comprised three bays, but only a single bay remains, incorporating two trusses, Trusses A and B (Fig 4). Truss A (Fig 5) is embedded in the east wall and is thought to mark the end of the open hall. Only part of the upper section of this truss is visible and hence it is not clear what cruck truss type this is. The few exposed timbers, including the plain crown post and associated brace, appear less substantial than those in Truss B. Truss B is a base-cruck truss which was an open truss at the end of the first bay of the hall. Only the upper part of this truss is visible (Figs 5 and 6) but the base crucks, along with the tiebeam and upper crucks, are clearly chamfered. The arch-braces continue the decorative theme with moulding, including chamfering, present. The crown post is elaborately moulded, though the collar above is plain. At the east end of Truss B there are also sizeable deep-chamfered wind-braces. In addition a notable feature of Truss B is the assembly marks in Arabic numerals inscribed on six of the timbers (Fig 7) similar to those present in other Wiltshire and Somerset buildings dating to the thirteenth and fourteenth centuries (Wiltshire Buildings Record forthcoming a). These marks are thought to represent the number three, indicating that two trusses to the west have been lost.

The structural evidence, the similarity of decorative features, and indeed the smoke blackening found on the surviving timbers strongly suggest that the extant elements are integral. The stylistic dating evidence from a range of features within this surviving single bay points towards an early fourteenth-century date for the original hall house. The substantial size of the timbers present in Truss B, combined with their highly decorative nature and the location of the building immediately to the south-east of the church, suggests that this base-cruck hall house was of high status.

## SAMPLING

Sampling and analysis by tree-ring dating of the timbers associated with the remains of the medieval core at Bremhill Court was commissioned by English Heritage. It was hoped to provide independent dating evidence for the construction of the original medieval hall 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 12 timbers associated with the extant remains of the medieval hall house were sampled by coring. Each sample was given the code BHB-C (for Bremhill, Bremhill Court) and numbered 01–12. In two instances duplicate cores were obtained from the same timber: BHB-C04A and BHB-C04B were taken in order to maximise the length of the derived ring sequence; BHB-C05B was taken as a replacement for BHB-C05A as the ring sequence was clearly distorted by knots and the sapwood had fragmented. The sampling encompassed as wide a range of elements as possible, whilst focusing on those timbers with the best dendrochronological potential. Unfortunately only a single sample was taken from Truss A, as the other timbers associated with this truss all appeared to be derived from fast-grown trees, similar to some of those associated with Truss B. These timbers were considered highly unlikely to provide samples with sufficient numbers of rings for reliable dendrochronological analysis.

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 and 9. Further details relating to the samples can be found in Table 1. In this table the timbers have been labelled following the scheme on the photographs and drawings provided.

## ANALYSIS AND RESULTS

Each of the 14 cores obtained from the 12 timbers sampled was prepared by sanding and polishing. It was seen at this point that one sample, BHB-C02, had less than the minimum number of 50 rings required for reliable dating, and so it was rejected from this programme of analysis. Sample BHB-C05A was also rejected as it had distorted rings. The annual growth rings of the remaining 12 samples were measured, the data of these measurements being given at the end of this report. Samples BHB-C04A and C04B, which have an overlap of 82 years, were at this point combined into a single sequence, sample BHB-C04.

The ring sequences derived from these 11 timbers were initially compared with each other by the Litton/Zainodin grouping procedure (see Appendix) allowing a single group of six series to be formed. During this analytical process, which was aided by the use of software written by Tyers (2004), a possible match was noted for BHB-C11, but this was based on only very short overlaps and therefore considered inconclusive. This possible match was however subsequently confirmed by the dating evidence obtained for this individual (Table 2) when it and the initial six-timber site sequence were compared to an extensive range of reference chronologies for oak. Once the date of sample BHB-C11 was confirmed, it was combined with the six other grouped series at the indicated offsets to form site chronology BHBCSQ01, this having an overall length of 213 rings (Fig 10). Site chronology BHBCSQ01 was compared to an extensive range of reference chronologies for oak, this indicating repeated cross-matching when the date of the first ring is AD 1111 and the date of its last ring is AD 1323 (Table 3).

The site chronology was compared with the remaining four ungrouped samples but there was no further satisfactory cross-matching. Each of the four ungrouped samples was 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) |
|---|---|---|---|
| BHBCSQ01 | 7 | 213 | AD 1111–1323 |
| | 4 | --- | undated |
| | 1 | --- | unmeasured |

## INTERPRETATION

The medieval core of Bremhill Court is represented by seven dated timbers (Fig 10). The timber from which sample BHB-C11 was derived had retained complete sapwood. However, unfortunately, up to 3 mm of sapwood was lost due to its very fragile nature from the outer edge of the core during sampling. The average ring width of this entire sequence is 1.46mm (Table 1) but the overall growth trend is towards narrower rings, the outer 10 measured rings having an average ring width of 0.74mm. Based on this information it is suggested that a maximum of approximately four rings are likely to have been lost. Thus, with a last measured ring date of AD 1323, an estimated felling date of *c* AD 1324–27 is obtained.

The remaining six dated samples in site chronology BHBCSQ01 have no trace of sapwood and thus it is not possible to calculate their likely felling date ranges. The dates of their last measured rings vary from AD 1225 to AD 1309. The overall level of cross-matching with a number of *t*-values in excess of 6.0 implies these six dated timbers form a coherent group, suggesting that they were likely to be part of a single felling programme (Table 4). The latest measured ring date is AD 1309 on sample BHB-C08. If the 95% confidence limit of 15–40 sapwood rings commonly used is applied, then the earliest that these timbers are likely to have been felled is AD 1325, although clearly they could have been felled significantly later than this, depending on how heavily trimmed they were during conversion from the parent trunk.

## DISCUSSION AND CONCLUSION

The dated timbers are predominantly from bay 1, with only a single timber being dated from each of the trusses. It is unfortunate that the dated timbers are not spread more evenly throughout the medieval structure, but this was unavoidable due to the lack of suitable timbers for analysis associated with the two trusses. The analysis clearly indicates that the seven dated timbers are broadly coeval, but the lack of sapwood on all but one of these timbers and the lack of conclusive intra-site cross-matching between the six timbers without sapwood and the single one with sapwood makes interpretation somewhat more difficult. These difficulties are exacerbated by the fact that the only two timbers with sapwood (one dated; one not dated) clearly have fewer than the expected number of sapwood rings. It is therefore possible that this timber assemblage from the hall house could generally have relatively small numbers of sapwood rings, though this clearly remains unproven. Thus it is feasible that the dated samples with no trace of sapwood were felled slightly earlier than the AD 1325 earliest date indicated above. The buildings analysis points strongly towards the entire extant medieval structure being integral. This, combined with the evidence from the dendrochronological analysis, suggests the possibility that all seven dated timbers were felled in the mid-AD 1320s, which is clearly in broad accordance with the stylistic dating evidence. However, it should be noted that this mid-AD 1320s construction date is actually based on an estimated felling date from a single timber.

The timbers analysed clearly demonstrate the variable nature of the material used in the hall house. The seven dated timbers are derived from relatively slow-grown trees, some of which had reached in excess of 200 years when felled. However, it is noticeable that the four measured but undated timbers were derived from faster grown, potentially younger trees. These four timbers are the crown post, a base cruck, and both upper crucks from truss B which, along with the other unsampled cruck from Truss A, are generally those timbers of the largest scantling. This could imply that these trees were specifically chosen 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. It seems likely that these two potentially slightly different sources of timber are both relatively local, though this suggestion is unsupported for the undated faster grown material. However, site chronology BHBCSQ01 produces many of the highest *t*-values, and thus shows the greatest degree of similarity, with reference chronologies from the south-west region (Table 2). This includes several from Wiltshire but the most notable is the match with the site chronology from Court Farm (now Winterbourne Court) barn, Winterbourne, in the very outer suburbs of Bristol, approximately 35km west of Bremhill. Court Farm barn is a rare example of a large multi-bayed barn built for a secular landowner and has been dated by dendrochronology to the early AD 1340s (Miles 2001; Verey and Brooks 2002).

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# TABLES

*Table 1: Details of tree-ring samples from the east wing roof of Bremhill Court, Bremhill, Wiltshire*

| Sample number | Sample location | Total rings | Average ring width (mm) | Sapwood rings | Cross-section dimensions (mm) | First measured ring date (AD) | Last heartwood ring date (AD) | Last measured ring date (AD) |
|---|---|---|---|---|---|---|---|---|
| BHB-C01 | Truss B north base cruck | 60 | 2.33 | no h/s | 230 x ? | -- | -- | -- |
| BHB-C02 | Truss B north arch brace | nm | -- | -- | 280 x140 | -- | -- | -- |
| BHB-C03 | Truss B tie beam | 123 | 1.44 | no h/s | 340 x 300 | 1187 | -- | 1309 |
| BHB-C04 | Bay 1 north roof plate | 155 | 1.02 | no h/s | 160 x 260 | 1111 | -- | 1265 |
| BHB-C05 | Truss B north upper cruck | 80 | 3.05 | 13C | 280 x 220 | -- | -- | -- |
| BHB-C06 | Truss B crown post | 68 | 4.29 | no h/s | 190 x 270 | -- | -- | -- |
| BHB-C07 | Truss B south upper cruck | 58 | 2.00 | 2 | 360 x 210 | -- | -- | -- |
| BHB-C08 | Bay 1 south roof plate | 111 | 0.87 | no h/s | 120 x 110 | 1157 | -- | 1267 |
| BHB-C09 | Bay 1 north windbrace | 93 | 1.33 | no h/s | 330 x ? | 1133 | -- | 1225 |
| BHB-C10 | Bay 1 south common rafter | 89 | 1.63 | no h/s | 100 x 130 | 1220 | -- | 1308 |
| BHB-C11 | Bay 1 crown plate | 51 | 1.46 | 10c | 120 x 120 | 1273 | 1313 | 1323 |
| BHB-C12 | Truss A south base cruck | 169 | 1.27 | no h/s | 320 x 240 | 1124 | -- | 1292 |

nm = not measured
h/s = the heartwood/sapwood ring is the last ring on the sample
c = there was complete sapwood present on the timber but some was lost during coring; up to 3mm of sapwood were lost from BHB-C11
C = complete sapwood is present on the sample; BHB-C05 was felled in late spring/early summer of relative year 81
The second dimensions are not known for BHB-C01 and BHB-C09 as they were partially embedded within the buildings fabric

*Table 2: Results of the cross-matching of sample BHB-C11 and relevant reference chronologies when the first-ring date is AD 1273 and the last-ring date is AD 1323*

| Reference chronology | t-value | Span of chronology | Reference |
|---|---|---|---|
| Court Farm Barn, Winterbourne, Gloucestershire | 9.1 | AD 1177–1341 | (Miles 2001) |
| St Catherine's Chapel, Wells Cathedral, Somerset | 7.7 | AD 1169–1325 | (Arnold *et al* 2004a) |
| Muchelney Abbey, Muchelney, Somerset | 7.3 | AD 1148–1498 | (Bridge 2002a) |
| New Inn House, Kingswood, Gloucestershire | 6.2 | AD 1191–1519 | (Arnold *et al* 2004b) |
| Bridge Farm, Butleigh, Somerset | 5.8 | AD 1195–1331 | (Miles *et al* 1997) |
| Long Sutton Courthouse, Somerset | 5.5 | AD 1174–1327 | (Miles *et al* 1997) |
| Bradford on Avon tithe barn, Wiltshire | 5.4 | AD 1174–1324 | (Groves and Hillam1994) |
| Meare Manor Farmhouse, Meare, Somerset | 5.2 | AD 1156–1315 | (Bridge 2002b) |

*Table 3: Results of the cross-matching of site sequence BHBCSQ01 and relevant reference chronologies when the first-ring date is AD 1111 and the last-ring date is AD 1323*

| Reference chronology | *t*-value | Span of chronology | Reference |
|---|---|---|---|
| Court Farm Barn, Winterbourne, Gloucestershire | 14.2 | AD 1177–1341 | (Miles 2001) |
| Fiddleford Manor, Sturminster Newton, Dorset | 10.2 | AD 1167–1315 | (Bridge 2003) |
| The Manor Barn, Avebury, Wiltshire | 9.8 | AD 1072–1278 | (Tyers 1999) |
| Abbey Barn, Glastonbury, Somerset | 9.8 | AD 1095–1334 | (Bridge 2001) |
| St Catherine's Chapel, Wells Cathedral, Somerset | 9.4 | AD 1169–1325 | (Arnold *et al* 2004a) |
| Bradford on Avon tithe barn, Wiltshire | 8.5 | AD 1174–1324 | (Groves and Hillam1994) |
| Salisbury Cathedral spire and tower, Wiltshire | 8.5 | AD 1053–1241 | (Miles *et al* 2004) |
| Apshill House, Lower Chicksgrove, Wiltshire | 8.5 | AD 1080–1332 | (Hurford *et al* forthcoming) |

*Table 4: Matrix showing the t-values obtained between the ring sequences in site chronology BHBCSQ01; - indicates t-values less than 3.00; \ indicates overlap of less than 30 years*

| Samples | BHB-C04 | BHB-C08 | BHB-C09 | BHB-C10 | BHB-C11 | BHB-C12 |
|---|---|---|---|---|---|---|
| BHB-C03 | 4.75 | 4.22 | - | 4.31 | 5.21 | 4.19 |
| BHB-C04 | | 9.32 | 6.20 | 4.90 | \ | 7.23 |
| BHB-C08 | | | 4.89 | 4.49 | \ | 7.57 |
| BHB-C09 | | | | \ | \ | 4.18 |
| BHB-C10 | | | | | 3.78 | 6.53 |
| BHB-C11 | | | | | | \ |

# FIGURES

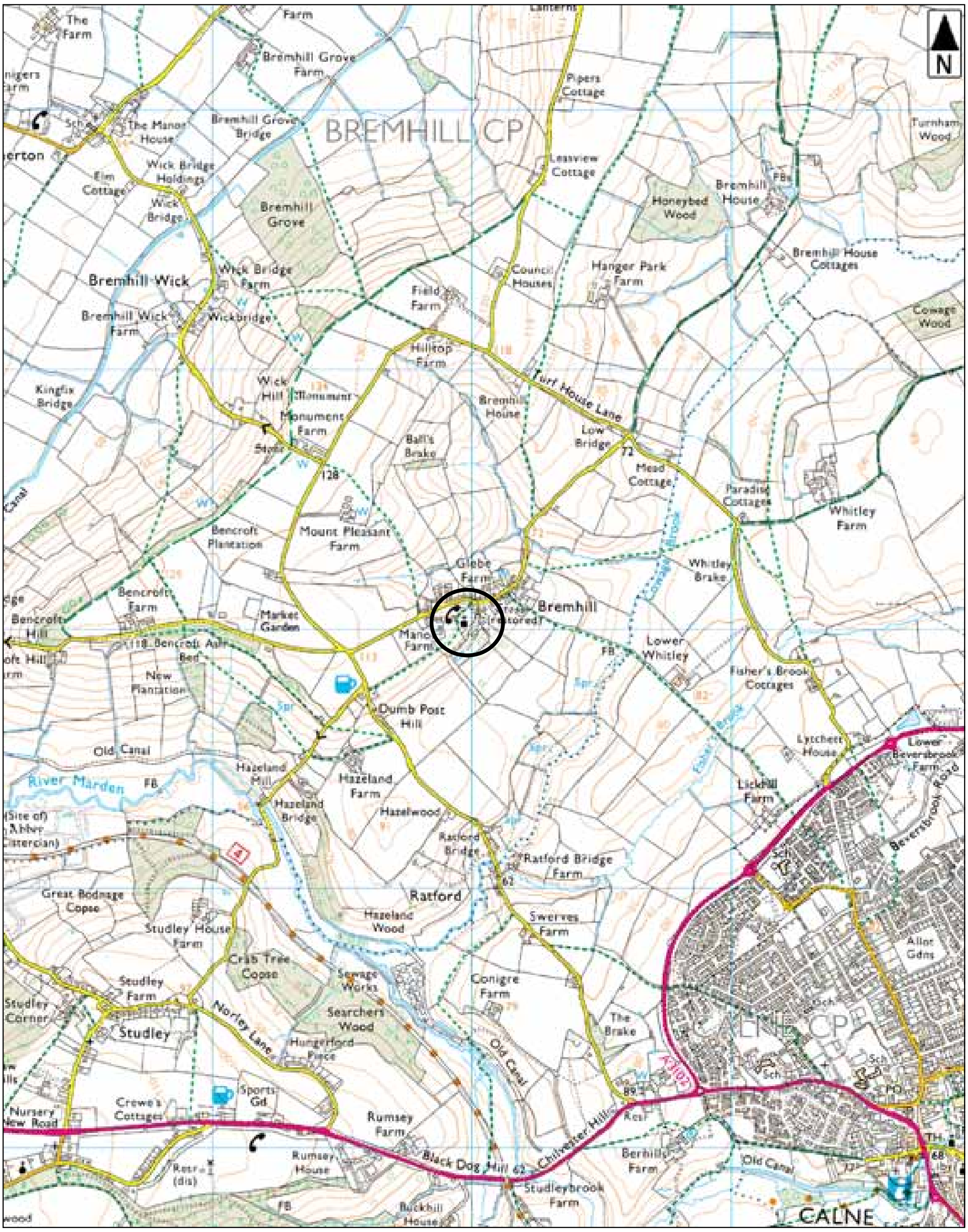


*Figure 1: Map to show the location of Bremhill Court, Bremhill, Wiltshire (based on the Ordnance Survey map with permission of the Controller of Her Majesty's Stationery Office, © Crown Copyright)*

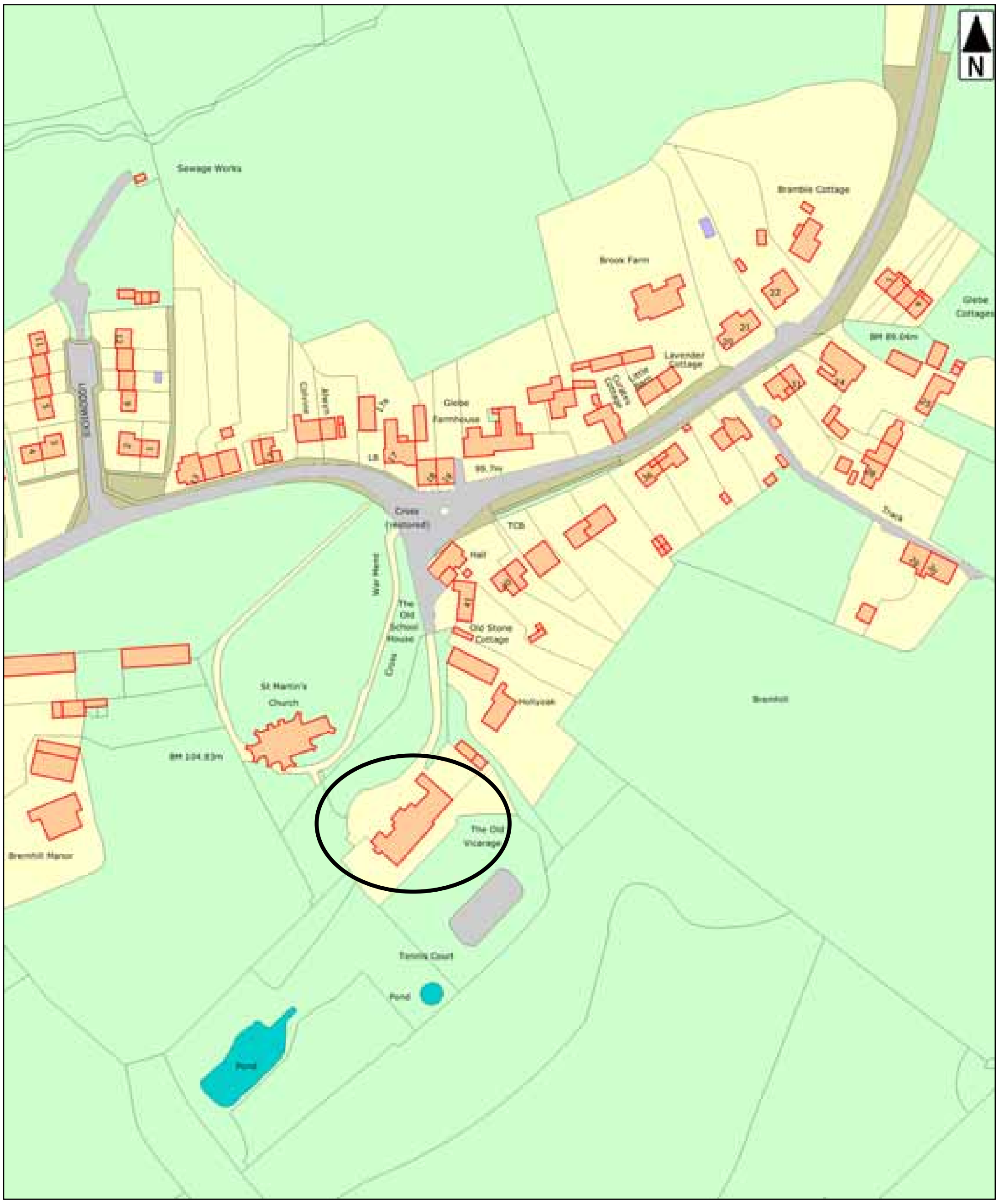



*Figure 2: Map to show the location Bremhill Court within the village of Bremhill (based on the Ordnance Survey map with permission of the Controller of Her Majesty's Stationery Office, © Crown Copyright)*


*Figure 3: The north elevation of Bremhill Court showing truss locations viewed looking south-east*

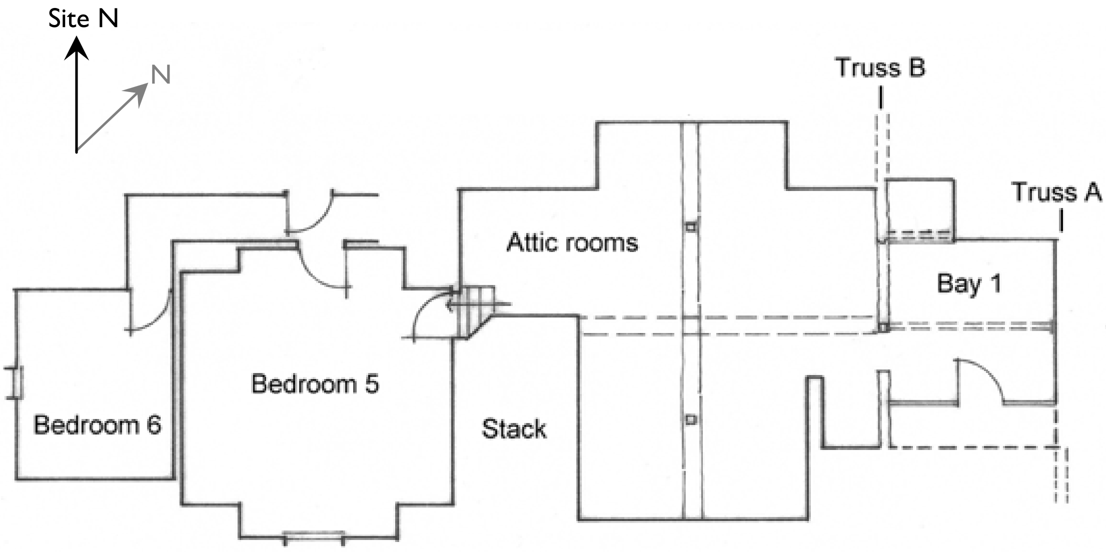



*Figure 4: General plan of Bremhill Court (based on a drawing by Clive Carter of the Wiltshire Building Record)*

*Figure 5: Crown post of Truss B with Truss A in the background, viewed looking south-east*

*Figure 6: Truss B viewed looking east*

*Figure 7:  Detail of the Arabic assembly marks on the west face of the upward braces from the Truss B crown post to the upper crucks viewed looking east*

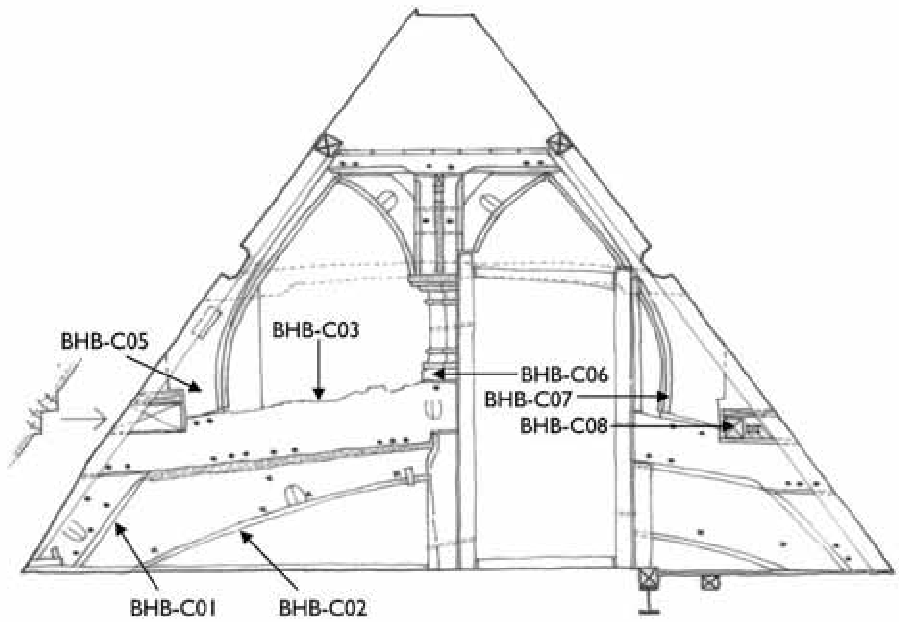



*Figure 8:  Truss B west face sample locations (based on a drawing by Clive Carter of the Wiltshire Building Record)*

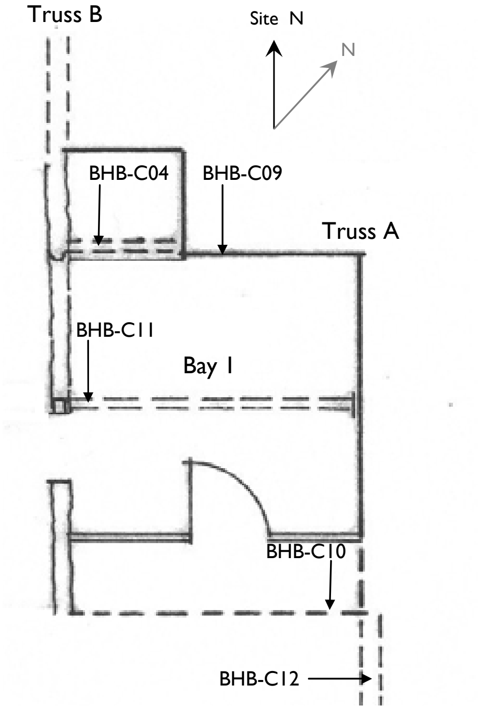
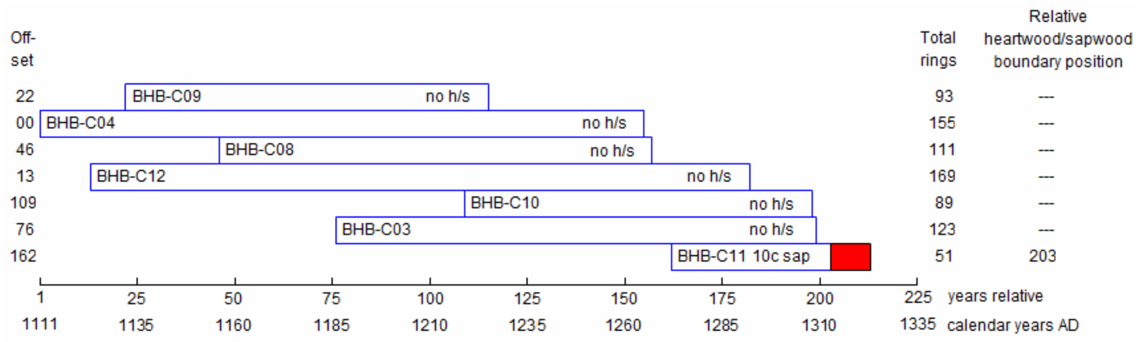



*Figure 9: Bay 1 sample location plan (based on a drawing by Clive Carter of the Wiltshire Building Record)*




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 exists on the timber but part of the sapwood on the sample has been lost during coring

*Figure 10: Bar diagram of the samples in site chronology BHBCSQ01*

## DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

BHB-C01A 60
307 299 519 305 293 257 325 468 479 391 228 198 300 277 332 256 344 272 224 317
223 183 258 223 312 308 310 371 397 235 230 208 169 186 264 284 144 147 121 157
209 191 133 150 98 151 138 191 155 98 107 164 132 180 150 117 129 131 91 137
BHB-C01B 60
318 284 517 315 289 248 317 464 471 397 228 213 301 277 331 257 342 271 241 317
220 179 251 238 320 310 301 376 395 211 226 197 176 170 284 291 154 146 132 161
207 236 144 161 112 136 113 184 157 99 117 164 130 178 152 131 122 142 77 129
BHB-C03A 123
319 152 245 306 185 101 141 163 180 216 242 158 161 139 122 141 164 168 185 182
116 168 171 217 215 161 178 173 191 190 192 140 244 299 272 149 157 220 242 245
141 139 183 113 195 116 149 135 160 123 151 197 136 139 127 122 157 139 117 72
97 119 105 189 187 128 207 209 406 266 103 54 142 210 183 207 114 118 116 42
54 51 72 60 80 54 78 82 51 60 62 66 57 87 75 82 59 64 79 138
110 92 105 162 139 233 230 153 95 73 94 86 84 184 97 104 57 58 62 114
91 102 93
BHB-C03B 123
318 143 244 308 186 90 139 163 174 230 233 165 146 135 133 144 163 160 188 185
111 165 168 212 220 163 174 165 184 188 190 147 246 298 279 157 146 234 231 255
140 136 185 117 187 132 154 146 159 127 148 190 142 137 116 120 143 139 101 70
96 105 107 190 188 127 208 208 406 263 92 63 136 211 181 214 107 109 120 50
49 56 70 59 89 53 78 85 48 58 60 71 54 85 79 79 55 61 84 141
110 90 105 168 130 247 238 166 91 80 89 92 83 183 93 104 56 51 64 110
93 96 94
BHB-C04A 118
36 72 110 129 138 134 145 129 143 141 169 321 370 343 224 249 219 326 209 251
235 239 203 213 190 256 179 243 196 213 232 228 190 172 187 165 184 153 207 165
213 135 159 117 129 128 139 107 141 163 134 98 102 134 175 139 126 107 106 123
89 65 75 103 107 97 64 74 73 62 63 93 80 45 53 56 76 59 87 81
61 45 60 67 64 75 83 59 67 74 65 92 56 53 69 64 59 67 60 86
64 43 47 55 60 63 50 46 59 71 86 47 46 47 60 79 54 71
BHB-C04B 119
159 128 193 154 153 96 150 115 108 109 139 112 129 152 119 94 110 119 165 146
99 86 98 92 65 54 57 89 95 83 57 67 64 57 56 103 78 50 56 46
69 57 100 75 56 47 56 59 66 81 86 61 59 68 68 83 38 49 86 78
63 96 62 106 61 46 48 56 63 59 53 46 59 60 86 43 38 55 69 97
51 74 83 57 52 42 35 69 49 55 70 53 74 56 59 42 69 81 79 80
87 41 76 81 109 89 124 125 128 121 63 61 62 63 100 112 100 105 154
BHB-C05A 80
476 417 391 343 583 414 169 336 342 296 199 329 383 350 322 375 381 355 367 345
559 307 274 346 296 329 310 225 326 227 226 226 280 254 344 223 325 276 288 380
298 276 259 260 315 195 259 278 257 325 201 227 202 202 317 403 271 194 240 274
310 292 252 266 307 365 322 250 217 261 383 297 330 242 329 322 370 287 254 304
BHB-C05B 80
475 428 403 344 577 415 174 331 337 299 197 323 396 341 324 378 376 358 365 342
557 305 282 328 299 320 318 228 316 240 216 224 277 257 323 240 298 268 291 370
295 279 252 271 308 196 259 277 255 324 199 235 182 210 318 400 276 190 251 276
308 294 242 275 301 360 326 244 219 268 381 302 352 250 336 312 363 291 267 296

BHB-C06A 68
233 204 403 476 481 592 537 586 628 489 490 380 438 367 483 425 672 643 538 780
542 635 671 500 422 509 493 583 425 379 384 389 449 496 578 492 366 481 408 394
510 551 423 326 326 384 272 354 345 401 403 140 154 212 292 352 360 335 354 356
349 327 276 378 342 451 333 395
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241 204 400 482 501 618 541 584 640 483 490 381 434 358 494 432 669 638 544 772
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380 483 231 320 363 244 292 406 387 252 232 298 332 174 208 254 192 157 163 132
189 137 169 191 165 115 166 174 144 111 145 207 210 202 162 125 153 68 112 167
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386 493 221 325 366 241 297 405 389 256 224 308 336 176 216 247 191 159 165 139
190 121 174 189 163 117 165 176 151 110 138 205 219 187 168 133 141 74 104 170
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47 55 48 38 35 40 36 42 32 33 22 37 35 29 36 31 56 69 41 36
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BHB-C10A 89
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180 150 128 186 183 139 139 136 84 76 107 100 103 99 125 196 126 86 95 91
122 169 182 145 136 126 97 89 166 137 138 202 212 302 160 160 162 206 195 154
133 160 185 218 217 188 260 179 146 211 290 209 445 262 248 178 120 112 122 116
129 164 210 191 146 134 200 197 134
BHB-C10B 89
78 95 76 57 90 104 193 163 276 369 212 120 91 109 162 229 140 284 225 156
187 146 127 186 179 139 138 141 81 72 108 102 102 98 122 196 126 85 103 85

125 169 177 148 141 128 92 90 166 130 143 202 216 300 161 158 164 211 190 156
131 159 189 217 217 193 248 170 137 215 290 207 446 268 240 181 124 110 121 114
131 159 212 194 149 134 203 205 138
BHB-C11A 51
295 205 75 84 111 120 139 171 179 164 204 134 192 203 158 83 151 255 160 234
217 180 144 175 181 126 152 188 156 172 99 101 89 204 149 108 95 72 92 101
113 109 130 141 110 94 115 129 125 115 113
BHB-C11B 51
294 217 78 79 118 120 142 166 193 155 213 117 195 203 161 84 152 252 168 240
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112 107 131 138 111 91 116 130 123 114 108
BHB-C12A 169
277 239 376 341 250 157 212 245 164 171 193 212 228 144 292 312 485 412 267 224
297 247 160 126 105 152 146 174 122 239 172 144 153 164 140 172 163 158 165 135
147 194 167 127 139 137 141 111 120 113 151 152 156 84 88 78 63 64 108 54
54 82 80 146 75 109 93 87 72 99 128 103 130 118 152 91 113 103 126 85
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45 58 70 58 67 97 66 61 51 58 60 84 57 94 101 101 90 92 84 92
93 78 80 71 37 49 63 61 69 82 56 86 73 57 52 62 74 59 76 59
76 79 79 71 88 54 52 115 141 141 105 102 103 115 125 175 169 153 160 207
171 174 188 124 137 150 214 187 241
BHB-C12B 169
290 235 375 330 260 156 211 241 168 167 195 215 228 140 298 312 487 416 265 220
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90 80 88 60 52 40 59 59 69 74 62 81 80 54 48 68 60 67 73 66
83 72 78 73 84 62 53 108 135 144 109 98 105 119 125 171 170 153 163 201
170 169 196 137 128 147 203 171 240

# 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

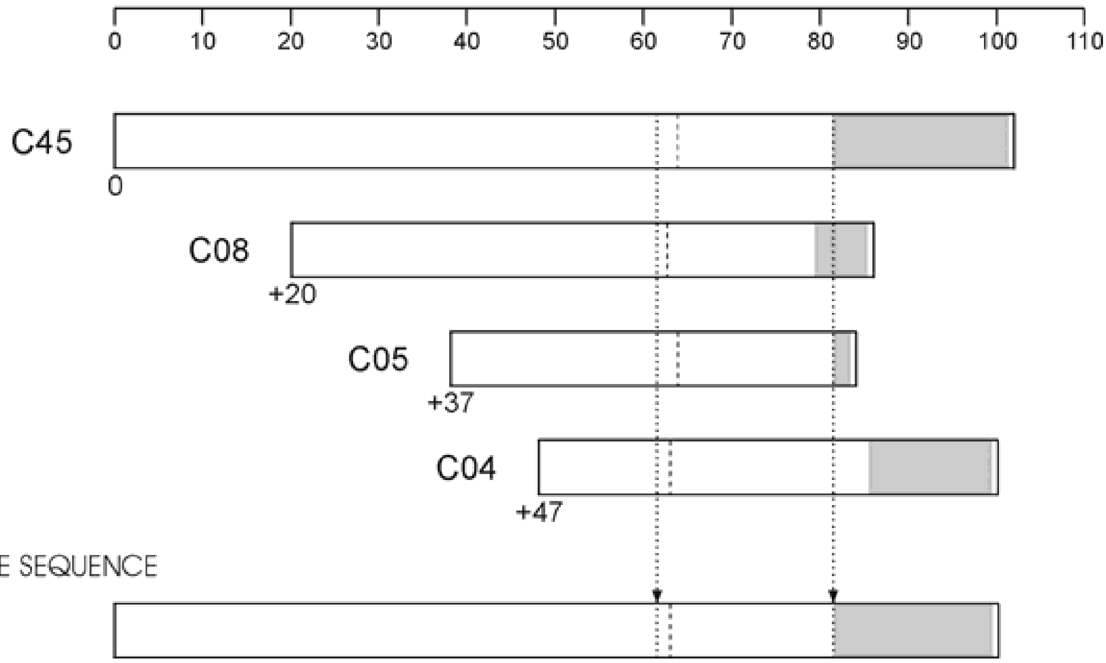



*Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them*

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

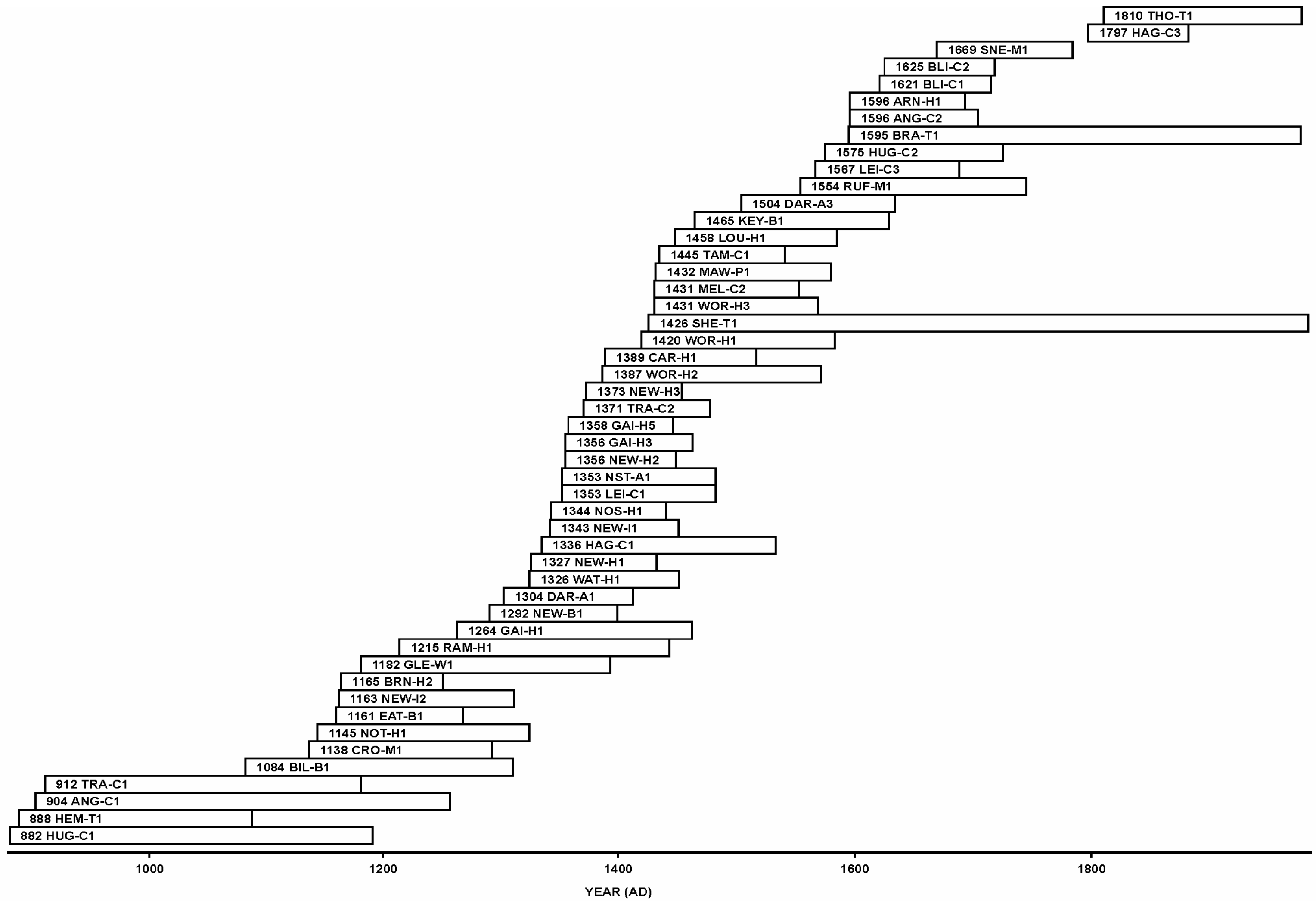
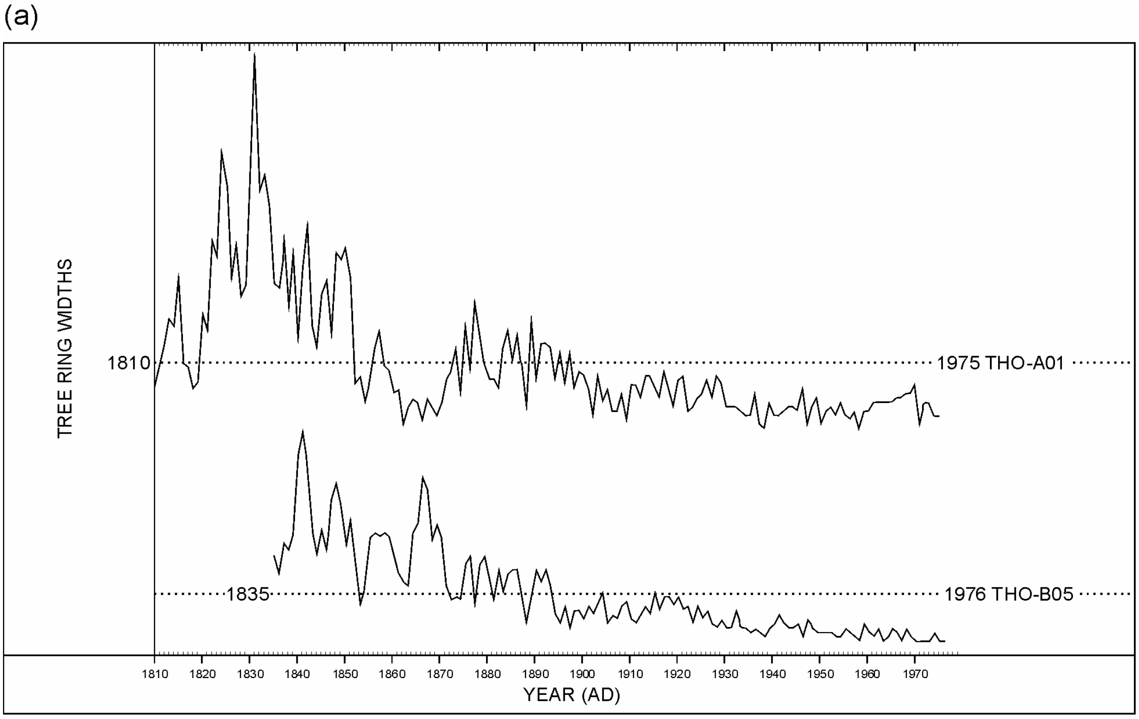



*Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87*



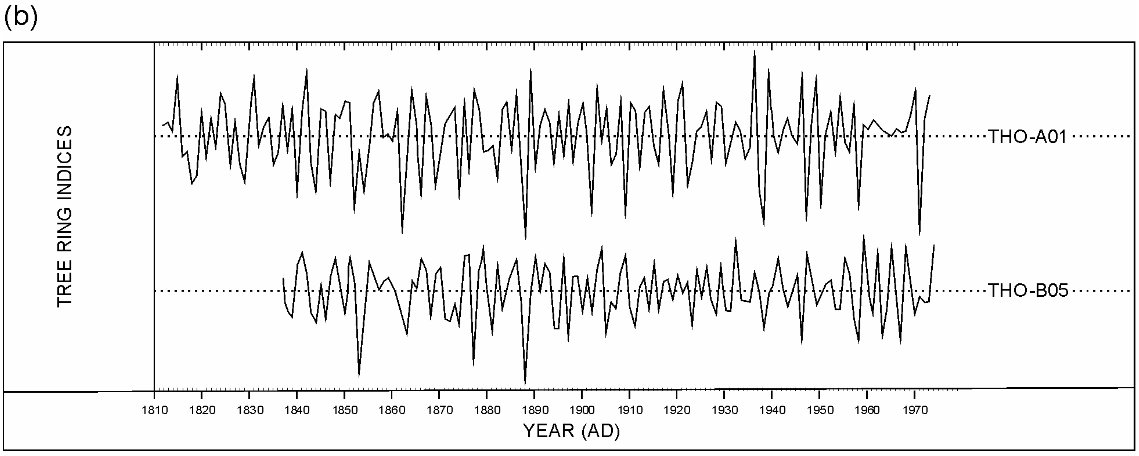




*Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known*

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

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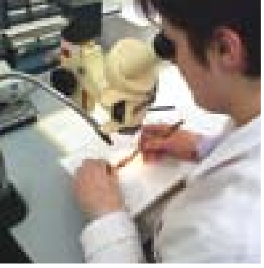
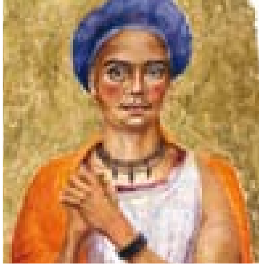



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