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CHURCH OF ST ANDREW, FENITON COURT, FENITON, DEVON
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold, Robert Howard and Matt Hurford

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SUMMARY

Dendrochronological analysis was undertaken on timbers of the south aisle and nave roofs at this church.

Seven samples from the timbers of the south aisle roof grouped to form three site sequences, which were successfully matched against the reference material to span the periods AD 1386–1477, AD 1422–79, and AD 1377–1471. A single sample, FEN-C07, was dated individually to the period AD 1409–73. Interpretation of the heartwood/sapwood boundary on these dated samples suggests felling of the timbers represented in AD 1489–1514.

Prior to tree-ring analysis, the south aisle had been attributed to Joan Malherbe and her second husband, some time between *c* AD 1520 and her death in AD 1554, although stylistically it was felt to be slightly earlier. The dendrochronology has now demonstrated that the roof over this part of the church contains timber of the late fifteenth or early-sixteenth century.

Two site sequences containing samples from the nave roof were also constructed, but could not be dated.

CONTRIBUTORS

Alison Arnold, Robert Howard, and Matt Hurford

ACKNOWLEDGEMENTS

The Laboratory would like to thank John Allen of Exeter Archaeology who arranged access and provided invaluable on-site advice. The description of the south aisle roof, below, is based on his survey of this part of the church and he provided the drawings on which samples have been located.

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DATE OF INVESTIGATION

2008

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INTRODUCTION

The Grade II* listed parish church of Feniton is located a few miles to the west of Honiton (SY 109 994; Figs 1 and 2) in the county of Devon. It consists of nave and chancel (which includes the Patteson Chapel, so named after John Coleridge Patteson, the missionary bishop who died in Melanesia in 1871), the south aisle, which runs the full length of both of these, west tower, and north transept and vestry to the north of the chancel. There is a porch in the angle of the tower and south aisle. Although the church has its origins in the Norman period, parts are thought to date to the fifteenth and early-sixteenth centuries and it is known to have undergone substantial renovations in AD 1877. This is believed to have included some work on the roofs of the nave and south aisle.

The south aisle is of six bays and seven trusses, with each truss consisting of principal rafters, cranked tiebeams, and braces which rise from the tiebeam to the principals. These latter elements are thought to be later insertions. There is a diagonally set ridgepiece and two sets of purlins to each slope (Fig 3). Stylistically the aisle belongs to the late fifteenth or early-sixteenth century. Other dating is suggested by the punning devices of the Ferrers family, the Malherbes, and the Kirkhams, displayed on the arcade capitals. Together these refer to Joan Malherbe, the daughter and heiress of William Malherbe, whose first marriage was to Richard Ferrers, and those second was to John Kirkham. On this evidence it has been suggested that Joan Malherbe was the patron of the building programme, perhaps with John Kirkham. Although it is not known when these two married, it has been suggested that, since John Kirkham became Sheriff of Devon in AD 1522, construction of the south aisle is likely have occurred some time from *c* AD 1522 and Joan Malherbe's death in AD 1554.

The roof over the nave is of a type known as wagon roof. It consists of 28 pairs of rafters, upper and lower arch braces, and collars (Figs 4 and 5). This type of roof is a particular feature of the south-west and research undertaken by this Laboratory on roofs of this type has successfully dated timbers from a number of these to the fifteenth and sixteenth centuries, such as at St Veep (Arnold *et al* 2005), East Looe (Arnold *et al* 2006a), Lansallos (Arnold *et al* 2006b), and St Teath (Arnold *et al* 2007).

This description has been based on the building's Listing Description (www.imagesofengland.co.uk) and the survey of the south aisle roof undertaken by John Allen of Exeter Archaeology (2007).

SAMPLING

Tree-ring dating of the nave and south aisle roofs of the Church of St Andrew was requested by Jenny Chesher, Historic Buildings Inspector at English Heritage's Bristol office, to inform statutory advice in the context of repairs taking place to all the roofs. It was hoped that successful dating of the timbers of the nave and south aisle roofs would provide an accurate date for their construction and establish the relative relationship between the two structures. Additionally, it was hoped to ascertain the extent of the survival of historic fabric and identify any secondary phases of work within the roofs.

A total of 34 timbers was sampled. Each sample was given the code FEN-C (for Feniton Church) and numbered 01–34. Nineteen of these were taken from the timbers of the south aisle roof (FEN-C01–19) and the other 15 from the timbers of the nave roof (FEN-C20–34). The location of samples was noted at the time of sampling and has been marked on Figures 6–18. Further details relating to the samples can be found in Table 1. Roof trusses and frames have been numbered from east to west (Fig 6).

ANALYSIS AND RESULTS

At this stage it was noticed that six of the samples from the south aisle roof (FEN-C01, FEN-C08, FEN-C09, FEN-C10, FEN-C18, and FEN-C19) had too few rings to make secure dating a possibility. These samples were rejected prior to measurement. The remaining 28 samples were prepared by sanding and polishing and their growth-ring widths measured; the data of these measurements are given at the end of the report. The samples were then divided into nave and south aisle samples and each set of samples compared with each other by the Litton/Zainodin grouping procedure (see Appendix).

South aisle roof

At a least value of t=4.5, seven samples grouped to form three site sequences. Firstly, two samples matched each other and were combined at the relevant off-set positions to form FENCSQ01, a site sequence of 92 rings (Fig 19). This site sequence was then compared against a large number of relevant reference chronologies where it was found to have a consistent match at the first-ring date of AD 1386 and the last-measured ring date of AD 1477. The evidence for this dating is given by the *t*-values in Table 2.

A further two samples matched each other and were again combined at the relevant off-set positions to form FENCSQ02, a site sequence of 58 rings (Fig 19). This site sequence was found to have a secure and consistent match at a first-ring date of AD 1422 and a last-measured ring date of AD 1479. The evidence for this dating is given by the *t*-values in Table 3.

Finally, three samples matched and were combined at the relevant off-set positions to form FENCSQ03, a site sequence of 95 rings (Fig 19). When compared against the relevant reference chronologies a consistent match was found when the first-ring date was AD 1377 and the last-measured ring date AD 1471. The evidence for this dating is given by the *t*-values in Table 4. Although consistent, the matching is not as good as one would hope and it was thought possible that a series of compacted rings towards the end of the site sequence might be adversely influencing the matching. Therefore, the last 20 rings were removed and the resultant site sequence of 75 rings was again compared against the reference material when it was found to produce greatly improved *t*-values (Table 4) at the expected date.

Attempts were then made to date the remaining ungrouped south aisle samples by individually comparing them against the reference material. This resulted in sample FEN-C07 matching at a first-ring date of AD 1409 and a last-measured ring date of AD 1473 (Table 5). The remaining samples could not be matched and remain undated.

The analysis has resulted in the successful dating of eight of the south aisle timbers. Five of these dated samples have the heartwood/sapwood boundary ring, the dates of which are broadly contemporary and suggestive of a single felling (Fig 19). The average heartwood/sapwood boundary ring date for these five samples is AD 1474, allowing an estimated felling date to be calculated for the five timbers represented to the range AD 1489–1514. The remaining three dated samples do not have the heartwood/sapwood boundary ring and so estimated felling dates cannot be calculated for them. However, with last-measured ring dates of AD 1467 (FEN-C11), AD 1450 (FEN-C16), and AD 1455 (FEN-C17) it is quite possible that these timbers were also felled in the late fifteenth or early-sixteenth century.

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

Nave roof

Analysis of these samples resulted in six samples forming two groups. Firstly, three samples matched each other and were combined to form FENCSQ04, a site sequence of 111 rings (Fig 20). A further three samples matched and were combined to form FENCSQ05, a site sequence of 79 rings (Fig 21). Attempts to date these two site sequences and the remaining ungrouped nave samples by comparing them against the reference chronologies were unsuccessful and all remain undated.

DISCUSSION AND CONCLUSION

Prior to the tree-ring analysis being undertaken, both the nave and south aisle roofs had been dated stylistically to the fifteenth or sixteenth century. Furthermore, it had been suggested that the south aisle was associated with Joan Malherbe and her second husband, John Kirkham, with the proposed construction date being *c* AD 1520–54 (Allen 2007). It was thought that repairs had been undertaken on both of these roofs during the restoration of the church in AD 1877 and it was hoped that dendrochronology might identify the extent of survival of historic timber and any secondary modifications.

It is now known that the south aisle roof contains timber felled in AD 1489–1514, supporting the late fifteenth/early-sixteenth century date assigned to it on stylistic grounds but slightly earlier than that suggested by other evidence. The dated timbers consist of four tiebeams, three principal rafters, and a plate, all major structural elements. It is still possible that Joan Malherbe was the patron of this work, but it does now seem unlikely that construction was undertaken during her marriage to John Kirkham, unless they married earlier than the suggested date of *c* AD 1520. Having said this, it should be noted that the precise date of their wedding is not recorded in any readily available sources. Alternatively, it may be the case that the decoration on the arcade capitals was a later addition, as suggested by Cresswell (1919), or at least the Kirkham family detail was added post-construction, perhaps in recognition of Joan Malherbe's new husband.

It is unfortunate that neither of the two sampled struts (FEN-C18 and FEN-C19) had sufficient number of rings to warrant measurement and analysis, as it would have been useful to have been able to confirm or refute the suggestion that these are later modifications, perhaps belonging to the repair campaign of AD 1877.

Although neither of the two site sequences constructed from timbers of the nave roof could be dated, it is possible to make some observations about them. By looking at the relative heartwood/sapwood boundary ring positions, where present, of the samples making up sequence FENCSQ04 and FENCSQ05, it is possible to say that in both cases at least two timbers would have probably been felled at the same time (Figs 20 and 21). However, whether those timbers represented by the samples in FENCSQ04 were felled at the same time as those in FENCSQ05 is not known. Also worth noting is that all three samples in FENCSQ04 are common rafters, whereas those in FENCSQ05 are collars.

Generally, there is poor intra-site matching of samples in both the nave and the south aisle roofs, with analysis of the former producing two separate site sequences and nine ungrouped samples and the latter three separate site sequences and seven ungrouped samples. Certainly, this will have made successful dating more difficult, as the better-replicated a site sequence is, the more chance there is of matching it against the reference material. This seems to be especially important in the south-west where, despite recent successes, tree-ring dating is still problematic. In the case of the south aisle samples, where a proportion of the timber is now known to be of the same date, this poor grouping suggests that rather than using a coherent group of trees from a single source for the timber, the joiners responsible utilised a disparate series of trees from potentially diverse sources. Of course, with no samples dating from the nave roof it is not possible to say whether this is the same situation or whether more than one phase of construction is represented amongst the timbers.

BIBLIOGRAPHY

Allen, J, 2007 *Initial archaeological report on the south aisle roof of St Andrew's Church, Feniton*, Exeter Archaeological Rep 07.28

Arnold, A J, Howard, R E, and Litton, C D, 2005 *Tree-ring analysis of roof timbers at the church of St Ciricus and St Julitta, St Veep, near Lostwithiel, Cornwall*, Centre for Archaeol Rep, 47/2005

Arnold, A J, Howard, R E, and Litton, C D, 2006a *Tree-ring analysis of roof timbers at the church of St Martin, East Looe, Cornwall*, EH Res Dep Rep Series, 46/2006

Arnold A, J and Howard, R, 2006b *Church of St Ildierna, Lansallos, Cornwall tree-ring dating of timbers from the roofs and pews*, EH Res Dep Rep Ser, 49/2006

Arnold, A J, and Howard, R E, 2007 *St Tetha's Church, St Teath, Cornwall, tree-ring analysis of timbers from the roofs and pews*, EH Res Dep Rep Ser, 58/2007

Bridge, M, 1993 London Guildhall University tree-ring dates, *Vernacular Architect*, 24, 48–50

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

Bridge, M, 2005 *Tree-ring analysis of timbers from ringing-chamber floor to the tower, Church of St Mary the Virgin, Axminster, Devon*, Centre for Archaeol Rep, 53/2005

Bridge, M, and Miles, D, 2004 *The tree-ring analysis of timbers from Tickenham Court, Church Lane, Tickenham, near Nailsea, Somerset*, Centre for Archaeol Rep, 45/2004

Cresswell, B F, 1919 The Fabric and Features of Interest in the Churches of the Deanery of Ottery St Mary, Typescript, West Country Studies Library, Exeter

Groves, C, 2006 *Leigh Barton, Churchstow, Devon: Scientific Dating Report - Tree-Ring Analysis of Timbers*, EH Res Dept Rep Ser, 10/2006

Hillam, J and Groves, C, 1993 Tree-ring dates from Sheffield University, *Vernacular Architect*, 24, 46–48

Howard, R E, Laxton, R R, and Litton, 1998 *Tree-ring analysis of timbers from Naas House, Lydney, Gloucestershire*, Anc Mon Lab Rep, 36/1998

Howard, R E, 2002 unpubl, composite site chronology for Ightham Mote, Ivy Hatch, Kent, unpubl computer file KIMASQ01 / 02 / 03, Nottingham Univ Tree-Ring Dating Laboratory

Howard, R, Litton, C, Arnold, A, and Tyers C, 2006 *Tree-ring analysis of timbers from Warleigh House, Tamerton Foliot, Bickleigh, South Hams, near Plymouth, Devon*, EH Research Dept Rep Series, 38/2006

Miles, D, 1998 unpubl, site chronology from Bishops Palace, Salisbury Chapel, Wiltshire, Oxford Laboratory

Miles, D 2003 Dating buildings and dendrochronology, in *Hampshire in Hampshire Houses 1250–1700: Their Dating and Development* (E Roberts), 220–6

Miles, D H, and Worthington, M J, 1998 Tree-ring dates for buildings: List 90, *Vernacular Architect*, 29, 111–7

Tyers, I, 1993 *Queen Elizabeth's Hunting Lodge*, MoLAS Dendro Rep, 02/93

Tyers, I, 1994 *Tree-ring analysis of oak timbers from Lancin Farmhouse, Wambrook, Somerset*, Anc Mon Lab Rep, 61/94

Tyers, I, 2000 *Tree-ring analysis of oak timbers from the church of St Swithin, Clunbury, Shropshire*, Anc Mon Lab Rep, 8/2000

Tyers, I, 2004a *Tree-ring analysis of oak timbers from Pendennis Castle, near Falmouth, Cornwall*, Centre for Archaeol Rep, 38/2004

Tyers, I, 2004b *Tree-ring analysis of oak timbers from Roscarrock, near Port Isaac, Cornwall*, Centre for Archaeol Rep, 30/2004

Tyers, I, and Groves, C, 2003 Tree-ring dates from Sheffield University: List 136, *Vernacular Architect*, 34, 98–101

TABLES

Table 1: Details of tree-ring samples from the Church of St Andrew, Feniton Court, Devon

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Aisle roof						
FEN-C01	Tiebeam, truss 1	NM	--	----	----	----
FEN-C02	North principal rafter, truss 1	53	h/s	----	----	----
FEN-C03	Tiebeam, truss 2	54	h/s	1426	1479	1479
FEN-C04	Tiebeam, truss 3	92	h/s	1386	1477	1477
FEN-C05	North principal rafter, truss 3	47	h/s	----	----	----
FEN-C06	North principal rafter, truss 4	78	h/s	----	----	----
FEN-C07	Tiebeam, truss 4	65	h/s	1409	1473	1473
FEN-C08	North principal rafter, truss 5	NM	--	----	----	----
FEN-C09	South principal rafter, truss 5	NM	--	----	----	----
FEN-C10	Tiebeam, truss 5	NM	--	----	----	----
FEN-C11	Mid-plate, bay 5 (truss 5-6)	53	--	1415	----	1467
FEN-C12	North upper purlin, trusses 5-6	44	04	----	----	----
FEN-C13	North principal rafter, truss 6	54	h/s	----	----	----
FEN-C14	South principal rafter, truss 6	61	h/s	1411	1471	1471
FEN-C15	Tiebeam, truss 6	50	h/s	1422	1471	1471
FEN-C16	North principal rafter, truss 7	66	--	1385	----	1450
FEN-C17	South principal rafter, truss 7	79	--	1377	----	1455
FEN-C18	North strut, truss 7	NM	--	----	----	----
FEN-C19	South strut, truss 7	NM	--	----	----	----

Table 1 (continued)

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Nave roof						
FEN-C20	North common rafter 3	79	--	----	----	----
FEN-C21	South common rafter 3	64	h/s	----	----	----
FEN-C22	North common rafter 8	91	h/s	----	----	----
FEN-C23	North common rafter 11	58	h/s	----	----	----
FEN-C24	South common rafter 13	98	--	----	----	----
FEN-C25	South common rafter 15	79	03	----	----	----
FEN-C26	North common rafter 18	94	h/s	----	----	----
FEN-C27	North common rafter 19	90	h/s	----	----	----
FEN-C28	Collar 4	58	h/s	----	----	----
FEN-C29	Collar 6	52	h/s	----	----	----
FEN-C30	Collar 10	64	h/s	----	----	----
FEN-C31	Collar 11	60	h/s	----	----	----
FEN-C32	Collar 12	59	--	----	----	----
FEN-C33	Collar 14	65	h/s	----	----	----
FEN-C34	Collar 18	62	03	----	----	----

*NM = not measured
**h/s = the heartwood/sapwood ring is the last ring on the sample

Table 2: Results of the cross-matching of site sequence FENCSQ01 and relevant reference chronologies when the first-ring date is AD 1386 and the last-ring date is AD 1477

Reference chronology	*t*-value	Span of chronology	Reference
Warleigh House, Tamerton Foliot, Devon	7.2	AD 1367–1539	Howard *et al* 2006
Devon county chronology	6.9	AD 775–1799	Tyers and Groves pers comm
Naas House, Lydney, Glos	6.7	AD 1373–1568	Howard *et al* 1998
Church of St Martin, East Looe, Cornwall	6.2	AD 1363–1518	Arnold *et al* 2006a
Townsend farmhouse, Stockland, Devon	6.2	AD 1422–84	Tyers and Groves 2003
Pendennis Castle, Cornwall	6.1	AD 1358–1541	Tyers 2004a
Church of St Ildierna, Lansallos, Cornwall	5.8	AD 1355–1514	Arnold and Howard 2006b

Table 3: Results of the cross-matching of site sequence FENCSQ02 and relevant reference chronologies when the first-ring date is AD 1422 and the last-ring date is AD 1479

Reference chronology	*t*-value	Span of chronology	Reference
Devon county chronology	6.7	AD 775–1799	Tyers and Groves pers comm.
Leigh Barton, Churchstow, Devon	6.0	AD 1345–1484	Groves 2006
St Teatha's Church, St Teath	5.4	AD 1362–1487	Arnold and Howard 2007
Church of St Martin, East Looe, Cornwall	5.4	AD 1363–1518	Arnold *et al* 2006a
Church of St Ildierna, Lansallos, Cornwall	5.3	AD 1355–1514	Arnold and Howard 2006b
Lancin Farmhouse, Wambrook, Somerset	5.3	AD 1374–1533	Tyers 1994
Woodhouse Farm, Staplow, Herefordshire	5.2	AD 1368–1558	Tyers pers comm

Table 4: Results of the cross-matching of site sequence FENCSQ03 and relevant reference chronologies when the first-ring date is AD 1377 and the last-ring date is AD 1471 and AD 1451 (truncated version)

Reference chronology	*t*-value (AD1471)	*t*-value (AD1451)	Span of chronology	Reference
Hampshire county chronology	4.8	5.6	AD 443–1972	Miles 2003
Ightham Mote, Kent	4.3	6.0	AD 1337–1580	Howard 2002 unpubl
Roscarrock, Cornwall	3.9	5.4	AD 1373–1500	Tyers 2004b
Devon county chronology	4.0	5.1	AD 775–1799	Tyers and Groves pers comm
Field Place Barn, West Sussex	4.7	5.1	AD 1309–1465	Bridge 1993
Tickenham Court, Somerset	3.4	4.8	AD 1372–1475	Bridge and Miles 2004
Clunbury Church, Shropshire	2.8	4.8	AD 1239–1494	Tyers 2000
Warleigh House, Tamerton Foliot, Devon	2.8	4.8	AD 1367–1539	Arnold *et al* 2005
South Coombe, Cheriton Fitzpaine, Devon	4.2	4.8	AD 1384–1513	Miles and Worthington 1998
South Yarde, Rose Ash, Devon	4.8	4.7	AD 1309–1447	Hillam and Groves 1993
Bishops Palace, Salisbury Chapel, Wiltshire	4.5	4.6	AD 1387–1540	Miles 1998 unpubl
Church of St Ciricus and St Julitta, St Veep, Cornwall	4.3	4.6	AD 1352–1512	Arnold *et al* 2005

Table 5: Results of the cross-matching of truncated site sequence FEN-C07 and relevant reference chronologies when the first-ring date is AD 1409 and the last-ring date is AD 1473

Reference chronology	*t*-value	Span of chronology	Reference
Devon county chronology	4.9	AD 775–1799	Tyers and Groves pers comm
St Mary's Church, Axminster, Devon	6.4	AD 1393–1520	Bridge 2005
Sherborne Abbey Church, Dorset	5.7	AD 770–1872	Bridge 1993
Queen Elizabeth Hunting Lodge, Chingford, London	5.6	AD 1398–1541	Tyers 1993
Church of St Ildierna, Lansallos, Cornwall	5.3	AD 1355–1514	Arnold and Howard 2006b
Muchelney Abbey, Somerset	5.2	AD 1148–1498	Bridge 2002
Tickenham Court, Somerset	4.7	AD 1372–1475	Bridge and Miles 2004

FIGURES

Figure 1: Map to show the location of Feniton

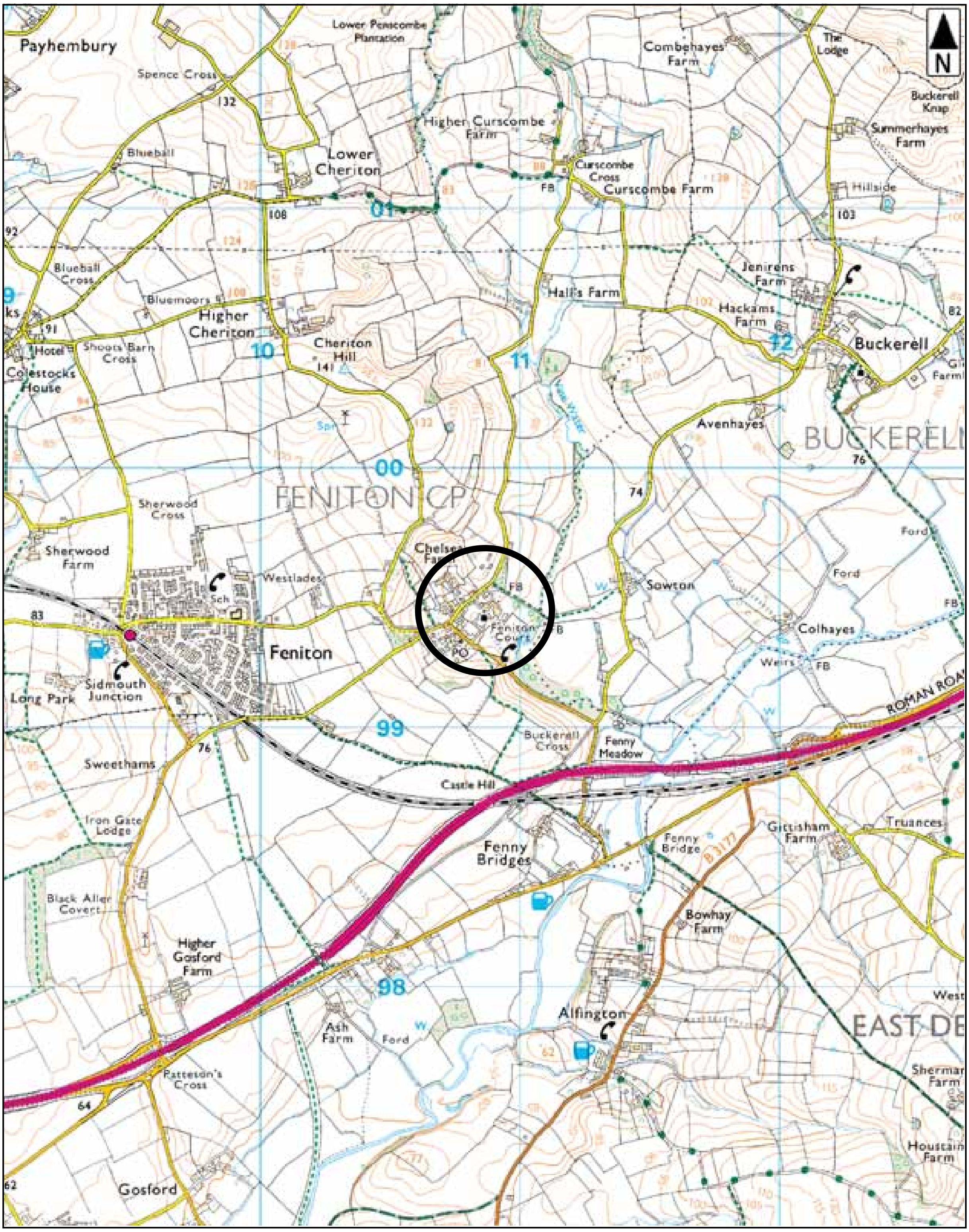


Figure 2: Map to show the location of St Andrew's Church, Feniton

Figure 3: St Andrew's Church, South Aisle roof, Truss 6 in foreground

Figure 4: St Andrews Church, Nave roof, looking west

Figure 5: St Andrew's Church, Nave roof

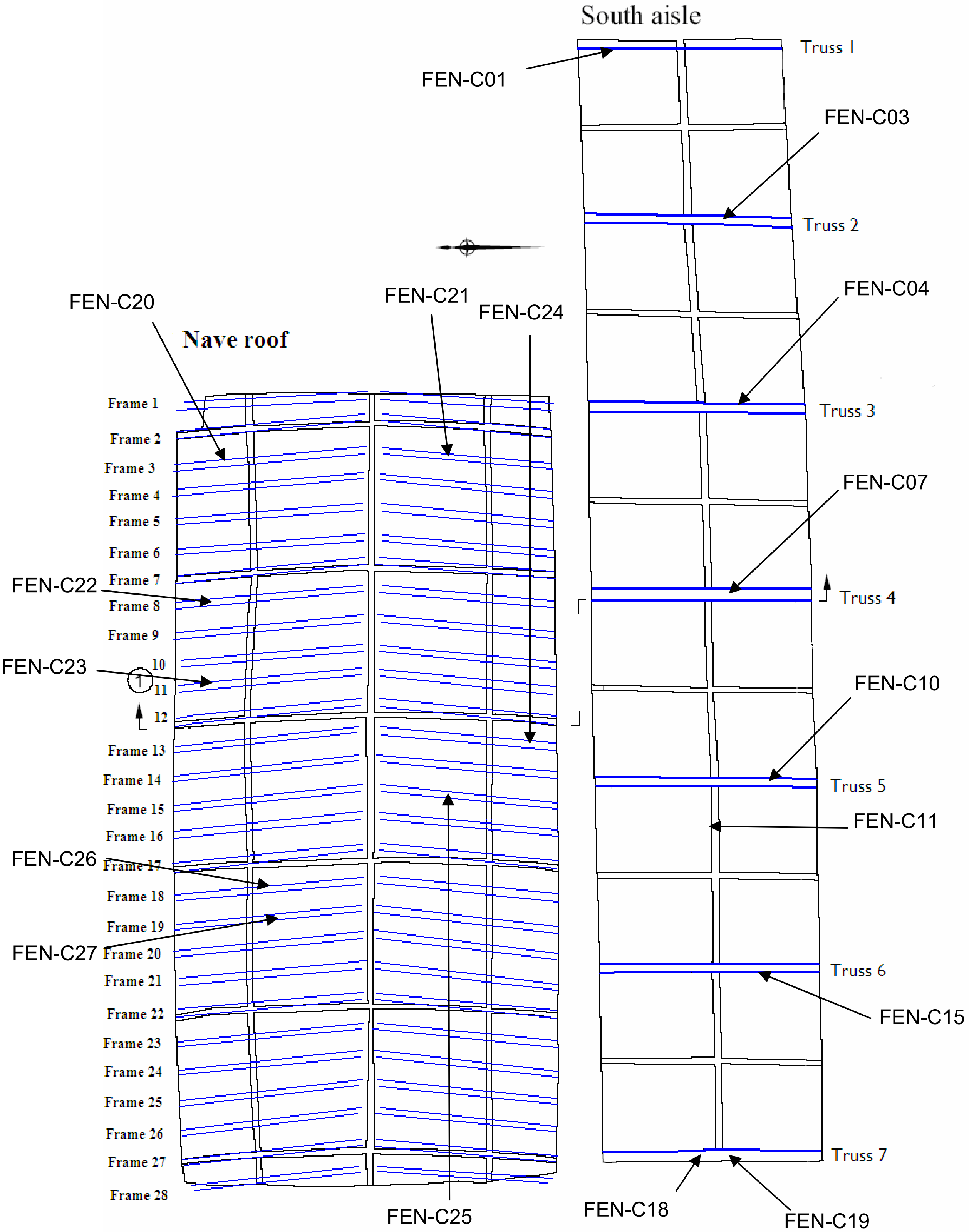


Figure 6: Plans, showing the location of samples FEN-C01, FEN-C03–04, FEN-C07, FEN-C10–11, FEN-C15, and FEN-C18–27 (based on a drawing provided by John Allen)

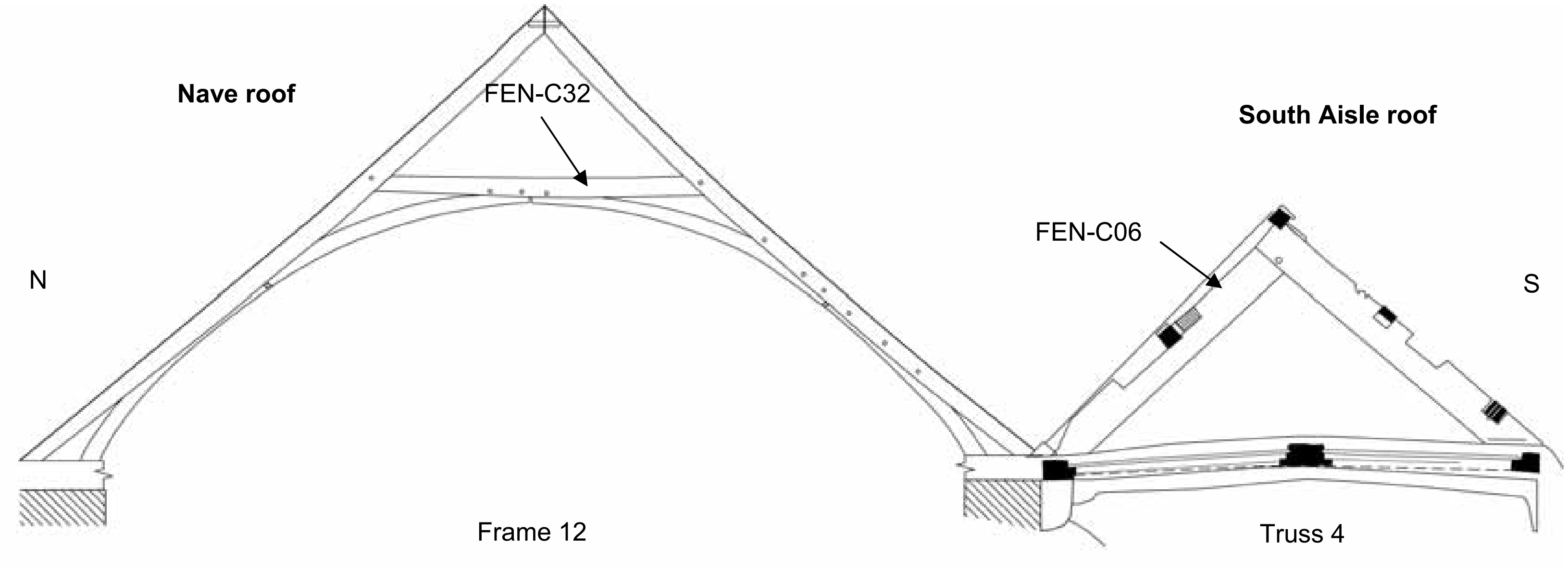


Figure 7: Section through the nave and south aisle roofs, showing the location of samples FEN-C06 and FEN-C32 (provided by John Allen)

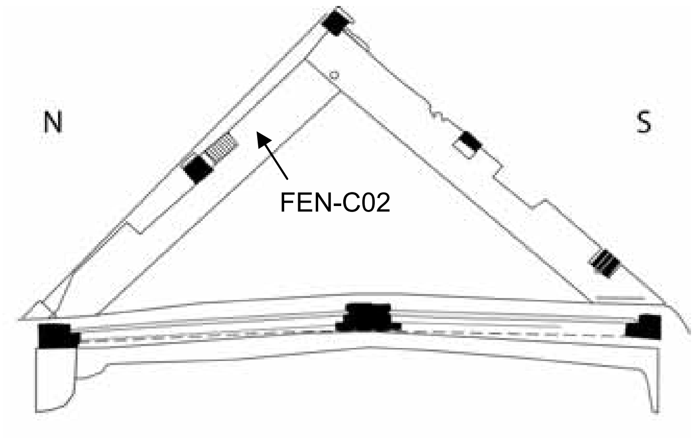


Figure 8: Truss 1, showing the location of sample FEN-C02 (based on Truss 4 provided by John Allen)

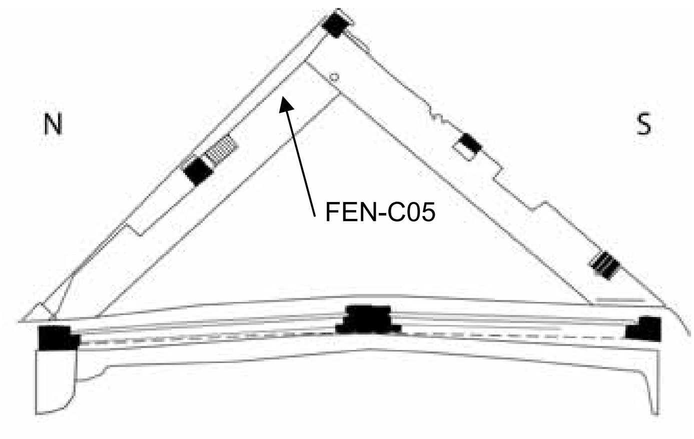


Figure 9: Truss 3, showing the location of sample FEN-C05 (based on Truss 4 provided by John Allen)

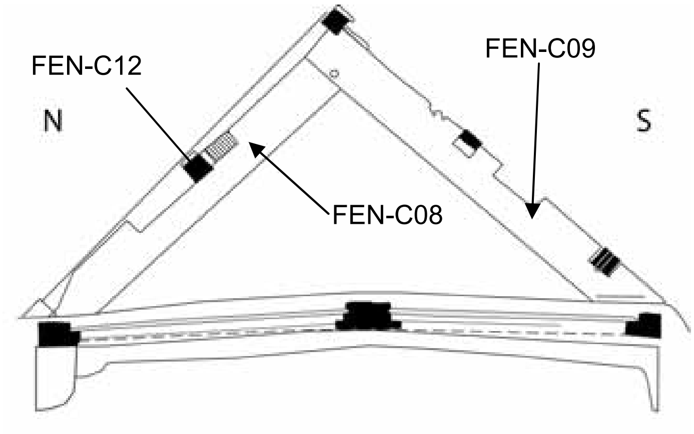


Figure 10: Truss 5, showing the location of samples FEN-C08, FEN-C09, and FEN-C12 (based on Truss 4, provided by John Allen)

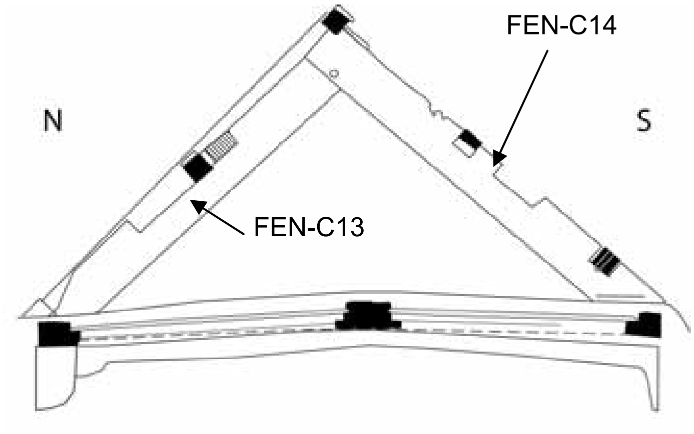


Figure 11: Truss 6, showing the location of samples FEN-C13 and FEN-C14 (based on Truss 4, provided by John Allen)

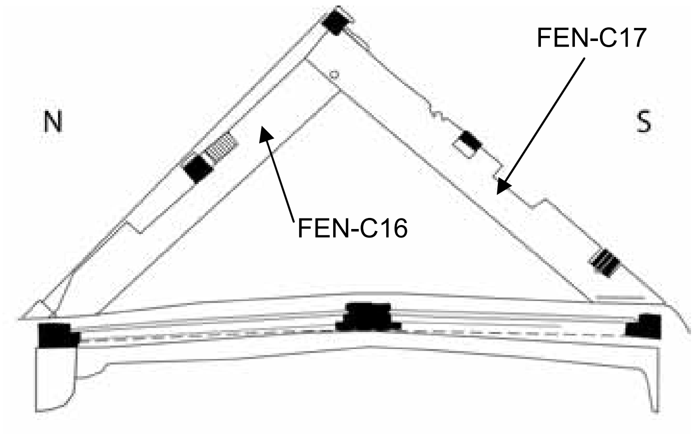


Figure 12: Truss 7, showing the location of samples FEN-C16 and FEN-C17 (based on Truss 4, provided by John Allen)

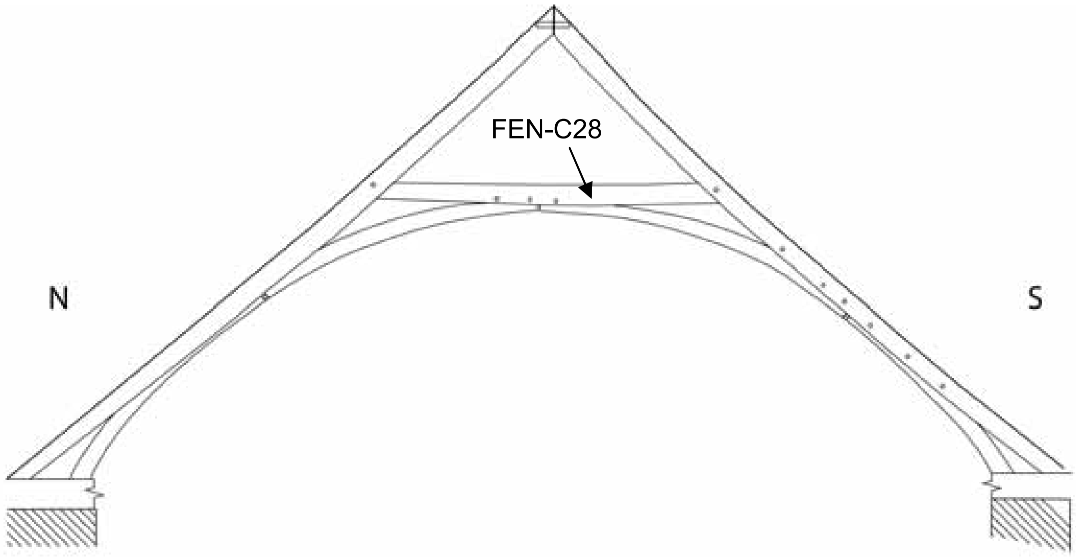


Figure 13: Frame 4, showing the location of sample FEN-C28 (based on a drawing provided by John Allen)

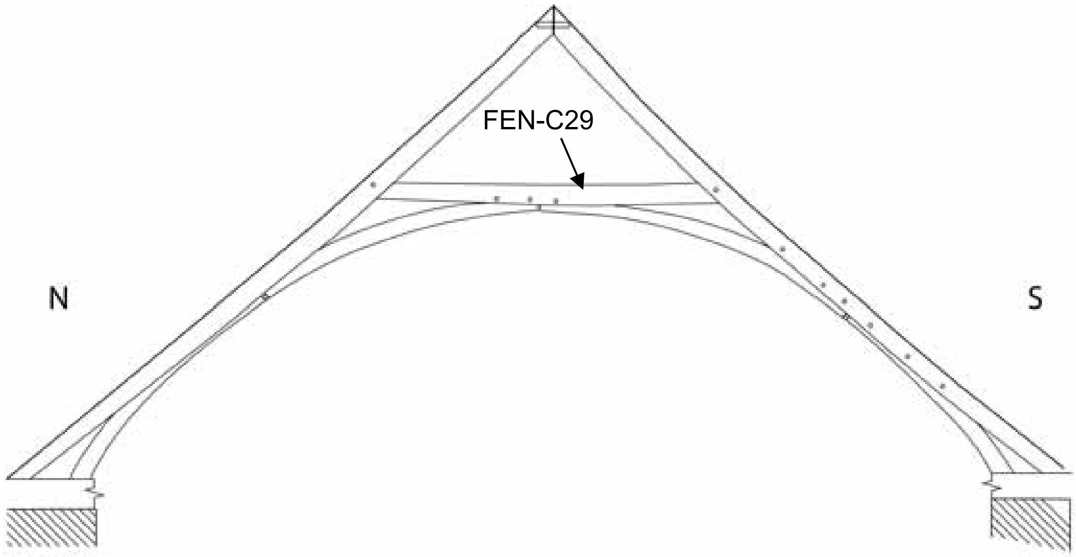


Figure 14: Frame 6, showing the location of sample FEN-C29 (based on a drawing provided by John Allen)

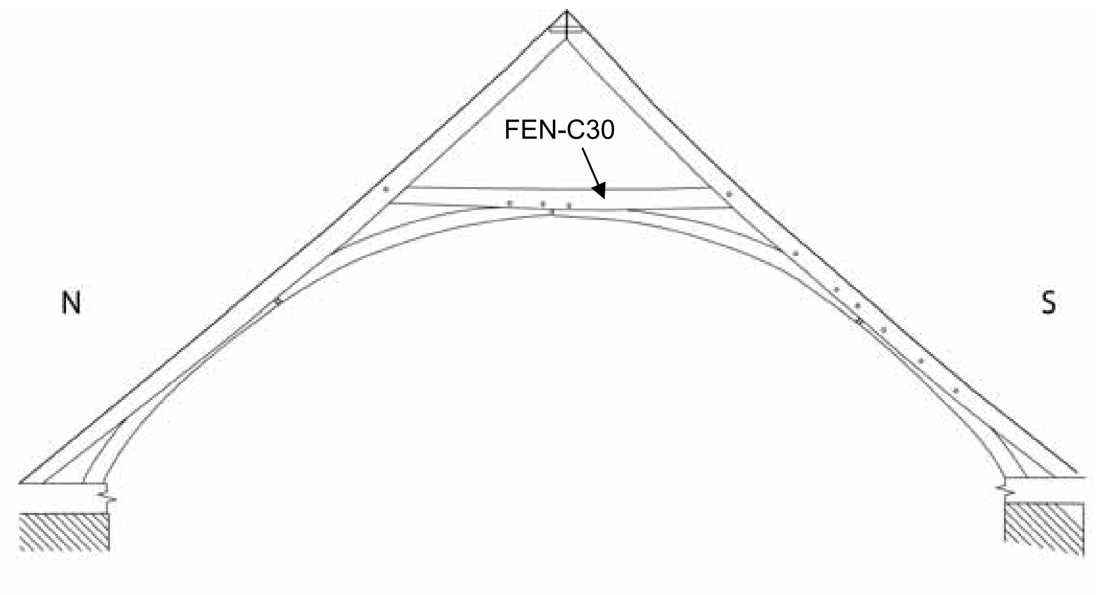


Figure 15: Frame 10, showing the location of sample FEN-C30 (based on a drawing provided by John Allen)

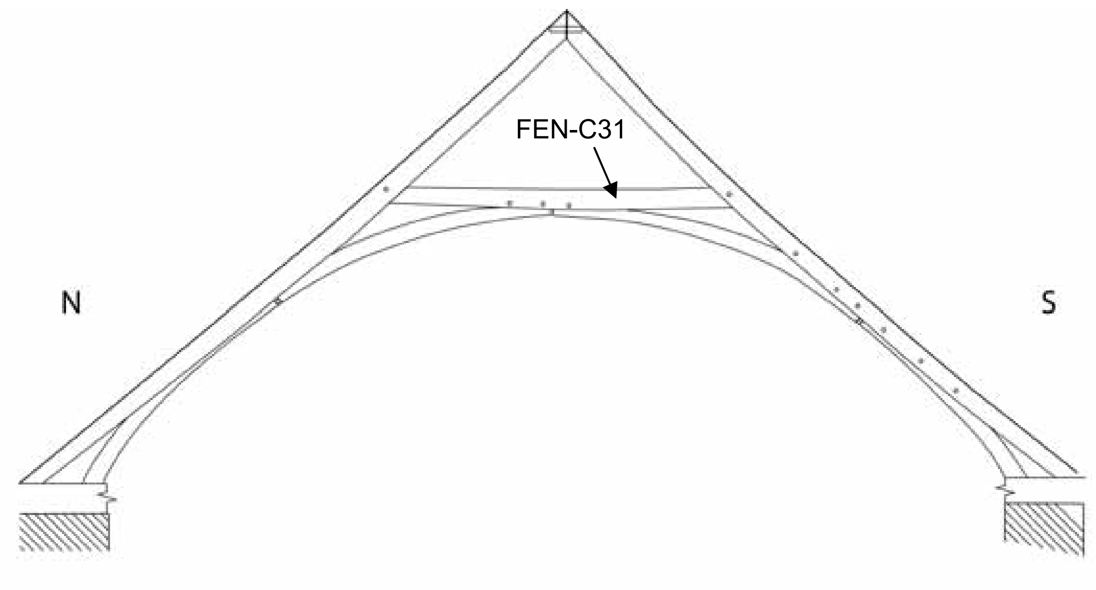


Figure 16: Frame 11, showing the location of sample FEN-C31 (based on a drawing provided by John Allen)

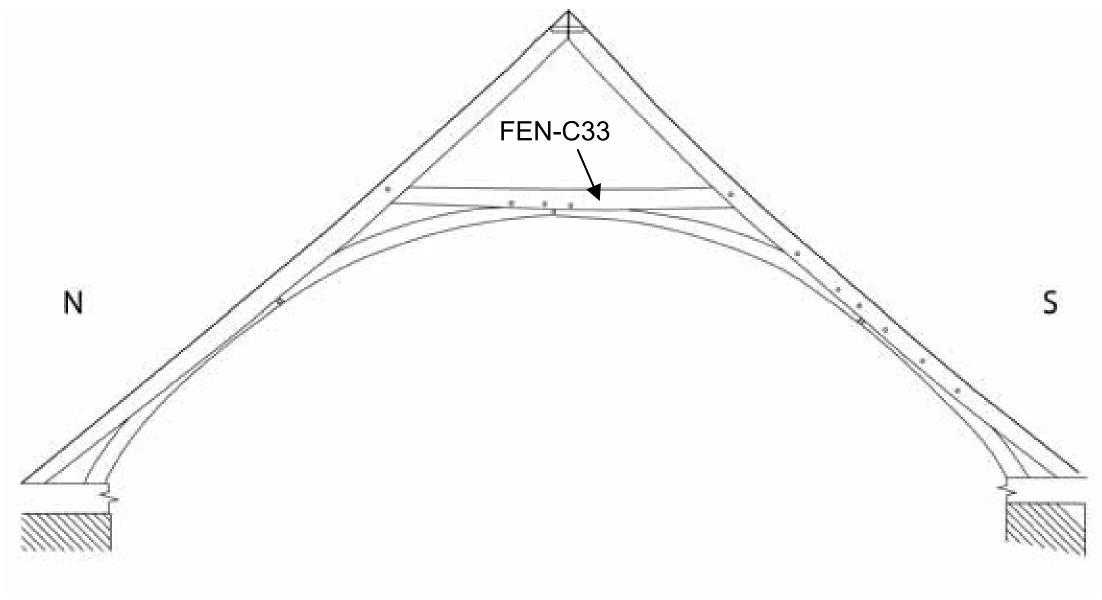


Figure 17: Frame 14, showing the location of sample FEN-C33 (based on a drawing provided by John Allen)

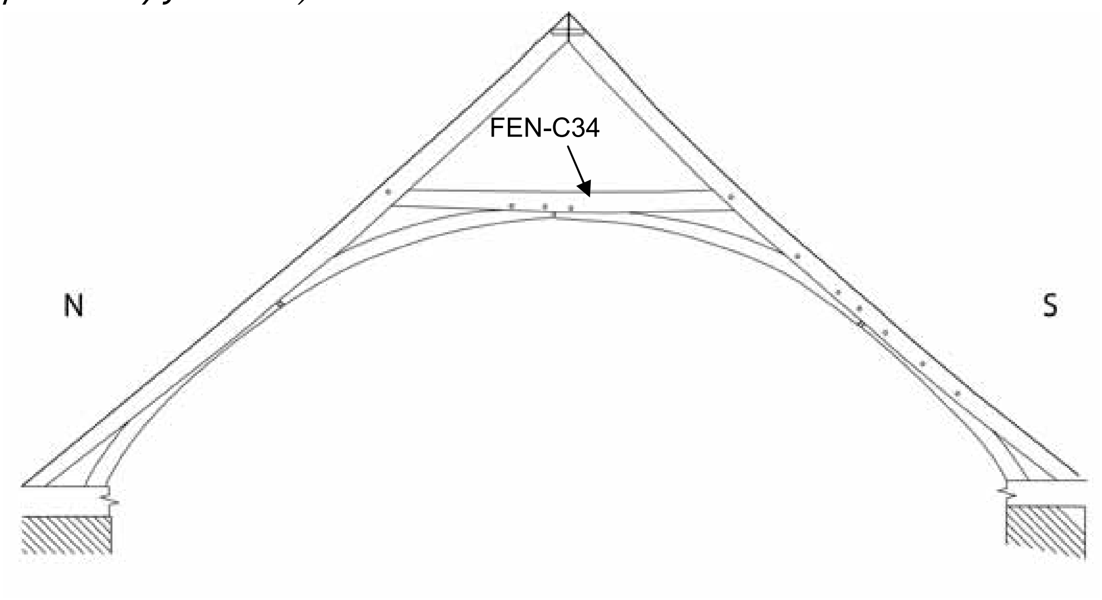
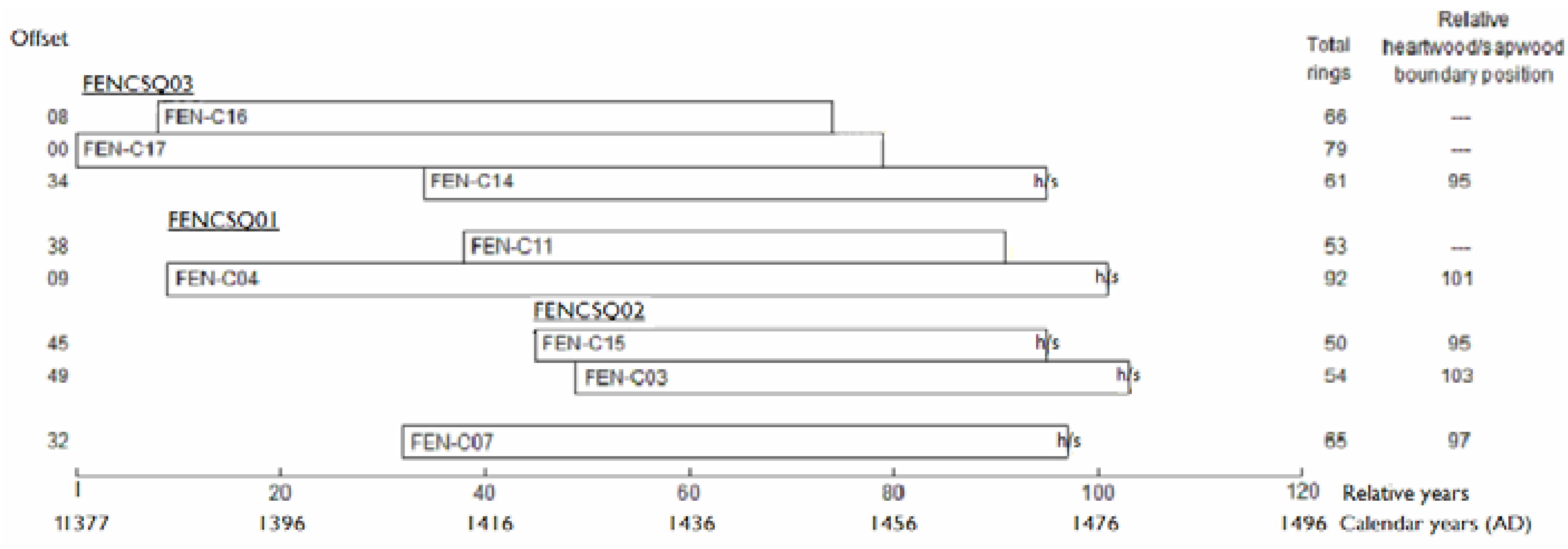


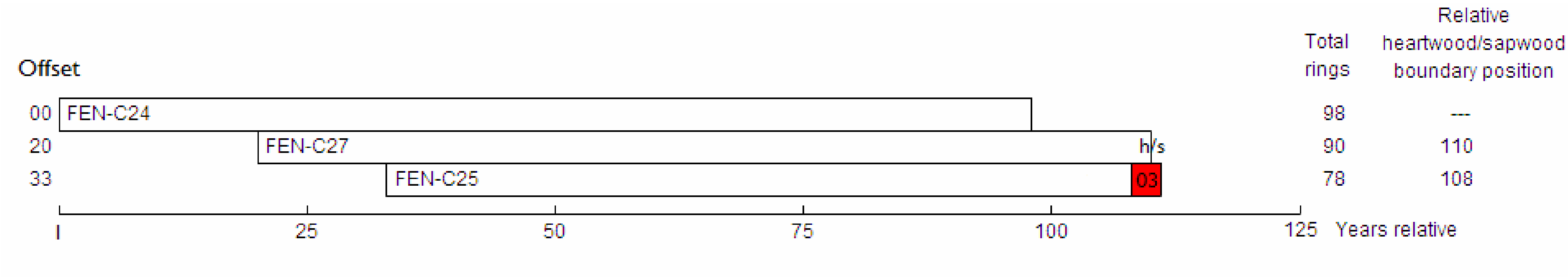
Figure 18: Frame 18, showing the location of sample FEN-C34 (based on a drawing provided by John Allen)



Heartwood rings

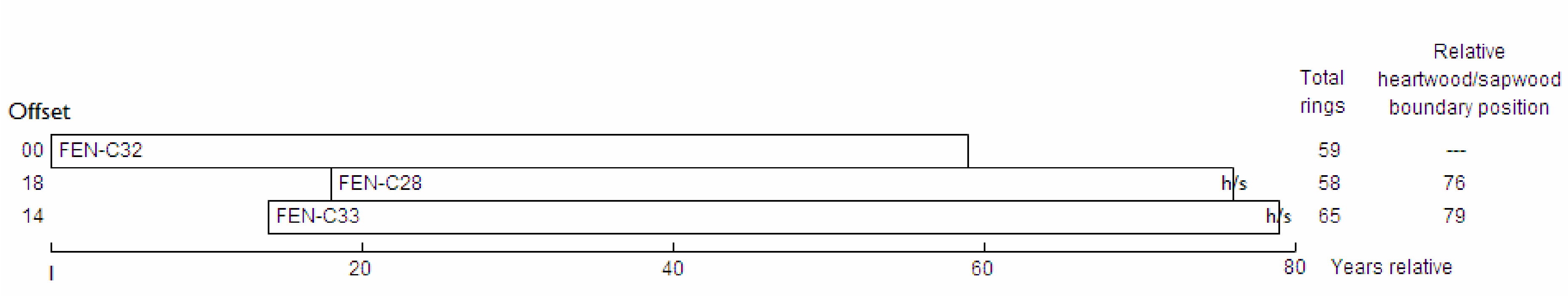
h/s = the heartwood/sapwood boundary ring is the last-measured ring on the sample

Figure 19: Bar diagram of dated samples



Heartwood rings Sapwood rings
h/s = the heartwood/sapwood boundary ring is the last-measured ring on the sample

Figure 20: Bar diagram of samples in undated site sequence FENCSQ04



Heartwood rings
h/s = the heartwood/sapwood boundary ring is the last-measured ring on the sample

Figure 21: Bar diagram of samples in undated site sequence FENCSQ05

DATA OF MEASURED SAMPLES

measurements in 0.01mm units

FEN-C02A 53
306 338 402 361 395 406 362 389 436 395 350 347 285 281 421 411 370 371 404 287
417 337 328 296 348 363 349 299 242 249 229 277 388 329 308 377 404 179 277 380
322 350 298 421 347 116 102 209 188 269 243 204 181
FEN-C02B 53
308 333 410 376 397 413 375 385 449 396 346 360 288 285 429 414 370 379 397 296
408 340 330 303 373 351 389 354 238 252 242 276 390 342 310 385 400 192 277 382
320 359 297 419 349 128 97 200 191 264 246 178 228
FEN-C03A 54
283 361 281 312 353 380 499 304 368 313 270 308 291 179 176 184 176 206 194 191
196 177 169 159 165 196 190 229 239 210 236 236 262 226 324 280 285 266 272 198
330 354 333 257 290 260 232 201 223 344 318 224 286 202
FEN-C03B 54
326 361 271 311 361 376 506 305 366 328 311 306 288 173 194 174 168 208 194 190
204 182 163 160 171 184 194 230 237 212 239 225 261 226 319 285 284 267 266 201
332 353 342 256 291 263 227 201 206 341 324 225 281 210
FEN-C04A 92
289 352 513 368 304 343 248 223 234 303 333 245 248 272 264 243 212 203 197 148
189 178 198 203 201 205 274 281 257 337 320 270 204 161 250 278 234 307 326 288
241 181 199 139 194 259 296 275 240 307 327 332 223 176 232 177 139 88 81 73
66 83 106 141 153 156 194 190 208 173 216 194 225 232 213 218 219 237 169 213
204 267 221 201 162 141 154 115 143 160 51 74
FEN-C04B 92
251 351 506 358 320 358 265 212 248 302 329 238 249 284 255 261 221 193 199 146
183 188 189 203 203 200 281 288 262 332 315 262 208 157 232 285 237 305 318 295
260 172 197 133 191 248 297 286 238 303 323 334 222 172 236 185 136 84 87 62
61 81 110 147 154 162 180 182 209 172 216 194 230 229 215 218 219 233 168 215
202 254 211 190 175 143 147 119 143 147 57 80
FEN-C05A 47
410 465 517 456 566 605 500 474 427 261 360 398 382 308 380 302 347 190 203 181
280 229 307 216 197 252 275 127 176 247 222 247 224 314 239 73 74 52 163 173
274 269 291 256 253 305 244
FEN-C05B 47
370 430 503 436 557 594 500 463 432 247 352 394 378 299 364 308 354 181 203 184
283 240 298 217 201 255 271 127 167 243 222 261 222 317 231 77 68 50 164 173
272 276 265 249 249 302 288
FEN-C06A 78
298 271 346 367 316 342 188 245 272 309 247 474 281 303 221 217 309 198 185 154
137 175 193 240 235 128 56 45 46 76 65 53 91 71 84 53 70 51 71 93
98 84 94 79 69 76 72 65 91 77 76 71 81 49 96 134 171 126 59 38
55 63 109 125 113 101 97 51 45 42 54 60 51 48 181 280 180 156
FEN-C06B 78
284 278 364 330 305 335 179 233 265 312 237 466 277 294 217 218 305 176 179 147
129 177 193 241 199 129 67 44 51 71 59 72 77 71 78 53 73 56 75 102
99 78 103 68 71 68 64 74 87 79 61 69 79 56 92 137 177 119 65 38
48 67 110 121 112 99 97 54 42 44 54 59 47 48 172 286 175 118
FEN-C07A 65
305 292 220 273 245 287 429 209 257 386 227 338 270 226 379 337 288 217 238 182

189 186 260 227 224 201 278 262 294 269 211 204 209 235 233 213 256 244 209 200
216 181 173 198 167 171 142 177 162 151 182 147 137 149 197 168 160 233 201 203
197 228 220 204 217
FEN-C07B 65
307 288 219 267 243 286 420 223 254 379 213 341 277 211 350 347 279 220 234 176
189 190 251 223 235 196 277 260 309 271 224 194 208 245 234 230 250 254 206 198
212 181 177 176 171 176 152 181 164 145 180 147 142 148 197 157 178 230 211 210
190 230 229 192 257
FEN-C11A 53
239 313 378 363 318 381 355 307 372 412 501 527 456 507 408 369 453 502 376 325
463 412 398 394 294 420 397 308 371 421 384 395 400 379 370 293 324 272 291 349
275 279 236 293 242 232 203 266 282 198 226 302 243
FEN-C11B 53
232 314 396 344 329 370 369 316 387 424 501 536 454 510 399 379 471 500 391 327
467 405 403 391 295 427 391 304 368 427 396 411 402 374 386 292 341 276 297 351
285 265 227 290 230 245 199 259 272 199 245 298 244
FEN-C12A 44
237 317 320 263 252 386 655 521 345 356 408 384 352 378 319 340 288 218 138 85
98 198 212 178 194 431 371 268 312 386 462 365 215 401 488 347 283 289 340 173
232 265 302 318
FEN-C12B 44
221 332 357 230 265 362 663 509 329 354 402 391 351 387 323 300 294 217 139 80
100 199 223 169 199 391 375 270 306 384 460 368 210 419 493 348 281 288 344 174
249 252 305 311
FEN-C13A 54
252 37 33 45 120 189 151 202 179 267 131 246 161 155 200 134 190 242 223 93
349 328 231 187 188 179 334 324 320 223 445 260 253 742 150 47 26 27 52 65
108 171 150 151 130 154 381 223 459 240 318 349 432 362
FEN-C13B 54
251 32 39 46 131 199 137 197 168 262 154 241 147 158 203 137 190 241 243 101
291 385 267 193 203 191 333 321 326 215 452 259 266 736 139 38 31 29 44 71
91 142 122 109 101 141 379 216 448 230 320 354 436 348
FEN-C14A 61
180 194 185 196 211 133 209 260 277 316 292 255 422 382 318 280 214 234 169 202
211 206 156 142 304 274 246 173 174 242 274 211 225 244 165 195 207 207 262 251
114 47 61 63 87 106 114 121 146 158 139 153 165 131 93 80 58 109 85 138
71
FEN-C14B 61
179 185 178 184 208 125 200 257 269 306 284 252 415 383 328 270 222 225 177 199
231 191 161 141 290 267 240 170 172 236 272 229 211 261 159 189 221 202 256 256
115 54 49 64 83 112 111 118 149 155 133 162 185 132 95 72 67 102 88 118
88
FEN-C15A 50
557 929 890 922 1089 758 710 652 637 542 664 370 374 365 452 448 359 195 271 218
256 422 319 261 282 260 204 215 161 277 313 275 379 372 297 280 290 204 222 215
165 167 168 153 241 233 233 164 166 147
FEN-C15B 50
503 928 940 886 918 763 736 666 619 521 669 361 377 367 444 458 363 212 284 233
271 407 314 266 271 263 199 209 163 278 302 283 404 359 312 274 290 215 225 209
170 168 170 149 239 236 232 163 165 125
FEN-C16A 66
227 294 253 267 251 218 218 214 202 229 227 236 114 206 208 248 291 220 258 281
239 260 239 226 147 245 206 251 241 258 291 207 254 228 245 249 344 223 452 369

424 321 291 248 209 252 263 315 266 178 350 245 268 211 219 229 292 241 266 279
199 253 298 250 332 293
FEN-C16B 66
242 295 242 279 242 213 225 204 199 227 226 211 132 194 218 256 275 223 259 283
237 264 238 220 158 231 217 251 241 259 281 217 252 225 249 255 343 221 446 383
419 322 296 251 221 248 258 315 263 192 351 248 254 205 221 232 289 243 265 272
200 256 296 248 318 309
FEN-C17A 79
272 293 270 261 201 240 183 167 134 195 176 175 192 159 133 166 176 249 273 327
202 237 266 251 153 83 91 110 95 96 112 77 93 151 134 192 175 198 180 151
120 166 212 196 242 194 291 305 279 253 203 217 178 261 230 290 231 215 289 265
280 188 162 227 218 219 205 216 220 238 241 283 325 298 177 70 75 81 89
FEN-C17B 79
273 299 268 255 206 242 183 184 136 199 185 184 182 173 116 164 160 280 295 327
210 240 257 253 142 81 92 112 97 93 110 72 94 150 130 214 171 202 171 150
116 175 208 194 241 196 297 297 278 254 204 214 178 253 234 295 227 198 281 264
275 202 148 227 216 226 203 214 223 237 239 234 326 294 176 82 65 79 105
FEN-C20A 79
184 487 420 377 407 288 334 324 283 342 272 270 345 279 165 187 274 245 273 267
256 213 200 181 214 186 185 185 163 132 137 174 195 179 197 165 196 288 192 228
160 183 171 221 202 168 176 189 209 183 182 146 172 172 202 240 178 137 144 148
219 216 124 175 132 177 159 187 139 143 138 165 152 117 124 90 159 128 124
FEN-C20B 79
197 478 412 363 390 285 341 312 274 348 275 264 302 293 123 212 275 238 264 264
231 230 202 173 215 190 183 181 156 144 136 178 199 179 203 160 190 275 195 218
144 190 174 221 199 174 176 196 214 183 186 139 168 173 201 242 175 141 161 137
212 213 130 175 132 176 159 191 136 140 137 170 152 113 128 100 158 137 140
FEN-C21A 64
152 152 203 166 177 158 177 182 197 225 154 115 62 91 122 115 111 133 170 173
151 136 121 82 81 146 185 249 290 302 286 253 214 213 231 228 277 328 222 225
311 366 358 430 349 250 318 354 321 249 334 256 311 252 224 292 207 280 250 260
264 226 254 150
FEN-C21B 64
148 168 200 171 174 158 180 175 187 232 161 119 62 98 113 117 116 126 173 173
152 139 122 76 87 142 181 239 291 298 302 256 219 202 237 227 289 314 220 234
313 372 360 427 350 248 313 362 312 245 314 252 313 256 222 298 211 283 239 259
253 225 267 150
FEN-C22A 91
211 175 232 208 178 210 264 212 190 195 252 245 220 170 144 193 188 291 274 264
150 150 172 230 234 135 214 154 224 282 249 275 155 200 200 294 185 225 212 164
163 138 124 115 148 177 136 136 181 110 146 210 192 126 109 125 94 203 165 61
63 67 62 69 83 96 96 77 70 109 90 115 94 127 137 200 265 215 235 132
118 82 88 68 101 123 149 146 133 124 191
FEN-C22B 91
218 170 223 215 181 216 255 222 192 187 256 242 225 161 146 199 182 289 262 281
157 144 172 240 227 131 220 152 217 279 243 268 160 191 199 296 179 231 208 164
171 128 124 112 149 173 140 138 176 113 150 195 203 126 100 130 98 200 173 56
54 69 60 70 80 89 101 75 79 92 89 112 91 123 136 204 268 223 225 143
116 83 91 68 103 125 145 139 122 124 176
FEN-C23A 58
193 231 267 286 325 303 392 323 288 268 173 279 406 299 244 245 349 304 245 203
374 408 401 334 342 313 320 252 291 258 221 219 260 252 333 250 370 294 254 257
263 348 269 250 219 311 342 193 218 167 215 166 204 192 184 259 215 215

FEN-C23B 58
260 213 255 289 297 313 403 316 267 327 170 283 401 300 236 255 353 288 258 205
367 410 402 336 342 305 317 261 293 251 230 222 255 253 330 245 351 313 255 252
258 351 252 225 260 307 339 195 224 175 200 174 195 172 188 265 218 209
FEN-C24A 98
200 264 314 410 514 407 334 286 326 304 208 236 183 188 239 199 225 156 122 145
98 100 142 103 124 137 89 157 153 153 113 118 115 163 138 201 122 187 129 218
89 168 121 103 100 86 100 61 80 93 84 118 130 103 134 103 120 114 86 150
162 143 180 163 144 208 150 162 127 153 174 102 115 120 257 195 144 99 142 91
101 119 115 92 134 83 154 114 95 87 115 180 143 125 111 86 113 101
FEN-C24B 98
200 271 315 386 517 409 335 286 329 293 213 231 190 184 244 202 198 175 124 145
94 99 149 102 129 130 84 167 154 152 106 127 113 157 135 205 128 175 131 216
89 166 112 106 106 85 105 58 75 100 81 121 128 108 127 112 124 101 91 159
138 161 170 172 140 204 149 174 140 148 166 90 114 120 268 189 141 97 143 89
100 122 113 109 130 84 157 112 97 114 93 189 144 128 116 89 110 142
FEN-C25A 78
229 168 224 132 213 98 215 154 190 93 115 142 114 81 88 92 94 122 126 161
129 157 146 98 106 106 243 172 157 127 144 127 198 110 75 83 139 142 164 114
132 232 211 187 200 191 199 172 221 140 170 208 172 286 262 247 202 349 296 230
190 202 178 224 237 247 146 201 135 156 126 165 137 104 156 90 79 84
FEN-C25B 78
226 148 243 140 202 100 215 158 196 94 119 145 113 78 73 103 93 118 114 167
128 159 121 107 130 96 275 164 159 133 149 130 209 133 74 89 140 136 176 109
138 218 191 182 202 194 202 168 223 131 182 208 170 277 254 260 203 336 303 234
192 202 183 227 216 252 145 195 136 142 137 178 141 112 138 95 80 81
FEN-C26A 94
115 113 105 101 80 91 100 100 114 66 54 100 126 129 123 134 156 153 133 101
68 92 154 180 151 113 124 140 161 160 108 122 123 145 148 154 89 82 89 128
115 91 101 76 122 119 159 111 177 120 127 126 95 62 86 106 155 151 141 103
141 109 167 197 116 95 142 134 137 130 161 122 123 153 133 150 199 148 104 114
85 92 81 109 114 94 95 88 132 180 126 107 124 107
FEN-C26B 94
116 115 99 110 89 75 107 103 110 72 55 94 128 133 131 130 166 143 134 103
63 103 156 170 153 115 127 142 164 161 108 122 119 145 157 149 94 88 91 116
104 102 100 77 118 133 160 103 174 128 129 130 84 68 90 109 159 141 145 104
139 109 211 148 115 112 122 131 137 134 151 125 126 152 134 137 200 148 114 111
92 86 83 113 110 98 82 94 132 173 129 97 137 126
FEN-C27A 90
169 195 191 187 263 190 99 142 228 219 163 173 147 155 172 182 162 177 81 209
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174 53 60 86 59 106 92 83 83 125 130 97 88 88 156 129 100 92 88 92
92 120 121 86 112 97 130 139 80 101 149 94 75 98 83 96 112 69 85 73
113 101 92 134 78 78 91 148 174 128
FEN-C27B 90
207 182 179 181 275 189 96 141 244 216 166 181 138 159 170 181 160 163 95 217
139 147 96 130 119 163 135 109 89 95 108 175 186 141 159 100 142 147 127 166
179 50 61 90 55 111 90 83 78 127 124 91 92 79 151 137 94 92 94 92
88 103 125 83 118 97 130 135 83 100 152 87 80 95 84 98 107 64 83 74
124 96 94 140 76 78 88 149 176 159
FEN-C28A 58
384 286 340 403 448 531 531 402 403 451 413 590 279 317 340 342 378 412 467 437
322 371 249 350 347 310 260 336 68 51 48 51 50 47 40 60 65 68 52 51

54 89 101 107 128 145 168 190 116 125 216 301 272 342 253 218 182 174
FEN-C28B 58
425 278 353 400 438 550 533 410 407 452 409 576 273 317 320 357 375 422 476 436
319 363 247 355 362 289 291 307 71 58 47 46 57 37 29 64 65 70 43 54
54 85 106 105 129 139 169 190 126 117 217 343 272 342 252 221 181 164
FEN-C29A 52
603 533 737 537 291 355 241 146 191 243 177 188 161 186 162 206 191 130 193 157
256 283 238 91 160 194 280 335 177 226 237 231 233 245 263 274 275 258 326 206
169 180 236 239 392 341 302 218 171 242 222 256
FEN-C29B 52
596 537 731 546 288 338 240 146 210 238 169 185 157 183 168 197 208 137 187 148
255 291 232 91 152 195 275 329 158 208 253 229 232 247 249 268 270 263 317 202
169 175 235 248 394 343 301 217 172 249 249 175
FEN-C30A 64
392 434 543 258 382 305 506 347 417 242 317 301 255 431 264 344 306 423 545 459
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258 223 228 220 155 171 128 196 141 113 115 112 129 154 114 177 242 123 194 144
155 173 208 142
FEN-C30B 64
404 447 547 264 386 319 516 367 412 261 298 292 229 380 263 349 309 418 546 459
205 183 206 265 363 203 363 289 381 378 389 342 316 188 341 256 265 277 162 205
252 231 227 212 158 166 141 187 142 114 117 103 123 151 108 187 227 134 192 151
145 170 213 129
FEN-C31A 60
354 568 453 488 227 320 277 238 392 284 416 356 476 566 509 265 200 218 312 384
200 229 208 208 257 309 286 305 260 312 242 277 128 59 81 141 133 125 117 94
92 80 85 137 93 64 63 39 85 127 92 106 86 115 134 124 101 178 229 187
FEN-C31B 60
346 555 458 491 210 320 275 239 390 289 405 351 459 538 512 265 200 222 305 384
199 246 190 210 269 296 270 310 267 313 248 276 126 67 86 144 135 129 122 88
91 85 86 147 95 61 69 43 83 118 92 101 85 119 134 118 104 179 254 195
FEN-C32A 58
454 481 411 354 253 321 436 382 179 379 261 342 322 295 175 251 280 279 238 266
306 273 359 317 369 385 213 219 197 282 196 247 249 266 268 285 324 305 254 322
305 432 379 220 204 284 78 55 45 47 39 42 40 40 47 45 41 49
FEN-C32B 59
445 477 409 350 250 316 461 342 138 372 272 351 308 286 167 253 275 266 238 267
300 265 344 295 376 379 200 221 199 282 196 248 250 274 267 291 319 319 264 321
288 429 358 227 199 308 84 51 46 47 38 32 45 41 57 51 42 42 61
FEN-C33A 65
216 324 348 350 356 292 455 203 336 323 349 344 196 191 203 255 160 160 210 187
226 341 323 334 306 268 256 296 273 174 183 229 54 54 64 80 81 74 70 88
119 76 78 83 67 116 121 92 79 67 73 96 101 113 115 184 144 252 235 175
123 123 180 165 152
FEN-C33B 65
215 328 345 350 357 296 456 203 338 317 351 345 194 194 201 247 157 160 212 188
224 343 317 338 305 273 249 302 271 173 185 228 51 57 69 73 85 74 73 88
114 83 66 95 63 119 122 96 84 65 72 93 99 124 112 194 136 251 225 180
127 114 182 160 149
FEN-C34A 62
403 442 467 253 260 201 411 404 546 762 540 236 283 288 238 181 179 202 249 342
260 358 239 291 265 239 305 127 117 255 171 247 210 135 113 69 119 226 204 154
183 191 171 220 261 208 225 222 191 177 131 130 133 100 122 105 105 78 118 111

129 116
FEN-C34B 62
427 439 474 250 265 195 420 426 533 734 520 237 274 288 222 188 179 211 236 335
255 359 253 271 260 221 305 128 120 267 156 264 243 132 109 67 110 219 176 135
177 198 179 219 274 196 221 204 177 173 127 131 135 104 113 113 105 86 115 110
126 116

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

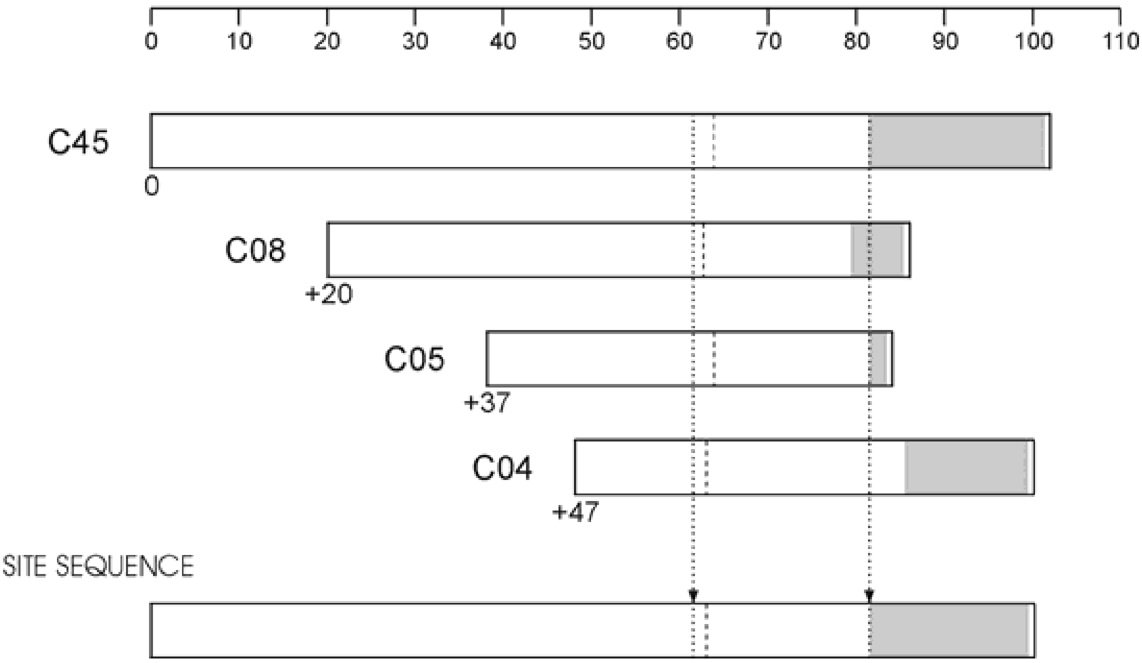


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

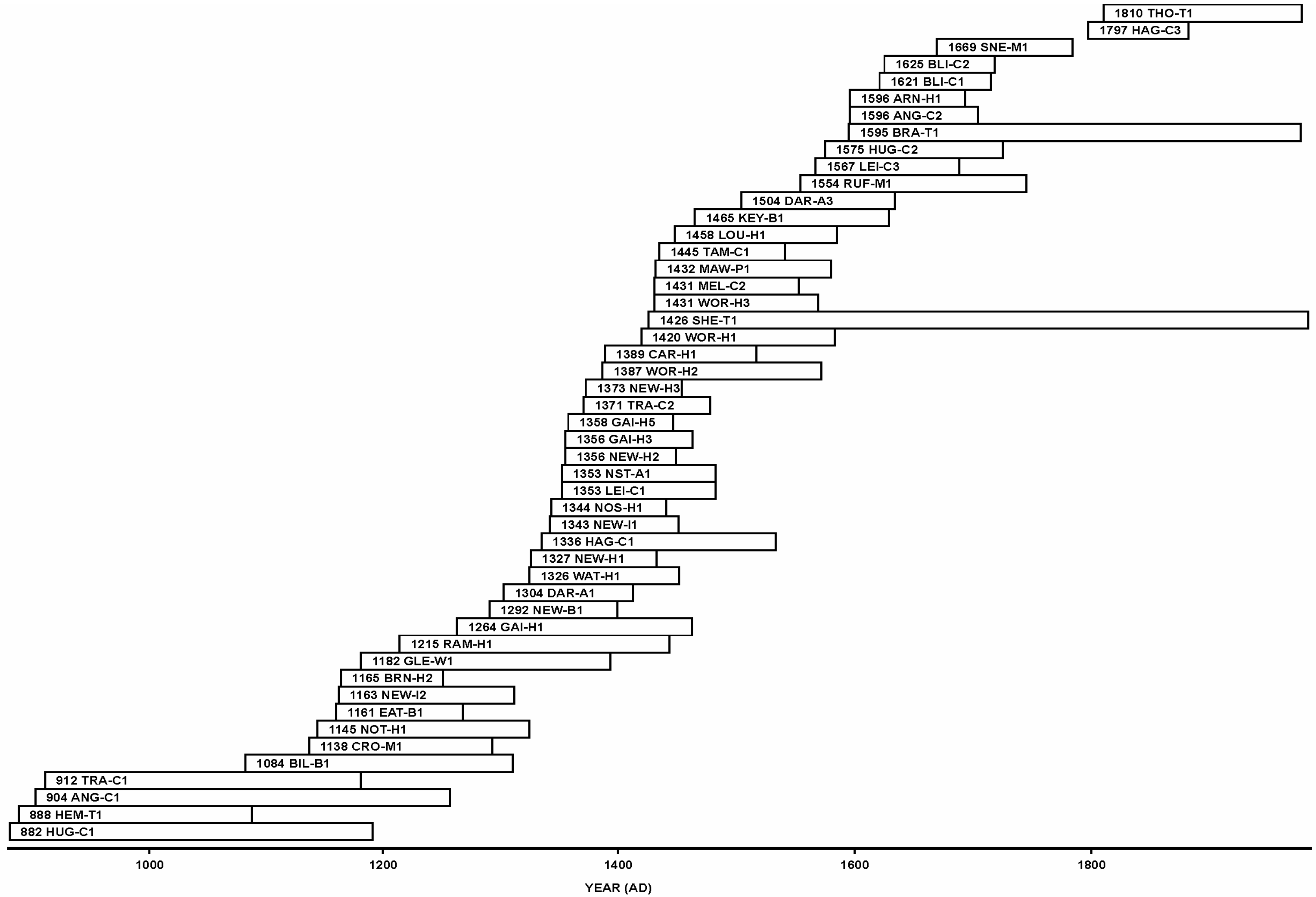
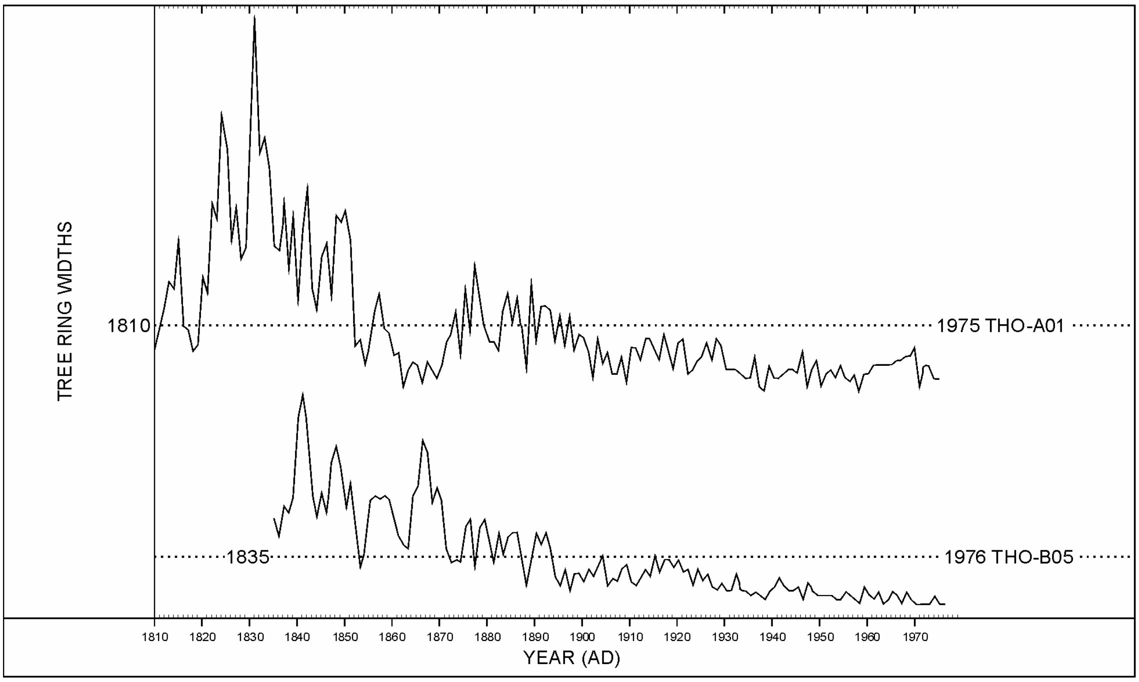


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

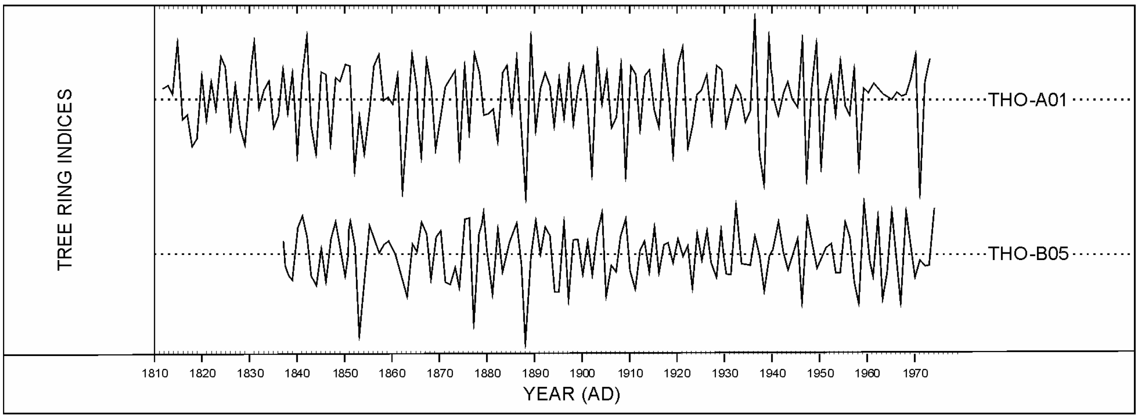


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

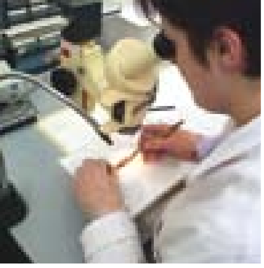
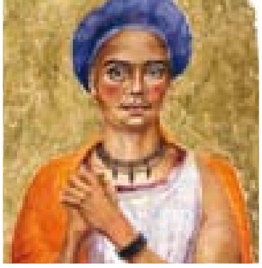
Laxton, R R, Litton, C D, and Howard, R E, 2001 *Timber: Dendrochronology of Roof Timbers at Lincoln Cathedral*, Engl Heritage Res Trans, 7

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



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