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DAUBENEYS, HIGH STREET, COLERNE, WILTSHIRE

TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Cathy Tyers, Matt Hurford, Robert Howard, and Alison Arnold

INTERVENTION
AND ANALYSIS

ENGLISH HERITAGE

Research Report Series 61-2014

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SUMMARY

Dendrochronological analysis was undertaken on 25 of the 27 samples taken from Daubeneys. This resulted in the production of two site chronologies, CLDBSQ01 and CLDBSQ02, incorporating a total of 21 samples. CLDBSQ01 can be dated as spanning the years AD 1347–1497, whereas CLDBSQ02 remains undated. The 16 dated samples in CLDBSQ01 indicate a programme of felling in the last few years of the fifteenth century in the hall and stable roofs and the stable ceiling, although at least one timber from the stable end roof was felled in the middle of the following decade. It is possible that several timbers from the hall end roof were felled several decades earlier towards the middle of the latter half of the fifteenth century.

CONTRIBUTORS

Cathy Tyers, Matt Hurford, Robert Howard, and Alison Arnold

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ARCHIVE LOCATION

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DATE OF INVESTIGATION

2009–10

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INTRODUCTION

In 2009 the Wiltshire Buildings Record (WBR) 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 was to establish a typological chronology of archaic roof types and hence elucidate the development of carpentry techniques in the county. This would 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) combined building survey, historical research, and dendrochronological analysis.

A group of 25 buildings identified by the WBR 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 for dating these detailed dendrochronological assessments and the WBR assessments of the significance of each building informed the final selection of buildings subsequently subjected to detailed study.

A single final Project Report produced by Lloyd (2012) summarises the overall results. However, each building included in the project has an associated individual report on the structural analysis produced by the WBR, whilst the primary archive of the dendrochronological analysis is the English Heritage Research Report Series.

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

Daubeneys

Daubeneys, a Grade II* listed building, lies in the centre of the village of Colerne, immediately north of High Street and west of Silver Street (Figs 1 and 2). The building is aligned broadly north-east to south-west but for the purposes of this report it has been described as being aligned east to west. Thus, the south elevation, the main front, faces the High Street. The following information is taken from the WBR report (2012).

Daubeneys appears to have been a substantial late medieval open hall house with attached animal accommodation. The hall end to the east and the stable end to the west are of cruck construction, now encased in stone (Fig 3). There is a continuous eight-bay windbraced roof with cruck trusses, a single row of purlins and a diamond-set ridge (Figs 4–6). However, in spite of this, the hall and stable ends are not thought likely to be coeval. Stylistic evidence suggests that the five-bay hall end had its origins in the latter decades of the fourteenth century, when it passed to New College, Oxford (founded AD 1379; inaugurated AD 1386). It was built, or possibly rebuilt, on the footprint of an original longhouse. It appears to have consisted of the two-bay open hall with a cross passage to the immediate west of the open hall and a service room to the west of the cross passage. At the east end was a storage room on the ground floor with a two-bay solar above set into the gable end. The hall and solar are of raised-cruck construction (trusses A-E). The trusses have cranked collars and tiebeams, with the exception of the central open truss in the solar (truss B) which has a collar with a straight underside and arch braces.

The stonework of the three-bay former stable end is more regular than that of the hall end and it is thought that this end was constructed after the hall end but before the demise of cruck construction in Wiltshire, around the end of the fifteenth century. The trusses of the stable end (trusses 1–4) are similar to those in the hall end but notches present halfway between the collar and tiebeam on some of the cruck blades suggest the possibility that struts may have been present at some time. The stable is thought likely to have been open to the roof originally with a floor being inserted at a later date (Fig 7). The exposed ceiling joists to the central bay are tenoned into two transverse beams. Whilst some of these joists are clearly replacements, others appear likely to be associated with the original insertion of the floor.

SAMPLING

Dendrochronological sampling and analysis of the primary timbers associated with the stable and hall ends was commissioned by English Heritage. It was hoped to provide independent dating evidence for the construction of the two parts of the extant building and hence inform the overall objectives of the ‘Wiltshire Cruck Buildings and other archaic roof types’ project. The dendrochronological study also formed a key component of the English Heritage-funded training programme for the second author, although the reporting was not completed within the duration of the training programme.

A total of 27 timbers (15 from the stable end, 12 from the hall) was sampled by coring by trainee Matt Hurford, supervised by the Nottingham Tree-ring Dating Laboratory. Each sample was given the code CLD-B (for Colerne, Daubeneys) and numbered 01–27. The sampling encompassed as wide a range of elements as possible, whilst focussing on those timbers with the best dendrochronological potential.

The location of the samples was noted at the time of coring and marked on the drawings subsequently provided by the WBR, these being reproduced here as Figures 8–17. Further details relating to the samples can be found in Table 1. In this table the timbers have been located and numbered following the scheme on the drawings provided.

ANALYSIS AND RESULTS

Each of the 27 samples was prepared by sanding and polishing. It was seen at this point that two samples, CLD-B05 and CLD-B18, had too few rings for reliable dating (the lower limit applied within this project was generally 50 rings), and so were rejected from this programme of analysis. The annual growth rings of the remaining 25 samples were measured, the data of these measurements being given at the end of this report. The measurement and analysis were undertaken using a combination of the Litton/Zainodin grouping procedure (see Appendix) and software written by Tyers (2004a). Tyers (ibid) facilitates cross-matching and dating through a process of qualified statistical comparison and visual comparison. It uses a variant of the Belfast CROS programme (Baillie and Pilcher 1973).

The analysis resulted in two groups (15 samples and 5 samples) being formed. The samples of each group cross-matching with each other as shown in Tables 2 and 3 and Figures 18 and 19. During this analytical process a possible match ($t = 5.00$) to the group of 15 samples was noted for CLD-B14. This was confirmed by the dating evidence obtained for this individual sample when it was compared to an extensive range of reference chronologies for oak (Table 4). CLD-B14 was therefore combined with the 15 other grouped series at the indicated offsets to form site chronology CLDBSQ01, this having an overall length of 151 rings (Fig 18). The dating evidence for site chronology CLDBSQ01 when the date of the first ring is AD 1347 and the date of its last ring is AD 1497 is presented in Table 5.

The second group, of five series, were combined at the indicated offsets to form site chronology CLDBSQ02, this having an overall length of 115 rings (Fig 19). A potential match was identified for CLDBSQ02 with CLDBSQ01, which would suggest that this group of timbers was coeval, but unfortunately comparison to an extensive range of reference chronologies for oak could not conclusively confirm this, so CLDBSQ02 remains undated.

Each site chronology was compared with the remaining four ungrouped samples but there was no further satisfactory cross-matching. The ungrouped individual samples were also compared to an extensive range of reference chronologies for oak. However, no conclusive cross-matching was identified so these all remain undated.

This analysis can be summarised as follows:

Site chronology	Number of samples	Number of rings	Date span (where dated)
CLDBSQ01	16	151	AD 1347–1497
CLDBSQ02	5	115	undated
	4	---	ungrouped and undated
	2	---	unmeasured

INTERPRETATION

CLDBSQ01

The dated site chronology, CLDBSQ01, comprises eight samples from the stable end and eight samples from the hall end (Fig 18). To aid interpretation the two ends of the building are dealt with separately below. For consistency the sapwood estimate used in all of the dendrochronological reports on individual buildings with this project is the Nottingham Tree-ring Dating Laboratory estimate of 15–40 (95% confidence range).

Stable end

Two of the dated samples (CLD-B06, CLD-B07) from the roof have bark edge present. The outermost measured rings date to AD 1496 and AD 1497 respectively but both have a partially formed ring for the following year. Thus the two timbers represented, a collar and a purlin, were felled in the late spring/early summer of AD 1497 and late spring/early summer of AD 1498 respectively. The three remaining dated samples from the roof all have the heartwood/sapwood boundary present which varies from AD 1476 (CLD-B10) to AD 1483 (CLD-B08). The average heartwood/sapwood boundary date is AD 1480 which produces an estimated felling date in the range AD 1495–1520. This encompasses the precise felling dates obtained and it thus appears likely that these three timbers, a purlin and both cruck blades from truss 4, were also felled in the last few years of the fifteenth century.

Two of the dated samples from the ground-floor ceiling have the heartwood/sapwood boundary present dating to AD 1482 and AD 1473. The average heartwood/sapwood boundary date is AD 1478 which produces an estimated felling date in the range AD 1493–1518. This encompasses the precise felling dates obtained for the roof and it thus appears likely that these two timbers, a main beam and a joist, were also felled in the last few years of the fifteenth century. CLD-B14 that has no trace of sapwood, has an outer ring dated to AD 1403. This timber, which is another ceiling joist, could simply be the inner section of a heavily trimmed tree and hence be coeval with the late fifteenth-century felling or alternatively it could have been felled earlier and have been subsequently reused in the ground-floor ceiling.

Hall end

Two timbers at the hall end, CLD-B22 and CLD-B25, had complete sapwood present but due to its highly friable nature this was partially lost during coring. Approximately 15mm and 5mm of sapwood was lost respectively. Comparison of the average overall ring width and that of just the last ten years, which allows for the expected overall growth trend towards narrower rings, results in relatively little variation for either series. Thus, estimated felling dates in the middle of the first decade of the sixteenth century and the last few years of the fifteenth century are derived for these two timbers, both of which are purlins, respectively. Sample CLD-B27, also from a purlin, has no trace of sapwood, and with an outer ring dated to AD 1479 it appears likely to be coeval with the late fifteenth- or early sixteenth-century felling dates obtained.

Four of the remaining five dated samples from the hall end represent cruck blades, whilst the fifth (CLD-B26) represents a collar. These have last measured rings somewhat earlier, ranging from AD 1421 to AD 1445. It is clearly possible that these were also felled in the late-fifteenth or early sixteenth century and hence represent the inner sections of longer-lived heavily trimmed trees. However it is also possible, but not proven, bearing in mind that the identification of the heartwood/sapwood boundary on CLD-B26 is only probable rather than certain, that these five timbers were felled in the middle decades of the latter half of the fifteenth century.

CLDBSQ02

The undated site chronology also incorporates timbers from both the hall end and stable end (Fig 19). These are all clearly broadly coeval but in the absence of complete sapwood it is not possible to determine whether or not they are precisely coeval. Two of the samples, a joist from the stable end ground-floor ceiling (CLD-B15), and a purlin from the hall end roof, did retain their heartwood/sapwood boundary, which varies by only four years, and suggests that they may well represent a single felling programme. The remaining three samples, representing two purlins from the stable end roof and a purlin from the hall end roof, have no trace of sapwood but the relative dates of their last measured rings, combined with the overall level of cross-matching (Table 3), suggests that they are a coherent group representing the same felling programme.

DISCUSSION AND CONCLUSION

Prior to tree-ring analysis being undertaken at Daubeneys, it was thought that the hall end may have dated to the latter decades of the fourteenth century and that the stable end was a later addition constructed by the end of the fifteenth century, with the floor having been inserted at a later date.

The tree-ring results for the stable end are relatively straightforward indicating that the dated roof and ceiling timbers are coeval and, in the absence of any clear evidence for reuse, suggest a construction date shortly after felling of the timber in the last few years of the fifteenth century, right at the end of the expected date range. The dated timbers are however confined to the western end of the stable roof and the exposed ceiling in the central bay, and it should be noted that one of the ceiling joists has a much earlier outermost measured heartwood ring (see above).

The results produced for the hall end are somewhat less straightforward and have not identified any timbers dating to the latter decades of the fourteenth century. Three purlins from bays 3 and 4 represent at least two felling phases: one in the last few years of the fifteenth century, coeval with the felling date obtained for the stable end timbers; the other, a few years later, in the middle of the first decade of the sixteenth century. The cruck blades from trusses A, C, and E, along with a collar from truss D may be more heavily trimmed timbers that are coeval with the late fifteenth- or early sixteenth century fellings identified. However, as indicated above, they could potentially represent a felling programme several decades earlier in the middle of the latter half of the fifteenth century. Interpretation is problematic as it is based only on the early outermost measured ring dates and a probable identification of the heartwood/sapwood boundary on the collar. During sampling however, it was noted that at least one of the cruck blades had possible heartwood/sapwood boundary at a point which was not accessible for sampling. It was also noted that the outer exposed surfaces of the cruck blades appeared degraded as demonstrated by both ends of the core CLD-B16, thus hampering the identification of heartwood/sapwood boundary. If this latter interpretation is correct, then it would suggest that repairs or modifications were being undertaken, possibly even rebuilding utilising reused timbers, in the hall end roof at a similar time as the apparent construction of the stable end. Unfortunately the dendrochronological evidence from the intra-site cross-matching (Table 2) cannot positively support one or other of these possibilities as there are no apparent same-tree matches (t=>10.0) identified between relevant timbers (the only likely same-tree match being between the two cruck blades from truss 4 in the stable end), although the evidence from the undated site chronology also supports the likelihood of work being undertaken on the hall end and stable end at the same, or a similar, time. Detailed structural analysis may clarify the uncertainties in the dendrochronological interpretation as to whether the hall end and stable end are the product of a single phase of construction or represent two separate phases of construction and repairs to the hall end roof.

The overall level of cross-matching between the component series of site sequence CLDBSQ01 (Table 2) is such that it suggests a common woodland source for the dated timbers from both the hall end and stable end. The levels of cross-matching for the timbers highlighted as having somewhat earlier end-dates appear generally lower, but this may simply be a product of the shorter overlaps between ring sequences. This site chronology generally produces the highest t-values, and thus shows the greatest degree of similarity, with reference chronologies from Wiltshire and the surrounding counties which indicates that a relatively local woodland source was probably used (Table 5). The component series of site sequence CLDBSQ02 also appear likely to form a coherent group of timbers from a common woodland source (Table 3), although clearly this could be a different one whilst most likely still relatively local, from the dated timbers.

It is interesting to note that the variation in number of sapwood rings present on the two samples (CLD-B06, CLD-B07) from the stable end with bark edge. The heartwood/sapwood boundary dates are AD 1454 and AD 1485. Such a variation would frequently, in the absence of complete sapwood, be taken to imply that the timbers may represent different felling phases. However, in this instance, it is known that they were only felled a year apart.

The inability to date CLDBSQ02 does not necessarily suggest that the component timbers are of a different date, but may simply mean that they are derived from a source that has responded to slightly different, potentially highly localised, growth conditions. The early part of this sequence is clearly dominated by a band of narrow rings followed by a period of recovery, indicating that these trees suffered a sudden and severe growth-retardation event (Fig 20). This, combined with a series of lesser growth-retardation events, will have had a detrimental effect on the more general climatic signal required for successful dating purposes.

One of the four ungrouped and undated samples, CLD-B20, shows some disturbance to its growth pattern (Fig 21), which again would reduce the chances of successful cross-matching and dating. However the chances of dating individual ring sequences are always lower than that of a well-replicated site sequence in which the common climatic signal is enhanced at the expense of background ‘noise’ resulting from local growth conditions of individual trees. Again the inability to date these individual samples does not necessarily mean that they are of a different date.

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TABLES

Table 1: Details of tree-ring samples from Daubeneys, Colerne, Wiltshire

Sample number	Sample location	Total rings	Sapwood rings	Average ring width (mm)	Cross-section dimensions (mm)	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Stable end								
CLD-B01	Truss 2 north cruck blade	69	no h/s	2.00	300x120	--	--	--
CLD-B02	Truss 2 south cruck blade	54	11	2.56	290x150	--	--	--
CLD-B03	North purlin truss 2–3	71	no h/s	2.32	220x130	--	---	--
CLD-B04	South purlin truss 2–3	90	no h/s	2.61	220x140	--	---	--
CLD-B05	Truss 3 north cruck blade	nm	--		340x140	--	--	--
CLD-B06	Truss 3 collar	88	42C	1.15	250x120	1409	1454	1496
CLD-B07	North purlin truss 3–4	106	12C	1.85	230x150	1392	1485	1497
CLD-B08	South purlin truss 3–4	102	8	2.01	230x150	1390	1483	1491
CLD-B09	Truss 4 north cruck blade	79	h/s	1.71	300x120	1403	1481	1481
CLD-B10	Truss 4 south cruck blade	77	h/s	1.62	300x150	1400	1476	1476
CLD-B11	East transverse ceiling beam truss 2–3	88	16	1.94	300x300	--	--	--
CLD-B12	West transverse ceiling beam truss 2–3	85	11	2.14	300x300	1409	1482	1493
CLD-B13	Ground floor ceiling joist 3	90	h/s	1.49	170x110	1384	1473	1473
CLD-B14	Ground floor ceiling joist 7	55	no h/s	2.41	160x120	1349	--	1403
CLD-B15	Ground floor ceiling joist 8	96	1	1.20	150x120	--	--	--
Hall end								
CLD-B16	Truss A north cruck blade	75	no h/s	2.39	300x120	1347	--	1421
CLD-B17	Truss A south cruck blade	61	no h/s	2.66	300x130	1363	--	1423
CLD-B18	Truss B collar	nm	--	--	200x120	--	--	--
CLD-B19	Truss C north cruck blade	68	no h/s	2.54	220x130	1372	--	1439
CLD-B20	Truss D north cruck blade	58	h/s	1.62	200x120	--	--	--
CLD-B21	Truss E south cruck blade	63	no h/s	2.97	200x120	1380	--	1442
CLD-B22	Truss D–E north purlin	98	14c (~15mm sap lost)	1.45	220x110	1399	1482	1496
CLD-B23	Truss E–1 north purlin	110	5	1.90	240x120	--	--	--

Table 1: (cont)

Sample number	Sample location	Total rings	Sapwood rings	Average ring width (mm)	Cross-section dimensions (mm)	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
CLD-B24	Truss E–1 south purlin	81	no h/s	1.93	230x120	--	--	--
CLD-B25	Truss D–E south purlin	90	9c (~ 5mm sap lost)	1.87	240x100	1405	1485	1494
CLD-B26	Truss D collar	56	h/s?	2.39	160x90	1390	1445?	1445
CLD-B27	Truss C–D south purlin	102	no h/s	2.20	230x140	1378	--	1479

nm = not measured

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

c=complete sapwood was present on the timber but part of the sapwood was lost during coring

C=complete sapwood is present on the sample

Table 2: Matrix showing the t-values obtained between the ring sequences included in the site master CLDBSQ01; - indicates t-values less than 3.00; \ indicates overlap of less than 30 years; grey shading indicates possible same-tree match

	cld-b07	cld-b08	cld-b09	cld-b10	cld-b12	cld-b13	cld-b16	cld-b17	cld-b19	cld-b21	cld-b22	cld-b25	cld-b26	cld-b27	cld-b14
cld-b06	4.27	6.36	3.45	-	4.64	3.95	\	\	7.83	-	6.37	6.63	5.86	4.75	\
cld-b07		5.39	4.09	-	4.19	-	3.58	-	-	-	5.06	5.70	3.14	4.33	\
cld-b08			4.20	3.29	6.03	3.71	3.35	5.37	4.45	3.20	6.58	8.44	3.42	8.88	\
cld-b09				14.10	9.99	3.75	\	\	-	3.51	-	6.78	-	5.38	\
cld-b10					9.28	3.26	\	\	-	3.14	-	6.35	-	3.02	\
cld-b12						5.07	\	\	-	-	3.67	7.98	-	5.51	\
cld-b13							6.46	-	-	3.19	-	5.27	3.72	-	\
cld-b16								6.35	3.02	6.77	\	\	-	3.40	4.49
cld-b17									-	4.10	\	\	-	3.69	-
cld-b19										4.17	3.23	3.09	5.29	-	-
cld-b21											-	3.05	-	3.65	\
cld-b22												5.77	-	5.92	\
cld-b25													3.98	6.35	\
cld-b26														-	\
cld-b27															\

Table 3: Matrix showing the t-values obtained between the ring sequences included in the site master CLDBSQ02

	cld-b04	cld-b15	cld-b23	cld-b24
cld-b03	9.50	4.29	8.46	6.97
cld-b04		4.37	8.81	6.85
cld-b15			6.90	3.64
cld-b23				6.06

Table 4: Results of the cross-matching of the individual sequence CLD-B14 and relevant reference chronologies when the first-ring date is AD 1349 and the last-ring date is AD 1403

Reference chronology	*t*-value	Span of chronology	Reference
Moorstone Barton, Halberton, Devon	6.8	AD 1337–1439	(Tyers *et al* forthcoming)
The Garth, Pembridge, Herefordshire	6.7	AD 1315–11466	(Tyers 2002)
Westfields East, Pembridge, Herefordshire	6.3	AD 1288–1483	(Tyers 2004b)
Archdeacons House, Exeter, Devon	5.9	AD 1186–1404	(Howard *et al* 1999)
Chastleton House panels, Oxfordshire	5.6	AD 1347–1602	(Tyers 2001)
Farmers Club, Hereford, Herefordshire	5.5	AD 1313–1617	(Tyers 1996)
St Andrew's Church, Alwington, Devon	5.3	AD 1342–1490	(Arnold and Howard 2009)
24 High Street, Bruton, Somerset	5.2	AD 1335–1429	(Miles *et al* 1997)

Table 5: Results of the cross-matching of site sequence CLDBSQ01 and relevant reference chronologies when the first-ring date is AD 1347 and the last-ring date is AD 1497

Reference chronology	*t*-value	Span of chronology	Reference
St Andrew's Church, Alwington, Devon	9.3	AD 1342–1490	(Arnold and Howard 2009)
Mercers Hall, Gloucester, Gloucestershire	9.1	AD 1289–1541	(Howard *et al* 1996)
The Commandery, Worcester, Worcestershire	9.0	AD 1284–1473	(Arnold and Howard 2006)
Castle Farm, Marshfield, Gloucestershire	8.1	AD 1394–1515	(Howard *et al* 1998 unpubl)
Farmers Club, Hereford, Herefordshire	7.7	AD 1313–1617	(Tyers 1996)
Old Manor, West Lavington, Wiltshire	7.6	AD 1264–1497	(Tyers and Hurford 2014)
Ashleworth tithe barn, Gloucestershire	7.5	AD 1319–1475	(Bridge 2002)
24 High Street, Bruton, Somerset	7.2	AD 1335–1429	(Miles *et al* 1997)

FIGURES

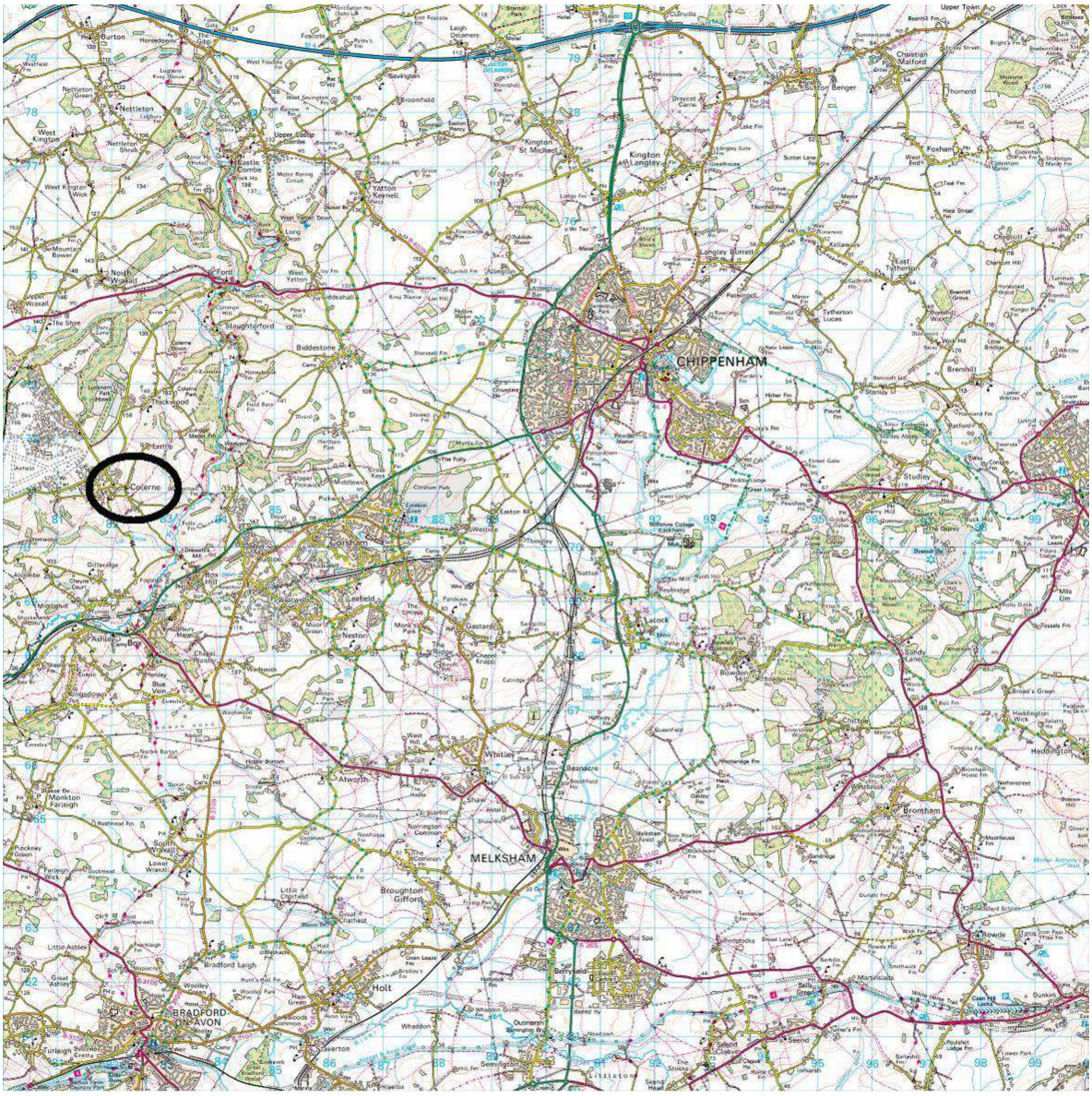

Figure 1: Map to show the location of Colerne, Wiltshire (circled). © Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900

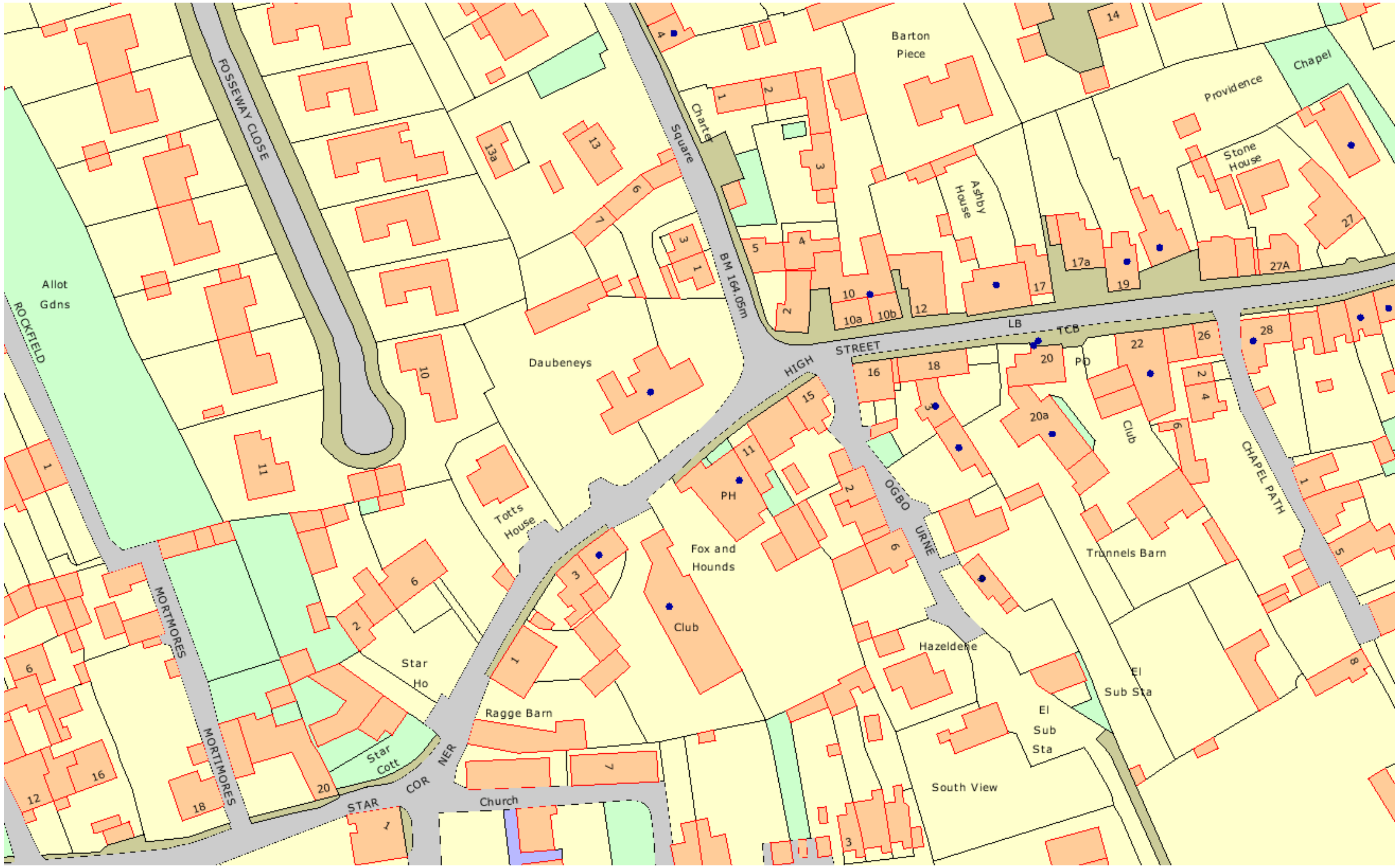

Figure 2: Map to show the location Daubeneys. © Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900

Figure 3: West gable end and south front of Daubeneys (Matt Hurford)

Figure 4: The hall end, truss E east face (Matt Hurford)

Figure 5: The hall end, open truss B in the solar, viewed looking south-west (Matt Hurford)

Figure 6: The stable end roof viewed looking east (Matt Hurford)

Figure 7: The stable end ceiling viewed looking east (Matt Hurford)

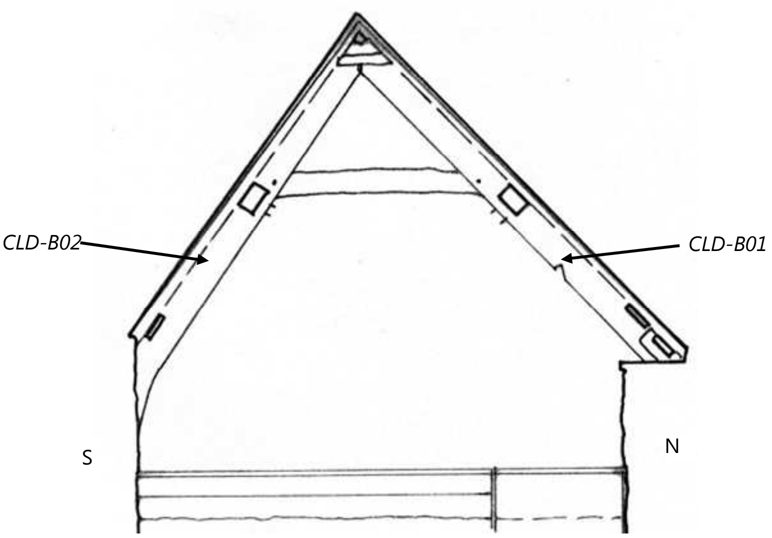

Figure 8: The stable end, truss 2, showing the sample locations (based on a drawing by Clive Carter of the Wiltshire Buildings Record)

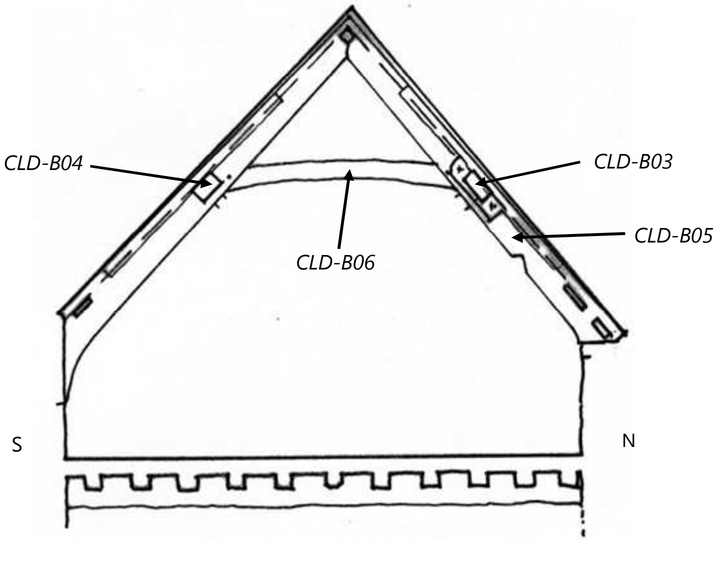

Figure 9: The stable end, truss 3, showing the sample locations (based on a drawing by Clive Carter of the Wiltshire Buildings Record)

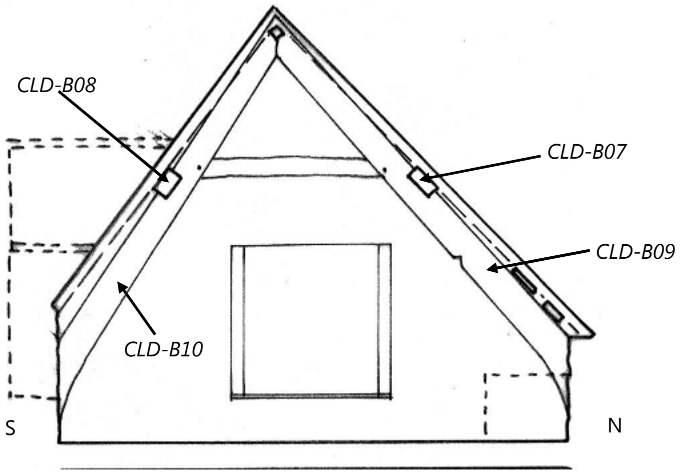

Figure 10: The stable end, truss 4, showing the sample locations (based on a drawing by Clive Carter of the Wiltshire Buildings Record)

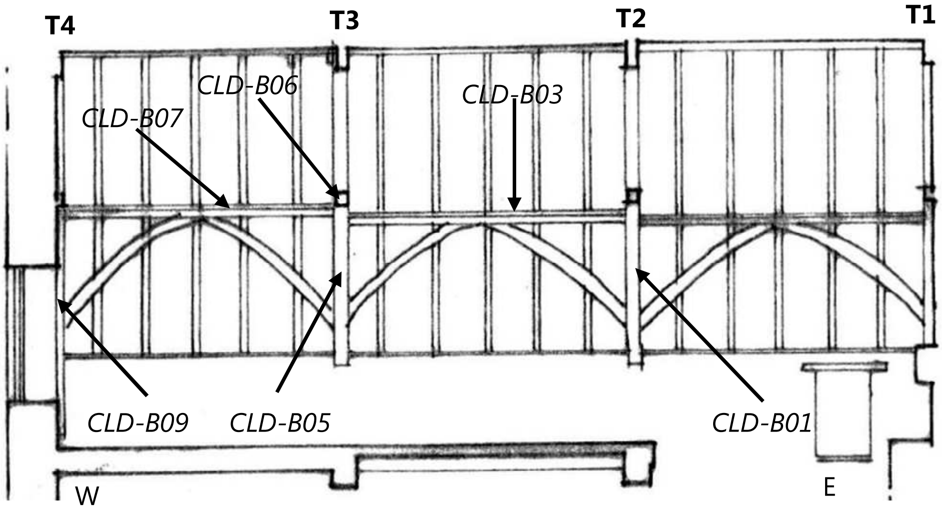

Figure 11: The stable end roof, viewed internally looking north, showing the sample locations (based on a drawing by Clive Carter of the Wiltshire Buildings Record)

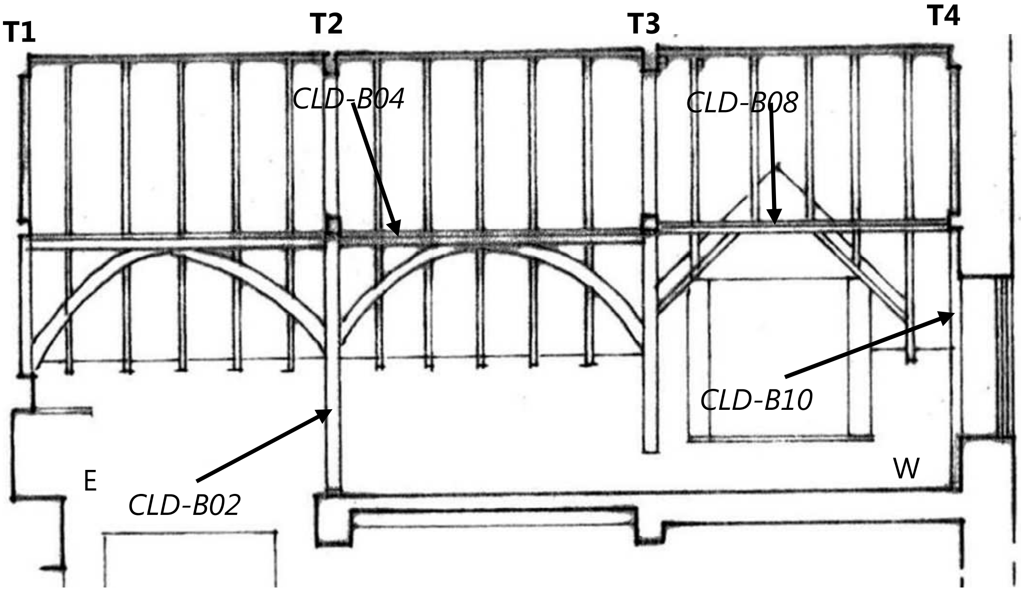

Figure 12: The stable end roof, viewed internally looking south, showing the sample locations (based on a drawing by Clive Carter of the Wiltshire Buildings Record)

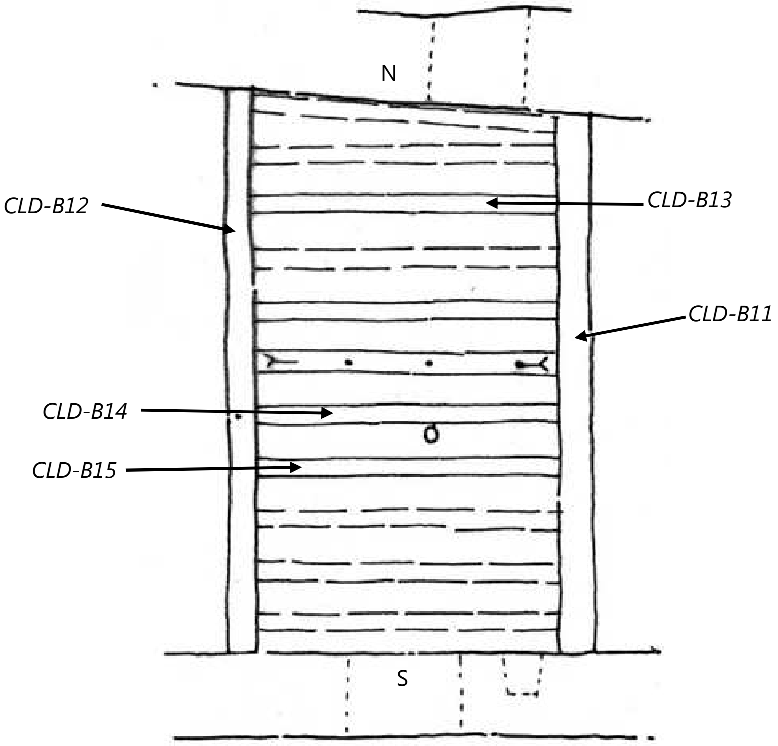

Figure 13: The stable ceiling showing the sample locations (based on a drawing by Clive Carter of the Wiltshire Buildings Record)

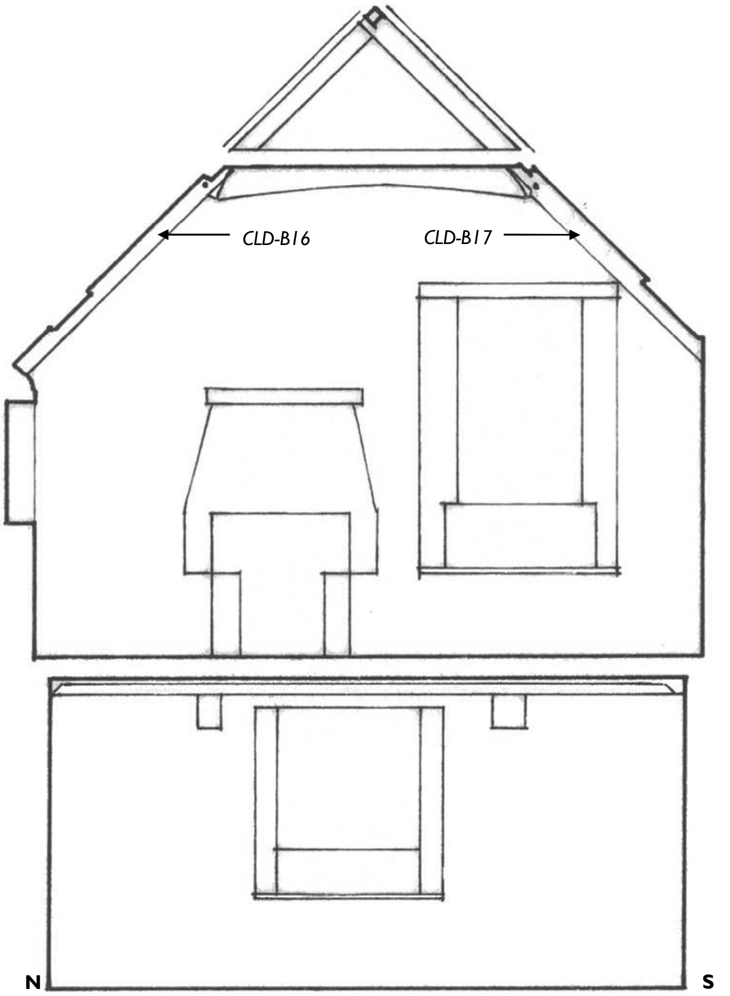

Figure 14: The hall end truss A showing the sample locations (based on a drawing by Clive Carter of the Wiltshire Buildings Record)

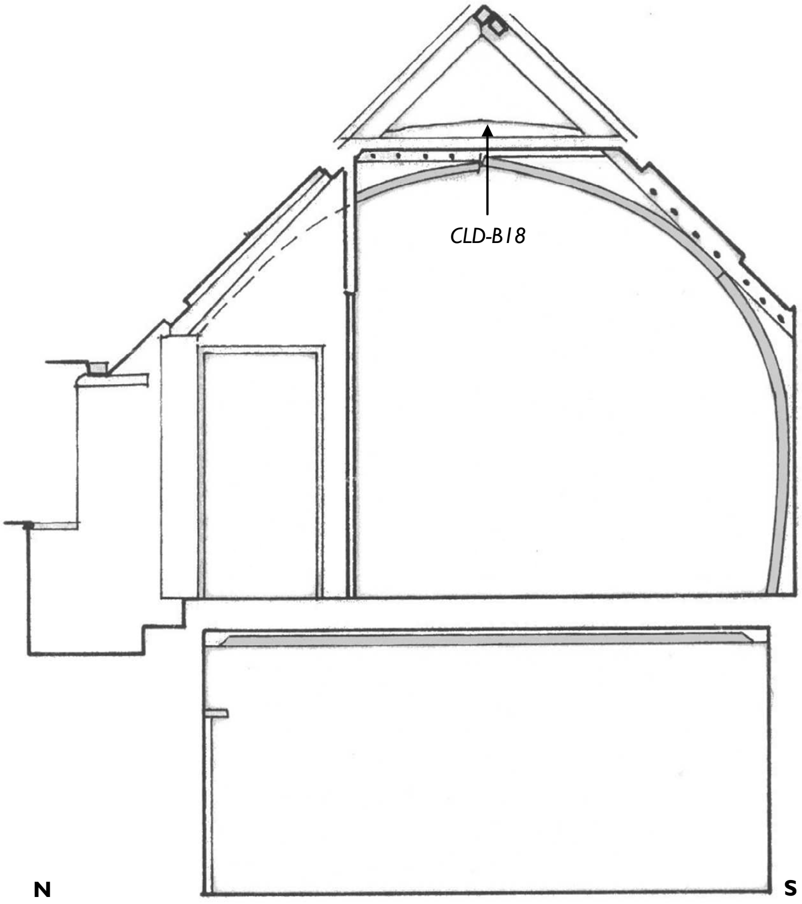

Figure 15: The hall end truss B, the open truss in the solar, showing the sample locations (based on a drawing by Clive Carter of the Wiltshire Buildings Record)

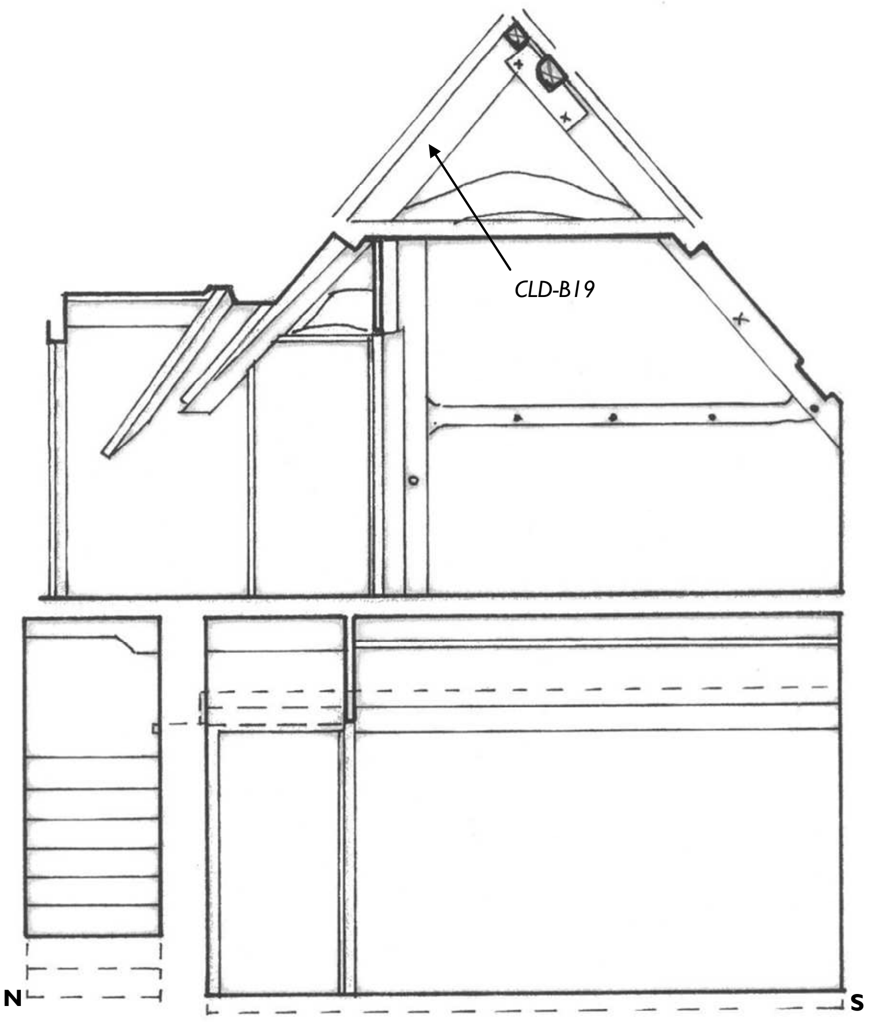

Figure 16: The hall end, truss C, showing the sample locations (based on a drawing by Clive Carter of the Wiltshire Buildings Record)

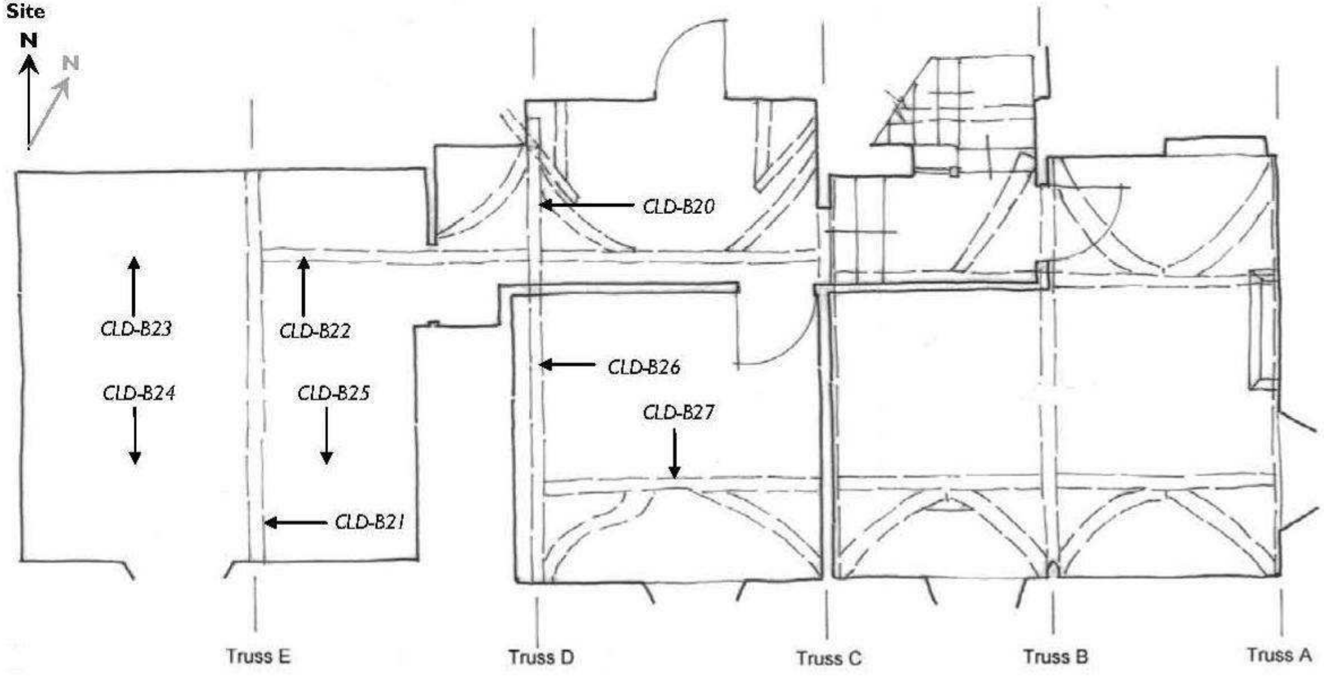

Figure 17: Roof plan of the hall end showing the remaining sample locations (based on a drawing by Clive Carter of the Wiltshire Buildings Record)

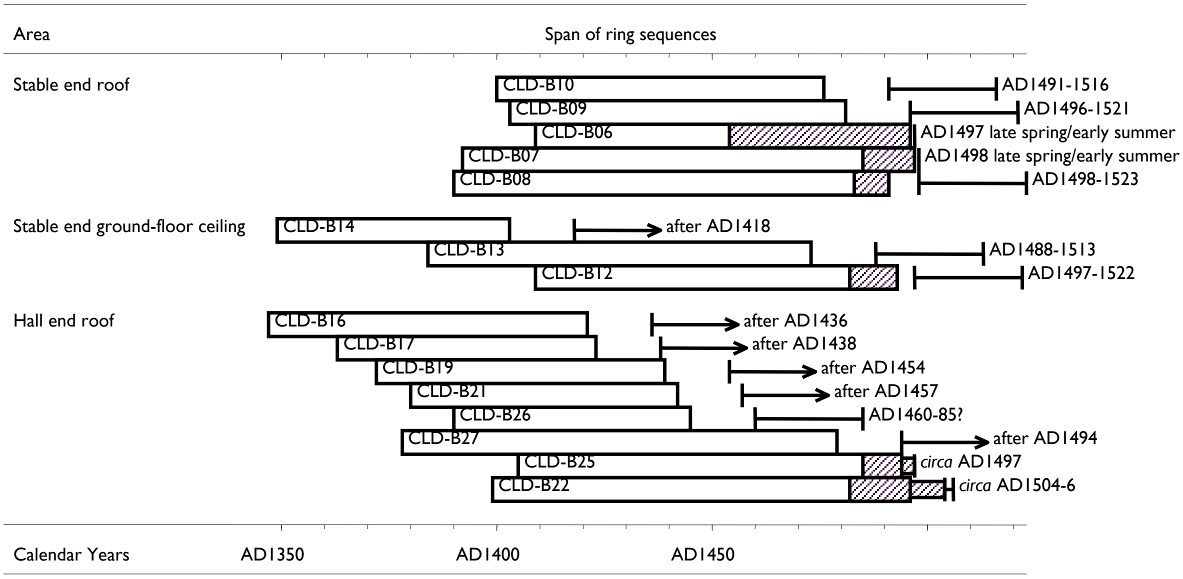

Figure 18: Bar diagram of the samples in site chronology CLDBSQ01 and their individual felling dates. White bar = heartwood rings; hatched bar = sapwood rings; narrow bar = unmeasured rings

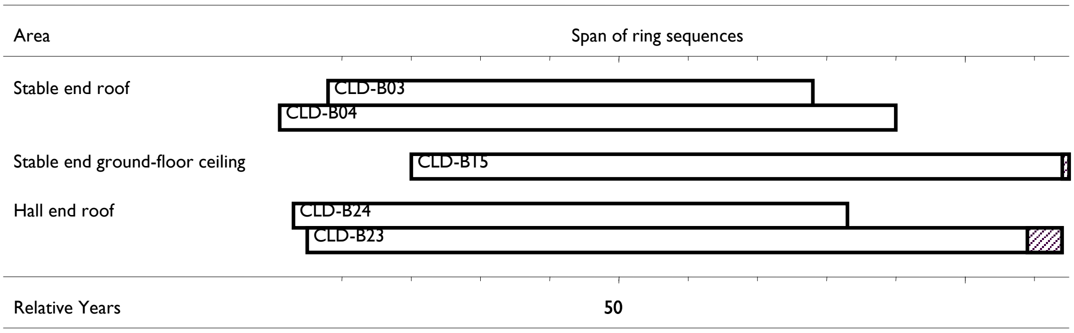

Figure 19: Bar diagram of the samples in site chronology CLDBSQ02. White bar = heartwood rings; hatched bar = sapwood rings

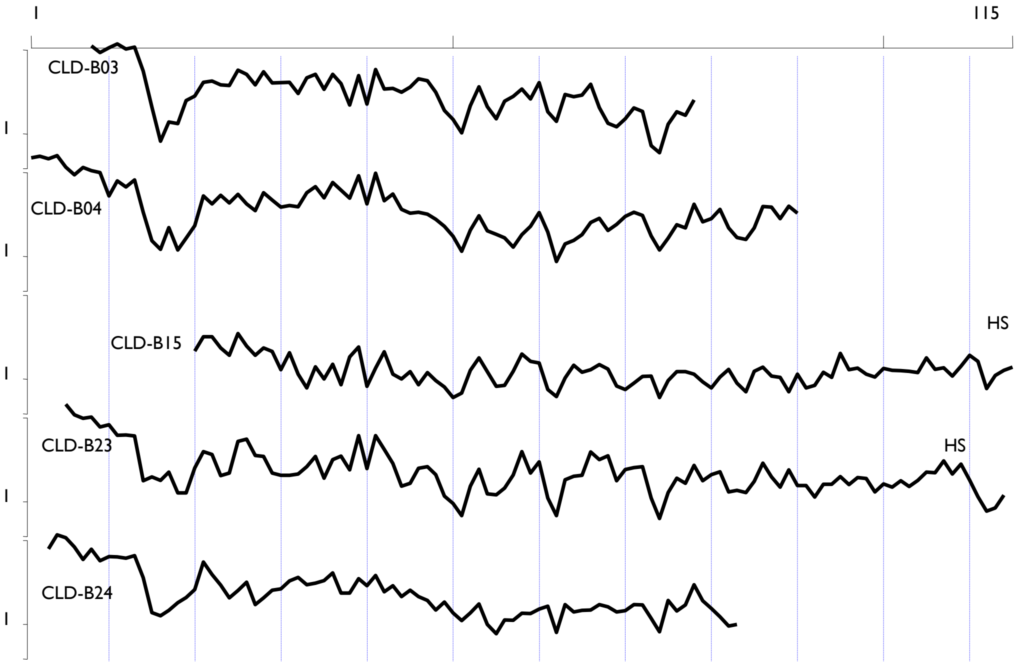

Figure 20: Diagram of the ring sequences in site chronology CLDBSQ02. HS = heartwood/sapwood boundary

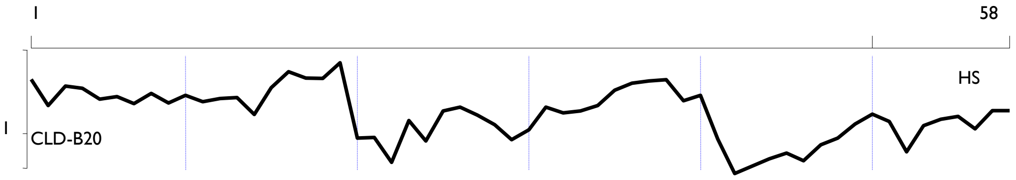

Figure 21: Diagram of the ring sequence of CLD-B20. HS = heartwood/sapwood boundary

DATA OF MEASURED SAMPLES

Measurements in 0.01 mm units

CLD-B01A 69
241 245 149 239 223 182 170 164 236 381 366 325 264 316 261 203 280 259 269 349
172 126 139 126 103 122 109 166 281 250 190 189 140 152 153 182 158 115 133 130
143 124 215 194 266 187 247 189 128 123 202 232 202 173 214 224 214 215 225 195
202 197 179 134 114 251 135 181 257
CLD-B01B 69
243 244 143 250 221 180 166 175 237 419 362 322 264 318 255 207 275 248 267 346
175 118 150 123 101 122 107 169 287 249 190 186 141 158 151 182 157 115 128 134
135 132 225 190 267 196 241 185 120 131 231 238 196 175 210 227 209 219 217 192
204 189 179 136 109 178 131 185 265
CLD-B02A 54
384 288 263 223 208 245 298 301 296 247 225 161 113 180 191 208 326 379 446 363
261 278 234 218 178 212 206 205 225 192 180 181 172 204 252 205 230 309 358 352
361 323 442 273 222 230 218 239 261 215 227 199 277 330
CLD-B02B 54
382 283 272 220 220 254 300 303 295 247 220 164 115 179 187 207 327 378 448 359
252 275 243 213 182 218 203 203 234 192 181 179 169 208 250 210 222 319 356 356
356 324 441 272 225 224 222 232 262 215 215 195 283 331
CLD-B03A 71
526 454 498 556 485 510 324 174 75 132 118 190 204 263 270 247 252 333 304 260
315 259 264 257 214 281 308 233 306 255 178 300 174 337 228 235 218 237 285 270
219 158 129 103 174 235 170 132 187 201 233 194 261 156 127 211 201 206 261 162
127 112 141 164 152 80 73 114 155 140 190
CLD-B03B 71
519 469 506 525 500 509 327 159 99 119 124 185 202 264 270 255 245 328 308 243
329 262 260 269 214 291 303 230 307 260 166 299 177 331 237 235 219 243 278 275
219 153 134 102 167 249 165 134 184 203 232 191 264 147 125 208 202 208 247 166
118 116 126 163 153 81 68 126 147 144 189
CLD-B04A 90
636 658 632 669 536 460 534 502 489 301 415 371 424 227 135 115 172 112 143 181
314 272 318 268 312 272 234 330 293 252 260 258 327 386 303 399 345 300 453 271
477 292 332 247 221 224 226 202 175 149 108 163 220 162 154 141 121 150 176 223
160 92 124 138 154 188 205 165 185 211 234 220 146 111 142 177 171 272 187 204
243 171 145 138 171 257 257 203 258 228
CLD-B04B 90
640 658 624 660 534 467 533 501 478 321 411 366 419 234 133 114 172 115 140 175
311 267 315 280 331 266 240 330 284 255 261 251 333 356 298 403 347 299 460 266
480 279 315 237 229 235 218 201 177 144 113 165 210 162 150 143 117 152 177 234
157 91 130 133 149 191 206 162 181 214 225 212 149 115 141 187 172 262 197 203
243 172 142 138 171 255 250 205 257 222
CLD-B06A 88
313 264 327 368 259 272 219 181 239 277 210 147 180 141 166 170 142 115 91 154
162 143 138 151 132 83 54 60 81 76 60 71 85 56 54 62 56 55 60 59
70 87 118 114 89 159 152 106 115 82 91 105 75 82 142 70 88 96 123 151
132 110 88 103 116 135 143 93 72 61 67 79 86 87 58 71 61 58 57 46
60 38 73 43 58 45 40 36

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CLD-B06B 88
 310 267 350 378 256 278 215 180 239 278 203 144 190 143 166 167 148 114  88 167
 153 150 142 157 133  73  58  61  80  76  55  73  79  63  58  59  53  56  58  62
  66  90 112 120  89 160 148 109 112  84  91 102  89  73 155  66  89  95 130 136
 125 108  89 105 117 131 141  98  64  64  60  81  79  88  58  69  67  53  56  46
  61  41  66  41  53  40  37  34
CLD-B07A 106
 306 475 364 478 405 332 476 453 390 366 290 293 271 217 295 214 196 289 230 190
 149 131 162 194 164 231 161 116  86 165 167 187 164 156 120  93 119 126 131 128
 174 127 118 104 119 108 121  82 110 102  96 105 118 114 100 116 129 110  66 118
 114  98  78 110 124 132 181 211 227 219 178 201 170 178 172 170 188 175 197 156
 152 161 195 187 133 107 114 120 172 163 172 156 179 180 145 179 169 192 170 201
 185 186 229 276 231 243
CLD-B07B 106
 303 475 366 475 396 345 472 449 400 368 277 294 257 232 285 212 191 287 239 193
 152 128 166 193 168 233 164 108  91 165 167 183 160 149 119  95 116 108 133 125
 181 139 117 118 110 112 118  83 108 105  97 102 113 123 101 111 132 109  76 115
 118 102  77 114 116 136 179 216 228 215 175 200 168 177 178 179 199 176 198 153
 150 169 184 183 141  98 106 123 181 164 191 154 190 184 146 175 162 201 159 208
 185 181 237 287 230 247
CLD-B08A 102
 391 593 346 449 389 349 410 371 397 341 528 319 332 353 385 288 291 288 381 375
 246 207 221 144 151 158 197 296 297 170 157 222 171 205 207 163 156 135 165 181
 205 189 214 159 150 130 127 162 160 125 127 209 174 149 133 114  91 102 117 127
 122 114 138 113  83 120  92 123 144 176 167 135 130 186 109 129 143 128 165 182
 156 166 150 165 211 228 142 105 107  95 182 167 201 165 152 149 135 120 165 189
 175 155
CLD-B08B 102
 383 584 350 446 385 358 402 381 383 345 527 318 325 361 383 290 292 283 388 366
 251 206 219 142 162 149 196 293 300 175 154 213 178 209 198 169 146 127 157 179
 220 186 224 158 149 129 131 148 162 129 121 200 180 147 141 117  91 100 115 125
 123 115 132 105  92 118  90 127 140 178 166 135 128 188 110 126 147 125 165 182
 160 164 152 172 207 223 145 102 106  98 176 177 196 159 161 145 135 120 156 192
 175 150
CLD-B09A 79
 194 150 177 218 195 244 285 203 244 209  98 173 185 222 238 197 122 155 220 131
 216 139 175 181 180 224 199 172 203 227 186 195  96 184 111 129 129 154 178 148
 191 156 149 108 137 146 161 146 197 166 128 109 112 142 153 185 183 164 132 128
 162  87 112 153 169 178 179 200 180 177 171 180 228 204 156 138 194 199 160
CLD-B09B 79
 201 156 182 217 190 242 279 200 250 205  99 170 165 227 231 198 127 166 208 134
 199 140 167 181 192 229 206 169 198 226 192 191  89 179 105 121 129 156 187 148
 186 170 147 107 136 144 163 146 187 169 122 117 106 140 170 186 177 169 127 124
 159  94 101 178 161 183 183 203 170 171 180 173 226 205 156 133 187 201 185
CLD-B10A 77
 240 223 190 166 149 172 228 180 209 201 109 142 154  66 130 174 160 166 141  81
 117 140 103 168 184 170 184 259 287 274 203 226 243 224 195 104 216 109 114 127
 136 178 142 179 169 146 103 128 138 164 151 169 177 160 128 112 157 175 244 191
 177 161 147 176  85 101 171 146 145 180 148 138 146 105 108 169 131
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CLD-B10B 77
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 112 136  98 172 187 168 183 264 285 269 207 227 243 224 193 107 214 109 110 126
 140 179 138 186 182 145 103 131 132 163 148 173 181 155 131 117 151 174 236 198
 176 157 143 172  85  98 173 141 154 155 150 142 153  97 105 158 125
CLD-B11A 88
 372 449 363 384 275 221 193 191 232 143 123 146 212 196 203 254 238 255 353 298
 240 141  88 148 175 183 227 228 148  99 114 109 113 100  99 154 224 195 205 216
 222 170 242 164 275 237 239 291 242 193 203 197 176 200 162 187 204 221 285 194
 140 169 191 119 135 201 195 155 195 155 196 119 112 152 139 126 181 186 193 195
 164 133 227 149 158 164 164 133
CLD-B11B 88
 376 442 359 352 278 221 196 205 199 138 114 122 157 199 197 266 246 256 365 305
 236 143 102 136 150 183 220 228 152  95 107 105 115 103 111 137 230 200 192 224
 212 189 217 164 275 259 231 297 241 191 210 195 168 197 153 185 215 216 282 200
 144 169 185 117 130 199 192 164 191 145 206 118 114 148 133 131 176 194 189 189
 161 135 222 144 162 173 160 133
CLD-B12A 85
 335 269 271 228 123 152 181 174 230 232 152 233 266 187 246 272 228 200 196 266
 238 208 224 328 290 238 152 198 161 186 185 169 255 241 202 251 144 135 152 204
 209 214 215 250 176 179 193 227 245 249 249 259 202 211 237 150 148 212 228 244
 287 284 271 255 258 225 304 235 179 168 198 231 262 208 197 177 231 140 182 180
 199 201 153 127 129
CLD-B12B 85
 351 256 283 224 128 142 185 178 224 235 155 240 249 187 250 270 230 194 197 268
 236 209 226 329 289 238 148 198 169 182 181 177 249 234 208 249 139 143 157 199
 209 216 222 239 178 178 199 229 256 245 241 250 210 207 239 154 142 205 228 252
 276 292 279 253 250 230 311 228 181 168 204 219 257 206 199 172 237 134 178 177
 197 197 150 120 148
CLD-B13A 90
 272 217 258 336 308 202 172 168 161 235 174 176 226 189 209 376 312 252 117 173
 261 218 360 202 241 244 208 215 199  62  64  86  97 140 163  89  93  92  67 136
 162 187 193 134 167 119 106  93 131 114  76 116  73  90  69  58  62  82  81  90
 100  68  63  56 110 133 109  99  65  69 122 126 126 129 128 105  83  85  85  95
  66  98 123 250 249 186 144 116 110 103
CLD-B13B 90
 281 229 263 336 310 199 172 165 168 233 177 177 222 182 222 371 324 256 116 173
 259 215 355 209 242 258 212 227 203  65  62  91  95 143 168  88  90  91  73 131
 163 195 203 128 186 134 125 106 146 108  85 114  77  84  73  54  66  87  77  87
 101  69  67  61 112 132 118  97  68  68 126 124 131 126 127 109  84  83  86  94
  61  90 120 235 247 193 150 115 109  98
CLD-B14A 55
 439 289 347 216 341 245 206 179 225 247 217 193 169 225 251 402 190 292 219 259
 266 328 133 122 153 239 241 250 214 171 276 298 162 181 250 189 209 234 277 319
 244 183 321 170 292 140 214 277 159 205 340 334 274 168 259
CLD-B14B 55
 432 320 359 220 368 260 220 180 225 249 219 190 171 221 255 402 190 287 226 240
 274 323 137 124 159 235 236 243 211 165 285 297 179 172 252 189 203 246 267 317
 245 184 315 174 294 143 214 279 158 205 336 324 276 178 252
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CLD-B15A 96
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 135  86  70 105 129 115 117 134 124  84  82  92 106 107  69  99 114 116 111  92
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 119 119 114 116 113 151 117 123 110 133 152 143  86 107 117 128
CLD-B15B 96
 172 221 224 181 156 235 181 158 180 168 124 169 102  89 122 102 138  86 147 178
  90 121 176 113 103 109  90 106 100  85  69  79 114 154 106  93  83 118 155 142
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  81 107 120  91  81 117 125 108 105  75 113  88  83 121 100 160 117 127 109 103
 126 117 120 116 113 147 123 125 102 121 160 136  83 108 120 122
CLD-B16A 75
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 152 161 253 241 157 177 144 117 142 152 174 164 223 260 287 247 260 247 221 318
 362 338 315 310 320 249 299 298 323 418 298 372 461 464 555 393 443 410 263 335
 252 262 294 249 232 196 126 106 153 179 224 252 146 198 213
CLD-B16B 75
 150 155 243 230 185 103 242 202 147 157 330 307 199 119  87  94 166 165 133 159
 159 155 246 239 159 179 147 120 137 159 176 163 221 262 294 249 249 248 227 311
 357 346 305 313 326 251 296 302 321 421 295 369 458 471 549 390 441 404 274 344
 242 262 298 250 231 197 129 103 152 175 217 252 148 185 210
CLD-B17A 61
 186 193 179 199 163 154 326 339 253 283 239 307 285 324 309 269 364 309 371 338
 343 310 299 439 387 348 337 360 271 202 224 164 176 252 223 199 278 340 351 380
 411 385 289 299 272 333 227 211 145 153  89  80  97 185 288 295 169 213 255 219
 314
CLD-B17B 61
 197 198 175 195 168 158 324 356 256 285 240 318 291 334 302 270 350 316 368 336
 341 306 298 417 383 354 334 355 252 201 234 160 172 262 234 216 281 347 366 402
 407 375 286 298 274 338 234 206 154 149  96  86  91 189 292 299 172 210 249 217
 316
CLD-B19A 68
 235 250 224 198 273 291 234 259 377 335 422 427 209 218 538 491 407 346 455 655
 333 335 310 316 374 395 441 399 563 428 343 286 380 353 455 304 227 243 177 169
 195 145 120  75  86 119 149 112 110 144 148 157 178 161 123  77 130 125 116 105
 146 117 106  97 101 186 118 110
CLD-B19B 68
 233 246 232 188 281 285 228 270 385 327 412 435 207 218 541 499 461 354 453 654
 335 324 310 319 383 389 441 456 563 430 348 275 388 373 457 288 230 251 172 169
 210 139 116  75  85 120 151 122 102 146 155 154 185 158 116  84 125 125 117  97
 148 122 108  86 117 175 124 106
CLD-B20A 58
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CLD-B20B 58
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CLD-B21A 63
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 517 377 321 325 294 201 271 201 257 291 199 192 198 130  93 121 103 148 130 104
 120 177 155 145 146 153 175 123 166 144 194 146 322 387 427 239 348 180 156 146
 250 292 286
CLD-B21B 63
 583 458 637 618 468 472 671 592 573 444 446 566 312 422 356 306 380 286 375 409
 504 372 323 332 290 197 272 199 256 295 191 190 199 136  86 128 102 153 119 104
 118 181 158 145 143 147 182 119 172 138 196 146 320 380 444 245 349 181 141 155
 245 301 287
CLD-B22A 98
 534 463 368 277 241 287 160 157 253 264 239 179 133 173 120 138 130 164 276 273
 139 110 128 107 142 158 147 118  86 126  91 119 103 124 119  85  80  73 101 100
 124 169 142 112 115 113 102  91 103 130  96  84  85  89  86  72  79  74  95 118
 154 177 149 119 157 122 134 122 145 188 174 144 106 123 143 146 147  98  79  82
  96 132 149 128 133 139 119 103 111 102 102 107 138 142 161 144 186 204
CLD-B22B 98
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 131 168 142 110 114 115 100  99  97 131  98  82  97  81  86  77  80  71 100 121
 157 181 137 108 161 123 137 117 147 186 180 136 105 125 144 135 155  97  74  81
 106 130 148 128 134 140 112 103 119  96 102 108 138 140 161 160 186 211
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 178 168 210 173 204 148 110  85  92 111
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 170 176 220 163 202 152 110  84  87 116
CLD-B24A 81
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  92
CLD-B24B 81
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 124 199 179 238 183 140 144 142 161 162 197 168 116 128 134 197 192 204 166 203
 168 146 149 133 196 183 151 133 157 292
CLD-B25B 90
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 185 164 152 200 209 207 208 227 207 139 137 157 166 148 134 176 220 168 168 175
 158 142 149 198 166 147 165 127 114 110  97 128 115 140 164 169 169 151 203 128
 130 190 178 245 176 147 138 142 155 162 201 170 123 128 135 195 192 209 167 200
 172 144 146 136 192 182 155 134 158 292
CLD-B26A 56
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 188 183 308 215 231 185 161 234 250 192 147 190 123 154 156 146 114 113 174 141
 148 160 168 124  71  96  67 104 108  84  98  99  94 103  99  89
CLD-B26B 56
 211 319 225 337 538 399 617 419 453 490 417 547 354 445 386 489 558 297 290 283
 186 186 307 218 234 192 159 231 247 193 143 196 115 154 163 142 116 103 176 139
 153 159 171 110  82  88  75 107 113  84  93  98  95 103  93  83
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 179 147 138 164 153 164 154 107 113 131 140 114 152 149 153 110  82  98 106 122
 220 264 260 193 179 244 170 201 233 190 189 222 206 127 175 188 183 237 152  97
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CLD-B27B 102
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 172 142 140 163 152 157 149 113 114 132 135 124 153 139 149 116  80 110 113 123
 210 259 251 191 185 255 170 195 233 189 189 228 199 132 175 184 179 232 144  92
 122 125
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APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

Tree-ring dating, or dendrochronology as it is known, is discussed in some detail in the Nottingham Tree-ring Dating 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 1998). 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

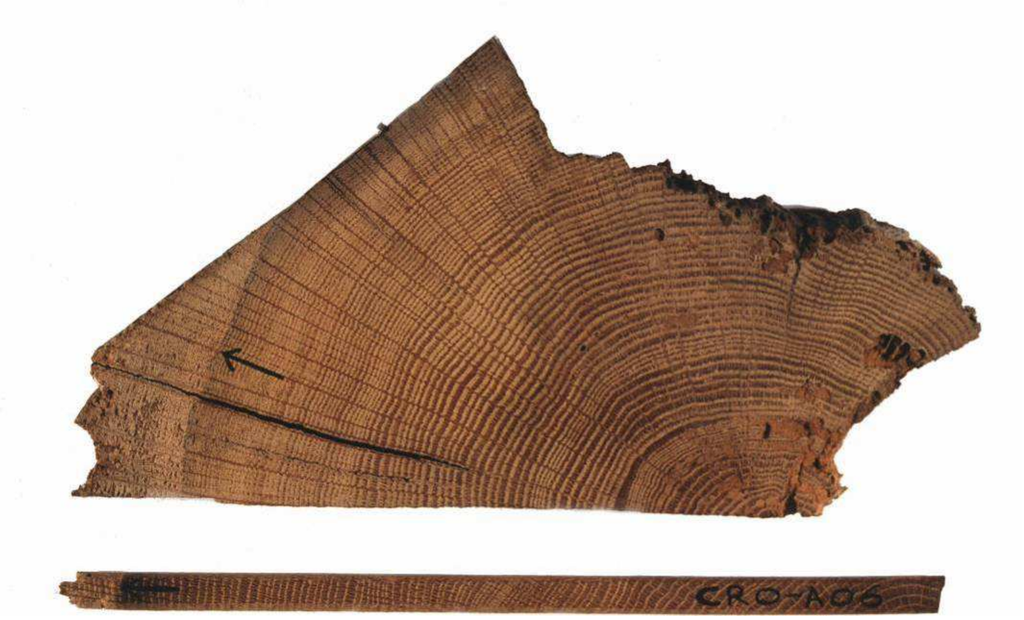

Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

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

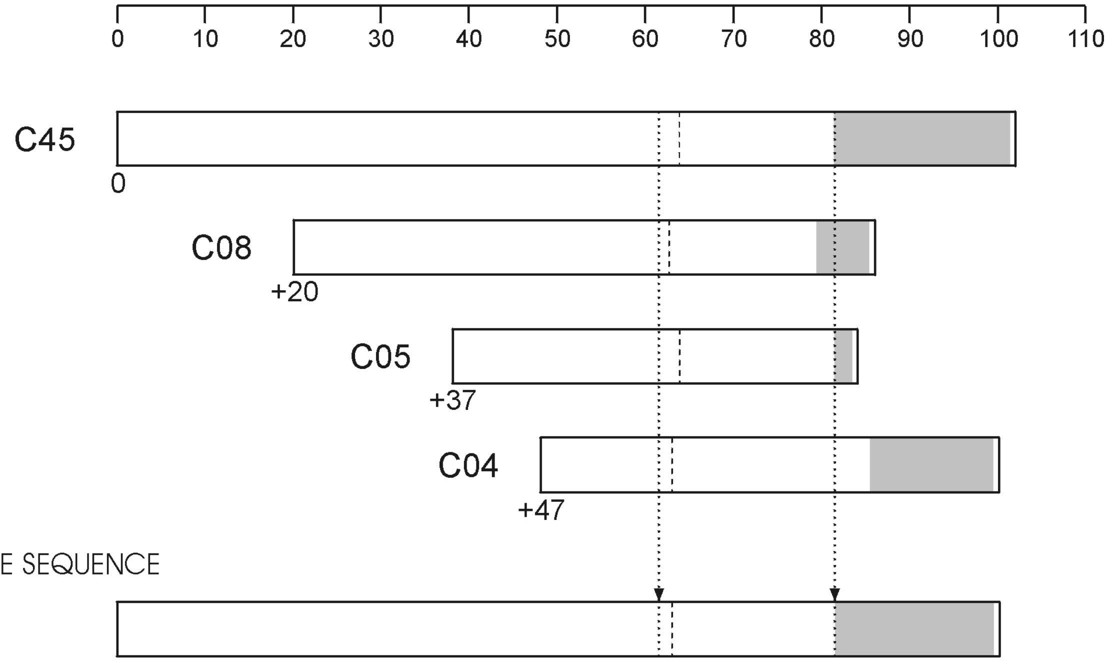

Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

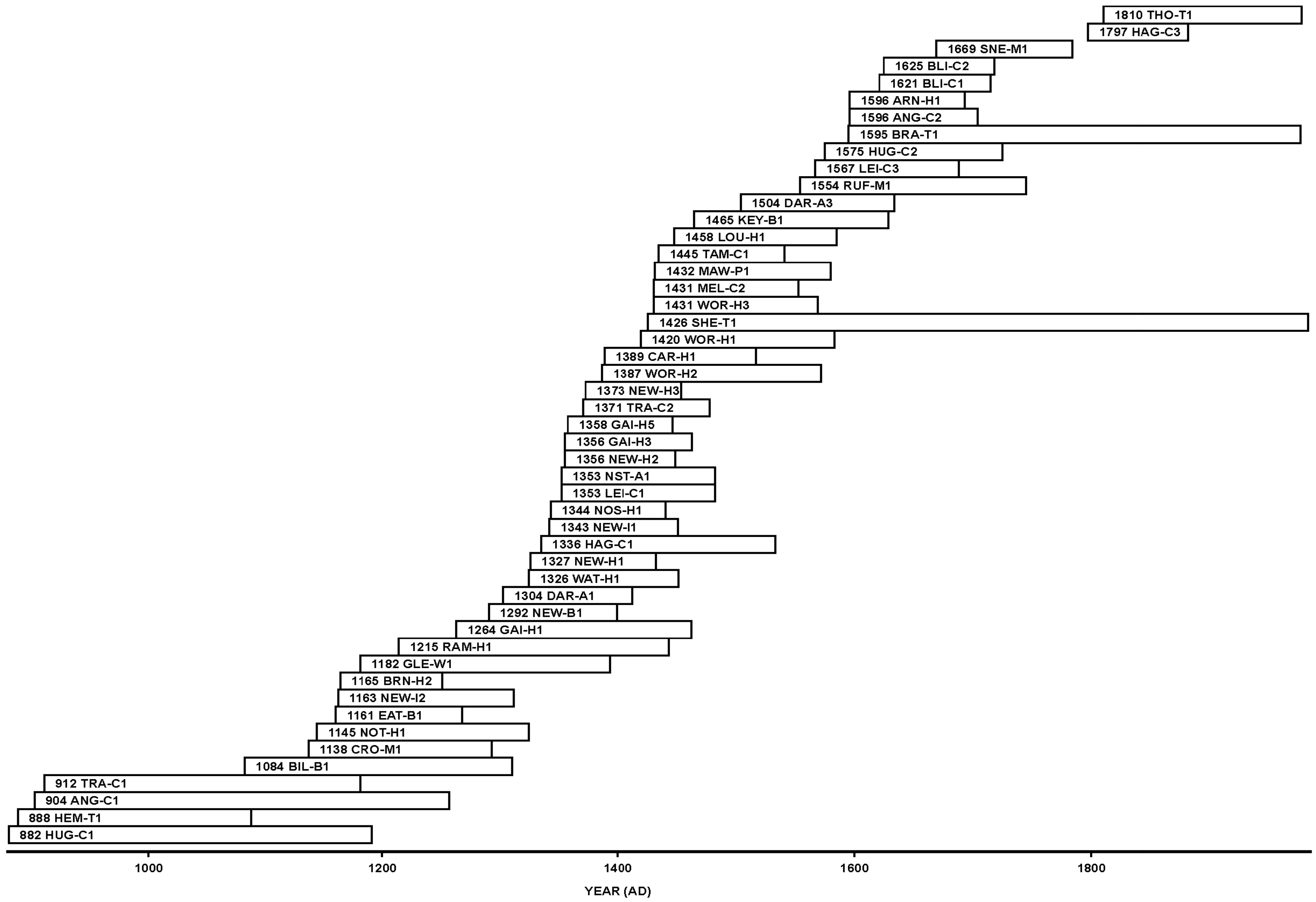

Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

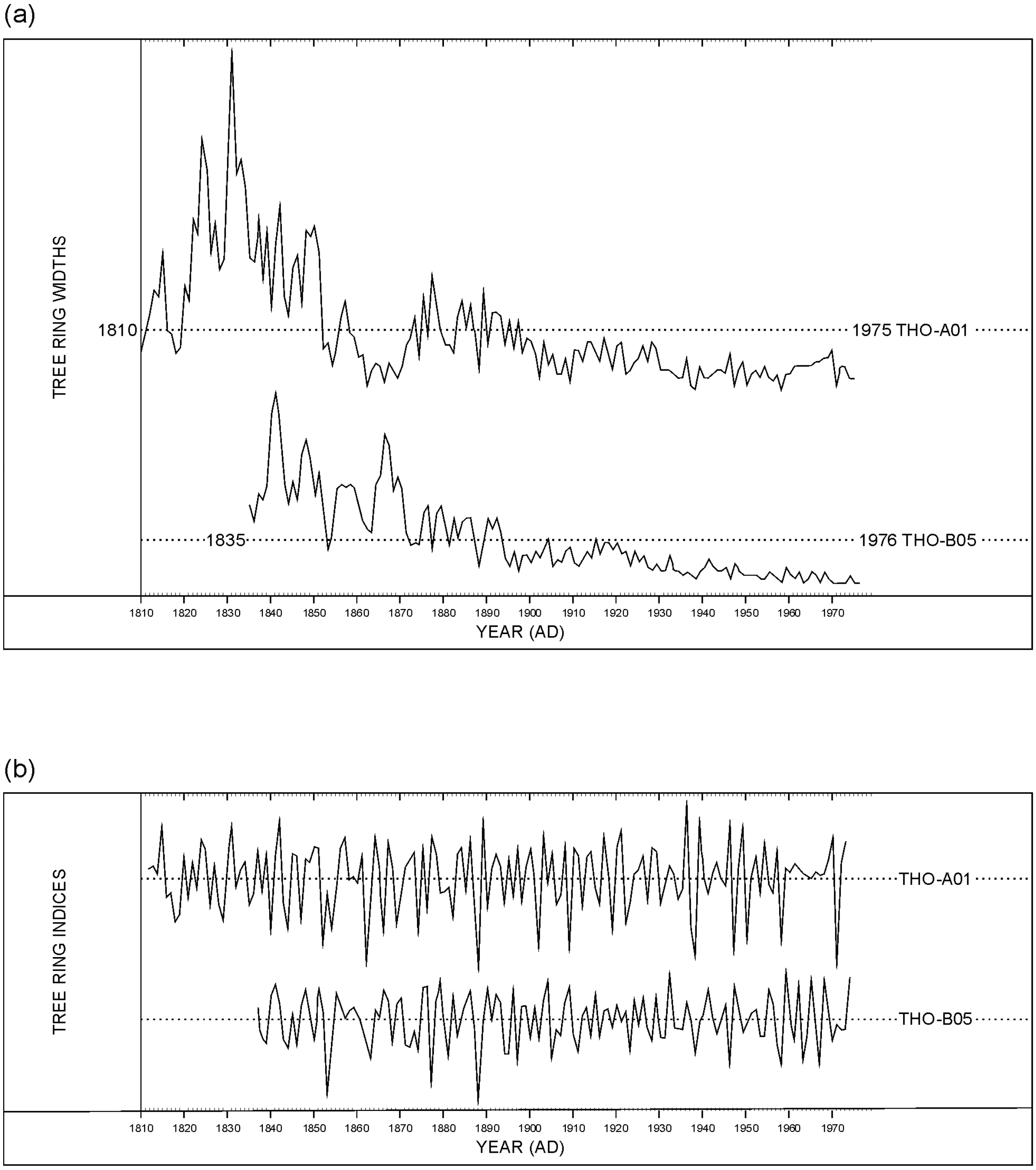

Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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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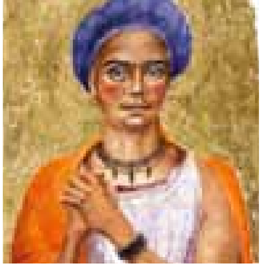


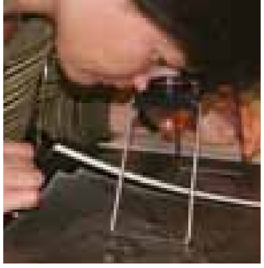


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