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The East Wing of the Bishop's Palace and the Gatehouse Palace Gate Exeter, Devon

Tree-ring Analysis of Oak Timbers

Alison Arnold and Robert Howard

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Front Cover: East Wing of the Bishop's Palace, view from the south. Photograph: Robert Howard.

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THE EAST WING OF THE BISHOP'S PALACE AND THE GATEHOUSE PALACE GATE EXETER DEVON

TREE-RING ANALYSIS OF OAK TIMBERS

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SUMMARY

Twenty-three samples were obtained from the timbers of the roof and cellar of the Gatehouse of the Bishop's Palace, 13 of which were analysed by dendrochronology. This analysis resulted in the production of three site chronologies, all comprising only two samples. Two of these, one with 55 rings, and the other with 86 rings, were dated as spanning AD 1221–75 and AD 1188–1273 respectively. Interpretation of the sapwood suggests that the timbers, all collars, were felled together at some point during the period AD 1287 to AD 1312. The other site chronology from the Gatehouse, also has 55 rings but cannot be dated, though it is probable that the two timbers were felled at the same time as each other. Seven measured samples from the Gatehouse remain ungrouped and undated.

All 21 samples from timbers of the roof of the east wing of the Bishop's Palace were analysed, producing two site chronologies. The first site chronology, comprising 10 samples and being 126 rings long, spans AD 1527–1652. The second site chronology, comprising seven samples and being 113 rings long, spans AD 1540–1652. Interpretation of the sapwood on these 17 samples suggests that all the dated roof timbers were felled in, or about, AD 1652. The remaining four samples are ungrouped and undated.

CONTRIBUTORS

Alison Arnold and Robert Howard

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INTRODUCTION

The Bishop's Palace at Exeter, listed at Grade I (LEN 1222943), lies to the south-east of the Cathedral in a large, roughly triangular area, bounded on the eastern side by the city walls and on the north by the Cathedral and the former Chancellor's house. The western and south-western sides are bounded by Deanery Place, the house of the Archdeacon of Exeter, and by Palace Gate (Fig 1).

The present residential portion of the Palace (Fig 2), with services, chapel, and other contiguous buildings, was erected during the episcopate of Bishop Brewer, AD 1224–44, though the building process may have been protracted. Additions, particularly to the west wing of the Palace, were made throughout the later-medieval period by subsequent Bishops, with Bishop Oldham (AD 1504–19) also undertaking work in the Great Hall and adding a tower over the porch leading to the screens passage. This remaining portion; the Great Hall and screens passage, constitutes the east wing of the original complex.

From the later sixteenth century there followed a period of neglect, with the Great Hall becoming dilapidated, and the Palace deserted by the time of the Civil War; the site was used as a barracks in AD 1646. The building was subsequently bought by the City, a pre-sale survey noting that the roof of the Hall was in a state of decay, and in AD1651 it passed to the Governors of St John's Hospital. The hospital leased it to a sugar baker who remained in possession until the Restoration of the Monarchy.

The great hall was re-roofed as a double-pitched roof (rather than a single span, as the original roof was), with its central valley supported on a tall, full-height, axial partition which incorporated reused sections of the thirteenth-century oak aisle posts cut up and reused in the frame. The trusses of the northern and southern roofs comprise principal rafters with collars, these supporting triple purlins to each pitch and, in turn, supporting common rafters (Fig 3a/b). At the time of Blaylock's 1985 survey it was thought that the most likely context for this work was the refurbishment of the palace that took place under one of the early post-Restoration Bishops. (The first, John Gauden is known to have not resided at the Palace, with the first resident bishop being Seth Ward, AD 1662–7, who is said to have refurbished the Palace and made it habitable; but with the possibility that the work was not undertaken until the time of Bishops Sparrow, AD 1667–76, or Lamplugh, AD 1676–88.) Since the work reported on here shows that the roof timbers were felled in AD 1652, it can now be confidently stated that these refurbishments took place in the period of the Commonwealth, presumably in order to render the former great hall usable for the sugar baker.

Subsequent bishops commissioned substantial changes which saw the demolition of the great kitchen, the brew house, buttery, pantry, and other service rooms over the course of the eighteenth and nineteenth centuries. Despite its original size, little of the former structures now remain, with only the shell of the chapel still *in situ*. These remains have been the subject of an architectural and historical survey (Blaylock 1987; 2017).

The approach to the Bishop's Palace is via the Grade I listed Gatehouse (LEN 1222909; Fig 3c). Although the Gatehouse is one of the best-preserved buildings relating to the medieval Palace, given its importance, surprisingly little has been known about it until a recent buildings archaeology survey (Parker 2013). The building probably stands on the site of a twelfth-century (or even earlier) gatehouse, but the greater part of the fabric that survives today is likely to date from around AD 1300. The form of the Gatehouse (Fig 4): a long range pierced by an arch, without flanking turrets, and with a relatively simple arrangement of arched gateways (the gates being hung on the inside of the front wall), compares with the later fourteenth-century gatehouse at Dartington Hall in South Devon. Other details of the structure are closely comparable to the domestic lodgings at Okehampton Castle.

As originally constructed, the Gatehouse contained accommodation on three levels at its eastern end, but on only two levels at its western end. This is clear from the layout of the primary windows in its gable walls, which show small, high-level windows at the eastern end consistent with three storeys and a very large window at its western end, suggesting low ground-floor rooms but a large chamber above first-floor level, rising into the roof. The floor levels varied in different parts of the building, not least because the floor of the room over the gate passage is necessarily higher than the rooms at either end.

The original roof of the Gatehouse is thought to survive over the whole of the eastern part of the building, appearing to be integral with the structure, and thus of exceptional interest (Fig 5a). That this roof is almost certainly primary is apparent because of its relationship with the thick stone wall rising on the western side of the gate passage, which is continuous into the roof space right up into the apex. The roof structure is continuous over the top of the wall, the timbers being trenched or embedded in the stonework in the same manner as the rafters of the fourteenth-century Vicar's Hall in South Street where this detail is still visible. The Gatehouse roof is possibly the earliest secular roof to survive in the city. Its construction has affinities with the carpentry of the roof of the Cathedral and of other roof structures in the Cathedral Close dating from the thirteenth and fourteenth centuries, which now survive only in fragmentary form. The roof over the western chambers is divided into two parts, both being constructed of conifer.

The Gatehouse also has a cellar beneath the chamber at its west end. The ceiling of this (the frame of the ground floor) comprises a series of 11 close-set north-south beams. The north ends of some of the beams are supported by a single east-west beam held by two vertical posts (Fig 5b).

SAMPLING

A dendrochronological survey at the Gatehouse to the Bishop's Palace was requested by Francis Kelly (English Heritage, Inspector of Historic Buildings and Areas) as a programme of refurbishment works were being undertaken, which required listed building consent. The work revealed far more than was anticipated, such as a large cellar with substantial, probably fourteenth-century, beams, and other puzzling features. There are also early wall-painting fragments, a seventeenth-century graffito fireplace surround, painted beams, and medieval joists, doorways, and a fireplace. Precise dating of the primary construction phase and other significant phases of intervention was requested to inform listing building consent for the proposals.

In conjunction with the tree-ring dating at the Gatehouse, the opportunity was taken to gain access to the extant east wing of the Bishop's Palace itself. It was hoped that sampling here might not only establish the date of any potentially primary timbers reused in the post-Restoration axial partition wall in the Great Hall, but also establish the date of the replacement roof.

Although at the time of the initial assessment of the timbers of the Gatehouse as to their suitability for tree-ring analysis, it was seen that many of them appeared to have only modest numbers of rings, there appeared to be a sufficient number of timbers with sufficient numbers of rings to make sampling worthwhile. The timbers to the replacement roof of the east wing were similarly plentiful, and, by contrast, appeared to contain high numbers of rings. Although there were a few other axial partition wall timbers potentially available, these were all derived from fast-grown trees and as such, appeared to have too few rings for reliable dating. Such timbers were therefore not sampled.

Thus, from the timbers of the Gatehouse a total of 23 samples was obtained by coring. Each sample was given the code EXT-I (for Exeter, site 'I') and numbered 01–23. Thirteen samples, EXT-I01–I13, were obtained from the timbers of the roof over the east part of the building, with a further 10 samples, EXT-I14–I23, being obtained from the timbers to the cellar. The locations of these samples were recorded at the time of sampling on plans taken from the building archaeology survey, these being shown in Figure 6a/b, with details of the samples being given in Table 1a. The roof frames and the beams of the cellar have been numbered from east to west, with individual timbers then being further identified on a north–south basis as appropriate.

In relation to the sampling of these timbers, it might be noted that due to a certain amount of decay and, particularly to the cellar timbers, rot, probably caused by dampness, it was difficult to obtain full-length cores, and the samples probably have fewer rings than they might have had otherwise.

The timbers of the east wing of the Bishop's Palace itself provided a further 21 samples, these again being obtained by coring. Each sample from the east wing was given the code EXT-J (for Exeter, site 'J') and numbered 01–21 (Table 1b). Of this number, 20 samples, EXT-J01–J10, were obtained from the timbers of the northern roof, with a further 10 samples, EXT-J11–J20, being obtained from the timbers to the southern roof. A final sample, EXT-J21, was obtained from the only available suitable timber in the axial partition wall of the Great Hall.

The locations of these samples were recorded at the time of sampling on plans taken from the building archaeology survey, these being shown in Figures 7a/b and 8, with details of the samples being given in Table 1b. Again, the roof trusses have been numbered from east to west, with individual timbers being further identified on a north–south basis as appropriate.

ANALYSIS AND RESULTS

Each of the total of 44 samples obtained from the Gatehouse and the east wing of the Bishop's Palace timbers was prepared by sanding and polishing. It was seen at this time that 10 samples, from both the Gatehouse roof and the cellar ceiling beams, had less than the 40 rings here deemed necessary for reliable dating purposes and they were rejected from this programme of analysis. The annual growth ring widths of the remaining 34 samples were measured, the data of these measurements being given at the end of this report.

The data of the 34 measured samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), this process producing several separate groups of cross-matching samples.

The first group comprises samples EXT-I04 and I10, both collars from the Gatehouse roof, the two samples cross-matching with each other at a value of t=4.4, as shown in Figure 9. The two samples were combined at their indicated offset positions to form site chronology EXTISQ01, this having overall length of 55 rings.

The second group comprises samples EXT-I16 and I17, both from the timbers of the Gatehouse cellar, the two samples cross-matching with each other at a value of t=5.4 as shown in Figure 10. These two samples were also combined at their indicated offset positions to form site chronology EXTISQ02, this having an overall length of 55 rings.

These two site chronologies were then compared to an extensive corpus of reference material for oak, this indicating a consistent and repeated match with a series of these for site chronology EXTISQ01 when the date of its first ring is AD 1221 and the date of its last measured ring is AD 1275 (Table 2).

The third and fourth site chronologies comprise ten and seven samples respectively, the two site chronologies each containing samples from both the north and south roofs of the east wing of the Bishop's Palace. The cross-matching samples included in each group are shown in the bar diagram Figure 11. The samples of each respective group were combined at their indicated offset positions to form site chronologies EXTJSQ01 (combining at a value of t=4.7), and EXTJSQ02 (combining at a value of t=5.7), these being respectively 126 and 113 rings long. The two site chronologies were then compared to an extensive corpus of reference material for oak, this indicating a consistent and repeated match with a series of these for site chronology EXTJSQ01 when the date of its first ring is AD 1527 and the date of its last measured ring is AD 1652, and for site chronology EXTJSQ02 when the date of its first ring is AD 1540 and the date of its last measured ring is also AD 1652 (Tables 3 and 4).

The four site chronologies were also compared to the 13 remaining measured but ungrouped samples, but there was no further satisfactory cross-matching. These 13 ungrouped samples were then compared individually to the full corpus of reference material for oak and, in this instance, individual timber series from Exeter Cathedral and associated buildings in the Exeter area. This indicated consistent and repeated matching for two of these series, EXT-I01 and I03, at dates compatible with the tenuous relative offset position identified between these two series (t=3.5). These were then combined to form site chronology EXTISQ03, which is 86 rings long, with the date of its first ring being AD 1188 and the date of its last ring being AD 1273 (Fig 9; Table 5). All other ungrouped samples remain undated.

This analysis may be summarised thus:

Site chronology	Number of samples	Number of rings	Date span AD (where dated)
Gatehouse			
EXTISQ01	2	55	1221–1275
EXTISQ02	2	55	undated
EXTISQ03	2	86	1188–1273
Ungrouped	7	---	undated
Unmeasured	10	---	undated
East wing			
EXTJSQ01	10	126	1527–1652
EXTJSQ02	7	113	1540–1652
Ungrouped	4	---	---

INTERPRETATION AND CONCLUSIONS

Gatehouse: site chronologies EXTISQ01 and EXTISQ03

As may be seen from Table 1a and Figure 9, none of the four dated samples in site chronologies EXTISQ01 and EXTISQ03 retains complete sapwood (the last ring produced by the tree before it was cut down), and it is thus not possible to determine a precise felling date for the timbers represented. The four samples do, though, retain the heartwood/sapwood boundary, that is, the timbers have lost only their sapwood rings, and it is thus possible to estimate a likely felling date range for the timbers.

The average date of the boundary on the four dated samples from this roof is AD 1272. Using a 95% confidence range of 15–40 sapwood rings would give the timbers represented an estimated felling date of AD 1287–1312. The heartwood/sapwood boundary on the four samples, furthermore, is at a similar relative position and date to each other meaning that the trees represented are likely to have been felled at the same time.

As such, the estimated felling date range for these timbers, all collars, determined on the basis of dendrochronology coincides very well with the date of around AD 1300 determined by the buildings archaeology survey on the basis of the surviving fabric, and may indeed make the covering of the Gatehouse the earliest surviving secular roof in the city.

As may be seen in Table 2, although site chronology EXTISQ01 has been compared with reference material from across the British Isles, there is a distinct trend for the highest *t*-values to be found against reference chronologies from other sites in southern and, particularly, south-west England. Site chronology EXTISQ03 matches best with a series of material from Exeter Cathedral and the Great Barn at Bishop's Court which lies immediately to the east of Exeter (Table 5). Thus, although the source of the dated timbers used here in the roof of the Gatehouse cannot be determined precisely, this strongly suggests that the trees have come from potentially relatively local sources.

Gatehouse: site chronology EXTISQ02

Likewise, as may again be seen from Table 1a and Figure 10, neither of the two undated samples in site chronology EXTISQ02 retains complete sapwood, and it is not possible to determine the precise relative felling for either of the timbers represented. The heartwood/sapwood boundary on the two samples, however, is at a similar relative position to each other meaning that the trees represented are likely to be coeval.

Gatehouse: ungrouped/undated samples

Of the 13 samples from the Gatehouse which were measured, nine remain ungrouped and undated. None of these nine shows any particular problems with its annual growth rings, such as distortion or compression, which would make cross-matching and dating difficult. The majority of them do, though, have very low numbers of rings, and it is this that may well contribute to the lack of grouping and dating.

East wing: site chronologies EXTJSQ01 and EXTJSQ02

Table 1b and Figure 11 indicate that a total of six dated samples in site chronologies EXTJSQ01 and EXTJSQ02 retain complete sapwood, this meaning that such samples do retain the last ring produced by the tree before it was cut down. In each case this last growth ring, and thus the felling of the trees represented, is dated to AD 1652. A few other dated samples in these two chronologies are from timbers that have complete sapwood on them but from which, due to the soft and fragile nature of this part of the wood, small amounts of sapwood have been lost in coring. The lost amounts of sapwood, measured in millimetres, would suggest that the trees these cores represent are likely to have been felled in AD 1652 as well.

The remaining eight samples in the two chronologies, whilst not having any sapwood, do retain the heartwood/sapwood boundary. This means that although the timbers have lost all their sapwood rings, it is only the sapwood rings that have been lost, and it is thus possible to estimate a likely felling date range for them. The average heartwood/sapwood boundary ring on these eight samples is dated AD 1625 which, using the same 95% confidence range as above, 15–40 sapwood rings, would give the timbers represented an estimated felling date of AD 1640–65. It will be seen that this estimated range brackets the known felling date of a number of timbers, the inference being that it is very likely that these final timbers were felled about, if not in, AD 1652 as well, and that both the north and the south roofs are of the same date.

In respect of these roofs, it is slightly unusual to find that two site chronologies were created from timbers within the same part of a building which, despite having trees felled at the same time and sharing an almost identical date span, do not show significant similarities with each other. This would strongly suggest that the trees used here have been sourced from two different woodlands, with trees from both sources being used in both roofs. Indeed, given that samples EXT-J06 and EXT-J14 (respectively from collars in the north and south roof), cross-match with a value of t=13.2, and that samples EXT-J05 and EXT-J11 (respectively principal rafters in the north and south roof), cross-match with a value of t=11.6, it is possible that these pairs have each been derived from two single trees.

Site chronologies EXTJSQ01 and EXTJSQ02 were also compared with reference material from across the British Isles. However, there is no distinct geographical trend apparent from the t-values obtained against the reference material. As can be seen from Tables 3 and 4, site chronologies EXTJSQ01 and EXTJSQ02 match a widely dispersed series of reference chronologies, with the two site chronologies matching different reference chronologies. This would suggest that these timbers were possibly sourced from geographically different, and possibly non-local, sources.

East wing: ungrouped/undated samples

Of the 21 samples from the east wing of the Bishop's Palace, four remain ungrouped and undated. Again, none of these four show any particular problems with its annual growth rings, such as distortion or compression, and all four samples have sufficient rings for reliable dating. However, it is not unusual in any programme of tree-ring analysis to find that some samples remain ungrouped and undated, often for no obvious reason.

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TABLES

Table 1a: Details of tree-ring samples from the Gatehouse to the Bishop's Palace, Exeter, Devon

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	Roof					
EXT-I01	Collar, frame 1	83	h/s	1188	1270	1270
EXT-I02	North rafter, frame 1	nm	---	------	------	------
EXT-I03	Collar, frame 2	52	h/s	1222	1273	1273
EXT-I04	Collar, frame 3	45	h/s	1231	1275	1275
EXT-I05	Collar, frame 4	45	h/s	------	------	------
EXT-I06	Collar, frame 5	nm	---	------	------	------
EXT-I07	South rafter, frame 6	nm	---	------	------	------
EXT-I08	Collar, frame 6	nm	---	------	------	------
EXT-I09	Collar, frame 9	nm	---	------	------	------
EXT-I10	Collar, frame 12	51	h/s	1221	1271	1271
EXT-I11	South rafter, frame 13	nm	---	------	------	------
EXT-I12	Collar, frame 15	nm	---	------	------	------
EXT-I13	Collar, frame 16	nm	---	------	------	------
	Cellar					
EXT-I14	Ceiling beam 3	52	h/s	------	------	------
EXT-I15	Ceiling beam 4	nm	---	------	------	------
EXT-I16	Ceiling beam 5	42	h/s	------	------	------
EXT-I17	Ceiling beam 6	51	h/s	------	------	------
EXT-I18	Ceiling beam 7	51	h/s	------	------	------
EXT-I19	Ceiling beam 8	50	h/s	------	------	------
EXT-I20	Ceiling beam 9	65	h/s	------	------	------
EXT-I21	Ceiling beam 10	58	h/s	------	------	------
EXT-I22	Ceiling beam 11	nm	---	------	------	------
EXT-I23	Horizontal support beam	66	h/s	------	------	------

Table 1b: Details of tree-ring samples from the double piled roof to the east wing of the Bishop's Palace, Exeter, Devon

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	North roof					
EXT-J01	South middle purlin, truss 2 – 3	87	10	1548	1624	1634
EXT-J02	North principal rafter, truss 3	88	28C	1565	1624	1652
EXT-J03	South principal rafter, truss 3	89	25c	1561	1624	1649
EXT-J04	Collar, truss 3	86	h/s	1531	1616	1616
EXT-J05	North principal rafter, truss 4	104	12	1540	1631	1643
EXT-J06	Collar, truss 4	96	h/s	1527	1622	1622
EXT-J07	North principal rafter, truss 5	82	27C	1571	1625	1652
EXT-J08	Collar, truss 5	78	18c	1570	1629	1647
EXT-J09	South principal rafter, truss 6	83	22C	1570	1630	1652
EXT-J10	Collar, truss 6	90	33C	1563	1619	1652
	South roof					
EXT-J11	South principal rafter, truss 2	111	23C	1542	1629	1652
EXT-J12	North principal rafter, truss 3	78	no h/s	------	------	------
EXT-J13	North principal rafter, truss 4	85	6	1545	1623	1629
EXT-J14	Collar, truss 4	112	36C	1541	1616	1652
EXT-J15	North principal rafter, truss 5	73	h/s	1557	1629	1629
EXT-J16	Collar, truss 5	98	21c	1551	1627	1648
EXT-J17	North upper purlin, truss 5 – 6	55	2	------	------	------
EXT-J18	North principal rafter, truss 6	72	7	1565	1629	1636
EXT-J19	South principal rafter, truss 6	60	15	1585	1629	1644
EXT-J20	South principal rafter, truss 7	77	10	------	------	------
	Axial partition wall					
EXT-J21	Post 2	62	no h/s	------	------	------

KEY for Tables 1a and 1b:
h/s = the heartwood/sapwood ring is the last ring on the sample. nm = sample not measured.
C = complete sapwood is retained on the sample; the last measured ring date is the felling date of the timber represented.
c = complete sapwood found on sampled timber, but all or part has been lost from sample in coring

Table 2: Results of the cross-matching of site sequence EXTISQ01 and relevant reference chronologies when the first-ring date is AD 1221 and the last-ring date is AD 1275

Reference chronology	Span of chronology	*t*-value	Reference
King John's Hunting Lodge, Lacock, Wiltshire	AD 1148–1318	6.8	Hurford *et al* 2010
Ulverscroft Priory, Charnwood, Leicestershire	AD 1219–1463	6.3	Arnold *et al* 2008a
Rudge, Morchard Bishop, Devon	AD 1124–1315	6.5	Groves 2005
Bury Barton, Lapford, Devon	AD 1132–1323	6.4	Groves 2005
Muchelney Abbey, Somerset	AD 1148–1498	6.2	Bridge 2002
Poplar Farm, Atworth, Wiltshire	AD 1161–1333	5.9	Arnold and Howard 2018 unpubl
St John the Baptist Church, Bradworthy, Devon	AD 1125–1367	5.9	Tyers 2003
Old Rectory, Bridford Barton, Devon	AD 1220–1278	5.8	Tyers *et al* forthcoming
Bridge Farm, Butleigh, Somerset	AD 1195–1331	5.6	Miles *et al* 1997a
Archdeacon's House, Exeter, Devon	AD 1186–1404	5.6	Howard *et al* 1999

Table 3: Results of the cross-matching of site sequence EXTJSQ01 and relevant reference chronologies when the first-ring date is AD 1527 and the last-ring date is AD 1652

Reference chronology	Span of chronology	t-value	Reference
St Marys' Church, Winkfield, Berkshire	AD 1534–1628	7.0	Howard *et al* 2006
Beeleigh Abbey, Maldon, Essex	AD 1511–1623	6.3	Tyers 2002a
Hays Wharf, Southwark, London	AD 1248–1647	6.1	Tyers 1996a; Tyers 1996b
White Tower, Tower of London	AD 1463–1616	5.8	Miles 2007
The Vyne Garden House, Sherborne St John, Hampshire	AD 1459–1630	5.5	Miles *et al* 1997b
Longport farmhouse, Hampshire	AD 1334–1599	5.4	Tyers 1996c
Cobham Hall, Cobham, Kent	AD 1317–1662	5.4	Arnold *et al* 2003a
Wilton House, Wiltshire	AD 1536–1636	5.3	Hillam 1990
Oak House Barn, West Bromwich	AD 1562–1655	5.3	Howard *et al* 1991
Church of St Peter, West Liss, Hampshire	AD 1464–1614	5.3	Arnold and Howard 2012

Table 4: Results of the cross-matching of site sequence EXTJSQ02 and relevant reference chronologies when the first-ring date is AD 1540 and the last-ring date is AD 1652

Reference chronology	Span of chronology	*t*-value	Reference
1–5 Bridge Street, Bideford, Devon	AD 1484–1706	7.7	Arnold and Howard 2012 unpubl
Nattonhall, Drewsteignton, Devon	AD 1530–1625	7.3	Tyers *et al* forthcoming
15/17 St John's Street, Wirksworth, Derbyshire	AD 1586–1676	6.9	Howard *et al* 1995
Sutton Scarsdale, Derbyshire	AD 1513–1658	6.3	Howard *et al* 1996 unpubl
Pembridge bell tower, Herefordshire	AD 1559–1668	6.3	Tyers 1999
The Market House, Ledbury, Herefordshire	AD 1485–1617	6.2	Arnold *et al* 2008b
Sydenham House, Okehampton, Devon	AD 1394–1654	6.0	Arnold *et al* 2015
Croft Castle, Croft, Herefordshire	AD 1475–1666	6.0	Tyers 2002b
Riding House, Bolsover Castle, Derbyshire	AD 1494–1744	6.0	Howard *et al* 2005
Lower Coombe Farmhouse, Bradninch, Devon	AD 1548–1624	5.9	Miles *et al* 2003

Table 5: Results of the cross-matching of site sequence EXTISQ03 (AD 1188–1273) and its two component series EXT-I01 (AD 1188–1270) and EXT-I03 (AD 1222–73) with relevant reference chronologies and component series

Reference chronology or component series	Span of chronology	*t*-value			Reference
		EXTISQ03	EXT-I01	EXT-I03	
Great Barn, Bishop's Court, Sowton, Devon	AD 1454–1386	6.8	6.3	6.1	Bridge and Miles forthcoming
bcb02		*4.2*	*4.7*	*3.4*	
bcb03		*4.8*	*3.9*	*5.0*	
bcb04		*5.1*	*4.1*	*5.1*	
bcb05		*4.9*	*5.2*	*4.4*	
Exeter Cathedral, Devon	AD 1132–1315	5.1	5.9	4.5	Howard *et al* 2001
ext-c16		*5.7*	*5.5*	*5.0*	
ext-c17		*4.2*	*3.4*	*4.6*	
ext-c30		*4.3*	*4.5*	*4.6*	
ext-c49		*4.5*	*5.1*	*2.7*	
ext-c50		*4.4*	*5.4*	*2.8*	
ext-c52		*4.3*	*5.6*	*3.3*	
ext-c57		*5.5*	*7.0*	*3.8*	
ext-c60		*4.5*	*4.5*	*2.6*	
ext-c61		*4.4*	*4.0*	*3.0*	
ext-c67		*5.0*	*4.3*	*4.9*	
ext-c68		*5.7*	*5.2*	*4.7*	
ext-c69		*4.3*	*4.9*	*3.8*	
ext-c73		*4.2*	*4.0*	*2.1*	
ext-c74		*4.3*	*3.6*	*3.2*	
ext-c75		*5.7*	*4.6*	*5.3*	
ext-c76		*5.9*	*5.0*	*4.5*	
ext-c101		*4.9*	*6.9*	*2.7*	
Exeter Cathedral, Devon	AD 1133–1337	4.6	5.0	5.0	Howard *et al* 2002; Arnold *et al* 2003b
ext-c113		*5.1*	*4.0*	*6.0*	
ext-c118		*4.1*	*5.3*	*4.4*	
ext-c124		*3.9*	*4.8*	*3.1*	
ext-c127		*4.5*	*5.6*	*2.9*	
ext-c128		*4.9*	*2.4*	*5.0*	
ext-c161		*5.7*	*5.6*	*5.4*	
ext-c165		*4.7*	*1.8*	*5.0*	
ext-c216		*4.7*	*5.1*	*5.1*	
ext-c222		*4.4*	*3.9*	*2.6*	
ext-c251		*4.2*	*5.4*	*4.3*	
Exeter Cathedral, Devon	AD 1151–1272	6.0	5.6	5.6	Arnold *et al* forthcoming
ext-c344		*4.8*	*4.0*	*3.6*	
ext-c347		*5.9*	*4.8*	*4.2*	
ext-c352		*3.8*	*4.4*	*2.2*	
ext-c355		*4.0*	*2.4*	*4.0*	
ext-c356		*5.6*	*4.5*	*4.8*	
ext-c358		*4.3*	*4.9*	*4.0*	

FIGURES

Figure 1: Maps to show the location of the Bishop's Palace in Exeter; marked in red. Scale: top right 1:20000; bottom 1:1250, showing the East Wing of the Bishop's Palace hashed in red, and the Gatehouse hashed in blue © Crown Copyright and database right 2021. All rights reserved. Ordnance Survey Licence number 100024900. © British Crown and SeaZone Solutions Ltd 2021. All rights reserved. Licence number 102006.006. © Historic England

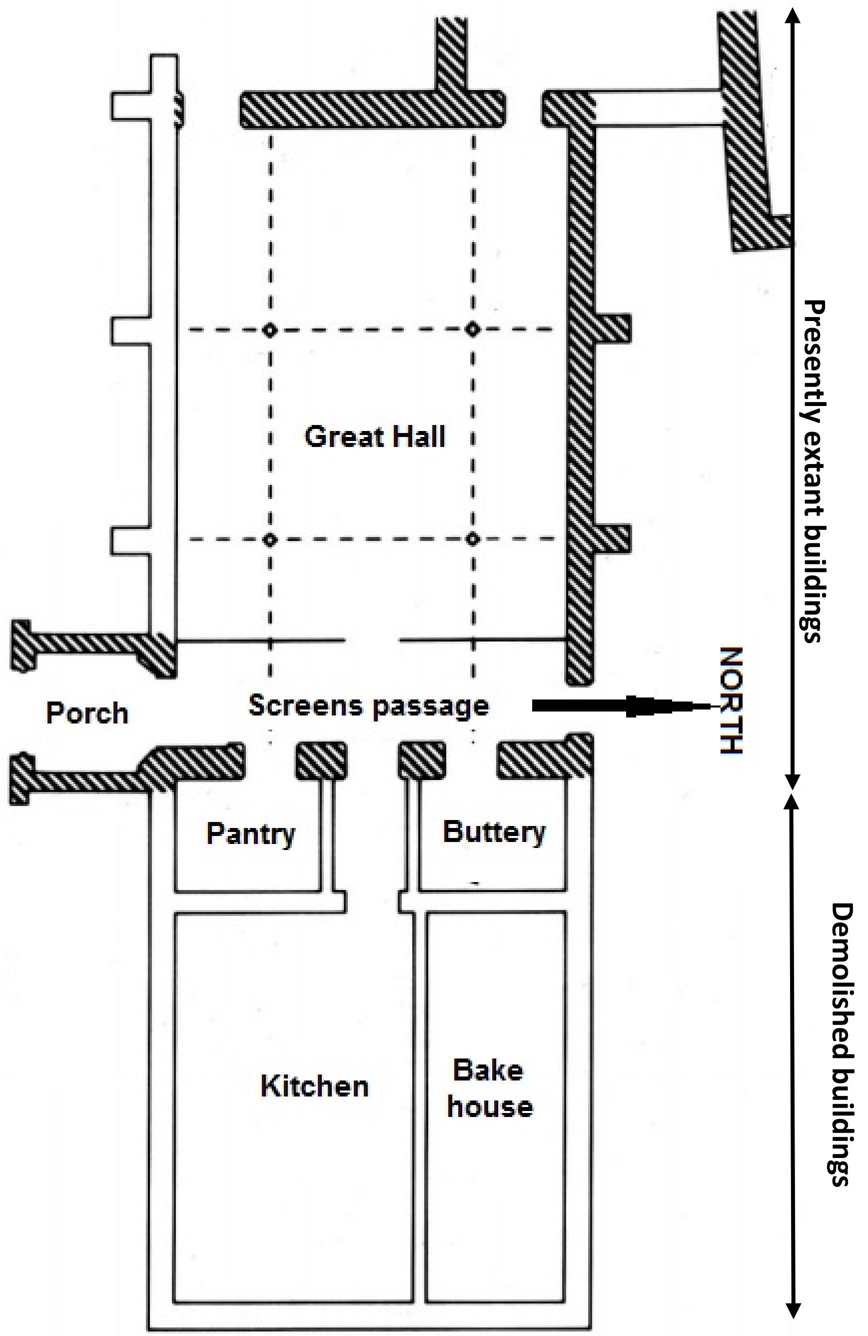


Figure 2: Medieval ground-floor plan of the Bishop's Palace at the time of Bishop Brewer, AD 1224–44 (after Blaylock 1987, fig. 1)

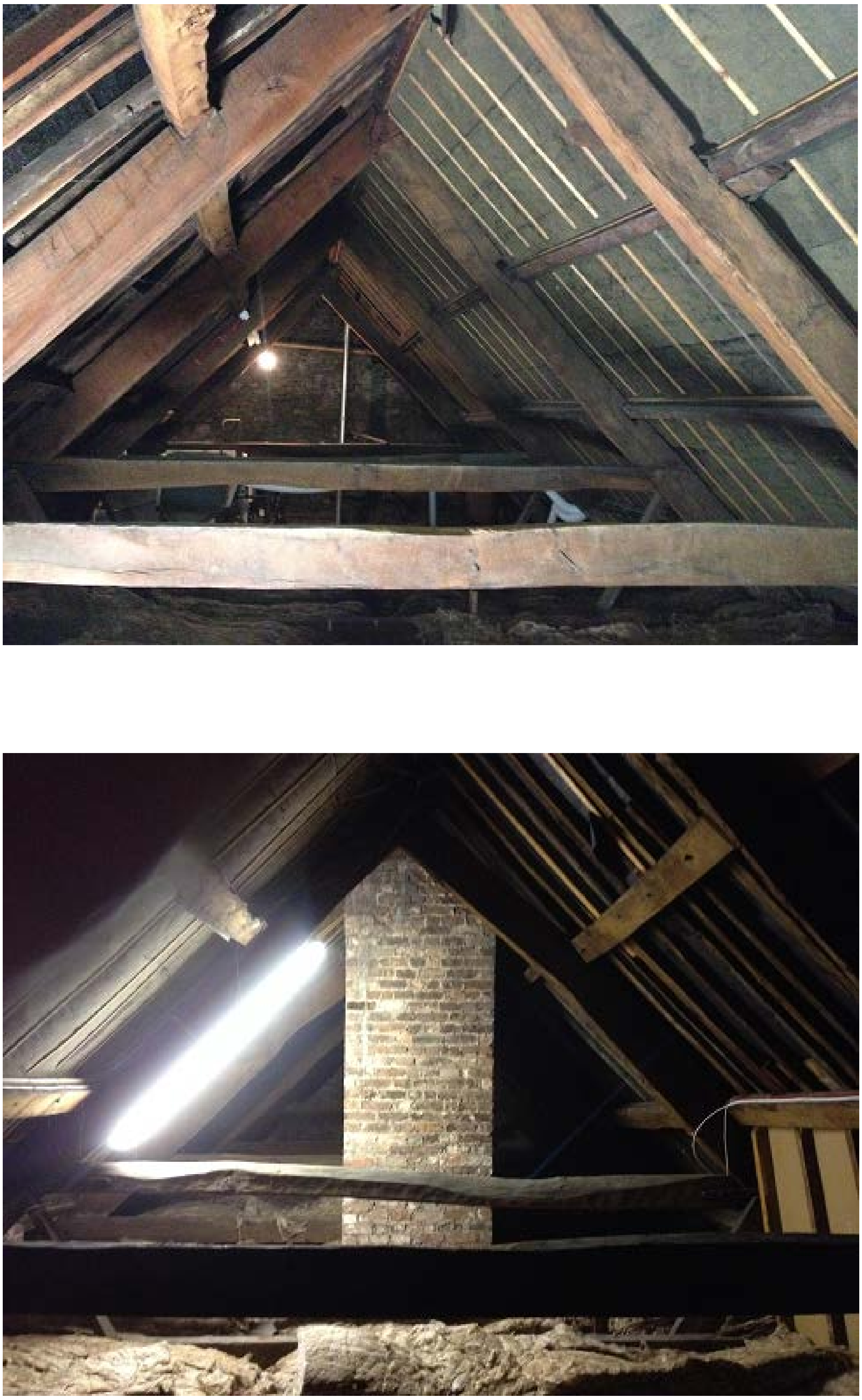


Figure 3a/b: (top) view of the north roof of the Bishop's Palace looking east (ref: 0574) and (bottom) the south roof looking east (ref: 0566; photographs Stuart Blaylock, April 2015)

Figure 3c: View of the Gatehouse to the Bishop's Palace from the north, or rear (photograph Robert Howard)

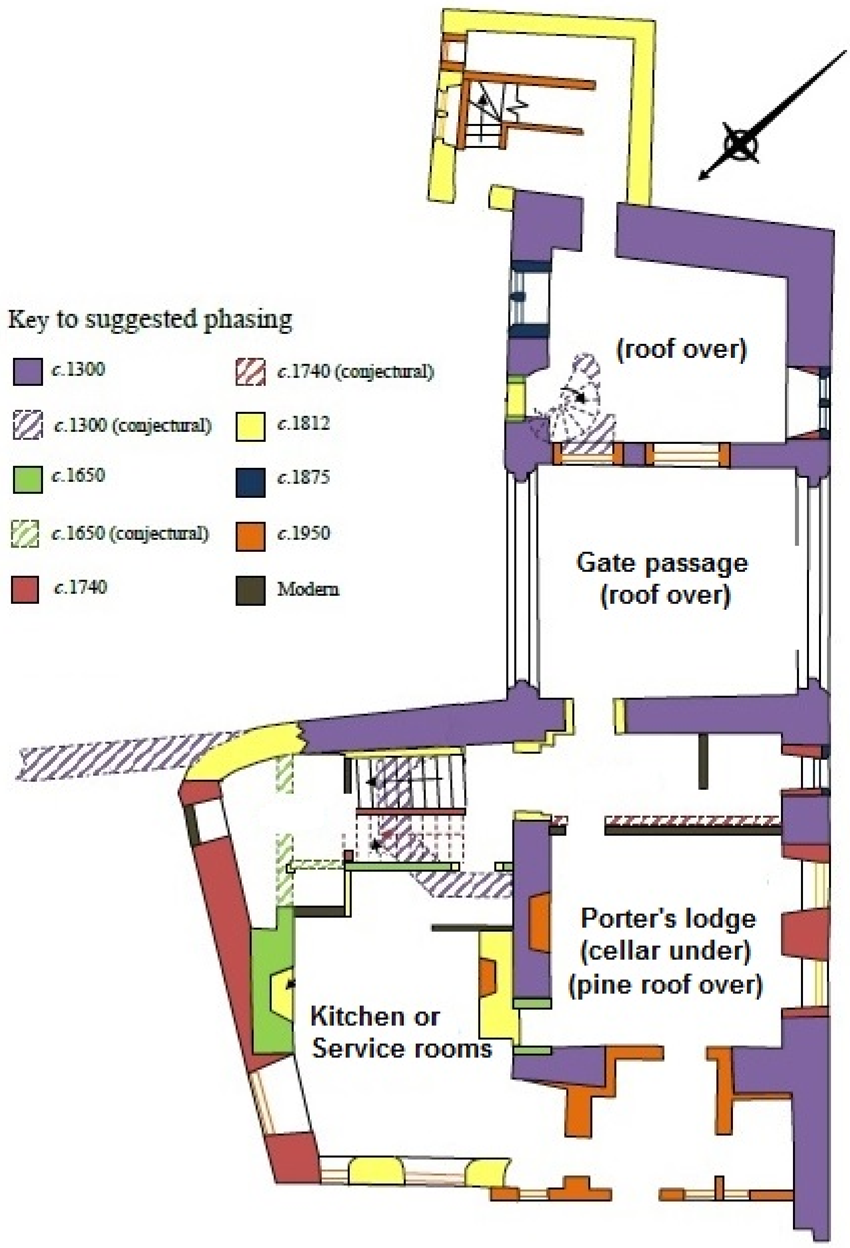


Figure 4: Phased ground-floor plan of the Gatehouse to the Bishop's Palace to show the location of the sampled roof area and cellar timbers (from Parker 2013 after Smith Gore Chartered Surveyors)

Figure 5a/b: View of the Gatehouse roof timbers looking east (top; photograph Richard Parker) and the cellar timbers looking east (bottom; photograph Robert Howard)

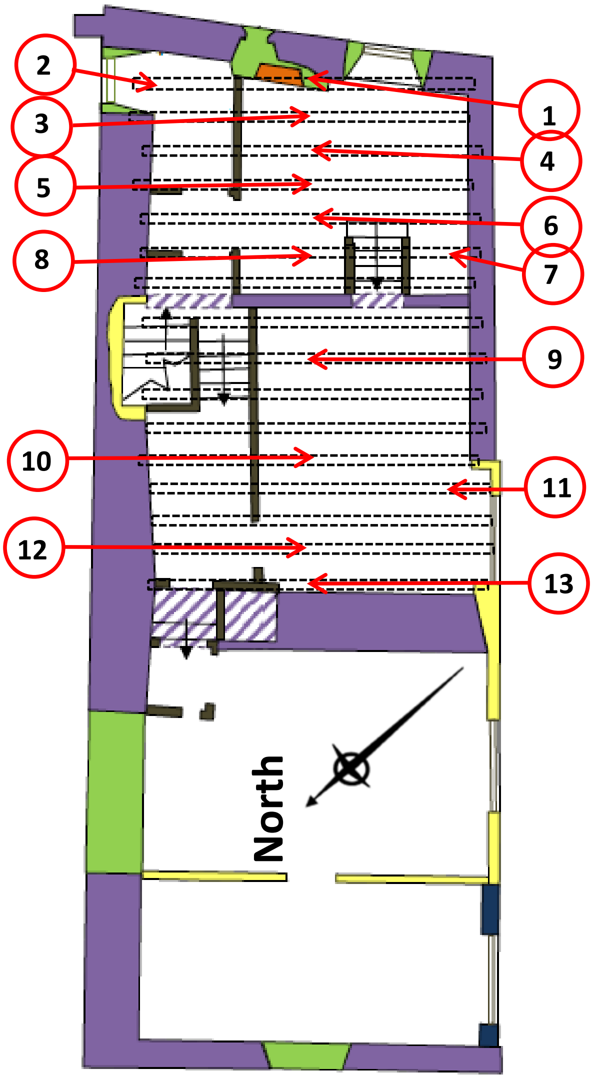


Figure 6a: Plan at roof level of the Gatehouse to help locate sampled timbers (from Parker 2013 after Smith Gore Chartered Surveyors)

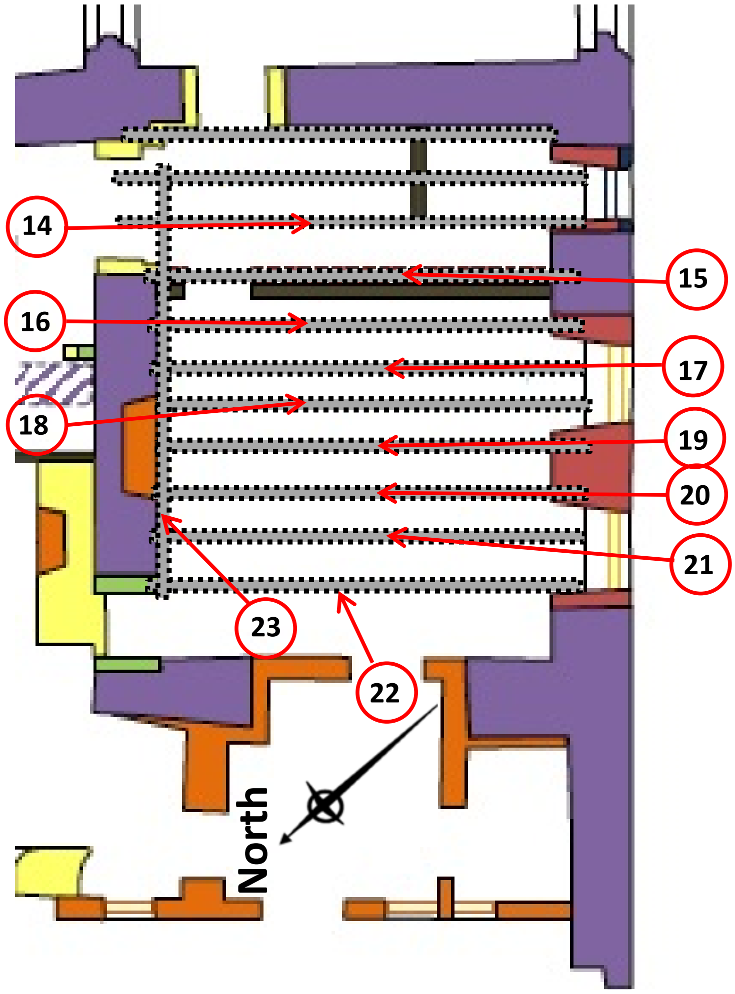


Figure 6b: Plan at cellar level of the Gatehouse to help locate sampled timbers (from Parker 2013 after Smith Gore Chartered Surveyors)

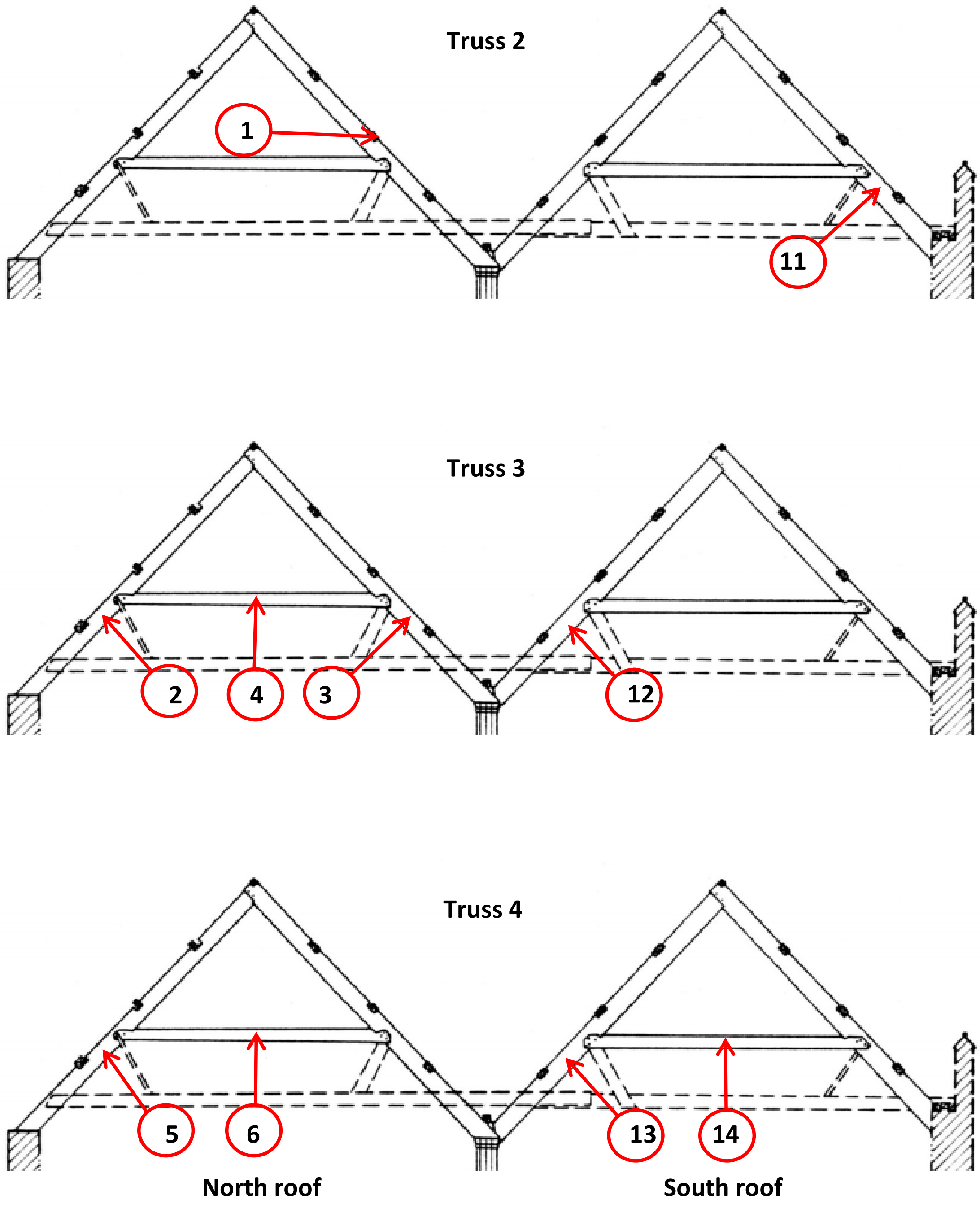


Figure 7a: Sections through the roof of the east wing of the Bishop's Palace (after Blaylock 1987, fig. 3)

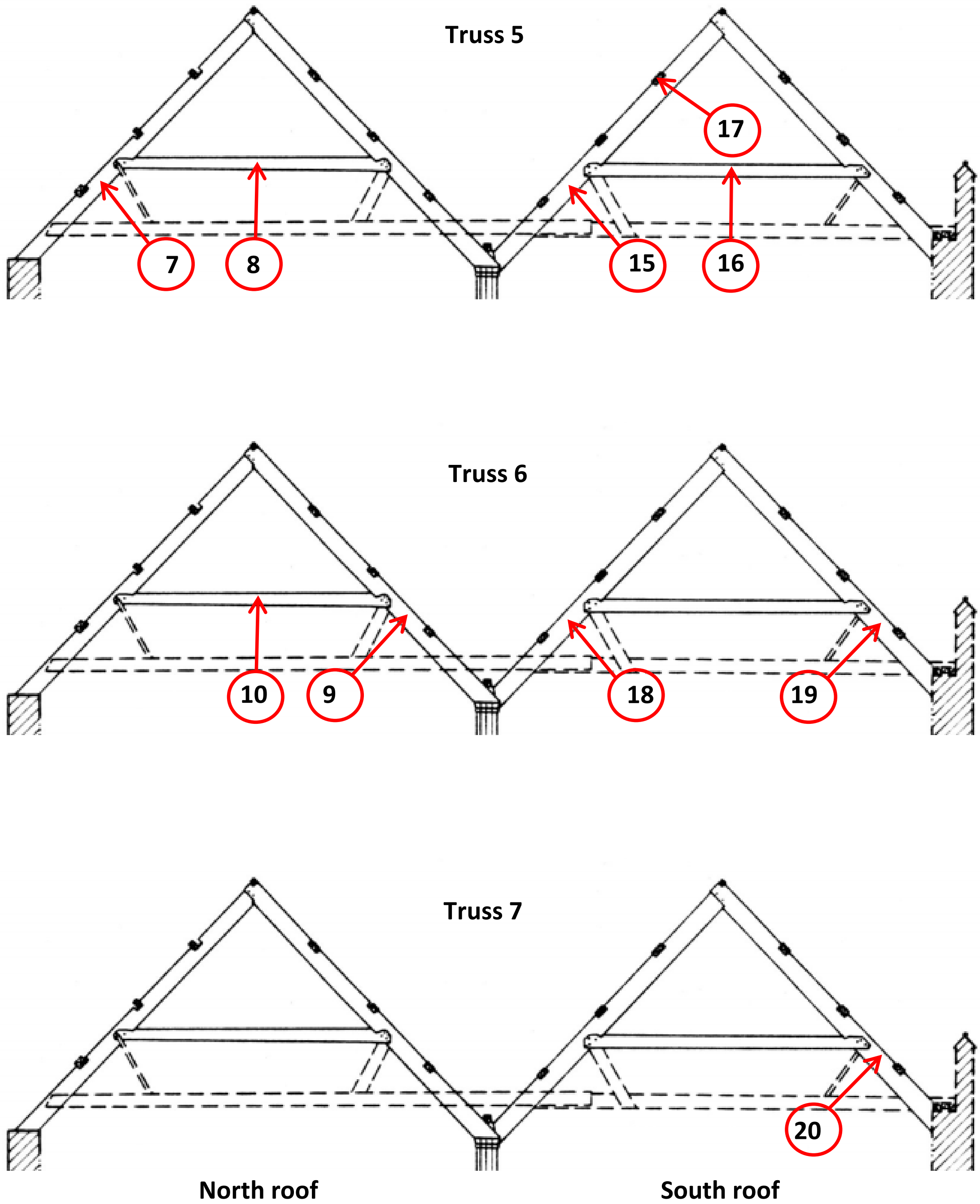


Figure 7b: Sections through the roof of the east wing of the Bishop's Palace (after Blaylock 1987, fig. 3)

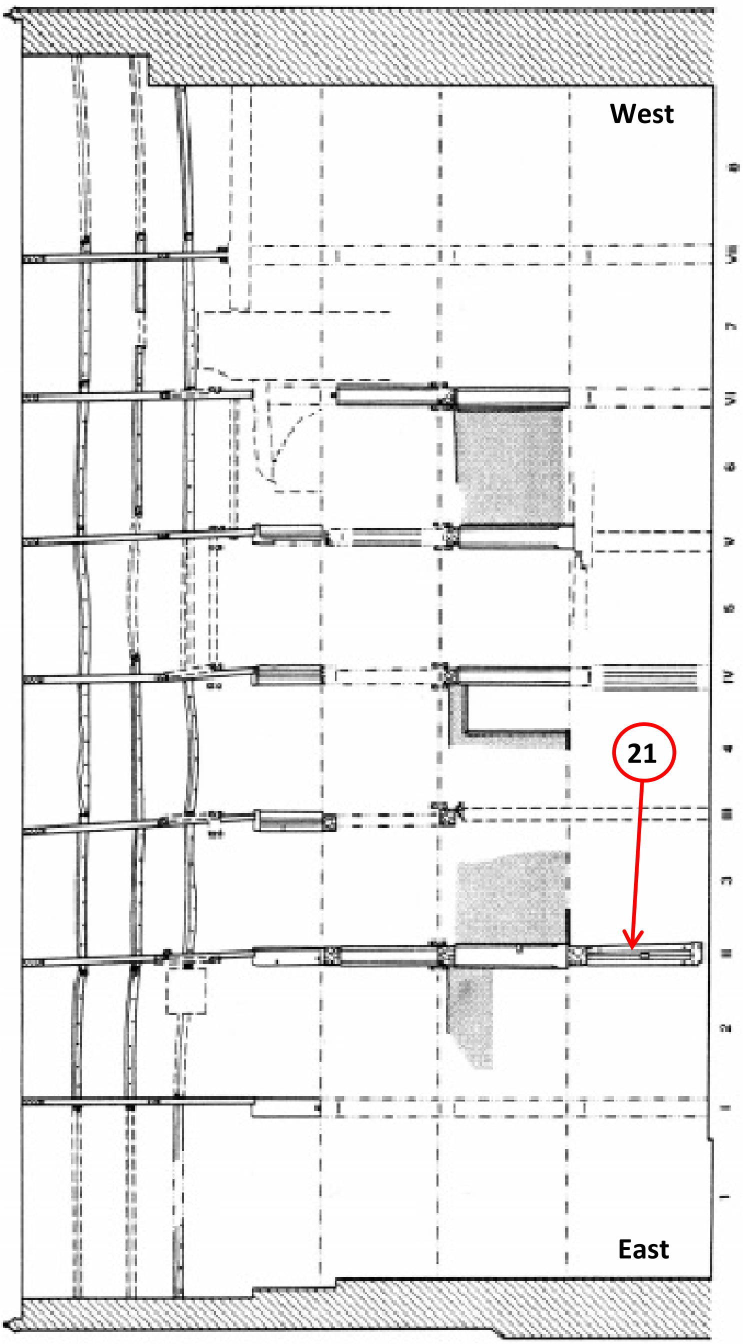
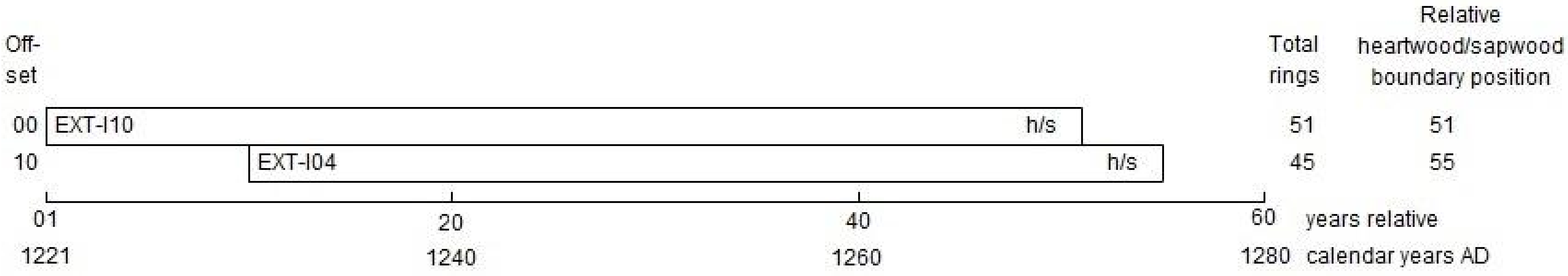
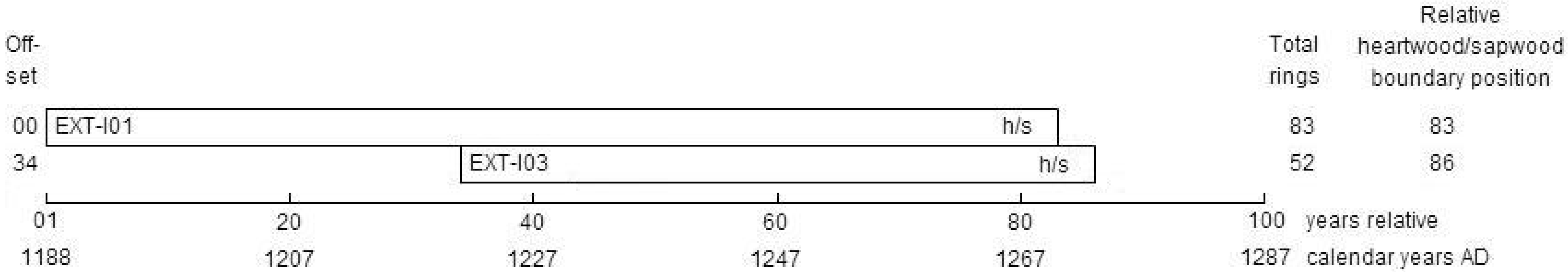


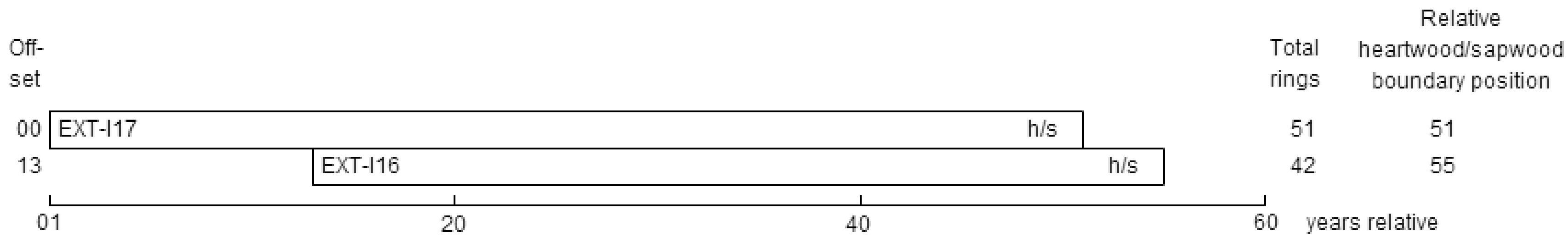
Figure 8: Section through the axial partition wall of the Great Hall of the Bishop's Palace to help locate the sampled timber (after Blaylock 1987, fig. 2)





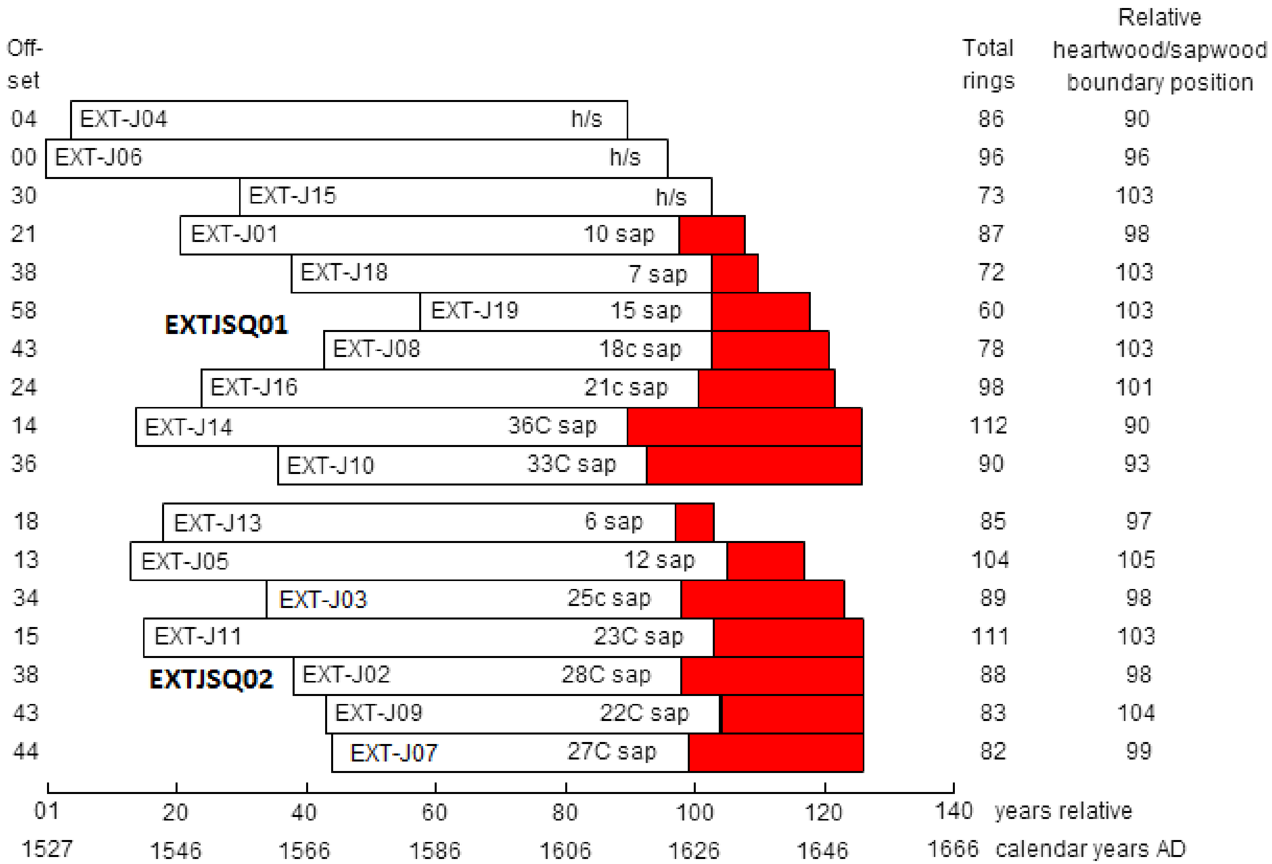
white bars = heartwood rings, h/s = heartwood/sapwood boundary

Figure 9: Bar diagram of the samples in site chronologies EXTISQ01 (EXT-I04, EXT-I10) and EXTISQ03 (EXT-I01, EXT-I03) from the roof of the Gatehouse



white bars = heartwood rings, h/s = heartwood/sapwood boundary

Figure 10: Bar diagram of the samples in site chronology EXTISQ02 from the cellar of the Gatehouse



h/s = the heartwood/sapwood ring is the last ring on the sample. C = complete sapwood is retained on the sample; the last measured ring date is the felling date of the timber represented. c = complete sapwood found on sampled timber, but all or part has been lost from sample in coring

Figure 11: Bar diagram of the samples in site chronologies EXTJSQ01 and EXTJSQ02, both of which comprise samples from the north and south roofs of the east wing of the Bishop's Palace

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

EXT-I01A 83
158 246 221 217 220 233 217 159 214 160 157 123 184 147 135 132 176 121 76 89
128 116 151 98 123 127 99 101 128 117 113 100 85 95 89 72 63 85 92 78
92 102 114 70 100 94 109 100 91 89 87 87 129 76 93 84 75 89 101 112
91 92 91 87 81 89 60 95 90 94 101 86 69 79 81 82 73 87 80 79
82 79 84
EXT-I01B 83
150 253 212 191 230 241 192 156 216 160 159 117 191 162 134 135 153 113 82 88
125 114 157 98 122 123 110 99 126 127 103 103 82 93 89 77 57 96 82 82
96 110 102 83 89 100 107 105 89 97 86 90 114 87 78 79 81 82 95 113
95 87 92 85 81 90 59 95 89 89 98 79 69 71 84 79 71 85 85 79
78 59 92
EXT-I03A 52
224 148 102 136 203 171 242 234 239 195 217 211 175 240 136 192 187 169 213 167
160 264 205 184 157 214 214 228 198 242 150 160 111 242 234 214 151 201 175 263
256 240 314 215 237 217 282 139 180 245 220 240
EXT-I03B 52
250 148 106 137 199 176 247 228 237 194 210 219 178 234 142 191 176 146 232 160
161 270 215 188 175 217 213 242 209 233 161 149 123 251 226 201 160 217 175 248
264 254 317 212 228 204 293 139 164 243 229 262
EXT-I04A 45
127 120 115 163 174 165 278 299 282 345 172 191 264 210 173 148 190 217 212 218
213 206 242 213 224 150 110 119 132 200 235 242 159 135 195 277 157 150 178 241
347 230 248 246 195
EXT-I04B 45
124 128 108 155 180 156 282 277 292 342 182 190 261 218 147 140 179 202 197 203
221 217 252 225 232 145 110 119 138 193 242 249 160 137 190 282 159 157 176 240
338 232 237 226 208
EXT-I05A 45
327 568 415 317 417 404 372 553 550 434 134 140 156 239 267 325 207 159 150 331
295 225 195 289 189 143 135 62 139 131 129 73 51 68 118 112 106 136 217 257
242 153 131 150 160
EXT-I05B 45
355 573 425 323 418 403 363 562 523 451 125 146 168 222 275 321 261 150 152 310
292 231 175 320 179 154 137 66 139 140 140 67 53 75 117 104 107 142 212 259
251 160 129 139 167
EXT-I10A 51
372 503 432 508 496 405 339 367 296 282 175 213 225 211 231 185 301 236 246 164
132 128 164 177 148 176 235 204 184 209 196 116 152 151 210 128 125 96 104 93
122 141 101 106 106 143 78 123 140 154 201
EXT-I10B 51
376 523 429 514 494 425 328 379 293 269 182 219 215 224 228 180 302 223 250 171
132 123 161 185 153 175 228 207 189 209 193 117 145 159 210 123 129 98 101 89
129 135 104 107 118 129 70 124 142 146 198
EXT-I14A 52
225 355 461 450 285 293 384 382 250 314 339 300 360 307 149 218 149 153 150 101
130 117 85 85 89 75 75 89 71 73 93 71 79 94 89 79 116 68 92 90
79 128 89 59 84 68 117 175 149 139 130 149

EXT-114B 52
144 361 280 395 267 280 357 382 253 329 313 305 358 318 153 213 146 147 153 95
128 122 89 79 89 67 83 89 66 79 100 72 88 93 90 87 119 65 92 92
81 143 81 57 91 81 112 159 120 190 160 167
EXT-116A 42
223 397 405 427 329 271 262 353 323 342 426 347 268 280 209 153 196 188 150 150
183 156 96 107 103 91 135 114 153 132 98 89 76 132 170 175 156 170 176 162
132 198
EXT-116B 42
217 400 402 424 340 278 266 351 316 349 422 320 272 277 203 154 214 183 136 152
188 157 95 100 109 92 132 115 148 144 96 94 78 123 170 173 160 167 182 154
136 180
EXT-117A 51
437 435 471 486 335 230 205 242 170 244 245 208 194 210 259 212 223 144 130 140
157 121 106 114 143 110 188 82 89 112 153 150 179 245 191 132 139 126 137 192
140 198 153 134 131 71 86 124 193 171 173
EXT-117B 51
438 439 466 481 334 237 200 236 172 251 251 195 199 209 266 211 227 147 132 134
158 121 103 110 142 106 196 89 85 114 143 157 175 243 196 134 139 128 129 195
150 190 154 128 140 62 101 133 182 171 175
EXT-118A 51
335 495 321 416 430 429 302 313 353 388 375 298 217 303 235 211 292 285 251 315
212 187 168 185 192 173 173 212 200 203 162 142 112 145 125 101 103 90 95 79
126 98 79 89 82 82 68 115 83 66 84
EXT-118B 51
313 485 318 416 419 443 300 309 366 375 383 307 224 314 246 226 294 279 242 318
212 198 176 173 200 168 172 217 201 192 160 142 110 145 137 95 98 92 98 76
131 95 79 101 82 75 60 90 95 90 64
EXT-119A 50
130 78 100 124 292 194 205 274 334 399 353 342 410 286 343 218 320 414 338 428
353 308 336 406 312 262 332 305 247 447 532 470 479 430 303 432 281 309 346 207
231 146 200 286 204 178 181 185 182 240
EXT-119B 50
157 70 102 128 311 187 209 269 321 394 366 352 401 286 328 234 293 410 340 400
334 321 307 418 317 259 326 298 234 436 556 466 464 431 315 429 294 314 343 196
212 153 184 284 196 184 175 180 178 206
EXT-120A 65
194 164 133 253 322 324 286 200 296 328 396 247 332 335 353 282 235 224 242 279
197 275 182 185 218 160 226 178 145 173 134 118 123 152 176 179 167 148 142 151
179 170 145 200 209 193 159 145 149 154 162 139 181 214 145 150 163 176 137 162
182 158 182 196 200
EXT-120B 65
166 166 133 255 317 343 265 192 268 328 396 244 345 331 354 280 239 235 233 272
176 268 185 196 217 156 229 175 163 176 120 118 112 157 173 162 171 156 125 148
176 173 150 195 201 204 158 155 157 159 146 155 179 215 137 155 168 143 139 184
180 157 172 193 218
EXT-121A 58
357 507 284 276 404 355 328 285 176 171 156 189 132 117 145 190 134 107 99 81
58 63 60 77 80 89 79 74 64 77 51 46 64 70 86 111 190 142 123 188
161 199 153 146 368 265 259 234 264 257 254 277 281 300 173 240 221 221
EXT-121B 58
381 505 281 273 405 346 309 290 188 170 166 153 125 121 150 178 146 110 100 80
51 57 67 85 85 103 87 70 67 78 46 60 52 73 85 103 192 135 127 178

170 193 165 168 376 274 248 228 248 232 258 316 273 262 171 250 194 260
EXT-I23A 66
152 162 119 210 167 135 137 156 226 214 234 187 187 146 194 146 132 142 137 162
195 246 224 234 184 167 192 146 114 185 254 238 141 145 138 132 185 93 115 94
119 222 150 143 114 87 129 231 232 229 239 182 112 166 115 203 220 183 216 276
229 224 157 221 175 248
EXT-I23B 66
163 180 102 205 164 141 146 163 212 208 248 182 194 130 186 155 134 146 142 157
200 243 226 231 170 174 196 132 117 191 263 232 171 149 132 130 171 101 122 92
116 239 162 151 110 87 123 243 217 250 252 182 115 164 123 190 248 179 201 262
235 207 187 181 179 200
EXT-J01A 87
496 556 401 269 218 230 214 165 207 194 162 167 103 125 132 211 218 196 159 193
246 205 198 221 171 96 65 100 85 121 142 154 162 162 148 157 148 170 226 348
270 255 234 300 296 267 243 229 120 157 165 128 185 237 175 205 250 151 168 139
193 146 110 161 162 183 181 217 154 120 182 206 189 210 215 146 125 168 146 125
161 185 177 146 170 152 162
EXT-J01B 87
520 524 436 272 207 233 203 182 197 200 157 175 123 111 151 201 228 182 160 200
246 200 221 209 171 100 69 97 85 137 140 171 150 184 151 179 153 153 240 360
250 256 239 290 306 265 242 234 139 151 159 145 179 228 171 218 238 170 148 118
198 148 109 167 154 184 187 215 168 111 172 218 193 209 209 140 121 184 147 122
162 189 188 146 162 159 158
EXT-J02A 88
175 119 122 108 187 347 280 172 119 207 179 177 153 152 212 251 194 204 162 217
147 161 241 185 282 189 184 332 251 253 206 207 239 251 275 193 260 176 218 246
153 215 246 237 221 184 293 143 131 132 120 78 81 139 144 136 105 180 221 170
118 90 121 176 220 168 111 125 100 84 94 77 171 154 162 193 137 90 96 129
157 131 89 111 106 63 54 74
EXT-J02B 88
173 106 114 106 192 301 281 166 131 178 216 187 146 150 219 248 197 193 173 211
151 161 236 196 285 171 190 331 271 263 209 206 246 270 270 181 251 173 212 242
170 204 235 237 214 176 285 145 147 150 127 60 86 148 118 137 104 206 240 162
117 101 128 179 204 166 115 126 106 74 87 78 170 147 161 199 137 93 96 131
161 125 96 102 118 57 47 75
EXT-J03A 89
215 236 212 221 236 221 247 324 407 414 459 341 292 235 235 268 261 298 272 410
284 328 339 335 239 289 343 217 262 209 191 251 345 251 248 253 260 287 239 140
115 106 154 148 154 170 175 135 128 179 189 196 143 109 116 96 56 100 100 115
104 125 125 93 73 62 63 84 99 100 75 84 68 58 56 71 94 103 70 94
86 48 60 68 66 84 72 96 115
EXT-J03B 89
209 227 217 214 242 221 245 331 343 405 468 339 292 223 239 269 264 297 272 410
285 326 316 340 239 284 345 207 258 207 175 273 343 239 269 246 271 278 237 151
115 103 157 159 157 162 162 131 131 167 207 178 143 100 117 87 65 95 99 113
111 118 130 91 71 58 63 93 91 113 75 78 77 59 59 65 88 106 74 97
78 50 59 75 64 76 79 104 121
EXT-J04A 86
397 270 184 174 243 266 337 365 364 387 216 239 307 262 275 193 181 296 312 153
172 178 240 315 216 260 191 207 259 201 221 317 307 232 129 139 206 335 250 232
235 189 137 115 96 134 209 220 234 262 197 176 198 196 117 157 154 106 159 165
173 237 142 153 127 93 114 125 131 143 169 155 156 134 137 159 121 146 106 106
125 162 159 176 156 149

EXT-J04B 86
420 272 181 170 265 266 319 356 351 373 200 209 299 260 254 190 174 259 318 185
168 168 232 308 225 257 184 208 272 206 220 315 301 236 124 137 212 325 233 237
242 197 135 103 94 140 210 206 228 264 189 168 206 187 149 145 160 126 157 159
169 237 141 156 128 90 118 128 123 153 163 149 159 158 109 151 130 137 114 116
109 157 152 176 153 150
EXT-J05A 104
212 200 182 185 217 245 214 275 251 267 211 205 214 198 219 208 125 168 143 153
142 196 198 196 203 157 144 139 150 148 297 226 128 112 89 121 135 148 228 276
265 233 202 230 222 173 187 248 160 211 188 164 212 231 231 232 226 218 264 185
109 63 64 85 115 123 168 135 159 142 191 206 146 156 95 84 71 62 112 106
115 113 137 134 109 94 68 84 131 168 143 139 75 81 80 68 75 169 164 81
100 119 71 104
EXT-J05B 104
206 210 179 187 226 243 223 263 293 259 209 194 214 217 225 207 112 172 128 169
126 224 192 199 198 160 137 140 141 157 296 231 111 115 86 110 129 153 222 280
294 226 223 235 210 168 201 242 153 210 190 153 214 252 225 228 225 221 264 190
107 65 79 78 121 116 167 143 142 135 197 196 156 143 102 99 70 70 106 103
118 103 142 136 96 92 66 90 134 168 153 129 73 80 79 64 93 153 147 81
100 110 87 106
EXT-J06A 96
383 451 331 278 329 218 118 134 156 184 182 137 142 226 170 187 209 162 174 191
158 185 314 232 246 232 285 263 225 190 164 106 162 165 190 240 218 156 128 126
167 264 197 187 200 222 142 132 154 175 246 192 256 326 188 218 256 220 207 251
238 206 263 210 234 340 250 233 186 131 156 157 150 177 181 165 164 121 122 146
118 136 103 96 137 152 143 122 141 102 133 145 131 151 111 152
EXT-J06B 96
376 440 334 277 328 207 137 131 144 164 185 132 155 225 175 181 203 152 165 196
152 171 314 224 256 219 261 257 212 169 171 96 160 168 192 228 222 160 133 122
160 271 189 184 216 209 160 132 143 146 240 185 261 324 183 226 264 223 204 260
239 214 252 207 259 340 257 228 185 133 148 160 164 169 180 169 159 125 114 140
118 134 104 90 130 143 154 115 143 96 144 146 128 155 110 154
EXT-J07A 82
149 136 178 256 314 298 313 284 393 502 278 334 351 421 272 219 182 144 203 147
210 239 239 225 205 189 209 207 170 140 146 137 209 209 132 153 190 128 153 170
196 93 137 106 96 62 135 170 145 154 156 165 179 95 66 53 117 145 180 95
112 75 60 56 100 121 111 150 110 117 105 53 76 71 98 127 75 66 68 59
55 53
EXT-J07B 82
132 143 175 250 318 298 319 291 407 501 305 356 353 423 277 218 191 150 196 140
208 230 253 217 196 192 214 209 165 145 139 137 209 207 128 159 187 134 146 181
198 93 140 107 85 68 126 176 143 150 162 168 179 100 64 57 107 145 175 104
111 78 70 74 98 116 131 170 100 125 110 49 80 68 100 120 76 65 62 56
50 59
EXT-J08A 78
175 187 186 147 100 104 151 163 168 169 173 173 142 152 160 138 171 183 148 200
196 221 290 187 187 165 128 131 147 143 160 195 175 203 188 157 167 146 149 105
104 125 157 182 179 186 135 145 181 175 181 146 137 125 93 139 181 117 151 168
168 109 159 185 125 113 125 114 128 119 142 146 89 83 86 101 121 115
EXT-J08B 78
175 181 204 135 120 120 133 151 159 176 175 167 146 173 176 148 181 190 144 216
202 220 284 159 168 181 127 139 157 156 172 205 154 189 183 144 159 157 144 123
107 128 159 173 168 185 131 157 162 184 144 155 142 121 90 142 181 121 142 168

175 111 150 183 130 117 120 107 125 120 142 148 90 83 87 103 120 115
EXT-J09A 83
284 229 184 209 193 246 207 171 141 160 161 150 134 123 178 166 134 182 155 165
148 140 264 210 229 229 261 264 235 188 192 253 211 226 239 163 182 256 206 137
165 281 150 193 171 248 147 138 164 167 185 160 192 203 150 100 129 196 167 248
150 118 114 119 116 110 129 173 167 98 118 111 104 91 81 108 143 103 119 128
100 82 134
EXT-J09B 83
272 223 188 211 191 246 200 180 141 166 166 146 130 132 176 162 132 195 144 171
150 141 252 207 228 220 265 266 244 178 217 268 214 232 228 155 182 215 185 151
140 246 146 199 164 268 143 162 176 146 181 163 185 200 131 114 121 176 194 233
141 108 125 135 109 119 128 165 162 112 101 102 101 92 84 96 141 100 112 114
100 91 132
EXT-J10A 90
312 241 179 181 201 291 250 257 275 178 159 134 128 155 230 247 318 407 233 289
258 249 183 206 196 246 269 251 321 295 302 251 253 168 162 185 148 148 162 201
178 155 142 157 151 118 103 90 126 122 130 126 129 97 139 142 96 96 95 110
68 64 100 96 115 106 96 96 85 103 106 67 98 78 75 81 71 65 78 68
78 72 61 75 81 85 75 77 68 72
EXT-J10B 90
306 249 183 164 208 290 249 269 266 185 153 132 146 150 232 251 311 445 231 230
248 264 203 191 190 221 268 283 313 298 298 251 250 159 154 196 132 143 150 209
160 160 135 159 148 112 110 87 122 124 131 114 131 96 148 153 105 98 84 120
68 62 95 101 104 106 98 96 90 100 112 67 96 76 82 74 72 65 68 71
75 68 65 73 69 91 81 77 65 70
EXT-J11A 111
248 198 200 179 135 143 108 137 140 125 106 104 128 114 79 95 95 89 96 137
144 123 139 121 88 81 96 142 328 343 89 143 110 115 116 114 168 201 245 229
181 206 200 165 179 223 159 168 157 137 184 307 240 251 217 189 192 167 107 87
107 118 151 131 164 154 156 140 178 208 190 165 168 125 82 101 108 124 115 129
129 156 117 101 79 86 115 175 146 132 79 59 44 50 55 81 81 46 68 66
55 75 65 85 116 94 115 77 51 38 53
EXT-J11B 111
249 204 196 179 130 131 118 142 153 89 101 114 128 121 77 110 87 94 103 138
133 128 146 112 92 76 97 149 335 341 96 149 120 125 119 110 170 200 250 230
186 211 190 160 184 211 160 175 164 132 196 303 231 234 221 207 187 162 100 103
107 123 145 128 170 142 160 134 187 214 190 177 145 131 76 104 123 115 131 137
128 156 123 84 71 93 123 151 167 125 95 50 49 50 52 82 84 53 60 75
55 65 71 75 108 96 115 81 37 39 60
EXT-J12A 78
424 597 494 262 210 78 174 344 407 487 443 390 382 471 467 428 345 336 276 232
220 126 168 142 225 250 240 340 251 192 257 309 264 266 296 210 306 229 210 237
252 189 143 148 114 127 136 173 185 246 303 209 207 253 240 253 239 157 200 292
371 190 161 140 212 221 186 171 169 190 181 143 127 122 130 162 136 231
EXT-J12B 78
430 579 498 268 202 88 171 325 360 479 421 374 421 461 475 384 362 326 264 221
221 131 164 132 203 239 264 356 238 193 225 301 262 262 279 209 289 212 220 234
253 189 143 151 109 129 160 166 200 227 290 221 203 264 243 249 240 171 196 291
356 205 159 146 210 216 191 175 159 196 165 147 128 116 140 146 136 199
EXT-J13A 85
274 193 236 222 249 221 247 187 164 167 157 114 112 134 184 123 112 112 117 101
110 98 92 288 474 385 272 103 94 87 75 89 61 85 145 186 163 180 198 121
114 123 147 91 110 136 155 235 219 167 202 200 171 194 124 92 79 62 140 153

106 175 195 153 175 159 205 161 157 75 111 84 101 123 140 139 103 139 122 82
65 40 76 128 150
EXT-J13B 85
279 188 254 227 234 249 290 178 173 160 153 104 116 131 182 117 111 120 111 106
108 101 90 277 469 400 282 109 92 100 92 60 78 100 143 195 160 184 221 103
89 125 149 86 120 131 164 225 243 148 192 204 173 193 112 84 78 70 146 137
115 201 198 123 172 139 168 167 160 107 86 90 101 117 141 137 107 134 123 84
62 43 75 117 146
EXT-J14A 112
409 300 390 266 318 271 178 205 332 300 256 221 243 306 235 246 189 89 190 139
212 250 239 196 125 85 138 230 182 169 170 150 118 103 82 104 134 152 160 240
156 157 170 204 142 214 206 168 250 205 291 379 293 201 167 113 110 106 106 107
134 123 141 122 118 115 89 96 81 68 84 81 98 94 97 76 121 109 112 120
122 75 65 71 94 87 87 102 105 113 112 117 134 86 90 84 86 84 71 86
62 55 58 55 71 50 62 70 64 59 73 70
EXT-J14B 112
394 298 377 258 316 259 182 221 350 287 258 224 239 307 243 237 196 98 148 136
202 250 260 182 140 91 117 232 195 162 171 149 115 109 82 106 139 146 208 220
151 145 178 195 140 223 195 182 251 204 270 360 293 211 168 110 120 121 104 112
132 135 150 110 103 107 99 93 81 65 73 75 110 83 107 87 116 113 123 135
121 68 71 65 96 90 87 100 96 109 91 118 135 71 94 76 87 75 70 92
66 60 56 52 67 51 64 73 65 56 72 67
EXT-J15A 73
641 620 627 475 471 520 484 532 433 251 405 630 457 385 376 285 254 302 183 194
183 222 206 273 150 167 191 175 199 233 274 210 256 192 200 250 193 277 159 178
175 139 176 174 203 215 234 210 207 271 190 196 183 206 243 288 240 153 196 162
165 190 184 197 190 191 143 175 253 129 184 200 275
EXT-J15B 73
640 625 579 516 475 515 474 525 423 257 390 654 474 371 396 289 245 293 185 192
193 215 207 282 151 187 188 171 196 232 282 203 242 195 193 245 189 273 161 172
187 160 155 168 219 190 240 178 221 258 204 172 168 237 253 293 240 162 198 157
166 200 192 191 190 197 138 181 241 128 183 221 281
EXT-J16A 98
343 318 364 375 320 262 280 235 321 271 210 274 271 314 300 247 280 362 372 232
208 147 106 131 89 51 101 98 128 146 100 125 146 91 101 100 90 128 203 153
148 112 112 153 128 105 81 76 81 79 106 132 167 140 104 132 107 139 101 80
122 126 117 109 120 65 59 98 88 85 111 109 107 104 104 75 75 120 112 137
112 128 109 86 78 62 108 93 53 118 77 86 102 84 87 83 70 161
EXT-J16B 98
348 318 343 372 312 273 278 239 311 264 225 268 276 314 300 257 275 368 370 167
210 143 111 128 93 50 114 91 117 154 100 121 131 70 90 84 76 128 201 156
143 118 115 149 132 103 79 85 78 85 102 117 165 131 114 125 114 128 101 92
117 113 119 104 100 82 64 98 101 89 103 112 89 107 110 78 90 115 112 123
104 136 137 87 75 72 95 84 63 114 80 88 106 81 93 87 74 159
EXT-J17A 55
199 200 229 207 147 145 233 182 179 184 153 194 189 162 167 175 170 287 226 194
101 117 139 225 200 235 231 191 194 155 150 135 97 240 256 273 248 210 126 140
182 198 176 222 177 151 185 159 134 169 232 323 279 211 227
EXT-J17B 55
204 202 242 205 148 159 227 174 181 175 150 192 155 164 158 201 182 273 211 197
116 120 144 222 193 252 233 200 195 148 148 135 89 247 251 267 215 192 123 160
187 193 176 228 173 156 183 170 131 175 259 306 303 214 233
EXT-J18A 72

480 317 515 849 719 498 631 372 328 156 148 237 232 375 335 424 350 341 485 487
492 446 634 362 385 329 330 450 368 459 384 419 353 393 374 368 405 376 377 421
387 335 352 409 275 258 310 340 364 257 308 197 205 230 278 270 236 226 174 200
235 201 193 231 250 270 231 241 225 166 171 227
EXT-J18B 72
480 337 510 849 707 504 627 385 292 157 153 206 275 382 336 398 342 321 421 481
468 467 620 368 355 346 305 430 420 434 364 418 359 387 371 350 419 387 390 421
390 337 315 393 259 268 304 325 356 252 314 194 199 239 273 271 264 202 181 203
231 183 188 243 243 272 228 255 278 159 169 229
EXT-J19A 60
288 309 295 250 277 251 239 297 233 303 250 190 160 179 126 170 272 272 228 249
233 219 179 164 127 141 252 332 264 179 164 162 164 221 256 228 196 231 140 203
301 146 185 235 271 290 170 228 176 157 173 173 232 221 195 259 204 206 189 265
EXT-J19B 60
292 282 308 237 279 252 235 292 235 303 250 185 167 190 125 179 252 271 243 225
233 222 186 183 125 140 252 289 250 165 179 162 178 217 251 263 194 215 140 209
293 150 182 233 271 282 184 218 181 144 169 182 221 218 218 255 207 196 192 268
EXT-J20A 77
225 121 65 42 34 64 118 110 232 214 131 137 184 191 228 229 189 332 219 251
267 250 296 429 332 196 106 85 155 264 314 285 274 262 210 278 224 258 152 142
290 231 305 250 179 140 109 203 214 273 248 265 209 254 195 195 191 228 284 215
194 270 205 96 78 68 131 174 150 162 168 198 223 200 184 153 196
EXT-J20B 77
220 117 62 44 33 64 127 120 223 196 125 141 175 191 235 218 191 278 205 252
272 253 282 438 357 209 100 78 144 269 300 250 275 260 217 268 264 246 118 121
300 215 321 228 193 126 118 203 184 281 256 259 237 194 203 182 190 240 275 214
193 267 212 106 68 68 129 196 142 181 171 216 244 194 180 154 190
EXT-J21A 62
629 511 474 416 376 375 357 167 242 364 339 335 210 295 333 282 210 153 250 272
278 339 218 240 215 146 164 182 206 163 300 282 170 104 87 68 130 148 156 206
139 90 71 59 50 64 55 101 237 219 238 243 212 277 367 356 257 250 309 236
334 368
EXT-J21B 62
597 497 459 437 335 383 373 153 243 345 341 319 216 277 325 285 201 162 235 273
206 331 223 242 215 162 159 195 200 173 310 274 161 110 87 68 132 151 151 199
122 95 65 56 55 60 56 107 228 217 235 265 200 285 367 357 266 238 308 237
350 373

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 Buildings (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

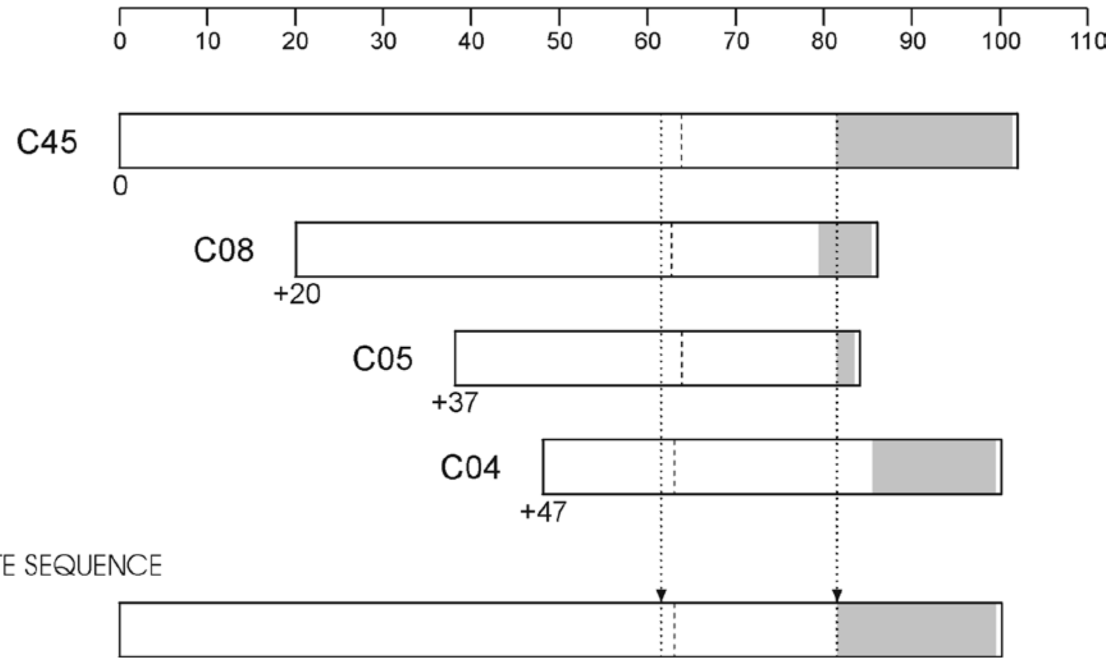


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

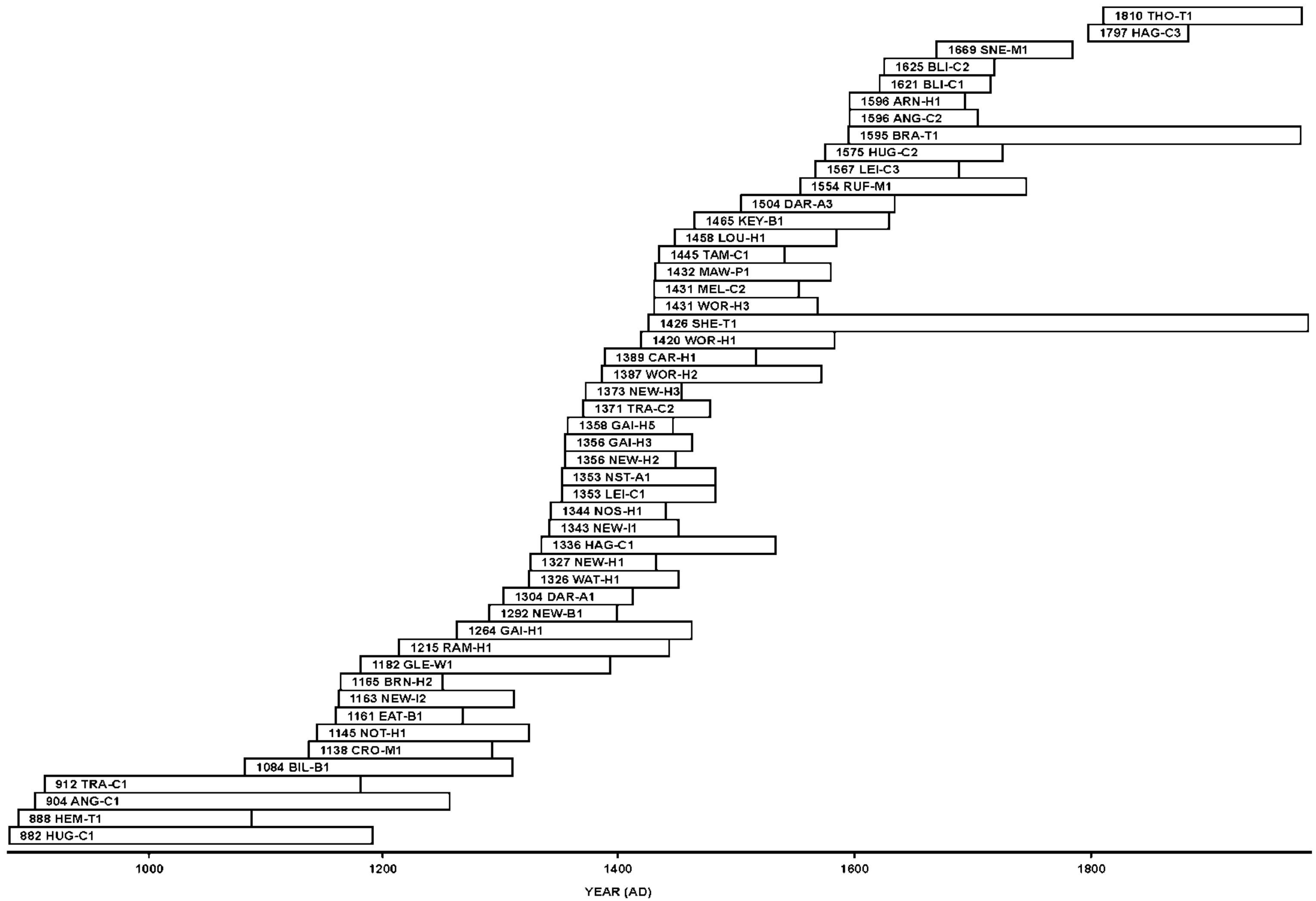
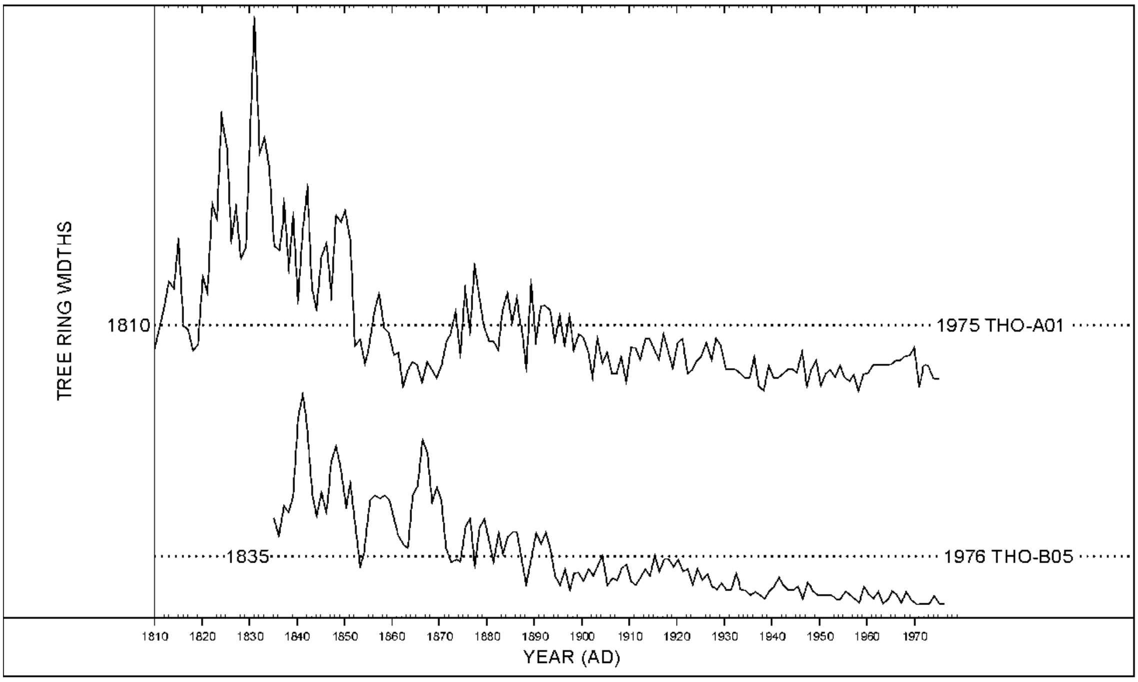


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

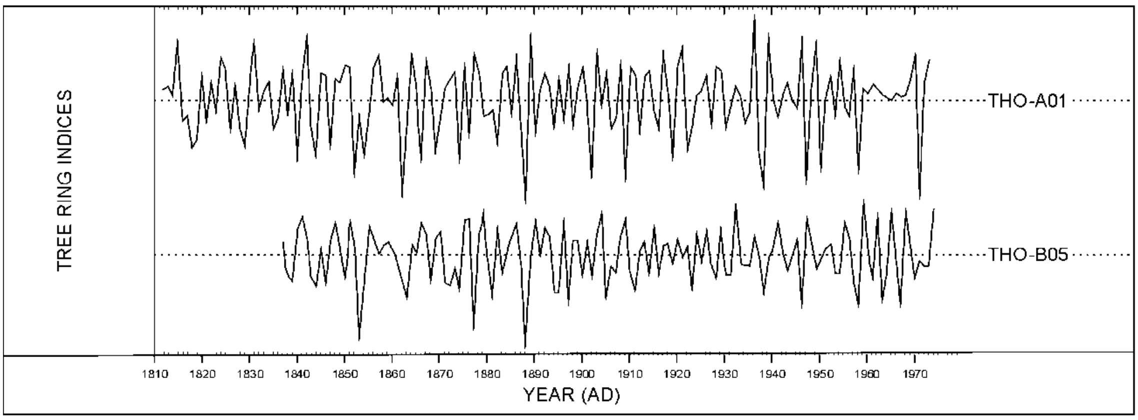


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

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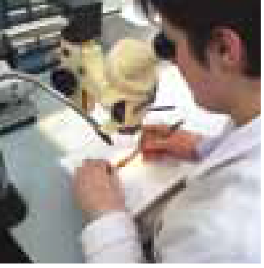
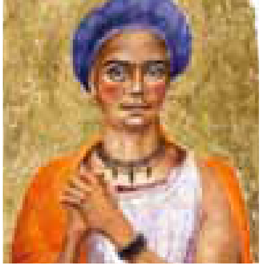


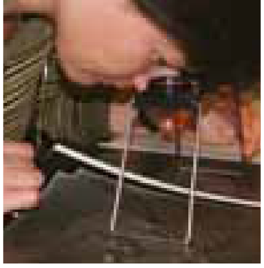


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