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The Bede House, Church Lane, Lyddington, Rutland

Tree-Ring Analysis of Oak Timbers

Alison Arnold, Robert Howard, and Cathy Tyers

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CHURCH LANE
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Tree-Ring Analysis of Oak Timbers

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SUMMARY
Dendrochronological analysis was undertaken on 100 of the 113 samples obtained from this building, producing five dated site chronologies comprising 81 samples. Interpretation of the sapwood indicates a number of different phases of felling of timbers ranging from the late-twelfth/early thirteenth centuries to the late-eighteenth century. A small number of timbers have been identified that may be associated with the early development of the medieval palace of the bishops of Lincoln of which the Bede House is the sole surviving block. The majority of the dated timbers were felled during the fifteenth and early sixteenth centuries and appear likely to be associated with several different documented phases of redevelopment or remodelling of the medieval palace. The later timbers identified appear to be associated with the change of use to an almshouse and subsequent repair works or modifications.

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INTRODUCTION

The Grade 1 listed Bede House, also a Scheduled Monument, stands immediately north of the church in Lyddington (Figs 1a–c). The site and its buildings have been the subject of a number of historical and archaeological surveys (Page 1935; Thornton 2009; Woodfield and Woodfield 1983, 1988) from which the following information is summarised.

The existing early seventeenth-century almshouse has its origins as part of a medieval palace of the Bishops of Lincoln, Bishop Remegius (AD 1067–1092) having been granted the Lyddington estate towards the end of the eleventh century. Although the understanding of the early development of the site is uncertain, it is thought that a house and park were already present at the time of King John (AD 1199–1216). It was clearly in use as a major residence from at least the time of Bishop Grosseteste (AD 1235–53) with the Great Park thought to have been created at this time or possibly a little earlier in the thirteenth century. Bishop Burghersh (AD 1320–40) undertook major redevelopment and was given a licence to crenellate in AD 1336. It is thought that the extant building, the bishops private accommodation, was remodelled at this time and that the Little Park was established. There is only limited survival of architectural evidence linked with the continuation of works during the later fourteenth and early fifteenth centuries and that of the apparent remodelling of this block by Bishop Alnwick (AD 1436–49), prior to the major works carried out in the later fifteenth century by Bishop Russell (AD 1480–94) and Bishop Smith (AD 1496–1514) when the extant building began to take on its current appearance. The Lyddington estate was transferred to the crown in AD 1547 with it being granted to Gregory Cromwell in AD 1548 and then, after his death in AD 1551, to William Cecil, Lord Burghley. It lost its status as a major residence which resulted in much of the complex becoming redundant and falling into a state of decay with extensive demolition probably occurring during the latter half of the sixteenth century. Following the death of William Cecil in AD 1598, his son, Sir Thomas Cecil, 1st Earl of Exeter, inherited the remaining buildings and it was he who is believed to have converted the bishop's residence into a hospital or almshouse. It functioned as an almshouse until the 1930s, still under the ownership of the descendants of the Cecils, and was taken into guardianship in 1954.

The north side of the extant Bede House block probably faced onto a courtyard, a timber pentice to this face probably replacing a two-storeyed gallery (Fig 2a). Doors off the pentice lead to the individual Bedesman rooms, formed by partitioning the original large ground-floor chamber. Towards the east end of the pentice, a projecting porch leads to both other ground-floor rooms and, via a stone staircase, to the Great Chamber on the first floor (Fig 2b), through which access is gained to the Presence Chamber, which retains a blocked doorway to a now lost gallery. Further west, beyond the Presence Chamber is a smaller inner chamber, perhaps an Oratory or office, as well as a garderobe. To the east of the Great Chamber are two rooms, the inner one of which may have been a Chapel, but both of which are thought to have subsequently been Bedeswoman rooms.

The roof appears to have originally been of nine arch-braced trusses with collars, wind-braces, and moulded tiebeams (Fig 3a). A ceiling was subsequently inserted, probably in the early sixteenth century, with the attic being accessed by a set of wooden stairs. The extant roof to the east end is a post-medieval replacement (Fig 3b). Also of note are a number of plank or board doors of which some are of relatively simple construction (eg those to the Bedesman rooms), whilst others are more substantial with cross-board backing and ironwork straps and studs (Figs 4a/b).

SAMPLING

Dendrochronological analysis was requested in order to provide independent dating evidence relating to the historical development of this extant block of the medieval palace. It was hoped that this would inform understanding and significance and hence add to the research program that was being undertaken by the English Heritage Properties Historian team. Dendrochronological assessment of the potential of key areas/elements (Figs 5a–c), as identified by the Properties Historian team, was undertaken and following further discussion sampling proceeded on those key areas/elements of the building with good dendrochronological potential.

Thus, a total of 113 samples was obtained during a number of separate sampling visits, necessitated by the need to undertake some sampling outside of public access times. The majority of these samples, 92, were obtained by coring. However, 21 from plank doors and floorboards, were obtained by *in situ* measurements. Whereas core samples are normally measured twice by the Nottingham Tree-ring Dating Laboratory, the *in situ* measurements were single-measurement series.

The locations of these samples were recorded at the time of sampling on drawings, sketch plans, or on annotated photographs (Figs 6a–20b). Each sample was given the code LYB-H (for Lyddington Bede House) and numbered 01–113 (Table 1). The trusses, frames, beams, joists, and any other appropriate elements have been numbered from east to west or south to north, with individual elements then being further identified as appropriate, apart from the door planks, stair-treads, and floorboards, which have also been located in plan or photograph (Table 1 and Figs 6a-20b).

ANALYSIS AND RESULTS

Each of the 92 core samples obtained from the Bede House was prepared by sanding and polishing. It was seen at this time that 13 samples had less than the minimum of 40 rings here deemed necessary for reliable dating and so they were rejected from this programme of analysis. The annual growth ring widths of the remaining 79 core samples were measured, the data of these measurements, plus those of the 21 elements measured *in situ*, are given at the end of this report.

The data of the 100 measured series were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix). This comparative process allowed five separate groups of cross-matching samples to be formed, the samples of each respective group cross-matching with each other as shown in Figures 21–25. The samples of each group combined at their indicated offset positions to form site chronologies LYBHSQ01–LYBHSQ05, these five chronologies between them accounting for a total of 81 measured samples.

Each of the five site chronologies was then compared to an extensive corpus of reference material for oak, this indicating consistent and repeated matches for each of them (Tables 2–6). Each of the five dated site chronologies was also compared to the 19 remaining measured but ungrouped samples, but there was no further satisfactory cross-matching. Each of the 19 ungrouped samples was then compared individually to the full corpus of reference data, but again there was no satisfactory cross-matching and all 19 must, therefore, remain undated.

This analysis may be summarised as follows:

Site chronology	Number of samples	Number of rings	Date span AD (where dated)
LYBHSQ01	5	137	1085–1221
LYBHSQ02	8	305	1110–1414
LYBHSQ03	49	250	1245–1494
LYBHSQ04	7	101	1498–1598
LYBHSQ05	12	131	1623–1753
Ungrouped	19	---	undated
Unmeasured	13	---	undated
Total	113		

INTERPRETATION

Dendrochronological analysis of a series of samples of timbers in the Bede House has produced five dated site chronologies comprising 81 of the 100 measured samples. The dated samples indicate, perhaps not unexpectedly given the history of the Bede House, that these timbers represent a number of different felling episodes related to various phases of construction/modification. To aid interpretation, the results are presented area by area below and in Figures 26a–b, with a summary of the interpretation for each area presented in Figure 27. In each case, where sapwood is not complete (ie the sample does not have the last ring produced before the tree was felled), the estimated felling date is calculated on the basis of the 95%

confidence interval for the amount of sapwood the trees are likely to have had which is 15–40 rings.

Great Chamber/Presence Chamber roofs

Eighteen samples (LYB-H01 – LYB-H15 and LYB-H98 – LYB-H100) were obtained from these roofs (see Fig 5c). All 18 samples were measured of which 11 were dated (Figs 23 and 26a). Ten of these samples, representing a tiebeam, two collars, two archbraces, and five principal rafters, appear likely to be coeval. The date of the heartwood/sapwood boundary on those eight samples varies by only 16 years with the average boundary being dated AD 1429. Using the standard sapwood estimate gives these timbers an estimated felling date in the range AD 1444–69.

The remaining dated sample (LYB-H14) from this roof has a later heartwood/sapwood boundary, this being dated AD 1476. This, therefore, provides this timber, a tiebeam, with an estimated felling date in the range AD 1491–1516.

East-end roof

Eight samples (LYB-H16 – LYB-H23) were obtained from this roof (see Fig 5c), of which one (LYB-H23) was not measured as it contained too few rings for reliable dating. The remaining seven measured samples, representing a purlin, two collars, and four principal rafters, all dated and appear to be coeval (Figs 25 and 26a). All seven have retained the heartwood/sapwood boundary, which varies by only five years. However, four of these samples have retained complete sapwood, the outermost ring dating to AD 1744 in each case, indicating that this group of dated timbers were all likely to have been felled in AD 1744.

Presence Chamber ceiling (westernmost bay)

Five samples (LYB-H24 – LYB-H28) were obtained from the ceiling beams accessible from the attic area above the Presence Chamber (see Fig 5b). All five were measured but only one, LYB-H27, could be dated (Figs 23 and 26a). The heartwood/sapwood boundary on this sample is dated AD 1387 which, using the standard sapwood estimate, gives this ceiling joist an estimated felling date in the range AD 1402–27.

Bedesman room ceilings

Main ceiling beams were sampled in Bedesman rooms 1 and 2, as well as a series of ceiling joists in Bedesman rooms 2 and 4 (LYB-H29 – LYB-H43), the other

Bedesman rooms on the ground floor either having no exposed timbers or none that were accessible and suitable (see Fig 5a). Three of these samples were not measured as they contained too few rings for reliable dating purposes. Eight of the 12 measured series dated, indicating two distinct periods of felling (Figs 21, 23, and 26a).

Four samples, all from ceiling joists in room 3, appear to be coeval. The date of the heartwood/sapwood boundary on those three samples with it varies by only seven years with the average boundary being dated AD 1219. Using the standard sapwood estimate gives these timbers an estimated felling date in the range AD 1234–59.

The remaining four dated samples, representing a main ceiling between rooms 1 and 2 and ceiling joists from room 2, also appear likely to be coeval. Two of these have the heartwood/sapwood boundary present which varies by seven years and produces an average boundary date of AD 1478. This indicates that these four timbers were all probably felled in the range AD 1493–1518.

West roof over small inner chamber

A small number of timbers that looked potentially to have sufficient rings for analysis in this room (see Fig 5b) were sampled (LYB-H44 –LYB-H47). Three samples proved to have too few rings for reliable dating purposes so only one of these samples (LYB-H46) was measured. It was successfully dated and, with a heartwood/sapwood boundary date of AD 1461, a felling date in the range AD 1476–1501 is obtained for this principal rafter (Figs 23 and 26a).

Pentice

A total of 13 samples (LYB-H48 – LYB-H53 and LYB-H89 – LYB-H95) were taken from the pentice located on the north elevation of the Bede House block (see Fig 5a). Two of these samples were not measured as they contained too few rings for reliable dating purposes and, of the 11 measured series, only one failed to date. Interpretation of the sapwood on the 10 dated samples suggests that three distinct periods of felling are represented (Figs 23–26a).

The earliest period of felling is represented by four samples, all from tiebeams, which are probably coeval. Two of these have the heartwood/sapwood boundary present which varies by 10 years, the average boundary being dated AD 1477. This gives these four timbers an estimated felling date in the range AD 1492–1517. The second period of felling is represented by two samples, one from a post and one from a tiebeam, which again appear coeval having heartwood/sapwood boundaries varying by five years. The average heartwood/sapwood boundary dates to AD 1584 and, thus, an estimated felling date in the range AD 1599–1624. The latest period of felling found in the pentice structure is again represented by four samples, all from posts, which appear to be coeval. All four have the heartwood/sapwood boundary present which varies by six years. The average heartwood/sapwood boundary on these samples is dated AD 1750 and hence, using the usual sapwood estimate, these timbers have an estimated felling date in the range AD 1765–90.

Stair treads up to attic

Six samples (LYB-H54 – LYB-H59) were obtained from the wooden treads of the stairs leading up from the east end Bedeswoman rooms (former Chapel and adjacent room) landing to the attics above (see Fig 5b). All six samples were measured and dated (Figs 23 and 26b). In this case, because of the square-cut nature of the treads and the wear which they have undergone over the years, none of the timbers retain the heartwood/sapwood boundary. They do, however, show a very high level of similarity between the ring sequences (t-values ranging from 6.6 to 14.8) suggesting that these are derived from either a single tree or trees growing within a discrete area of woodland and are hence coeval. This means that not only are all the sapwood rings missing, but an unknown number of heartwood rings as well. It is thus not possible to provide a felling date range for the timbers. However, given that the latest ring on any sample, LYB-H59, is dated to AD 1449, and allowing for a minimum of 15 sapwood rings, felling of these six timbers is likely to have taken place after AD 1464.

Great Chamber/Presence Chamber partition wall

Four samples (LYB-H60 – LYB-H63) were obtained from the partition wall between the Great Chamber and Presence Chamber at first-floor level (see Fig 5c). All four samples dated indicating two distinct phases of felling (Figs 23 and 26b).

The earlier phase of felling is represented by one sample, representing the main post, this having a heartwood/sapwood boundary date of AD 1412, and thus an estimated felling date in the range AD 1427–52. The later phase of felling is represented by three samples that appear coeval having heartwood/sapwood boundary dates varying by 13 years. These three have an average heartwood/sapwood boundary date of AD 1473 giving these two cross-rails, and a stud, an estimated felling date in the range AD 1495–1513 allowing for the outermost measured sapwood ring present on LYB-H61.

Cupboard under stairs adjacent to porch

Four samples (LYB-H64 – LYB-H67) were obtained from joists forming the ceiling of an under-stair cupboard adjacent to the projecting north porch (see Fig 5a).

Again all four samples dated, and again indicating two distinct phases of felling (Figs 23 and 26b).

The earlier phase of felling is represented by one sample, LYB-H64, this having a heartwood/sapwood boundary date of AD 1373, and thus an estimated felling date in the range AD 1388–1413. The later phase of felling is represented by three samples that appear to be coeval having heartwood/sapwood boundary dates varying by eight years. These three have an average heartwood/sapwood boundary date of AD 1406 giving these joists an estimated felling date in the range AD 1421–46.

Doors

Fifteen planks from five different doors were measured *in situ* (LYB-H68 – LYB-H82). Three of the doors were to Bedesman rooms, one door to the Chapel/Bedeswoman room 1, and another to Bedeswoman room 2, the room immediately adjacent to the stairs to the attic (see Figs 5a–b). All 15 samples dated (Figs 22, 23, and 26b). Again, given the square-cut and well-trimmed nature of these planks, none of them retains the heartwood/sapwood boundary. This, again, means that not only are all the sapwood rings missing, but an unknown number of heartwood rings as well. It is thus not possible to provide a felling date range for the planks.

The planks from each of the individual doors appear broadly coeval. Thus, the four dated planks from the door to Bedesman room 1 were probably felled after AD 1484, the two dated planks from the door to Bedesman room 2 were probably felled after AD 1467, and the three dated planks from the door to Bedesman room 4 were probably felled after AD 1484. The four dated planks from the Bedeswoman room 1 (former Chapel) were felled after AD 1482. The two dated planks from the Bedeswoman room 2, adjacent to the stairs, unlike the other door planks which appear to be of native origin, are derived from timbers imported from the Baltic. Thus, using the appropriate sapwood estimate of 8–24 rings, the 95% confidence interval (Tyers 1998), they were probably felled after AD 1357.

Attic floorboards above small inner chamber

Six of the floorboards in this attic room were distinctly different to the others present and these were measured directly on site (LYB-H83 – LYB-H88). All six samples dated (Figs 22 and 26b) but again, having been heavily worked, none of the samples retains any sapwood and it is not possible to produce a felling date range for these floorboards.

Five of these floorboards have last measured heartwood ring dates ranging from AD 1391 (LYB-H84) to AD 1414 (LYB-H85). In this instance, with the floorboards being derived from timbers imported from the Baltic, allowing for the minimum number of missing sapwood rings (Tyers 1998) indicates that these timbers were all probably felled after AD 1422.

The sixth dated floorboard sample, LYB-H86, has a much earlier last measured heartwood ring, this dated to AD 1194. Allowing for the minimum likely number of sapwood rings, this timber was felled after AD 1202. It is possible that it was derived from a tree felled significantly earlier than the other floorboards. However, it crossmatches LYB-H87 with a high *t*-value (7.3) which, combined with the fact that its ring series starts at AD 1110 within a few rings of the very long series of LYB-H83 (AD 1119) and LYB-H87 (AD 1124), suggests that it is more likely to simply represent the inner part of a longer-lived tree and hence, coeval with the five other dated floorboards.

Porch

The porch entry, projecting from the north elevation of the Bede House (see Fig 5a) and housing the steps to the Great Chamber, contains a small number of timbers in its west flanking wall of which two were considered suitable for sampling (LYB-H96 and LYB-H97). Sample LYB-H97 proved to have too few rings for reliable dating purposes but sample LYB-H96 was measured and dated (Figs 25 and 26b). It has no heartwood/sapwood boundary and has a last measured heartwood ring dating to AD 1716. Allowing for a minimum of 15 sapwood rings, this post was probably felled after AD 1731.

Attic partition wall above the Great Chamber/Presence Chamber

Three timbers from the partition wall in the attic above the Great Chamber/Presence Chamber were sampled (LYB-H101 – LYB-H103). One, containing too few rings for reliable dating, was not measured, while neither of the two measured samples could be dated.

Chapel/Bedeswoman rooms partition walls and stair framing

The partition walls between the Bedeswoman rooms (former Chapel and the adjacent room) and the timbers support and framing the wooden stairs leading up the attics (see Fig 5b), appear part of an integral structure. Eight samples (LYB-H104 – LYB-H111) were obtained from these timbers although two samples were not measured as they contained too few rings for reliable dating. Five samples dated out of the six that were measured and appeared likely to be coeval (Figs 24 and 26b). The heartwood/sapwood boundary on the four samples with it varies by five years, with the average boundary dating to AD 1581. This gives these five timbers - a jamb, a newel post, two cross-rails, and a door head, a felling date in the range AD 1599–1621, allowing for the outermost measured sapwood ring on LYB-H110.

Presence Chamber niche (cupboard)

Sample LYB-H112 was obtained from an east-west timber in a niche or small cupboard to the south wall of the Presence Chamber (see Fig 5b). This sample was measured and has a last heartwood ring date of AD 1405 which, allowing for a minimum of 15 sapwood rings, indicates that it was probably felled after AD 1420 (Figs 23 and 26b).

Chamber (shop) ceiling

Finally, sample LYB-H113 was obtained from an east-west ground-floor ceiling beam to the Chamber (currently the shop; see Fig 5a). This sample was measured and has a heartwood/sapwood boundary of AD 1171 which, with the usual minimum/maximum complement of sapwood, gives the timber an estimated felling date in the range AD 1186–1211 (Figs 21 and 26b).

DISCUSSION AND CONCLUSION

The successful dating of 81 timbers has identified a series of different episodes of felling from the late-twelfth/early thirteenth century through to the late-eighteenth century (Fig 27). The complex history of this remnant of a medieval palace, and hence the possibility that timbers have been salvaged and reused from buildings elsewhere in the medieval palace complex, even in the absence of clear evidence of reuse, highlights the importance of the dendrochronological evidence being combined with detailed documentary and architectural records in order to ensure that the results are placed in an appropriate context. Thus, the following discussion, based on the episodes of felling identified during the dendrochronological analysis, should be viewed in conjunction with detailed documentary and architectural analysis.

Late-twelfth – mid-thirteenth century

The earliest timber, the ceiling beam in the shop, felled in AD 1186–1211, pre-dates the documented residency of the medieval palace by Bishop Grosseteste. Thornton (2009) states that "*it is possible that the residence had already developed beyond a typical manorial establishment by later 12th century*". Hence, this timber may well be associated with the early development of the medieval palace on the site but caution over its wider interpretation is needed as it is only a single timber. However, there is a group of four ceiling joists in Bedesman room 3 that were felled in AD

1234–59 which appear most likely to coincide with Bishop Grosseteste's residency but could possibly relate to the subsequent bishops, Henry of Lexington or Richard of Gravesend.

Late-fourteenth to mid-fifteenth century

Although it is documented that Bishop Burghersh undertook major redevelopment (Thornton 2009), including the remodelling of the bishops private accommodation (the Bede House range), no timbers were identified as dating to this period. There is little architectural or documentary evidence in relation to works undertaken in the later fourteenth century or early fifteenth century but it is believed that Bishop Alnwick remodelled the Bede House range (Thornton 2009) and a series of 25 timbers have been identified as having been felled in the late-fourteenth to mid-fifteenth centuries.

The earliest felling date range identified, AD 1388–1413, is for a single joist in the cupboard under the stairs adjacent to the porch and the latest felling date range identified, AD 1444–69, is for 10 timbers from the roof of the Great Chamber and Presence Chamber. Thus, some of these timbers clearly pre-date Bishop Alnwick, indicating at least limited works in the late-fourteenth and early fifteenth centuries, whilst others could be associated with Bishop Alnwick or just post-date his residency.

A number of timbers included within this group of late-fourteenth to mid-fifteenth timbers only have a *terminus post quem* date for felling, these being the single timber from the Presence Chamber niche (after AD 1420), as well as the two groups of timbers derived from Baltic imports, namely the two planks from the Bedeswoman room 2 door (felled after AD 1357) and the attic floorboards above the small chamber (felled after AD 1422). Although all could be felled significantly later than the *terminus post quem* this seems unlikely. The niche timber is a substantial timber and would have to have been trimmed very heavily, and hence derived from a very large tree, if it was to be associated with the later fifteenth- to early sixteenth-century felling episodes, whereas Baltic imports tend to be only relatively lightly trimmed to produce the relevant element, with the timbers within groups of imported material generally having outermost heartwood ring dates that are usually very similar (eg Groves 2004).

Later fifteenth – early sixteenth century

A series of 32 timbers have been identified as having been felled in the later fifteenth century to early sixteenth century, most of which appear likely to be associated with the major works that Thornton (2009) indicates were undertaken during the residencies of Bishop Russell and Bishop Smith to this Bede House range.

The earliest felling date range identified, AD 1476–1501, is for a principal rafter from the small chamber roof and the latest felling date ranges identified all span the late AD 1490s to early AD 1510s. These latter comprise a single tiebeam from the Great Chamber/Presence Chamber roof, four tiebeams from the Pentice, four timbers from the ceiling of Bedesman rooms 1 and 2, and three timbers from the partition wall between the Great Chamber and Presence Chamber. The tiebeam from the Great Chamber/Presence Chamber roof, truss 1, is notably slightly later than the other dated timbers from this roof (felled AD 1444–69), including the tiebeam from truss 2, and it is noticeable that neither of the principal rafters or the collar from truss 1 were successfully dated.

Again, a number of timbers included in this later fifteenth-century to early sixteenth-century group only have a *terminus post quem* date for felling, these being six samples from the stair treads up to the attic (felled after AD 1464), two planks from the door of Bedesman room 2 (felled after AD 1467), four planks from the door of Chapel/Bedeswoman room 1 (felled after AD 1482), four planks from the door of Bedesman room 1 (felled after AD 1484), and three planks from the door of Bedesman room 3 (felled after AD 1484). The stair treads, potentially derived from either a single tree or trees growing within a discrete area of woodland (see above), show high levels of similarity with the two long sequences derived from tiebeams in the Pentice (felled AD 1492–1517) and, thus, it seems likely that the stair treads were felled at a similar time. The planks from all four of these doors show a consistent level of cross-matching and include at least one possible same-tree derivation for three planks (LYB-H69 from Bedesman room 1/LYB-H78 and LYB-H79 from the Chapel/Bedeswoman room 1, *t*-values ranging from 9.8 to 11.3). This indicates the all thirteen dated planks from these four doors are likely to be coeval and the overall similarity in the dates of the outermost heartwood rings suggests that most are only likely to have lost a relatively small number of heartwood rings during conversion and hence, whilst these were felled after AD 1484, it seems likely that they were felled no later than in the early decades of the sixteenth century.

Early seventeenth – late-eighteenth century

The Lyddington estate was transferred to the Crown in AD 1547 and then subsequently granted to the Cecil family with the bishops private accommodation being converted to an almshouse in AD 1601 by Thomas Cecil (Thornton 2009). A number of timbers clearly relate to the ownership of Sir Thomas Cecil, 1st Earl of Exeter, the five dated timbers from the Chapel/Bedeswoman rooms partition walls and stair framing being felled in AD 1599–1621 and the two dated timbers (a post and a tiebeam) from the Pentice being felled in AD 1599–1624. These seven timbers cross-match consistently well and are likely to all have been felled at the same, or a very similar time, and probably relate to the conversion to an almshouse.

A series of twelve timbers have been dated to the eighteenth century during the ownership of the Bede House by Brownlow Cecil, 8th Earl of Exeter (died AD 1754), and his son Brownlow Cecil, 9th Earl of Exeter (died AD 1793). The six dated timbers from the east-end roof were felled in AD 1744, indicating works to the almshouses being undertaken during the ownership of the 8th Earl of Exeter, whereas the four dated posts from the Pentice were felled in AD 1765–90, indicating works to the almshouses during the ownership of the 9th Earl of Exeter. The remaining eighteenth-century timber is a wall plate from the porch dated as being felled after AD 1731. It is not possible to determine whether it is coeval with either of the other felling episodes identified but the fact that it cross-matches well with the posts from the Pentice suggests that it could also be related to the later eighteenth-century felling episode, although this is not proven.

Woodland Source

As may be seen from Tables 2, 4, 5, and 6, although site chronologies LYBHSQ01, LYBHSQ03, LYBHSQ04, and LYBHSQ05 have been compared with reference chronologies from every part of Britain, there is a tendency for the highest *t*-values (ie the greatest degrees of similarity) to be found with those from other sites in the surrounding areas, most notably Leicestershire and Northamptonshire. Although, of course, the precise woodland sources of the trees used at these reference sites are themselves not known, such matching would suggest most of the timber used at the Bede House was obtained from a similarly relatively local source.

The exception to this use of relatively local woodlands are the timbers represented by site chronology LYBHSQ02. As may be seen from Table 3, these are clearly of eastern Baltic origin, although is not possible to say exactly where due to the lack of a local network of reference data for the relevant regions.

The high level of cross-matching between various samples, furthermore, may be taken to indicate that the source trees for some timbers were growing close to each other in the same woodland and in some instances the level of similarity is such that some timbers may have been derived from the same tree. It is likely that at least some of the trees used for the trusses of the roof to the Great Chamber/Presence Chamber (LYB-H01 – LYB-H15) were growing close to each other, or at least in the same general woodland area, with a number of *t*-values in excess of 7 being produced between the samples, including a possible same-tree match between LYD-H04 and LYD-H07 which represent principal rafters. The east-end roof timbers (LYB-H16 – LYB-H22) show strong similarity with each other, with several of the principal rafters having *t*-values with several of the principal rafters having *t*-values in excess of 8. The ceiling joists to Bedesman room 3 (LYB-H39 – LYB-H42) also cross-match well with each other (*t*-values ranging from 5.1 to 10.8, although with one exception). The stair treads (LYB-H54 – LYB-H59) produce *t*-values ranging from 6.6 to 14.7 which is suggestive of them being derived from the same woodland area with some elements potentially being derived from the same-tree. Given that each tread is a relatively short length of timber, a number of pieces could be taken from a single tree. Three of the joists (LYD-H65 – LYD-H67) from the cupboard under the stairs adjacent to the porch show strong similarity (*t*-values ranging from 6.6 to 9.4). The planks of English origin from the doors of Bedesman rooms 1, 2, and 4 and the Chapel/Bedeswoman room 1 show good similarity with many *t*-values in excess of 5, including possible same-tree matches between LYB-H69, LYB-H78, and LYB-H79. There are also a number of pairs of samples of possible same-tree derivation, including two of the dated Baltic origin floorboards, LYB-H83 and LYB-H87 (*t*-value = 10.9) and two posts (LYB-H91 and LYB-H92) from the Pentice which match with a *t*-value of 11.5.

Interestingly, with the exception of two of the doors, no possible same-tree derivations have been identified between areas. There is, however, as can be seen from the above, a coherence of woodland source within areas, or groups within areas, which is apparent throughout all of the periods of felling identified.

Undated timbers

Nineteen of the 100 measured samples remain ungrouped and undated. With some of these undated samples, though they have sufficient for reliable dating, the ring numbers are towards the lower end of the usual acceptable limits. Other undated samples, however, have higher ring numbers, the longest undated sample, LYB-H24, having 100 rings. None of these samples show any particular problems such as compression or distortion which might affect their growth pattern. It is, however, a common feature in tree-ring analysis to find that some samples remain undated for no apparent reason. In this respect, the analysis at the Bede House has been successful in dating 81 out of the 100 samples obtained, thus, achieving the broadly expected success rate of 70–80% for historic standing buildings.

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TABLES

Table 1: Details of tree-ring samples from The Bede House, Lyddington, Rutland

Sample number	Sample location (trusses/frames/beams etc usually numbered from N–S or E–W)	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	Great Chamber/Presence Chamber roof					
LYB-H01	Collar, truss 3	66	6	1361	1420	1426
LYB-H02	North archbrace, truss 3	56	no h/s	1372	------	1427
LYB-H03	South principal rafter, truss 4	55	h/s	1378	1432	1432
LYB-H04	North principal rafter, truss 4	53	h/s	1383	1435	1435
LYB-H05	South archbrace, truss 4	54	no h/s	------	------	------
LYB-H06	North archbrace, truss 4	55	no h/s	1374	------	1428
LYB-H07	South principal rafter, truss 5	54	h/s	1382	1435	1435
LYB-H08	North principal rafter, truss 5	52	h/s	------	------	------
LYB-H09	South archbrace, truss 5	54	no h/s	------	------	------
LYB-H10	Collar, truss 6	57	h/s	------	------	------
LYB-H11	South principal rafter, truss 6	50	h/s	1384	1433	1433
LYB-H12	North principal rafter, truss 6	48	h/s	1383	1430	1430
LYB-H13	Collar, truss 7 (westernmost truss)	69	h/s	1352	1420	1420
LYB-H14	Tiebeam, truss 1 (easternmost truss)	91	h/s	1386	1476	1476
LYB-H15	Tiebeam, truss 2	103	h/s	1324	1426	1426
	East-end roof					
LYB-H16	Collar, truss 1 (east truss)	63	17C	1682	1727	1744
LYB-H17	South principal rafter, truss 1	67	13c	1671	1724	1737
LYB-H18	North principal rafter, truss 1	84	21C	1661	1723	1744
LYB-H19	North purlin, truss 1–2	54	8	1682	1727	1735
LYB-H20	Collar, truss 2	64	20C	1681	1724	1744
LYB-H21	South principal rafter, truss 2	87	6	1645	1725	1731
LYB-H22	North principal rafter, truss 2	89	18C	1656	1726	1744
LYB-H23	South common rafter 1, bay 3	nm	---	------	------	------

Table 1: continued

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	Presence Chamber ceiling					
LYB-H24	Ceiling joist 1 (from south)	100	h/s	------	------	------
LYB-H25	Ceiling joist 2	82	h/s	------	------	------
LYB-H26	Ceiling joist 3	54	h/s	------	------	------
LYB-H27	Ceiling joist 4	104	h/s	1284	1387	1387
LYB-H28	Ceiling joist 5	65	h/s	------	------	------
	Bedesman room ceilings					
LYB-H29	Main north-south ceiling beam between rooms 1 & 2	68	h/s	1414	1481	1481
LYB-H30	Ceiling joist 3 (from south), room 2, bay 1	94	h/s	1382	1475	1475
LYB-H31	Ceiling joist 5, room 2, bay 1	87	no h/s	1367	------	1453
LYB-H32	Ceiling joist 8, room 2, bay 1	nm	---	------	------	------
LYB-H33	Main east-west ceiling beam, rooms 1 & 2	nm	---	------	------	------
LYB-H34	Ceiling joist 1, room 2, bay 2	73	h/s	------	------	------
LYB-H35	Ceiling joist 3, room 2,bay 2	62	no h/s	1381	------	1442
LYB-H36	Ceiling joist 5, room 2, bay 2	nm	---	------	------	------
LYB-H37	Ceiling joist 6, room 2, bay 2	66	no h/s	------	------	------
LYB-H38	Ceiling joist 3, room 1 / 2 lobby	83	h/s	------	------	------
LYB-H39	Ceiling joist 1 (from south), room 4	90	no h/s	1116	------	1205
LYB-H40	Ceiling joist 2, room 4	102	h/s	1114	1215	1215
LYB-H41	Ceiling joist 3, room 4	137	h/s	1085	1221	1221
LYB-H42	Ceiling joist 4, room 4	99	h/s	1123	1221	1221
LYB-H43	Ceiling joist 5, room 4	56	h/s	------	------	------
	West roof over small inner chamber					
LYB-H44	Wall post	nm	---	------	------	------
LYB-H45	Cut-off tiebeam	nm	---	------	------	------
LYB-H46	Principal rafter	120	h/s	1342	1461	1461
LYB-H47	Wall plate	nm	---	------	------	------

Table 1: continued

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	Pentice					
LYB-H48	Tiebeam 1 (easternmost)	102	no h/s	1319	------	1420
LYB-H49	Tiebeam 2	59	h/s	1528	1586	1586
LYB-H50	Tiebeam 3	58	h/s	1415	1472	1472
LYB-H51	Tiebeam 4	nm	---	------	------	------
LYB-H52	Tiebeam 5	76	h/s	1406	1481	1481
LYB-H53	Tiebeam 6	174	no h/s	1290	------	1463
	Stair treads up to attic					
LYB-H54	Tread 2 (from bottom)	135	no h/s	1269	------	1403
LYB-H55	Tread 3	149	no h/s	1270	------	1418
LYB-H56	Tread 4	126	no h/s	1245	------	1370
LYB-H57	Tread 5	155	no h/s	1286	------	1440
LYB-H58	Tread 6	133	no h/s	1300	------	1432
LYB-H59	Tread 7	129	no h/s	1321	------	1449
	Great Chamber/Presence Chamber partition wall					
LYB-H60	Central main post	94	h/s	1319	1412	1412
LYB-H61	South cross-rail	101	15	1394	1479	1494
LYB-H62	North cross-rail	62	h/s	1406	1467	1467
LYB-H63	Upper stud 4 (from north)	90	5	1389	1473	1478
	Cupboard under stairs adjacent to porch					
LYB-H64	Joist 1 (easternmost)	94	h/s	1280	1373	1373
LYB-H65	Joist 2	90	h/s	1314	1403	1403
LYB-H66	Joist 3	94	h/s	1313	1406	1406
LYB-H67	Joist 4	73	h/s	1338	1410	1410

Table 1: continued

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	Doors					
LYB-H68	Bedesman room1, plank 1	76	no h/s	1383	------	1458
LYB-H69	Bedesman room1, plank 2	150	no h/s	1318	------	1467
LYB-H70	Bedesman room1, plank 3	103	no h/s	1302	------	1404
LYB-H71	Bedesman room1, plank 4	99	no h/s	1371	------	1469
LYB-H72	Bedesman room 2, plank 1	73	no h/s	1356	------	1428
LYB-H73	Bedesman room 2, plank 2	115	no h/s	1338	------	1452
LYB-H74	Bedesman room 4, plank 1	189	no h/s	1281	------	1469
LYB-H75	Bedesman room 4, plank 2	95	no h/s	1364	------	1458
LYB-H76	Bedesman room 4, plank 3	80	no h/s	1344	------	1423
LYB-H77	Chapel/Bedeswoman room 1, plank 1	116	no h/s	1352	------	1467
LYB-H78	Chapel/Bedeswoman room 1, plank 2	118	no h/s	1332	------	1449
LYB-H79	Chapel/Bedeswoman room 1, plank 3	137	no h/s	1327	------	1463
LYB-H80	Chapel/Bedeswoman room 1, plank 4	96	no h/s	1363	------	1458
LYB-H81	Bedeswoman room 2 (adjacent to stair), plank 1	144	no h/s	1206	------	1349
LYB-H82	Bedeswoman room 2, plank 2	121	no h/s	1171	------	1291
	Attic floorboards above inner small chamber					
LYB-H83	Floor board 1	288	no h/s	1119	------	1406
LYB-H84	Floor board 2	147	no h/s	1245	------	1391
LYB-H85	Floor board 3	160	no h/s	1255	------	1414
LYB-H86	Floor board 4	85	no h/s	1110	------	1194
LYB-H87	Floor board 5	284	no h/s	1124	------	1407
LYB-H88	Floor board 6	132	no h/s	1268	------	1399

Table 1: continued

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	Pentice (additional samples)					
LYB-H89	Rail, posts 1–2	nm	---	------	------	------
LYB-H90	Rail, posts 2–3	55	no h/s	------	------	------
LYB-H91	Post 5	55	h/s	1697	1751	1751
LYB-H92	Post 6, upper part	54	h/s	1699	1752	1752
LYB-H93	Post 8, upper part	76	h/s	1507	1582	1582
LYB-H94	Post 10, upper part	54	h/s	1694	1747	1747
LYB-H95	Post 11, upper part (westernmost)	66	4	1688	1749	1753
	Porch					
LYB-H96	West wall plate	94	no h/s	1623	------	1716
LYB-H97	West wall post	nm	---	------	------	------
	Great Chamber roof (additional samples)					
LYB-H98	South principal rafter, truss 1	54	h/s	------	------	------
LYB-H99	North principal rafter, truss 1	55	h/s	------	------	------
LYB-H100	Collar, truss 1	52	h/s	------	------	------
	Attic partition to Great Chamber/Presence Chamber					
LYB-H101	Stud post	74	h/s	------	------	------
LYB-H102	Door jamb (hanging)	nm	---	------	------	------
LYB-H103	Top rail	61	h/s	------	------	------
	Chapel/Bedeswoman rooms partition walls/stair framing					
LYB-H104	Stair head closing jamb	54	h/s	1527	1580	1580
LYB-H105	Stair head hanging jamb	nm	---	------	------	------
LYB-H106	Stair support post	nm	---	------	------	------
LYB-H107	Newel post	56	10	1539	1584	1594
LYB-H108	Under-stair rail	76	h/s	------	------	------

Table 1: continued

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	Chapel/Bedeswoman rooms partition walls/stair framing					
LYB-H109	Party wall, north cross-rail	57	no h/s	1498	------	1554
LYB-H110	Party wall, south cross-rail	69	17	1530	1581	1598
LYB-H111	Corridor rail/door head	59	h/s	1522	1580	1580
	Presence Chamber niche (cupboard)					
LYB-H112	East–west beam in niche to south wall	115	no h/s	1291	------	1405
	Chamber (shop) ceiling					
LYB-H113	East – west ceiling beam	65	h/s	1107	1171	1171

nm = sample not measured
h/s = the heartwood/sapwood boundary ring is the last ring on the sample
c = complete sapwood is found on the timber, but all or part has been lost from the sample in coring
C= complete sapwood is retained on the sample, but in this instance the outermost rings of CPS-B14 cannot be reliably measured

Table 2: Results of the cross-matching of site sequence LYBHSQ01 and some relevant reference chronologies when the first-ring date is AD 1085 and the last-ring date is AD 1221

Reference chronology	Span of chronology	*t*-value	Reference
Billingsgate (BIG82), London	AD 611–1243	9.5	(Tyers and Hillam pers comm)
Nevill Holt, Leicestershire	AD 1274–1534	8.8	(Arnold *et al* 2008a)
Manor House, Medbourne, Leicestershire	AD 1068–1287	8.0	(Howard *et al* 1999)
Southview Cottage, Norwell, Nottinghamshire	AD 1132–1306	7.7	(Hurford *et al* 2010)
Angel Choir, Lincoln Cathedral, Lincolnshire	AD 904–1257	7.5	(Laxton and Litton 1988)
Blackfriars Priory, Gloucester, Gloucestershire	AD 1024–1237	7.4	(Howard *et al* 2002)
7 Buttermarket, Thame, Oxfordshire	AD 1161–1289	7.4	(Howard *et al* 1993)
The Gatehouse, Polesworth Abbey, Warwickshire	AD 1095–1342	7.1	(Arnold and Howard 2007a)

Table 3: Results of the cross-matching of site sequence LYBHSQ02 and some relevant reference chronologies when the first-ring date is AD 1110 and the last-ring date is AD 1414

Reference chronology	Span of chronology	*t*-value	Reference
East Pomerania, Poland	AD 996–1985	8.7	(Wazny and Eckstein 1991)
Niedersaxon Nord, Germany	AD 915–1873	6.1	(Leuschener pers comm)
Neils Hemmingsensgade barrel, Copenhagen, Denmark	AD 1124–1399	12.0	(Daly 2000)
Copper wreck group 4, Gdañsk, Poland	AD 1094–1402	10.3	(Bonde and Wazny pers comm)
Vejby Skip Hanseatic cog, Denmark	AD 1109–1370	7.5	(Bonde and Jensen 1995)
Southwark boat planks (GAS88), London	AD 1052–1370	12.9	(Tyers 1996a)
Magistrates Court coffins, Hull, East Yorkshire	AD 1078–1369	11.7	(Tyers 1998)
Chapel Lane Staith boat planks, Hull, East Yorkshire	AD 1110–1393	10.7	(Tyers 2000)
St Helen's Church, Abingdon, Oxfordshire	AD 1117–1379	10.0	(Howard *et al* 1992)
St Lawrence's Church, Little Waddingfield, Suffolk	AD 1131–1339	9.7	(Bridge pers comm)
Thornham Parva retable, Suffolk	AD 1053–1309	8.8	(Tyers 2003)
Tadlow Granary Cambridgeshire	AD 1140–1406	8.4	(Laxton *et al* 1984)
The Guildhall, Hadleigh, Suffolk	AD 1157–1431	8.0	(Howard *et al* 1990 unpubl)

Table 4: Results of the cross-matching of site sequence LYBHSQ03 and some relevant reference chronologies when the first-ring date is AD 1245 and the last-ring date is AD 1494

Reference chronology	Span of chronology	*t*-value	Reference
Halesowen Abbey, Dudley, West Midlands	AD 1310–1535	12.1	(Arnold and Howard 2008a)
Leicester Castle, Leicester, Leicestershire	AD 1353–1482	10.5	(Laxton *et al* 1984 unpubl)
Cathedral Barn, Hereford, Herefordshire	AD 1359–1491	10.1	(Tyers 1996b)
Ulverscroft Priory, Charnwood, Leicestershire	AD 1219–1463	9.9	(Arnold *et al* 2008b)
Combermere Abbey, Combermere, Cheshire	AD 1363–1564	9.8	(Howard *et al* 2003)
Lower Brockhampton Manor, Brockhampton, Herefordshire	AD 1304–1543	9.8	(Arnold and Howard 2014 unpubl)
Apethorpe Hall, Apethorpe, Northamptonshire	AD 1292–1740	9.7	(Arnold *et al* 2008c)
St Leonard's Church, Apethorpe, Northamptonshire	AD 1211–1403	8.9	(Arnold and Howard 2008b)

Table 5: Results of the cross-matching of site sequence LYBHSQ04 and some relevant reference chronologies when the first-ring date is AD 1498 and the last-ring date is AD 1598

Reference chronology	Span of chronology	*t*-value	Reference
Apethorpe Hall, Apethorpe, Northamptonshire	AD 1292–1740	11.3	(Arnold *et al* 2008c)
Flore's House, Oakham, Rutland	AD 1173–1392	11.1	(Hurford *et al* 2008)
Church of St Nicholas, Bringhurst, Leicestershire	AD 1502–1687	8.7	(Arnold *et al* 2005)
St Leonard's Church, Apethorpe, Northamptonshire	AD 1211–1403	8.6	(Arnold and Howard 2008b)
Cressing Temple farmhouse, Essex	AD 1514–1608	8.1	(Tyers 1995)
Manor Farm, Stanton St John, Oxfordshire	AD 1480–1646	7.9	(Miles and Worthington 1998)
Moyns Park, Birdbrook, Essex	AD 1431–1606	7.9	(Tyers 1999)
Church of St Andrew, Welham, Leicestershire	AD 1443–1633	7.8	(Arnold *et al* 2005)

Table 6: Results of the cross-matching of site sequence LYBHSQ05 and some relevant reference chronologies when the first-ring date is AD 1623 and the last-ring date is AD 1753

Reference chronology	Span of chronology	*t*-value	Reference
Apethorpe Hall, Apethorpe, Northamptonshire	AD 1292–1740	9.2	(Arnold *et al* 2008c)
Stoneleigh Abbey, Stoneleigh, Warwickshire	AD 1646–1813	9.0	(Howard *et al* 2000)
Sarehole Mill, Hall Green, Birmingham	AD 1677–1767	8.6	(Howard 2008 unpubl)
Church Farm, Bringhurst, Leicestershire	AD 1664–1781	8.4	(Groves *et al* 2004)
Bingham, Nottinghamshire	AD 1445–1752	8.3	(Arnold and Howard 2013 unpubl)
Quenby Hall, Quenby Leicestershire	AD 1648–1765	8.0	(Arnold *et al* 2008a)
Green's Mill, Sneinton, Nottingham, Nottinghamshire	AD 1664–1787	7.9	(Laxton *et al* 1982)
The Gatehouse, Kenilworth Castle, Warwickshire	AD 1623–1727	7.4	(Arnold and Howard 2007b)

FIGURES

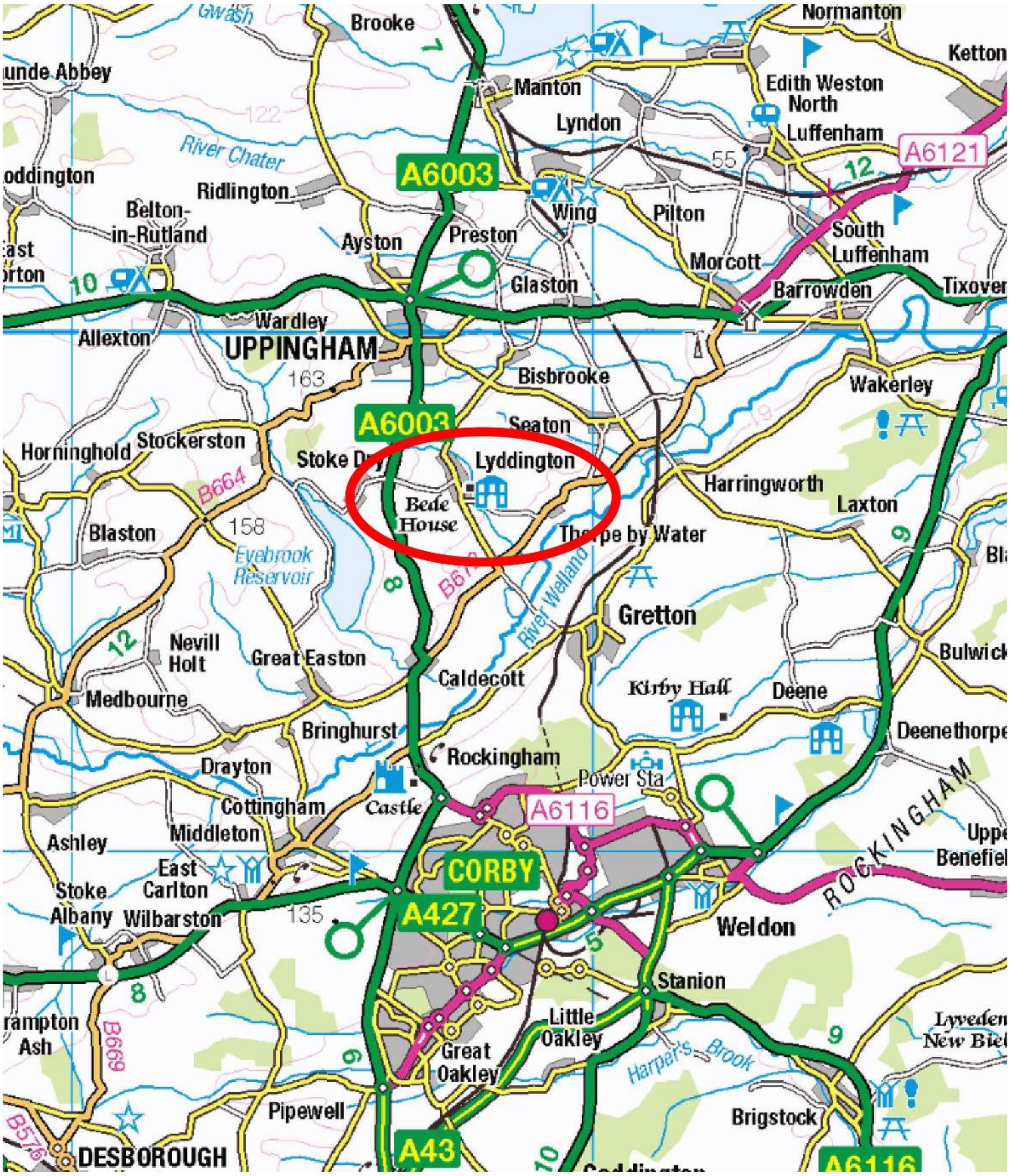

Figure 1a: Map to show the general location of Lyddington © Crown Copyright and database right 2018. All rights reserved. Ordnance Survey Licence number 100024900

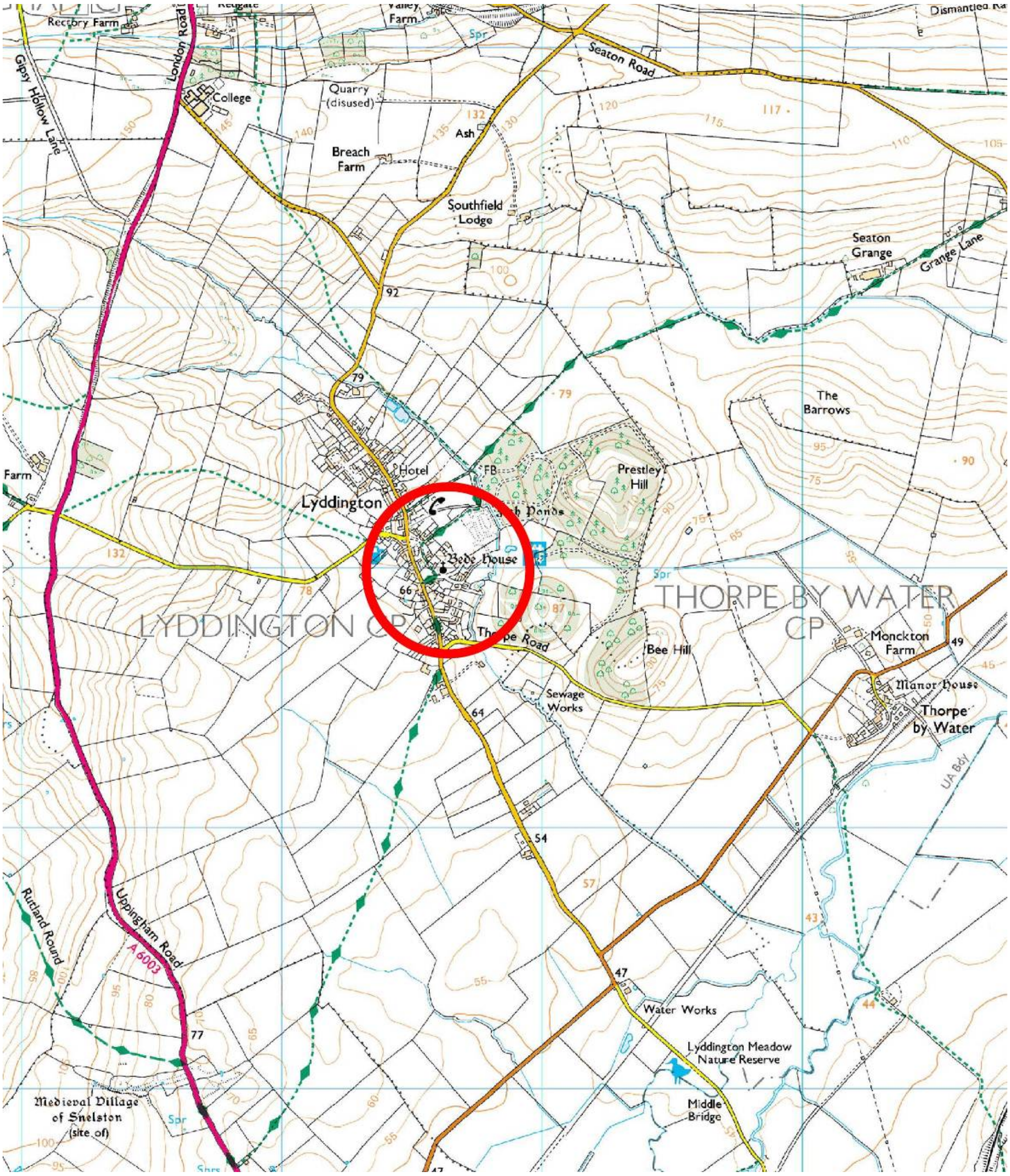

Figure 1b: Map to show the general location of the Bede House, Lyddington © Crown Copyright and database right 2018. All rights reserved. Ordnance Survey Licence number 100024900

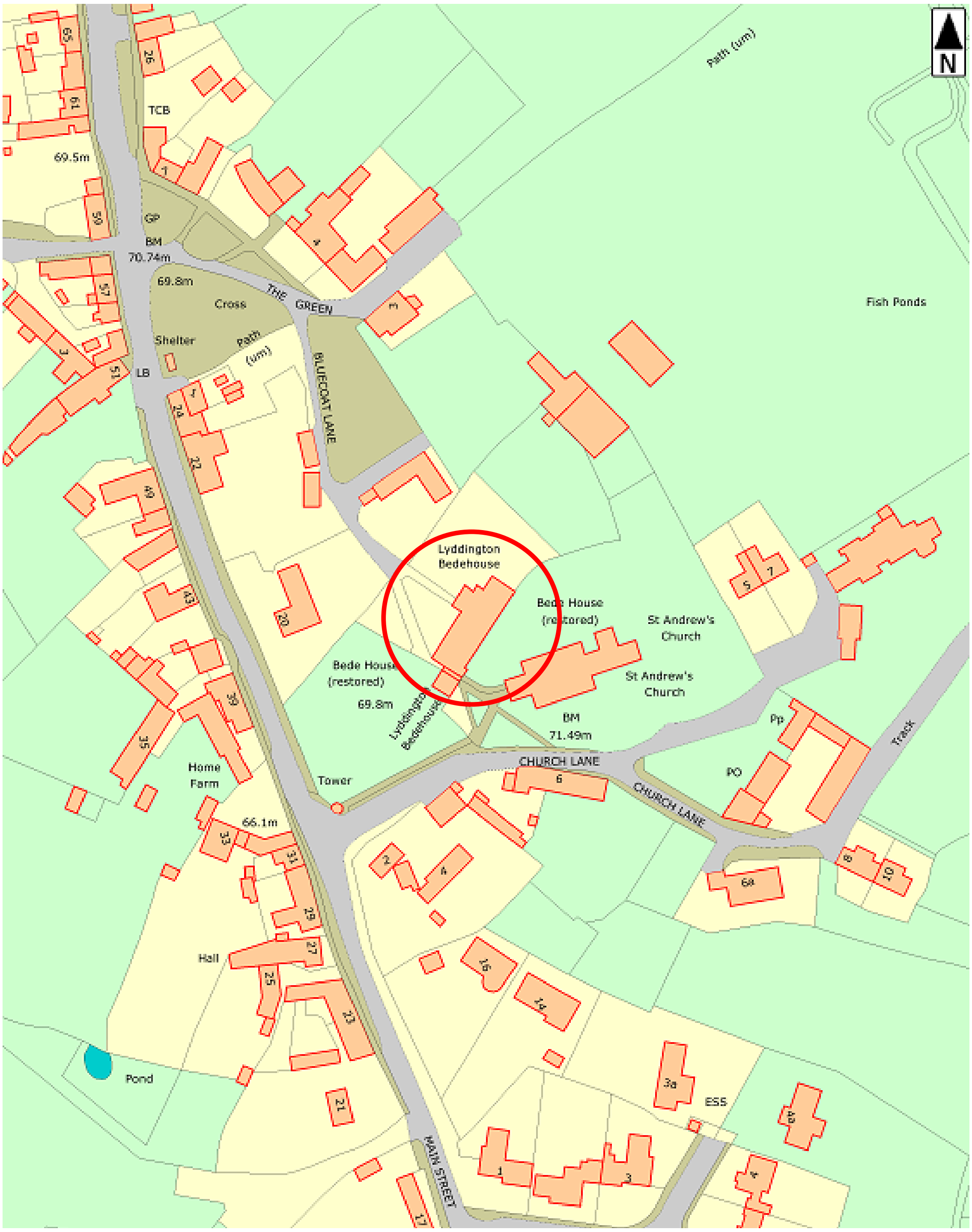

Figure 1c: Map to show the detailed location of the Bede House, Lyddington © Crown Copyright and database right 2018. All rights reserved. Ordnance Survey Licence number 100024900

Figure 2a/b: The Pentice to the north wall of the Bede House (top) and the Great Chamber, with Presence Chamber and small chamber beyond (bottom) (photographs Robert Howard)

Figure 3a/b: The roof above the Great Chamber looking east (top) and the roof at the east end of the Bede House (bottom) (photographs Robert Howard)

Figure 4a/b: Examples of the wooden doors to the Chapel/Bedeswoman rooms landing (L) and Great Chamber (R) (top) and to Bedesman room 5 (bottom) (photographs Robert Howard)

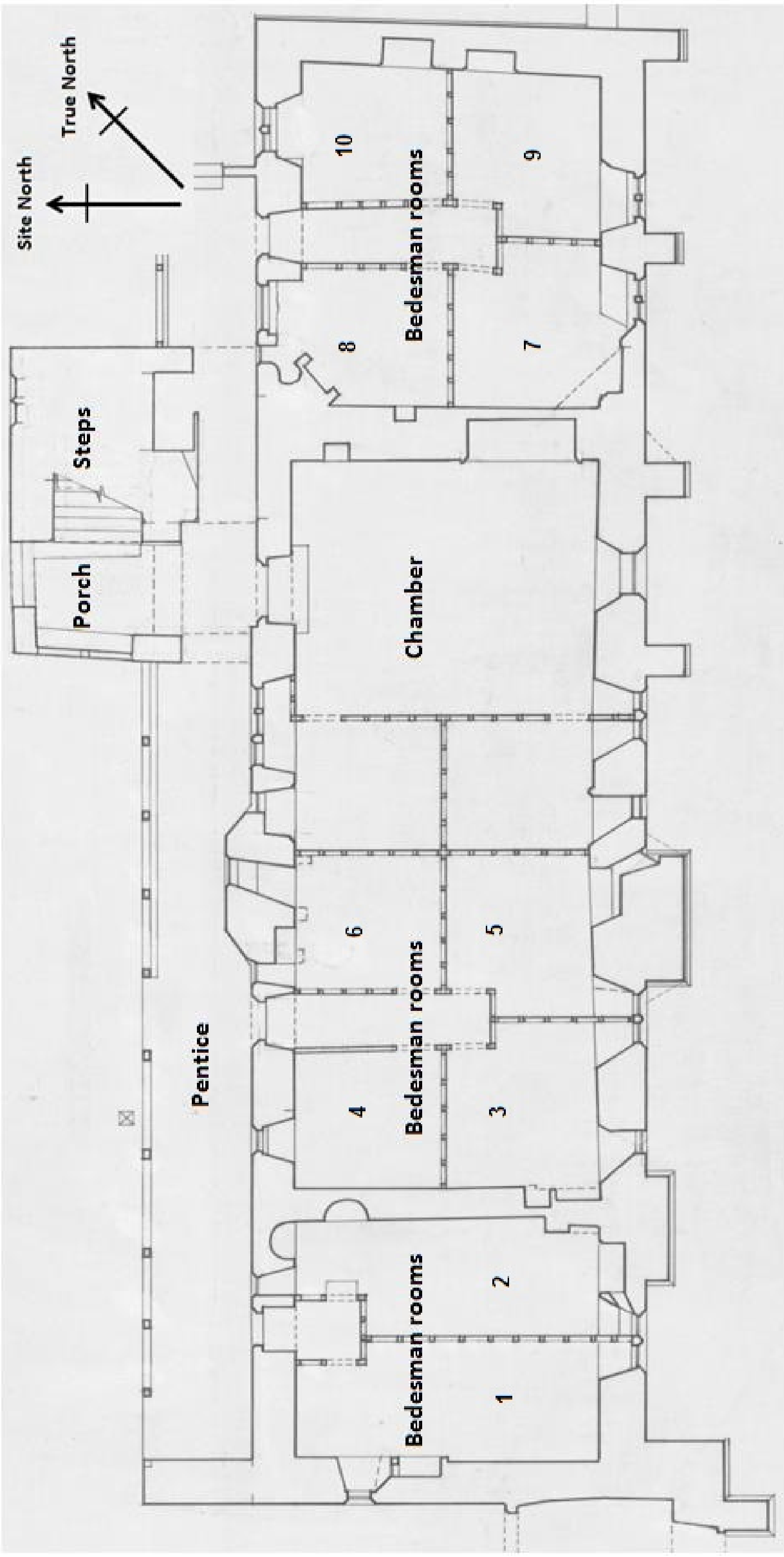

Figure 5a: Ground-floor plan of the Bede House (after HBMC 1986)

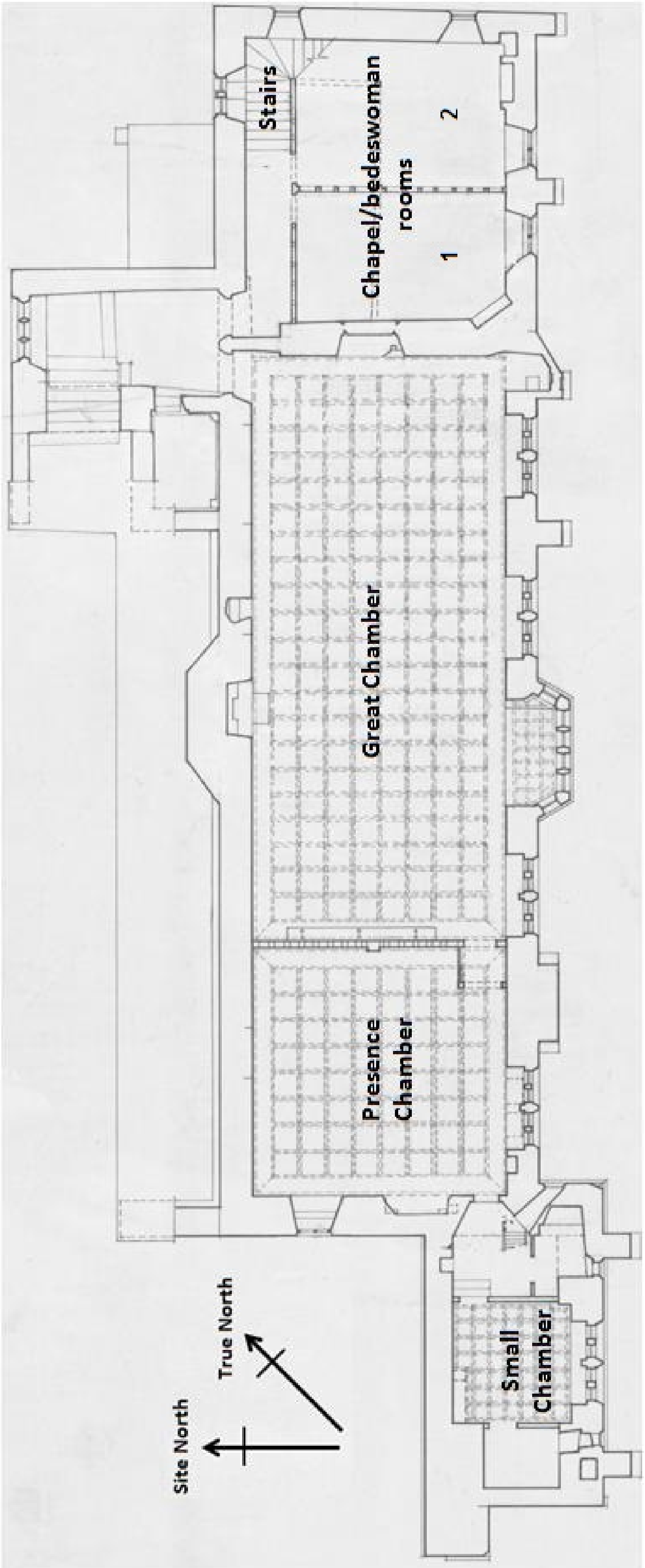

Figure 5b: First-floor plan of the Bede House (after HBMC 1986)

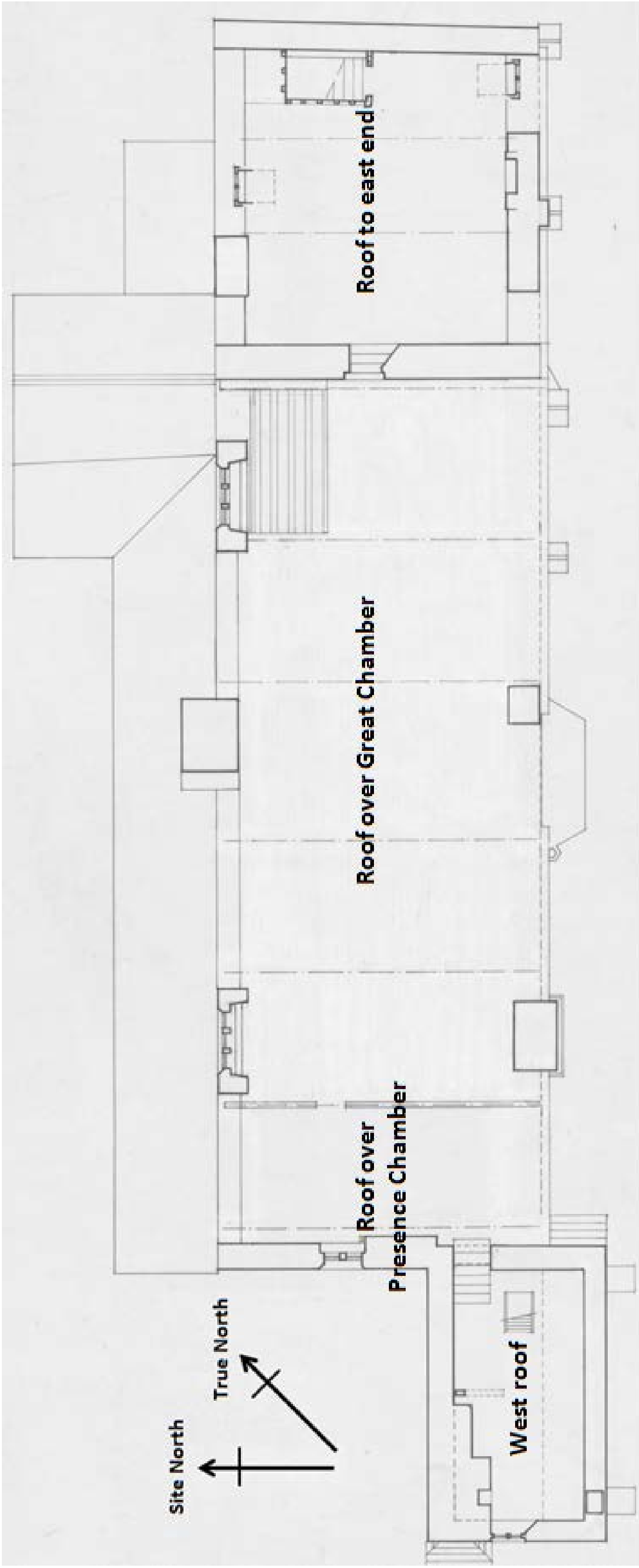

Figure 5c: Second-floor plan of the Bede House (after HBMC 1986)

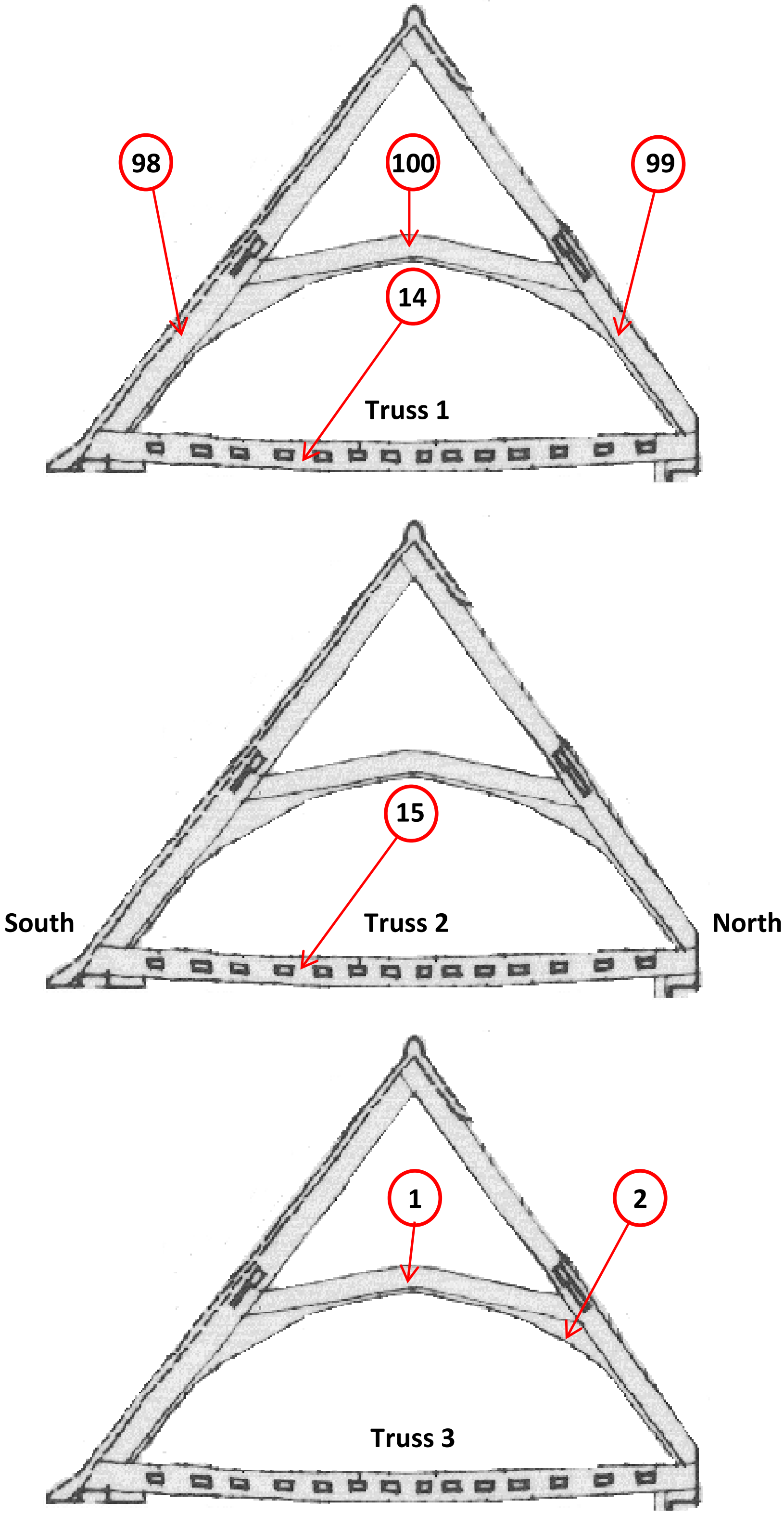

Figure 6a–c: Roof trusses above the Great Chamber and Presence Chamber to locate sampled timbers (after Ministry of Works Ancient Monuments Branch 1954)

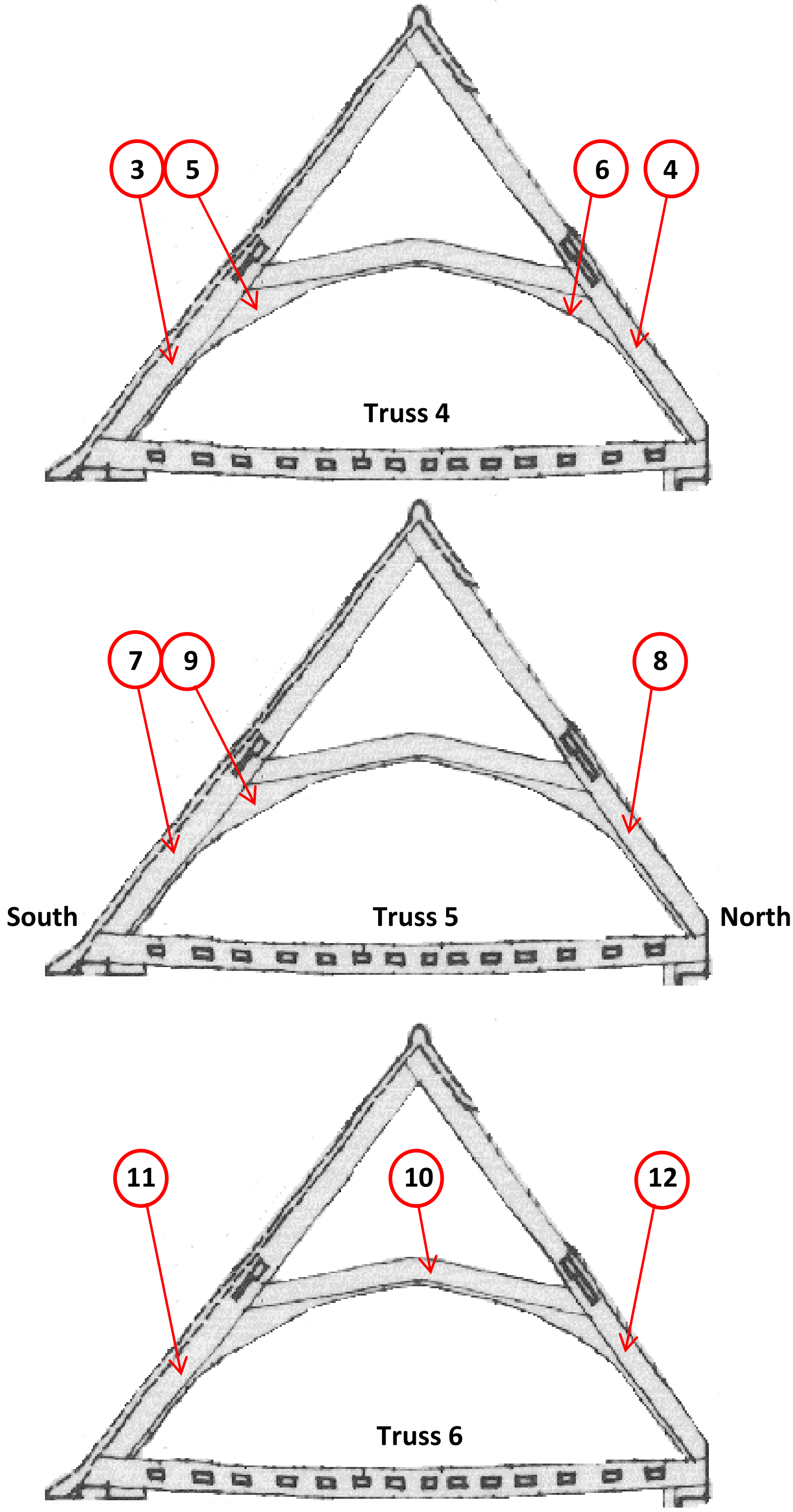

Figure 6d–f: Roof trusses above the Great Chamber and Presence Chamber to locate sampled timbers (after Ministry of Works Ancient Monuments Branch 1954)

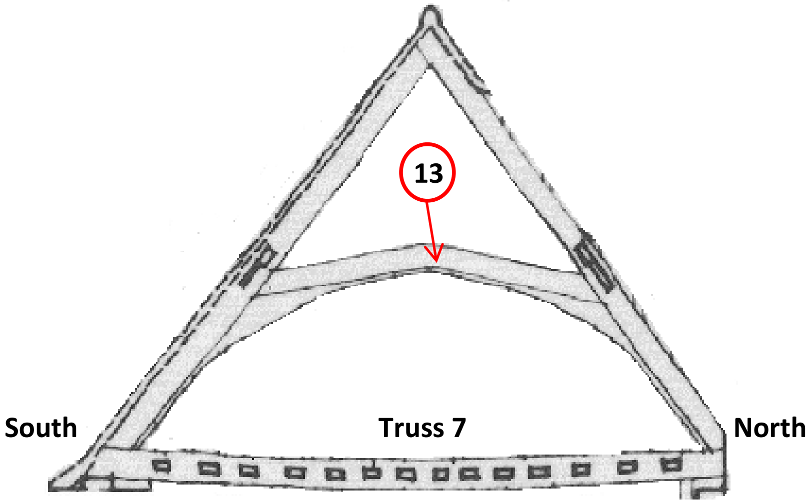

Figure 6g: Roof truss above the Great Chamber and Presence Chamber to locate sampled timbers (after Ministry of Works Ancient Monuments Branch 1954)

Figure 7a/b: Sections through the east-end roof to locate sampled timbers (after Ministry of Works Ancient Monuments Branch 1954)

Figure 8: Plan at attic-floor level to locate sampled ceiling timbers (after HBMC 1986)

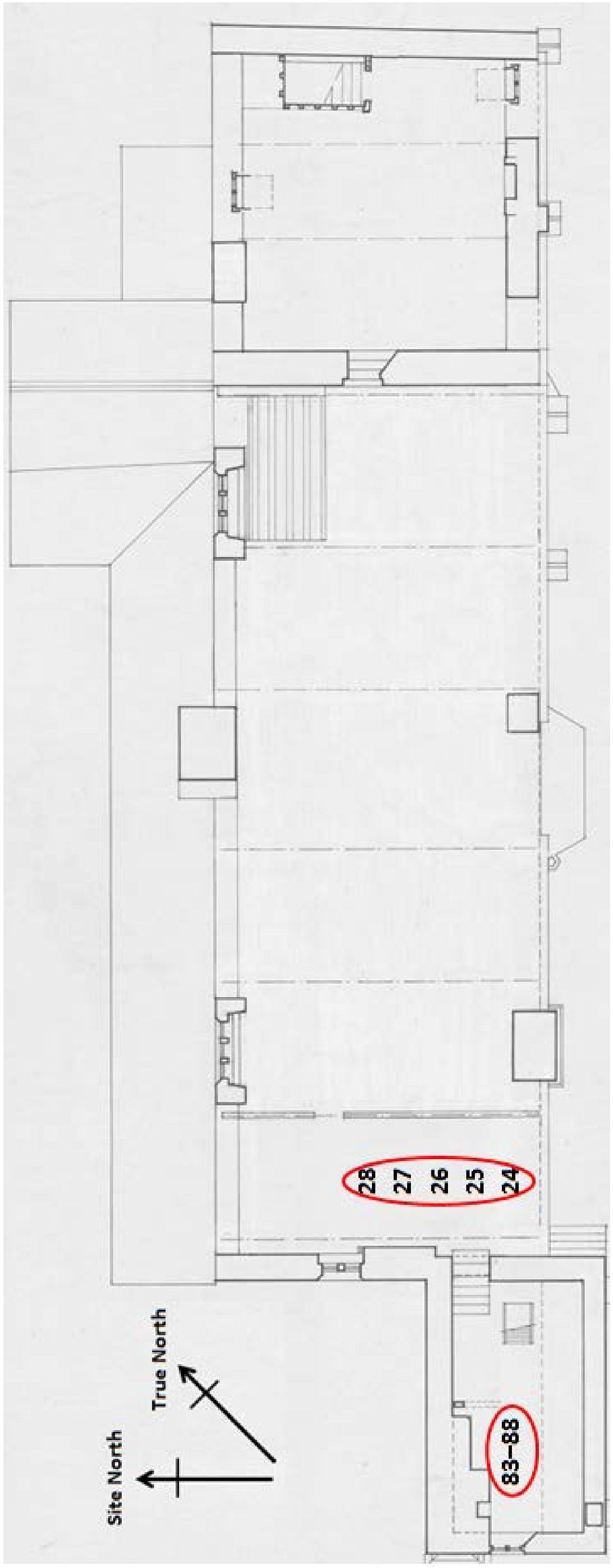

Figure 8: Plan at attic-floor level to locate sampled ceiling timbers (after HBMC 1986)

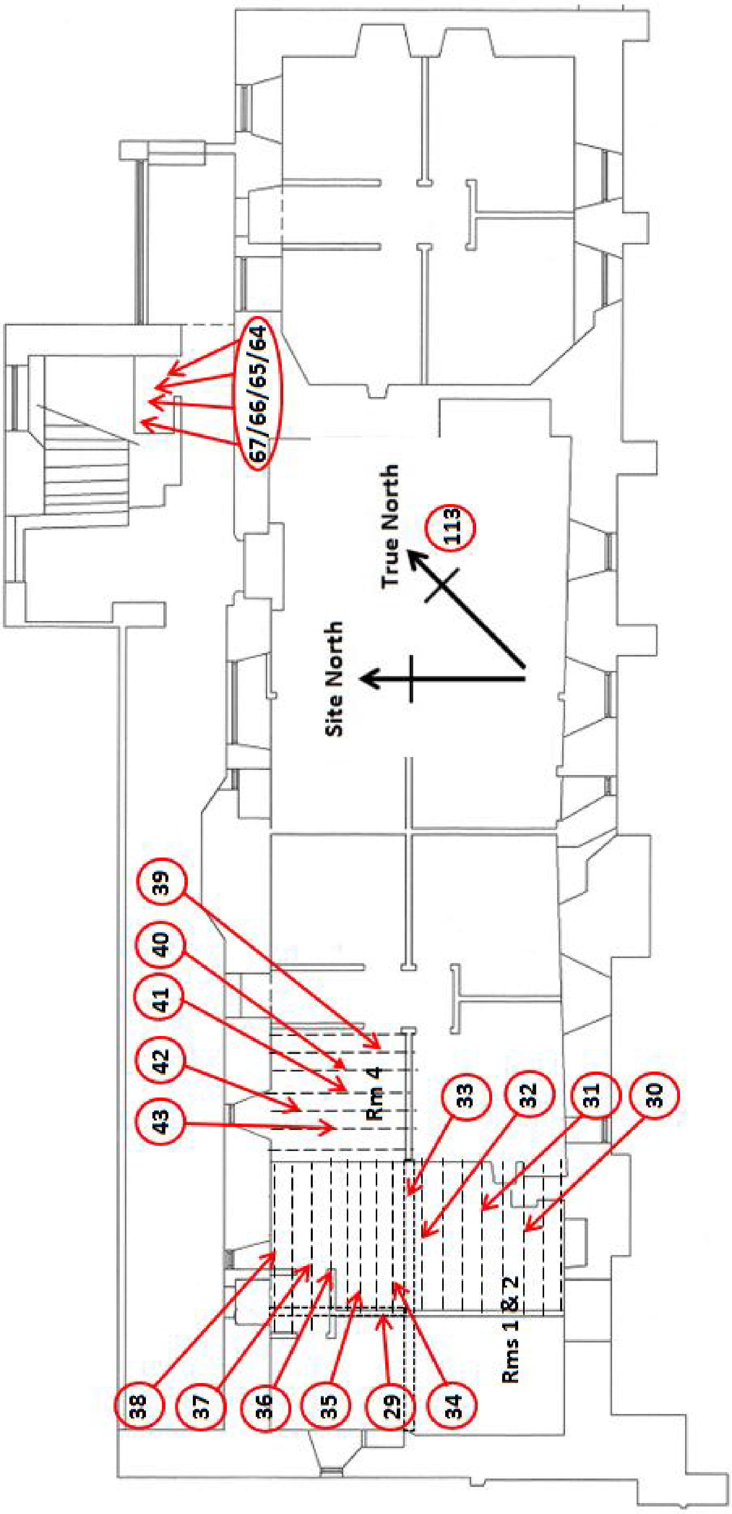

Figure 9: Ground-floor plan to locate samples from the Bedesman rooms and the under-stair cupboard (after HBMC 1986)

Figure 10: View of the west-end roof above the small chamber to locate sampled timbers (photograph Robert Howard)

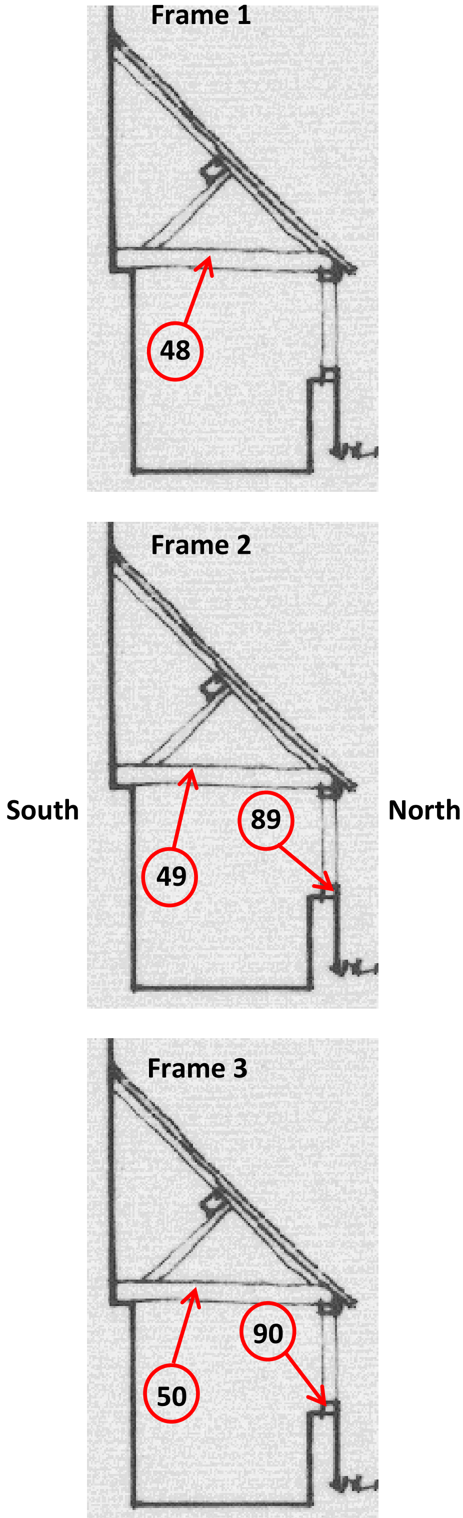

Figure 11a–c: Section through the Pentice to locate sampled timbers (after Ministry of Works Ancient Monuments Branch 1954)

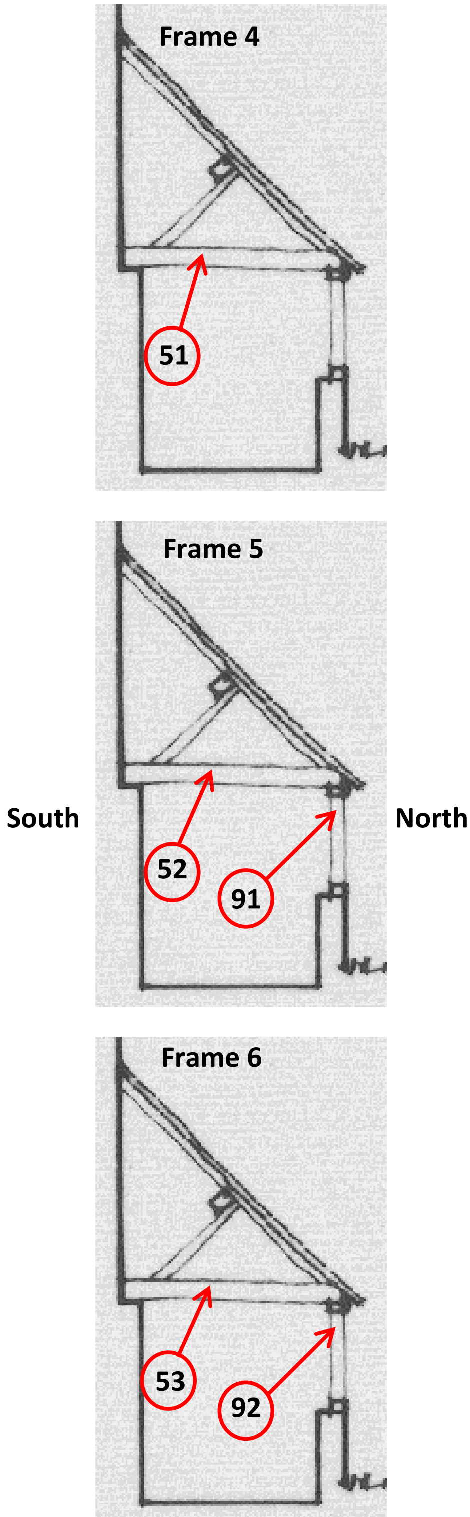

Figure 11d–f: Section through the Pentice to locate sampled timbers (after Ministry of Works Ancient Monuments Branch 1954)

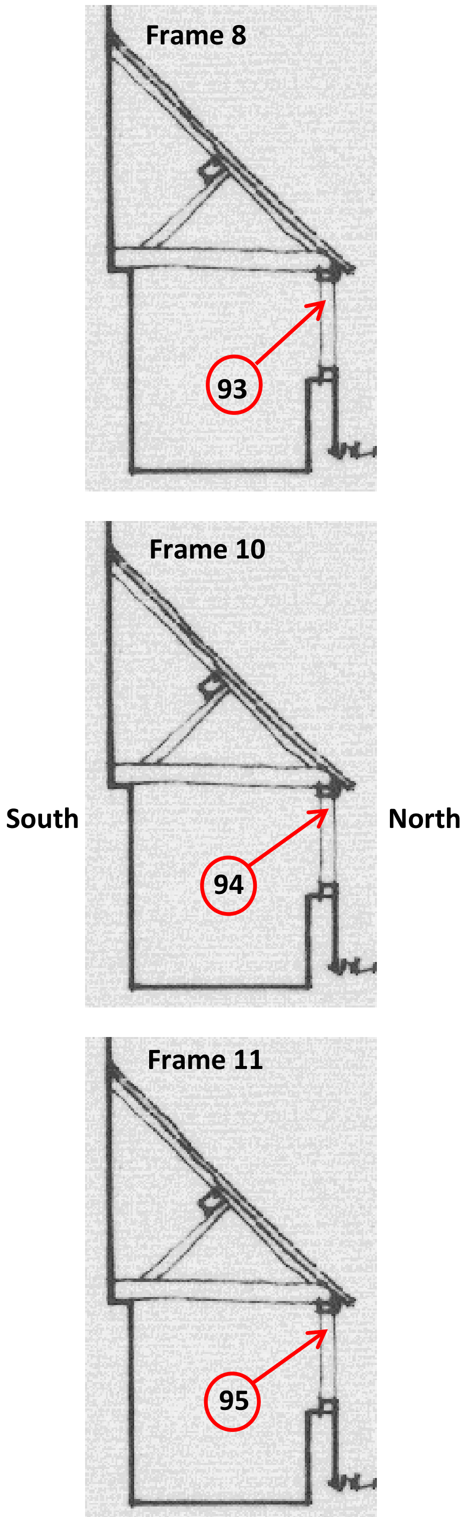

Figure 11g–i: Section through the Pentice to locate sampled timbers (after Ministry of Works Ancient Monuments Branch 1954)

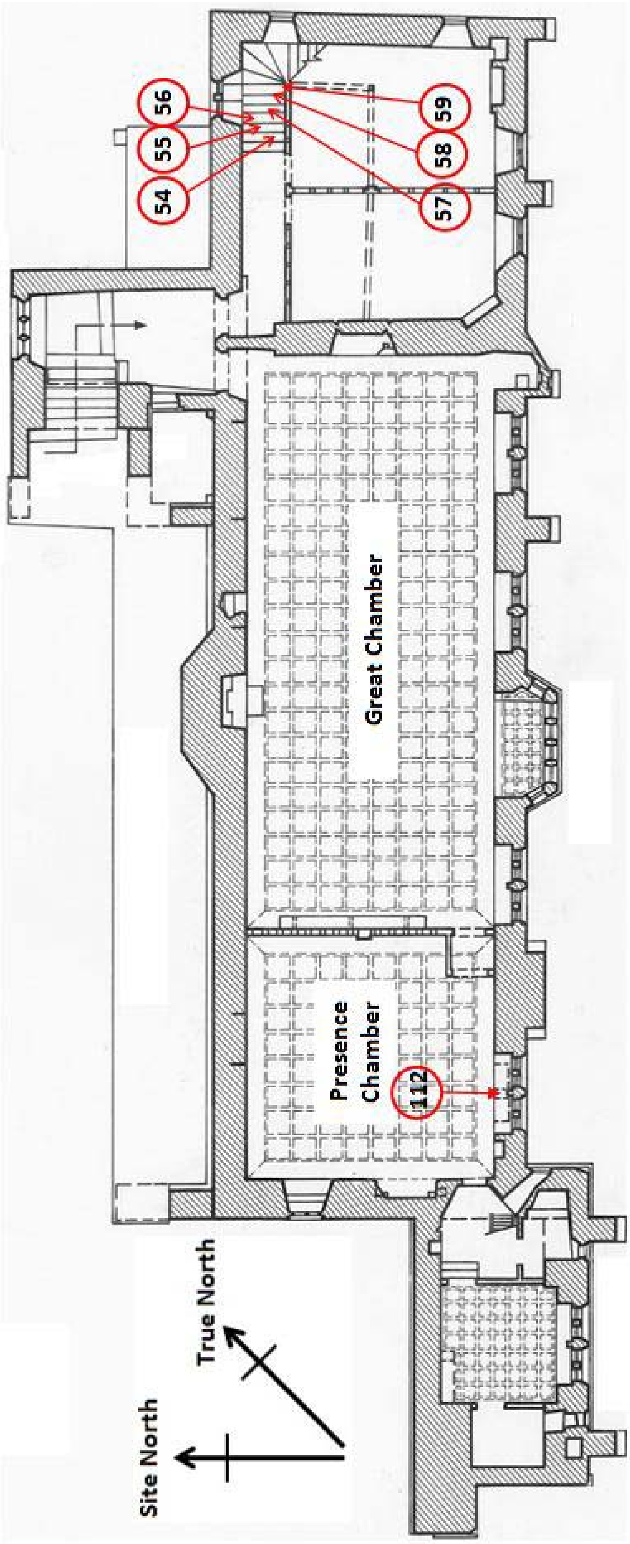

Figure 12: Plan to locate stair tread samples (after HBMC 1986)

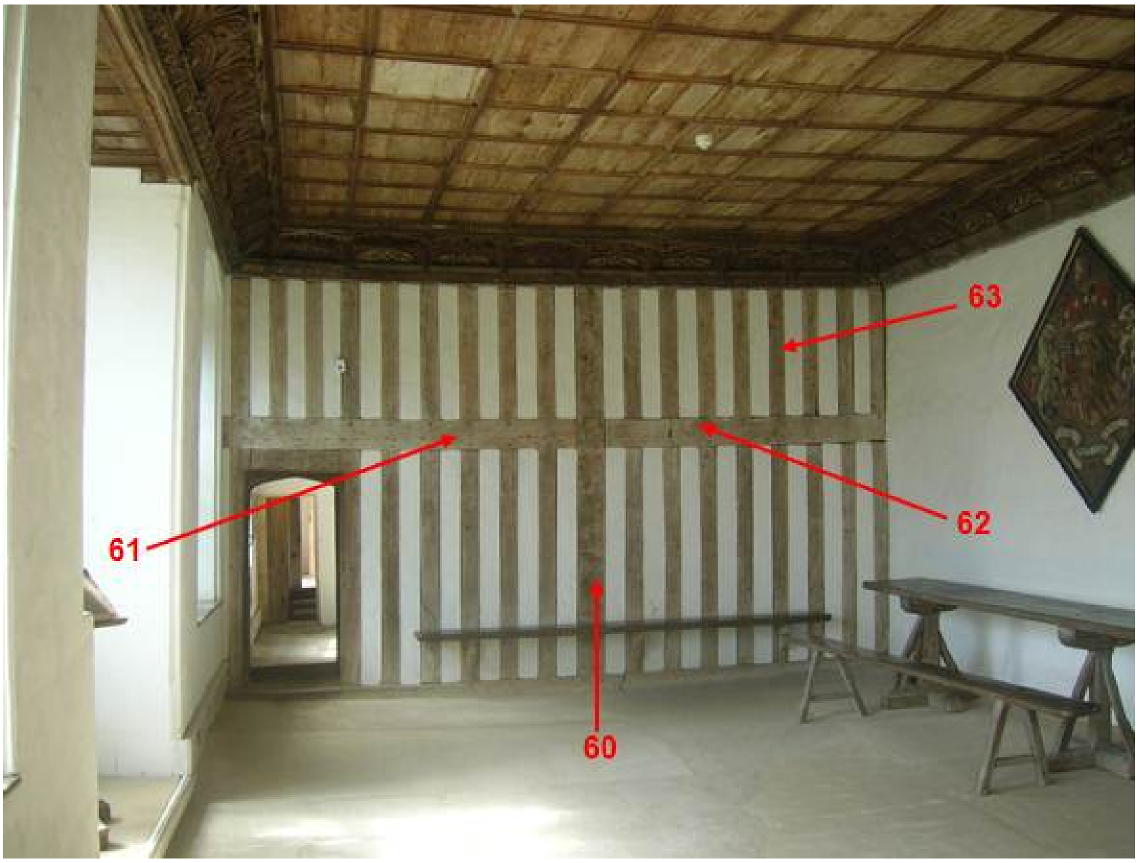

Figure 13: Great Chamber/Presence Chamber partition wall to locate sampled timbers (photograph Robert Howard)

Figure 14a–c: Bedesman room doors to locate sampled timbers (photographs Robert Howard)

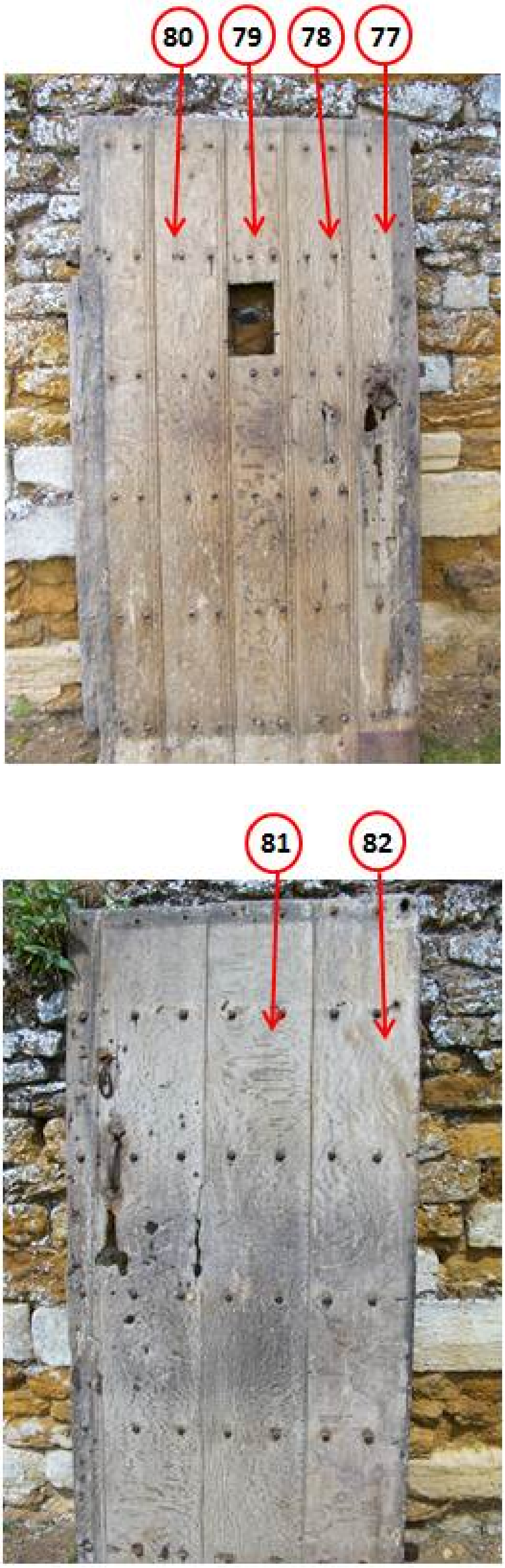

Figure 15a/b: Chapel/Bedeswoman room 1 door (top) and Bedeswoman room 2 door (bottom) to locate sampled timbers (photographs Robert Howard)

Figure 16: View of the floorboards to the west roof attic space to locate sampled timbers (photograph Robert Howard)

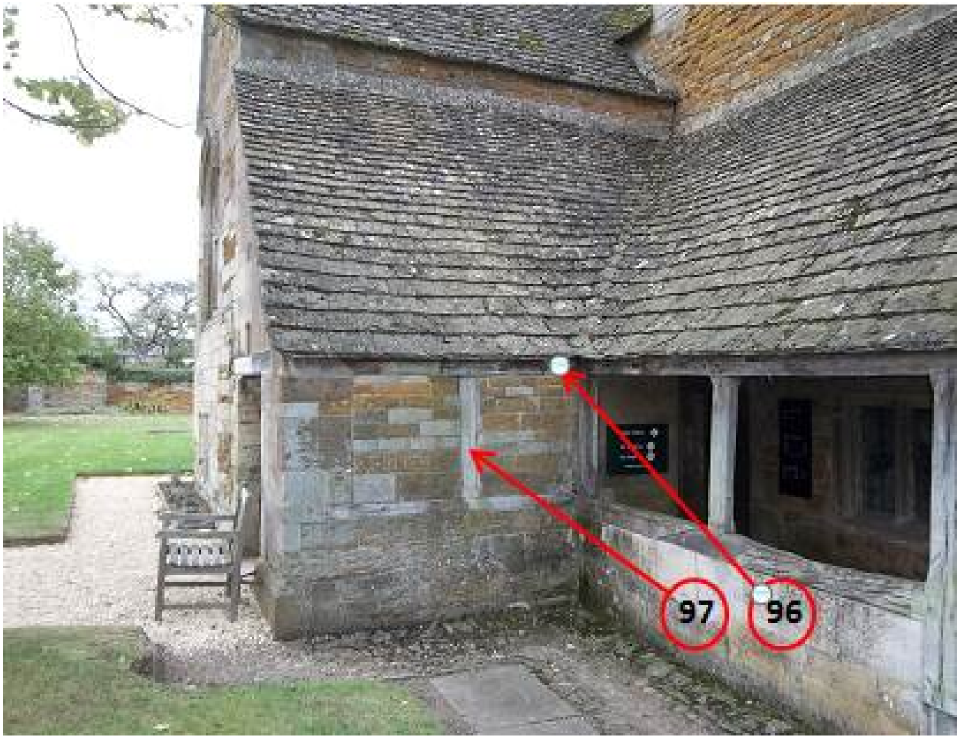

Figure 17: View of the porch to locate sampled timbers (photograph Robert Howard)

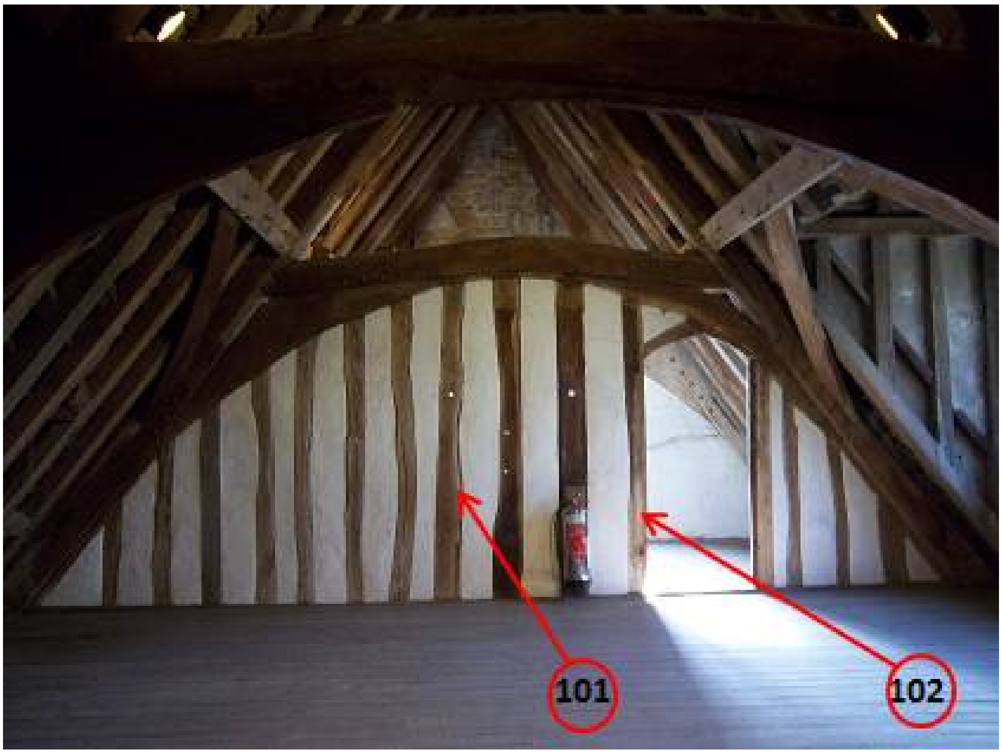

Figure 18a/b: Views of the partition wall and ceiling at the west end of the roof above the Great Chamber/Presence Chamber to help locate sampled timbers (photographs Robert Howard)

Figure 19a/b: Views of the Bedeswoman room 2 partition walls and stair framing to help locate sampled timbers (photographs Robert Howard)

Figure 19c/d: Views of the partition walls to the Chapel/Bedeswoman rooms 2 and 1 to help locate sampled timbers (photographs Robert Howard)

Figure 20a/b: View of the niche (cupboard) in the south wall of the Presence Chamber (top) and the ground-floor ceiling beam in the Chamber (currently the shop), to help locate sampled timbers (photographs Robert Howard)

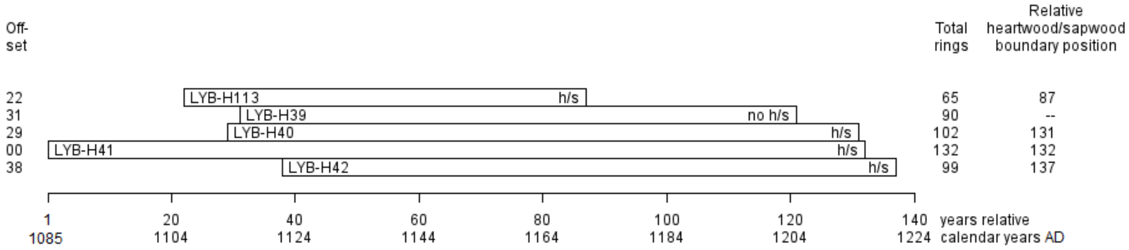

Figure 21: Bar diagram of the samples in site chronology LYBHSQ01. White bars = heartwood rings; h/s = heartwood/sapwood boundary

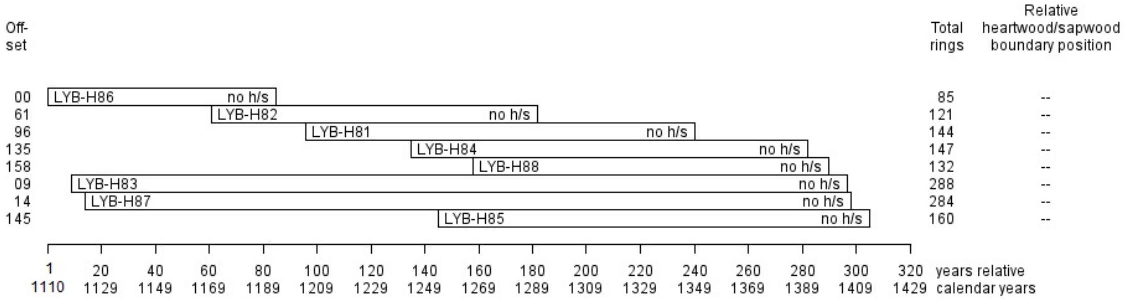

Figure 22: Bar diagram of the samples in site chronology LYBHSQ02. White bars = heartwood rings; h/s = heartwood/sapwood boundary

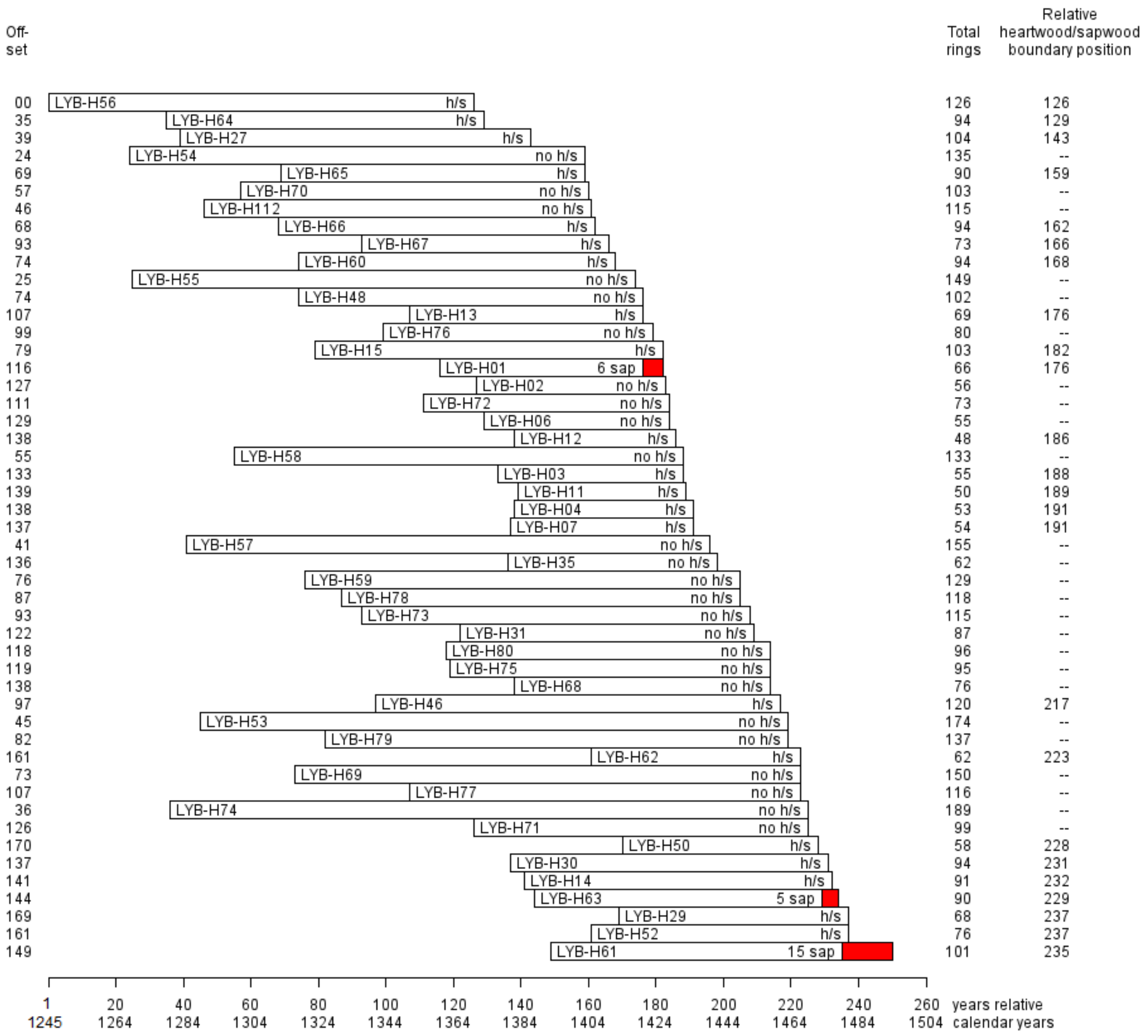

Figure 23: Bar diagram of the samples in site chronology LYBHSQ03. White bars = heartwood rings; red bars = sapwood rings; h/s = heartwood/sapwood boundary

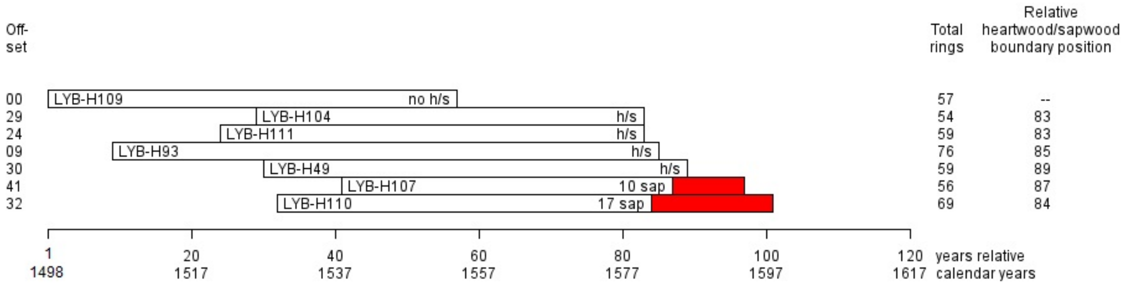

Figure 24: Bar diagram of the samples in site chronology LYBHSQ04. White bars = heartwood rings; red bars = sapwood rings; h/s = heartwood/sapwood boundary

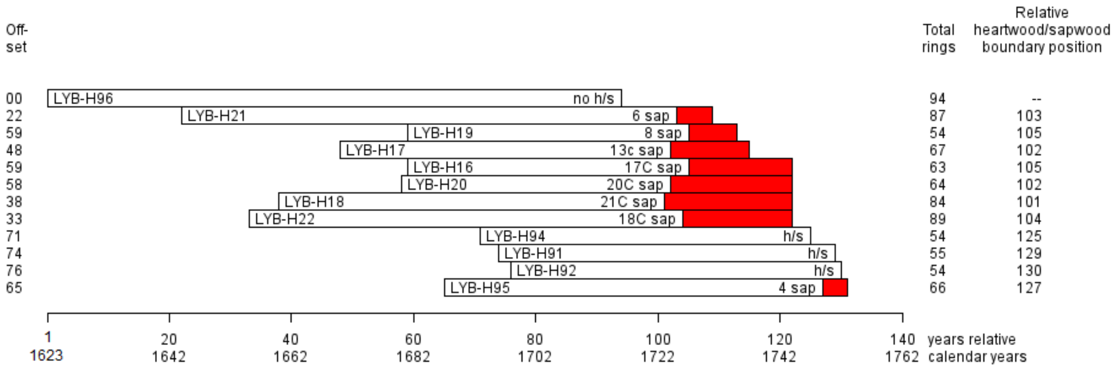

Figure 25: Bar diagram of the samples in site chronology LYBHSQ05. White bars = heartwood rings; red bars = sapwood rings; h/s = heartwood/sapwood boundary; C = complete sapwood is retained on the sample, the last measured ring date is the felling of the tree represented

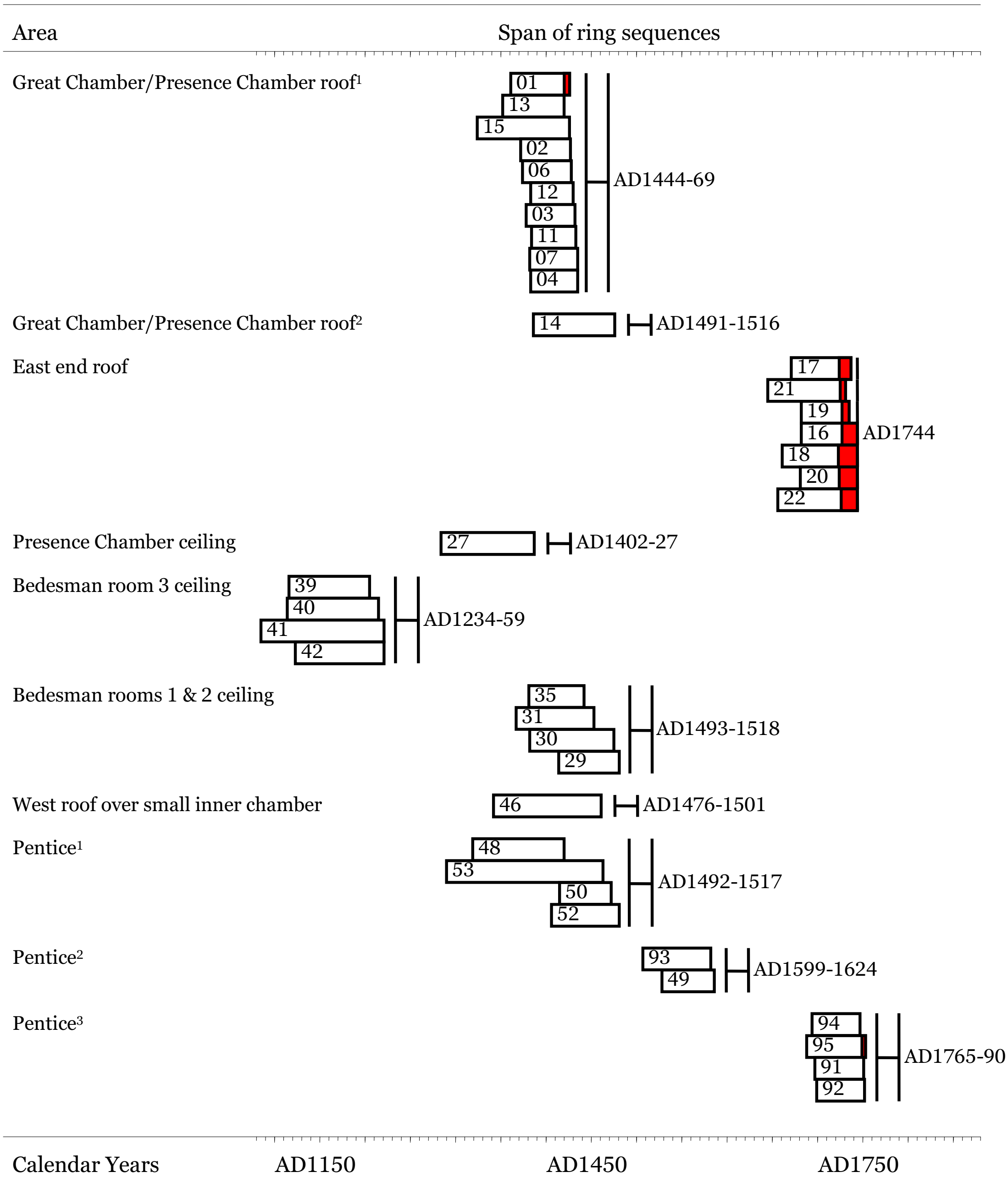

Figure 26a: Bar diagram showing the dated samples area by area with associated felling dates / felling date ranges / felled after dates. White bars = heartwood rings; red bars = sapwood rings

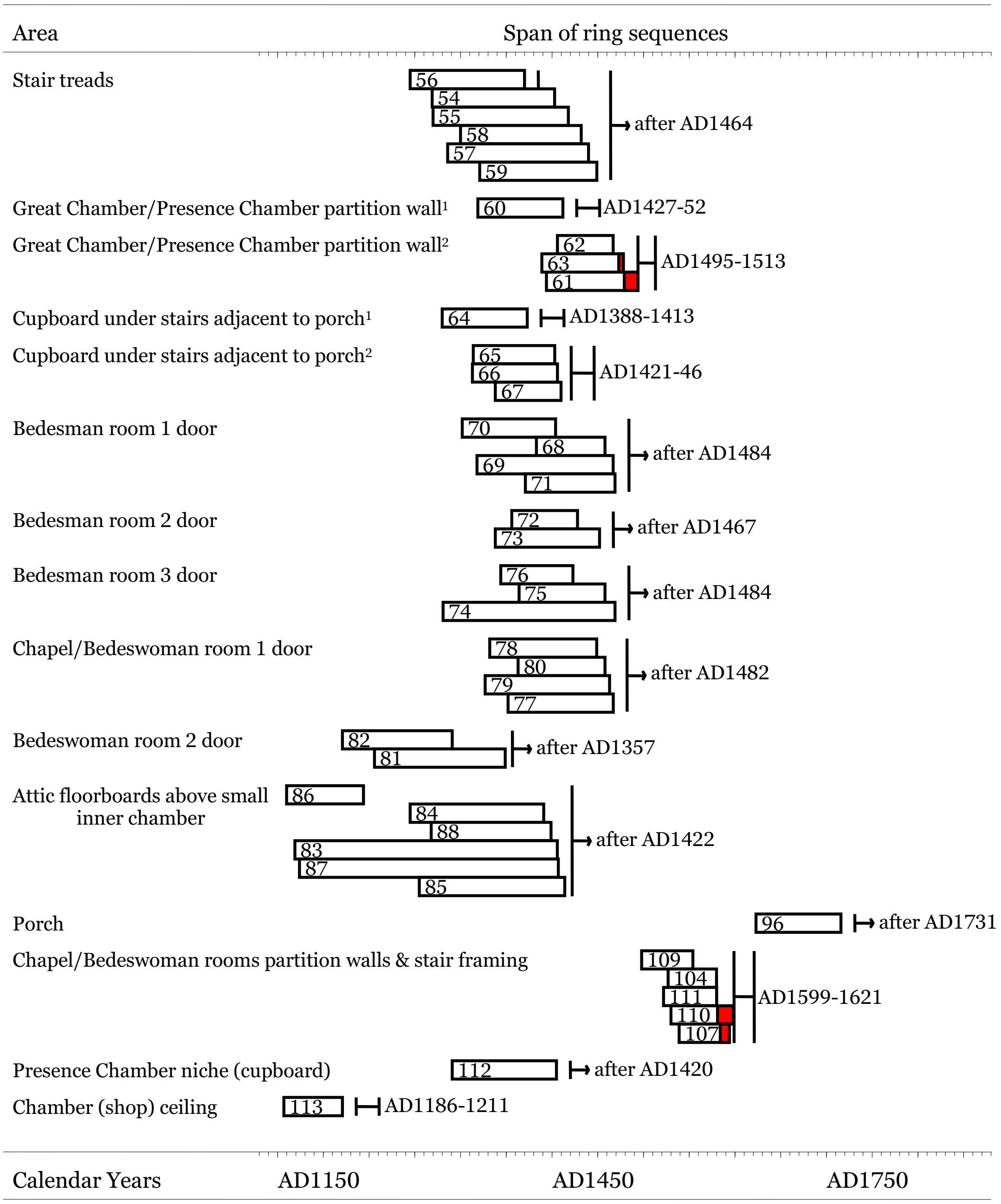

Figure 26b: Bar diagram showing the dated samples area by area with associated felling dates / felling date ranges / felled after dates. White bars = heartwood rings; red bars = sapwood rings

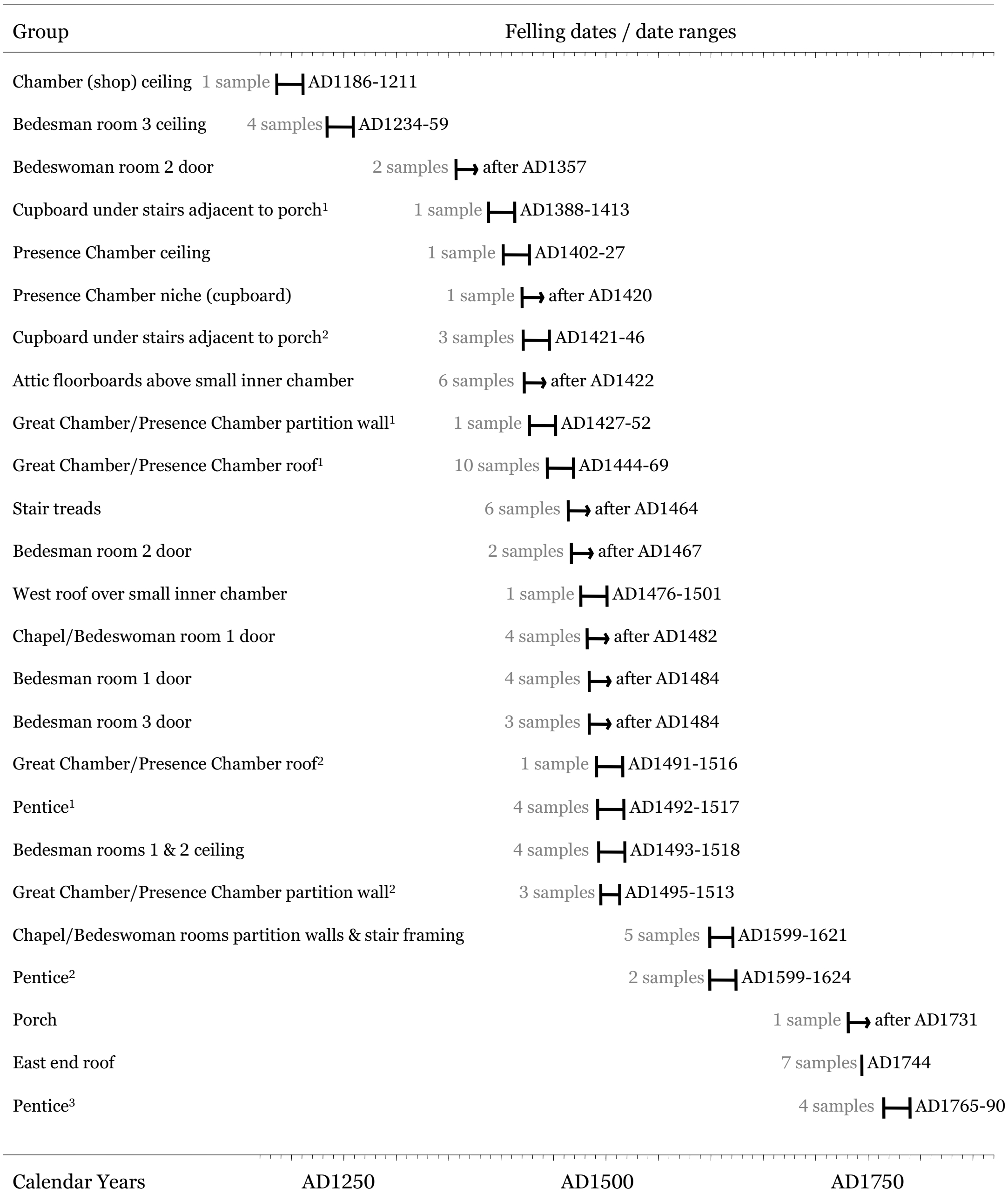

Figure 27: Summary of the felling dates / felling date ranges / felled after dates for the associated groups of timbers from each area in date order

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

LYB-H01A 66
339 376 340 456 265 341 241 320 343 304 252 311 290 301 186 256 303 314 365 319
317 361 258 249 244 315 376 369 274 260 322 164 304 202 124 171 136 132 178 160
168 191 253 212 202 173 137 138 132 110 105 150 154 120 140 169 150 143 107 147
116 134 124 159 172 171

LYB-H01B 66
321 390 320 434 278 321 263 300 352 265 246 328 289 285 196 234 296 293 389 338
294 377 273 226 247 317 368 380 284 268 315 148 326 187 124 176 118 128 189 156
177 187 252 231 184 180 149 148 126 105 122 144 155 107 152 166 145 145 111 136
123 130 132 142 169 166

LYB-H02A 56
468 342 361 299 461 304 382 417 299 340 539 439 505 465 535 585 592 519 608 740
534 549 433 478 346 406 338 339 362 610 628 748 488 605 528 474 426 405 340 349
356 208 251 269 295 340 275 249 403 244 244 338 243 275 311 328

LYB-H02B 56
462 329 356 300 450 310 370 406 300 340 508 445 501 413 528 540 639 510 557 764
541 545 425 497 357 404 342 309 368 615 648 747 511 632 484 470 439 407 344 335
372 214 236 273 308 330 295 243 398 249 236 331 251 284 281 341

LYB-H03A 55
206 314 105 140 212 256 185 193 374 424 392 306 313 375 331 296 338 334 395 333
361 394 355 375 399 359 413 380 364 301 253 359 350 322 356 323 315 256 274 219
275 220 347 293 324 335 356 259 212 292 327 272 252 253 283

LYB-H03B 55
143 304 116 134 208 261 168 198 377 444 392 314 309 374 321 294 339 335 399 342
346 405 342 380 400 361 403 384 340 338 254 366 359 314 361 318 305 269 270 212
280 210 360 287 311 340 346 287 200 275 334 285 222 266 277

LYB-H04A 53
245 180 191 369 429 388 300 311 252 328 315 356 369 455 481 536 547 508 448 509
663 667 554 431 373 303 390 239 270 278 258 299 297 273 233 220 259 404 292 313
366 369 247 245 340 303 343 291 329 360 329 280 285

LYB-H04B 53
239 176 181 358 418 378 299 310 223 322 313 354 382 444 491 527 513 472 440 529
657 653 548 432 357 315 376 266 261 281 265 290 305 268 219 274 262 370 266 324
330 377 306 215 344 326 330 300 324 364 301 306 297

LYB-H05A 54
381 437 539 421 511 398 471 360 364 326 428 319 383 434 289 150 233 268 330 316
323 303 386 408 344 337 538 499 468 438 391 301 422 296 346 340 313 300 269 277
238 304 282 274 270 258 277 405 573 492 578 420 560 311

LYB-H05B 54
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323 286 385 395 343 333 540 528 452 443 364 291 430 340 342 324 332 293 261 343
214 287 254 308 267 274 285 425 560 478 559 422 560 300

LYB-H06A 55
359 319 431 322 376 429 290 148 228 272 327 311 319 479 340 420 472 604 417 705
491 630 621 576 749 765 647 707 714 801 625 629 714 562 866 742 572 623 853 625
616 560 656 492 660 326 866 436 373 540 372 414 278 321 450

LYB-H06B 55
350 311 419 312 377 418 281 139 220 261 320 308 311 483 350 433 443 606 320 715
507 634 620 581 780 806 603 707 702 830 643 603 714 564 847 744 559 623 872 612
630 574 661 496 655 315 843 455 343 558 385 368 298 318 461

LYB-H07A 54
208 260 178 190 369 420 389 300 311 370 328 300 396 358 434 454 503 506 464 425
516 628 666 561 455 413 311 390 271 295 309 297 314 321 311 244 260 255 436 297
301 390 364 288 255 345 361 320 310 330 369 325 301 339

LYB-H07B 54
210 249 180 179 354 415 378 306 310 366 321 290 365 367 436 451 504 507 457 432
504 638 671 567 445 410 330 388 272 313 286 300 308 341 314 204 270 251 446 272
343 370 368 304 225 362 366 304 323 313 376 303 303 336

LYB-H08A 52
500 618 643 542 446 314 240 296 388 350 400 315 282 264 202 225 174 232 325 388
414 461 369 283 425 343 328 403 511 382 397 387 320 316 357 335 220 212 168 133
161 173 176 156 171 252 327 160 117 136 343 329

LYB-H08B 52
503 609 633 529 440 323 243 302 366 374 434 318 350 236 200 232 168 242 310 396
394 462 349 294 393 361 298 363 532 364 425 352 329 315 367 313 215 232 158 120
163 188 173 158 167 212 328 166 113 161 297 310

LYB-H09A 54
104 118 281 398 391 345 368 423 247 211 403 368 480 376 584 303 295 271 296 467
391 254 258 272 145 173 256 266 311 216 194 297 237 261 349 257 223 187 335 324
234 213 237 229 333 238 273 198 234 261 217 189 271 267

LYB-H09B 54
101 112 273 400 378 352 359 407 258 206 400 435 502 403 542 315 311 262 320 459
416 260 258 276 154 165 262 264 312 226 198 296 223 250 348 285 211 174 322 336
248 245 204 234 295 234 276 198 226 250 225 170 280 269

LYB-H10A 57
322 494 247 247 411 386 576 439 635 548 537 183 240 324 362 317 324 390 492 567
572 350 343 342 195 163 255 204 217 212 299 308 321 290 297 391 466 311 219 196
120 153 150 102 94 111 148 133 89 108 67 59 142 172 189 187 206

LYB-H10B 57
314 493 268 246 415 387 560 443 616 550 529 187 227 330 337 323 332 376 498 562
585 355 351 338 233 125 246 181 175 222 275 299 306 288 292 382 450 339 217 168
125 159 138 118 76 135 131 121 86 102 72 63 133 157 212 173 201

LYB-H11A 50
100 122 278 400 387 355 370 418 253 215 408 387 409 403 438 537 491 492 513 590
524 459 404 382 358 416 326 329 384 352 351 283 252 241 255 188 272 287 237 393
296 244 247 366 364 262 285 297 389 281

LYB-H11B 50
104 128 273 389 378 349 366 411 246 209 394 390 419 408 442 522 494 504 499 588
527 459 407 343 328 398 342 335 344 351 354 276 239 260 237 201 276 277 259 385
284 243 258 351 351 247 286 305 422 298

LYB-H12A 48
166 93 118 282 416 398 360 366 420 249 220 266 211 250 286 296 346 317 273 380
453 443 431 389 305 285 302 288 241 274 295 289 221 230 202 259 206 359 279 209
311 294 258 179 277 283 233 242

LYB-H12B 48
116 77 127 260 435 395 361 361 422 248 212 282 224 256 296 310 345 316 284 350
446 418 418 422 263 290 316 287 228 296 283 299 245 231 226 245 216 331 277 209
298 281 263 181 283 296 237 240

LYB-H13A 69
105 155 140 162 185 158 217 227 208 157 263 188 189 146 212 203 182 256 227 183
151 151 201 155 240 178 220 157 177 159 218 173 111 147 203 181 173 122 109 151
66 141 101 82 129 78 107 124 110 108 90 128 121 132 140 118 123 133 119 107
156 108 111 135 160 103 107 82 103

LYB-H13B 69
94 165 147 159 183 234 224 240 202 156 265 193 197 151 217 185 182 244 247 177
158 156 190 153 242 184 219 172 173 156 216 172 98 146 202 171 165 143 118 126
63 141 100 85 128 86 100 136 110 91 94 126 118 142 137 115 135 138 109 112
183 113 111 139 157 102 97 93 106

LYB-H14A 91
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340 280 206 332 143 184 155 254 468 415 325 222 205 96 213 220 184 199 163 190
98 151 167 195 183 171 216 196 98 113 153 171 151 156 160 129 110 89 103 72
110 84 143 111 127 175 147 189 175 195 188 166 129 120 93 124 128 132 126 129
166 123 89 86 155 104 151 154 122 162 136

LYB-H14B 91
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324 286 211 319 135 175 166 284 492 369 311 220 206 99 224 221 193 192 160 210
91 173 167 180 186 169 213 194 100 124 148 187 172 133 167 121 110 95 94 77
110 75 143 124 104 179 125 171 165 221 184 165 132 113 88 132 126 129 132 145
169 127 94 89 150 107 157 158 131 157 146

LYB-H15A 103
186 128 85 176 212 331 200 127 118 150 168 270 229 252 202 286 272 240 216 194
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356 220 226 174 97 129 152 153 148 140 90 97 99 105 148 142 131 110 81 103
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161 126 133 97 113 97 108 101 79 111 93 92 79 82 115 99 127 102 100 183
173 108 138

LYB-H15B 103
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360 217 224 172 103 127 153 133 114 110 101 88 106 106 147 142 137 109 79 95
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156 128 133 99 105 98 109 90 90 113 96 72 86 78 113 104 114 116 100 180
173 108 137

LYB-H16A 63
414 375 297 221 381 342 339 294 214 330 228 258 267 246 245 215 169 79 156 174
205 267 197 140 233 149 168 228 164 174 153 92 79 76 98 145 107 106 133 179
126 97 160 151 132 177 146 102 71 129 135 164 121 223 147 170 150 113 120 71
88 89 75

LYB-H16B 63
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186 255 193 145 237 133 171 227 162 191 153 91 80 73 92 150 97 114 125 165
117 91 189 142 129 177 151 117 57 126 137 159 139 208 173 156 163 129 111 68
90 93 77

LYB-H17A 67
616 361 352 218 185 150 392 347 318 402 230 431 212 210 179 203 142 211 257 243
301 204 302 172 237 179 227 221 129 159 157 187 289 228 149 195 163 131 187 165
177 234 241 189 265 213 195 141 130 158 182 181 151 251 195 128 168 177 183 156
182 227 246 156 221 124 139

LYB-H17B 67
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274 208 299 175 252 186 228 218 129 163 146 194 288 213 151 186 167 130 185 157
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LYB-H18A 84
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149 183 126 201 225 131 164 203 169 119 174 171 188 129 236 157 140 224 199 159
156 146 148 153

LYB-H18B 84
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149 177 135 208 221 132 163 206 154 138 158 166 195 131 246 156 140 235 180 160
142 160 146 154

LYB-H19A 54
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LYB-H19B 54
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LYB-H20A 64
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145 113 180 244 169 287 155 165 195 130 257 282 232 133 117 106 110 111 116 153
205 169 134 191 111 107 165 119 113 80 167 177 193 172 235 97 106 126 116 90
49 60 89 86

LYB-H20B 64
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50 68 75 110

LYB-H21A 87
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191 295 245 269 343 235 316 177 223 207 210 128 161 188 137 133 159 162 248 189
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140 126 166 179 163 186 181

LYB-H21B 87
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180 291 244 282 337 243 308 202 201 203 207 137 155 184 143 142 153 160 251 179
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134 110 159 167 167 181 198

LYB-H22A 89
235 370 356 283 328 261 231 290 252 241 290 265 224 323 411 494 368 303 204 164
123 238 278 336 347 212 399 271 233 163 215 135 204 314 215 218 142 280 163 209
155 184 245 169 182 188 225 303 224 163 183 123 105 186 185 191 165 160 136 162
195 160 96 85 102 140 182 116 189 175 131 207 220 185 142 160 218 197 199 243
136 111 229 231 205 150 160 184 150

LYB-H22B 89
259 361 369 276 331 251 245 279 257 237 294 255 241 320 404 491 362 301 219 162
122 247 291 346 345 226 390 272 225 158 209 142 214 296 166 260 155 294 174 196
147 202 233 171 173 204 230 284 225 151 191 136 107 170 181 191 170 169 120 171
183 156 102 81 122 121 185 131 173 169 117 202 236 176 126 164 222 210 188 235
114 129 245 232 196 121 161 181 138

LYB-H24A 100
67 62 39 41 58 62 53 100 81 70 50 20 25 34 117 164 154 51 121 155
103 53 30 19 21 35 41 71 83 128 85 45 72 79 95 66 70 142 76 61
37 71 73 93 127 123 185 71 48 53 56 85 84 88 98 87 93 121 72 53
65 130 215 146 116 79 89 107 182 173 130 194 250 106 113 103 177 151 291 151
154 117 139 79 90 195 149 150 120 88 69 68 51 68 91 140 149 233 182 134

LYB-H24B 100
56 58 45 48 44 77 51 88 93 58 60 25 26 27 120 164 154 51 119 174
97 47 43 27 23 25 33 82 76 137 81 53 69 80 91 65 70 143 75 64
56 55 69 93 134 112 190 73 43 53 61 73 99 72 107 82 100 118 72 53
75 120 216 128 113 81 85 110 178 171 119 203 249 81 119 114 170 154 278 149
166 110 128 83 89 174 145 161 124 87 75 58 52 80 86 153 141 228 189 202

LYB-H25A 82
422 447 368 509 328 217 276 158 179 188 206 166 139 206 149 126 126 95 145 217
185 264 344 349 209 292 277 200 142 114 141 113 171 297 236 184 176 171 126 121
122 144 138 145 120 75 50 43 62 85 72 62 48 59 42 50 64 73 81 72
106 104 96 123 77 88 124 85 132 103 122 174 142 170 125 145 136 76 108 111
107 115

LYB-H25B 82
384 442 378 506 347 211 264 174 184 199 179 179 122 199 165 129 132 95 141 209
199 284 336 327 229 271 276 199 139 116 144 140 169 287 243 189 173 170 108 123
111 153 144 142 130 64 37 59 57 68 76 60 44 60 47 48 65 69 78 64
91 107 101 138 78 93 112 90 128 122 120 166 144 174 134 148 129 84 105 136
90 131

LYB-H26A 54
234 53 168 239 216 228 279 336 352 237 190 186 256 266 258 269 218 229 209 220
206 271 263 273 241 172 162 203 177 226 224 192 214 114 74 145 150 154 80 131
151 187 216 93 121 115 57 106 95 100 103 97 88 59

LYB-H26B 54
267 58 174 238 217 226 281 333 349 233 199 168 268 263 265 264 223 225 220 215
211 276 254 262 244 172 162 194 198 219 222 163 214 117 79 143 155 160 72 132
165 179 217 96 115 123 56 103 92 98 100 92 83 53

LYB-H27A 104
188 125 141 89 106 160 157 160 109 127 113 96 52 90 115 105 109 140 136 84
93 82 123 149 96 130 159 95 101 121 106 84 82 65 58 60 75 59 57 67
32 44 44 69 60 80 74 54 62 88 69 87 63 57 79 76 55 45 57 33
50 73 64 73 77 83 58 83 58 48 75 69 99 104 204 140 136 137 186 113
109 59 53 72 53 68 61 41 60 70 95 64 70 65 108 98 99 83 75 84
64 80 120 145

LYB-H27B 104
199 131 143 81 116 153 160 154 111 131 105 102 44 102 112 97 126 141 123 91
71 85 103 145 98 114 176 96 106 114 119 85 75 54 68 59 63 55 48 54
36 48 39 57 56 81 73 68 54 93 74 82 62 56 72 84 52 46 46 41
60 69 58 79 68 69 65 96 45 49 80 71 101 107 193 144 127 129 198 101
101 64 58 56 64 73 67 42 58 72 93 73 77 66 99 95 94 88 66 88
62 72 114 138

LYB-H28A 65
253 182 182 223 227 276 215 150 136 202 198 279 186 181 198 204 172 141 137 132
106 121 133 124 87 109 98 136 162 132 151 80 85 73 90 112 124 109 133 132
123 151 132 132 124 123 116 145 120 100 89 71 77 81 91 100 108 105 104 108
93 100 96 96 134

LYB-H28B 65
232 181 188 224 234 283 206 126 133 197 200 277 194 166 192 207 169 126 120 133
120 129 131 138 90 95 123 141 156 136 145 86 82 71 90 115 128 113 131 130
121 145 136 125 129 126 116 153 119 98 100 76 75 81 83 107 99 96 106 111
104 82 100 112 149

LYB-H29A 68
394 332 463 409 769 355 612 376 244 335 356 216 173 297 431 301 314 386 610 317
276 360 461 464 324 196 251 367 272 552 512 243 196 222 331 316 329 472 317 343
412 364 406 264 297 304 427 265 260 297 239 321 239 373 376 530 432 290 239 234
346 398 258 270 251 297 273 412

LYB-H29B 68
391 332 460 399 778 352 612 376 236 342 348 214 168 289 411 332 336 444 610 319
278 348 446 488 333 192 233 368 264 542 515 251 207 222 342 311 320 481 324 341
416 362 398 276 288 304 424 281 255 300 232 322 241 373 380 515 429 298 250 233
324 406 279 260 247 324 254 421

LYB-H30A 94
309 267 269 331 330 305 350 164 169 208 220 167 53 71 120 128 245 219 176 168
305 179 163 115 175 73 195 202 142 97 158 193 137 139 86 84 144 67 233 136
138 202 175 106 130 104 147 163 106 125 114 112 66 159 116 190 126 193 134 158
158 194 163 145 101 132 151 176 157 172 122 113 126 123 117 107 126 115 147 134
92 98 89 116 129 143 133 109 116 98 71 74 62 91

LYB-H30B 94
322 245 281 335 341 286 362 152 179 212 231 155 61 77 102 137 242 213 166 168
324 182 181 111 177 81 184 181 148 107 167 194 133 131 82 84 142 72 229 131
143 204 172 108 136 101 150 155 92 148 105 108 78 157 120 175 141 187 128 160
156 210 165 159 103 119 161 176 144 160 127 113 106 131 120 94 129 132 153 132
95 103 91 118 115 141 130 120 110 110 68 66 57 80

LYB-H31A 87
356 348 170 281 246 387 299 483 274 336 335 274 260 376 171 326 175 231 214 257
204 220 189 288 247 222 183 144 146 200 150 248 264 132 164 239 177 250 111 178
95 143 176 146 122 180 141 99 105 79 64 119 73 175 103 133 138 120 92 107
90 109 151 91 187 149 92 124 120 188 125 149 123 167 165 166 206 146 139 108
103 123 150 137 160 119 131

LYB-H31B 87
361 339 165 264 243 370 297 496 250 338 325 260 269 375 168 319 175 230 220 253
189 217 192 292 248 242 184 133 141 194 142 265 257 127 160 244 170 229 130 171
110 134 174 150 113 176 142 107 109 67 69 119 68 172 108 131 141 123 98 108
86 113 135 104 186 150 93 128 124 219 128 144 100 175 163 155 202 142 119 98
102 115 156 144 145 123 136

LYB-H34A 73
267 183 161 179 167 146 149 166 153 107 160 93 55 54 60 80 80 101 101 114
64 53 78 74 80 188 245 235 214 295 209 326 290 337 253 222 295 223 221 289
259 314 283 368 240 312 304 310 275 400 275 207 285 233 260 262 269 234 328 222
152 165 250 304 389 250 255 240 204 162 224 304 285

LYB-H34B 73
261 181 164 183 159 150 153 176 160 107 149 94 42 58 61 81 87 100 108 94
76 52 76 69 79 189 247 248 210 290 191 341 302 345 240 230 276 234 214 289
285 296 287 348 256 296 316 290 279 397 276 233 266 251 233 288 260 224 329 190
124 187 234 304 400 254 252 246 195 166 225 267 245

LYB-H35A 62
249 346 403 345 430 482 388 465 376 352 330 314 253 251 246 353 240 249 363 523
285 304 321 257 312 249 186 367 331 361 242 226 153 144 184 100 75 98 80 114
85 72 111 75 50 41 56 67 113 152 294 561 323 304 336 385 565 456 268 388
302 268

LYB-H35B 62
293 356 409 332 387 485 403 443 379 350 337 321 250 248 251 365 231 260 349 511
299 305 332 260 303 249 183 369 331 367 243 230 158 148 179 105 72 95 74 104
89 70 112 77 38 35 57 77 113 139 308 616 307 299 298 334 580 450 262 382
302 272

LYB-H37A 66
287 177 295 265 193 235 92 84 88 92 149 120 144 140 118 103 66 104 121 147
349 432 543 260 336 256 460 410 364 250 360 325 236 303 308 287 325 208 364 292
308 360 273 266 288 252 238 290 350 282 399 443 382 470 335 230 334 376 506 627
403 345 281 300 204 393

LYB-H37B 66
252 181 266 257 183 224 89 88 93 93 155 128 137 141 121 95 77 104 113 156
348 426 554 264 329 270 431 400 360 222 349 335 225 318 286 306 326 208 354 262
313 368 281 260 302 277 233 286 345 299 391 447 372 515 326 209 335 394 509 620
439 361 294 304 217 372

LYB-H38A 83
506 248 234 233 314 481 457 561 751 658 482 252 446 764 859 492 266 235 162 206
159 54 36 31 35 26 26 46 35 38 43 30 47 41 32 27 38 60 58 61
87 68 49 54 40 95 156 161 110 121 250 191 310 337 209 196 126 193 169 204
188 170 154 147 136 144 129 99 94 108 138 175 185 86 61 72 122 158 165 171
263 262 173

LYB-H38B 83
484 259 245 227 317 502 458 566 770 644 488 254 440 758 842 521 277 238 159 218
156 43 35 30 37 31 18 40 41 39 42 28 43 43 33 30 35 49 59 58
96 68 49 52 42 92 147 159 109 129 244 191 304 329 224 181 140 189 164 202
172 168 160 150 140 146 129 101 84 118 134 171 197 78 72 65 123 154 162 171
267 266 177

LYB-H39A 90
183 186 206 159 219 132 168 202 279 246 274 231 187 165 281 220 163 142 85 89
36 48 51 47 100 185 100 78 52 60 64 79 105 148 89 94 111 187 163 182
121 125 107 179 227 154 174 140 119 145 164 128 137 149 214 110 89 65 102 142
178 147 149 213 129 136 128 109 80 99 80 127 79 75 166 117 83 101 67 86
82 103 78 66 64 87 111 115 130 171

LYB-H39B 90
201 200 204 157 219 134 156 208 271 258 272 204 198 174 285 205 162 131 93 68
38 53 50 48 104 187 121 77 53 48 67 75 110 145 92 93 111 187 152 181
114 131 104 173 233 157 164 149 114 158 154 144 111 158 216 128 98 58 105 141
176 151 141 218 121 138 134 101 85 96 68 122 87 83 155 119 83 100 71 83
77 100 72 72 68 88 101 124 132 177

LYB-H40A 102
222 278 310 316 203 171 318 194 203 301 305 258 244 142 223 184 289 203 160 134
184 185 104 63 84 106 191 307 133 123 66 111 126 97 165 120 105 127 103 196
193 127 107 141 134 162 165 163 113 93 73 90 150 120 148 236 172 170 121 90
130 173 177 140 186 242 154 163 236 165 102 155 163 201 110 77 113 115 77 145
86 57 104 110 89 77 75 87 106 151 124 151 120 133 167 146 111 128 97 102
111 91

LYB-H40B 102
325 283 310 307 198 169 309 209 199 294 311 261 235 152 227 182 294 206 167 136
184 188 98 79 75 97 198 312 122 127 67 109 128 106 172 124 110 116 114 204
187 121 108 132 123 166 164 161 122 104 72 86 137 121 142 225 159 158 121 95
128 184 175 139 193 231 146 168 240 161 100 149 174 214 106 79 110 113 78 148
83 60 109 107 90 76 74 87 105 152 103 168 123 133 171 141 105 137 88 111
107 94

LYB-H41A 137
254 166 98 217 230 139 140 199 192 106 104 136 187 233 149 151 104 125 158 134
164 160 147 146 99 91 58 58 140 138 107 107 135 121 73 124 69 140 162 217
122 141 91 106 98 128 117 76 59 91 114 55 50 83 87 154 165 89 66 43
76 67 67 67 90 62 73 75 130 82 65 64 101 94 108 106 71 57 62 65
142 89 95 89 152 119 97 92 70 116 100 111 67 116 137 86 98 140 100 56
43 53 103 43 52 75 68 75 78 47 72 80 61 60 65 63 126 86 97 53
73 52 46 98 70 61 94 61 143 54 49 45 62 75 72 104 109

LYB-H41B 137
263 153 112 207 241 114 127 193 194 112 94 145 166 234 159 149 125 140 155 138
149 146 148 153 105 91 68 61 139 130 96 99 128 111 55 111 72 112 163 193
120 134 95 103 92 133 106 66 64 72 107 68 51 81 84 159 176 73 67 48
66 68 70 68 87 69 64 76 150 87 55 54 111 89 114 114 80 64 55 76
117 78 84 102 157 132 91 102 78 109 108 102 64 120 143 76 106 142 85 54
47 48 111 42 46 76 74 73 102 44 34 80 63 53 55 65 126 97 107 76
63 49 59 105 67 84 83 69 120 74 48 49 69 70 76 102 108

LYB-H42A 99
364 328 167 162 103 182 157 220 222 140 131 129 210 114 99 187 118 274 239 165
110 85 201 218 179 139 182 139 165 179 236 190 112 190 211 152 195 209 175 118
117 103 159 156 144 153 235 149 161 133 85 173 168 195 105 151 101 102 140 198
163 81 104 133 240 119 78 147 114 107 148 107 95 147 142 146 134 112 143 172
153 89 127 156 121 137 104 138 142 145 150 163 109 148 129 141 172 164 160

LYB-H42B 99
371 327 166 139 110 179 156 226 217 141 133 128 215 106 93 199 115 275 246 166
118 97 189 199 185 132 175 135 155 172 233 173 128 210 192 146 199 239 192 107
117 102 156 168 137 144 249 167 152 128 102 175 169 182 104 154 106 109 133 204
161 80 96 122 233 123 90 146 112 115 157 104 98 141 132 154 119 112 138 154
174 103 119 152 101 130 107 136 155 128 178 158 116 130 135 158 175 160 157

LYB-H43A 56
417 291 364 377 390 505 365 349 237 257 256 364 389 397 340 172 160 98 109 146
187 122 100 226 194 200 219 233 225 234 88 54 77 65 79 112 148 147 158 84
82 65 34 42 46 57 44 61 93 93 87 84 84 88 173 274

LYB-H43B 56
422 279 396 350 384 512 356 356 245 267 241 354 393 386 314 180 150 96 120 141
190 112 102 232 191 206 215 209 228 220 79 66 72 59 70 120 147 152 154 84
84 60 38 41 47 56 48 59 94 93 84 82 89 88 174 272

LYB-H46A 120
89 108 130 194 154 112 135 56 46 70 99 136 140 174 160 174 85 67 51 84
135 170 141 127 86 121 163 186 163 111 140 128 209 105 178 190 201 146 228 203
155 131 103 124 185 171 140 87 82 86 89 84 130 91 121 86 164 144 144 116
90 101 116 86 108 67 68 126 81 64 66 89 82 93 86 108 119 101 97 109
133 181 121 58 46 72 63 88 108 93 89 50 58 53 67 70 72 45 51 77
58 78 99 67 56 69 82 80 74 78 76 83 63 61 56 61 39 55 50 50

LYB-H46B 120
99 112 172 189 140 103 116 54 49 68 90 134 137 188 170 177 84 65 50 90
128 168 139 124 96 110 128 172 168 105 138 136 200 112 186 218 199 153 228 219
168 127 103 128 184 157 156 83 81 99 103 76 134 89 92 85 178 143 142 108
92 102 125 86 107 59 69 125 99 80 80 88 74 97 91 91 108 110 102 113
138 181 121 63 50 66 67 84 99 99 94 54 54 55 67 63 63 49 54 77
54 85 109 66 60 73 81 76 73 84 69 73 73 71 55 53 42 60 48 49

LYB-H48A 102
81 69 97 71 50 74 49 50 73 65 67 56 40 42 60 79 106 91 126 80
129 124 124 111 112 90 99 108 122 108 101 107 190 123 191 146 84 121 162 127
125 142 125 193 196 145 119 94 88 82 89 93 63 89 97 93 89 73 80 87
101 85 119 104 81 66 88 87 99 92 89 44 58 61 78 45 46 55 62 84
70 69 71 56 70 86 79 123 70 107 86 104 120 158 151 158 120 142 135 144
138 195

LYB-H48B 102
61 78 94 81 50 49 58 54 61 77 62 52 49 54 46 81 95 105 100 102
121 109 120 128 101 84 92 121 125 102 95 118 194 121 194 151 88 119 158 127
127 134 119 196 184 143 124 94 87 86 91 90 71 87 92 102 78 78 86 87
97 86 115 113 74 61 93 82 99 87 74 52 62 52 62 54 49 48 69 86
75 70 66 48 79 86 87 112 75 104 90 107 121 153 150 164 119 147 130 137
144 170

LYB-H49A 59
211 309 275 307 311 194 184 341 396 394 414 460 196 201 134 322 418 417 227 110
207 343 149 183 122 182 277 343 287 202 311 257 226 236 288 329 171 222 163 161
304 193 143 163 138 141 140 129 264 197 131 204 289 170 174 169 186 302 604

LYB-H49B 59
236 277 270 332 318 225 190 373 367 403 415 471 188 200 126 318 420 427 222 105
212 354 143 179 124 187 282 342 299 190 310 244 220 247 290 331 159 238 158 161
292 198 144 163 143 142 154 143 218 215 116 201 277 178 185 161 189 271 659

LYB-H50A 58
426 434 300 428 254 311 369 388 442 344 197 185 292 359 356 357 273 395 176 142
100 112 122 186 218 233 272 222 273 332 252 194 217 277 239 257 277 190 195 205
236 203 165 179 208 184 148 154 149 113 110 81 124 131 81 124 130 147

LYB-H50B 58
388 480 291 439 276 318 350 393 415 344 178 184 273 354 362 369 279 404 166 150
100 113 123 172 236 221 267 226 292 328 263 174 226 275 261 240 275 188 196 189
243 194 191 177 201 179 155 151 144 113 97 95 119 126 89 117 136 141

LYB-H52A 76
533 317 242 232 172 199 154 225 143 168 166 144 132 137 185 207 213 258 244 182
190 215 200 214 220 215 183 151 164 174 190 268 257 191 255 233 197 239 280 234
191 155 176 217 160 193 203 207 247 200 203 208 195 206 197 164 154 171 137 123
99 210 224 213 203 219 164 138 196 274 189 138 167 245 209 241

LYB-H52B 76
489 319 245 233 170 196 168 172 162 169 164 144 132 138 185 204 216 248 239 200
175 222 201 214 212 226 177 169 152 160 177 266 263 192 245 245 188 237 285 221
185 166 171 212 163 204 197 212 246 198 202 228 193 205 189 173 152 171 138 129
108 216 221 201 217 208 181 155 183 277 192 139 163 244 209 239

LYB-H53A 174
144 145 186 177 105 100 94 100 107 108 128 135 132 64 105 70 119 98 88 83
79 54 67 53 55 66 62 56 60 68 63 79 70 97 79 89 58 144 109 90
93 54 56 89 97 131 110 115 112 117 111 113 127 93 92 91 90 93 110 104
97 165 119 135 114 86 86 114 96 95 79 88 141 147 98 114 108 77 88 69
90 61 77 61 78 78 89 81 117 92 86 103 98 73 58 70 116 109 97 64
57 44 61 62 57 58 62 63 82 68 64 72 61 89 131 133 169 95 128 138
145 112 172 171 174 131 162 128 164 150 148 121 139 196 148 101 73 117 119 124
99 92 146 89 90 102 111 123 148 123 117 117 120 200 164 111 92 107 128 109
80 161 207 120 98 86 79 90 86 110 126 100 109 125

LYB-H53B 174
126 150 183 179 97 100 93 105 106 106 117 133 117 66 97 73 147 103 82 106
65 65 67 52 72 52 71 60 48 68 68 69 87 82 86 71 81 131 107 95
84 56 62 74 107 124 96 141 90 128 122 102 117 106 85 95 88 103 100 100
96 160 106 157 113 74 100 99 95 105 97 77 141 141 89 113 104 60 73 96
77 76 80 68 85 62 79 82 102 105 89 104 88 76 57 85 110 109 92 78
54 48 55 70 49 59 59 53 95 64 72 67 66 90 142 131 155 104 115 146
144 108 180 170 170 136 141 133 154 148 153 112 136 197 134 87 82 123 105 117
99 89 133 97 91 113 107 116 149 124 119 125 137 197 180 93 93 103 132 104
79 153 205 129 94 93 84 89 88 96 125 107 107 123

LYB-H54A 135
83 133 165 121 134 143 117 79 72 62 52 145 177 166 129 131 107 104 44 76
116 115 67 105 123 73 105 77 85 86 60 74 106 77 41 35 71 67 86 76
76 62 45 52 36 32 20 32 58 42 36 47 45 32 31 27 31 39 56 46
41 40 36 39 49 57 73 45 45 28 33 58 79 89 38 35 100 150 115 134
106 98 106 94 82 119 69 64 128 79 80 99 76 144 118 123 116 121 78 140
183 206 151 248 162 129 146 155 190 223 221 214 205 213 166 118 135 160 200 219
182 113 135 129 99 86 74 101 113 179 202 177 190 178 179

LYB-H54B 135
89 132 172 115 128 152 114 74 80 61 51 147 176 165 135 131 124 99 49 65
128 107 69 99 130 70 101 80 89 85 61 72 98 84 42 37 71 71 76 85
76 59 50 51 34 30 21 32 54 45 38 47 38 33 33 28 36 36 59 44
37 44 39 40 45 59 71 41 40 36 40 53 78 86 47 40 108 143 118 122
113 98 106 81 89 117 68 70 117 77 90 101 84 135 124 124 117 107 74 128
173 218 158 264 172 129 141 143 185 247 219 227 196 208 163 134 136 161 201 206
192 110 145 126 87 94 74 93 106 184 196 179 183 178 181

LYB-H55A 149
177 173 102 117 154 163 145 150 150 140 151 137 167 116 140 108 144 86 86 153
127 130 164 123 75 68 96 68 101 73 115 120 113 81 46 56 110 114 143 85
52 70 99 66 60 93 113 143 94 108 131 140 116 120 57 70 81 118 128 107
84 85 70 91 63 136 66 55 59 74 94 88 97 55 48 77 118 117 104 98
74 105 90 109 135 64 43 105 68 74 90 90 141 166 143 108 87 64 70 96
117 90 174 102 113 101 151 174 211 185 184 202 178 174 142 158 163 194 227 219
153 160 121 119 119 108 150 140 208 189 164 207 184 188 190 174 205 154 158 173
134 134 216 195 145 149 121 129 160

LYB-H55B 149
177 149 92 124 163 158 144 150 144 137 168 151 159 117 129 118 158 67 91 141
131 124 165 122 67 71 75 77 92 69 111 120 109 71 56 56 114 113 132 86
51 76 94 72 62 88 106 140 102 114 137 135 106 119 52 76 72 120 121 100
83 81 70 87 70 127 68 60 53 68 103 84 89 49 37 83 118 106 118 95
77 99 83 112 135 75 42 102 71 77 97 94 135 176 139 102 81 55 69 108
113 93 161 114 106 104 158 185 207 181 180 205 186 172 143 164 160 201 225 218
148 162 119 128 113 113 142 142 206 189 159 218 186 198 189 177 192 155 166 170
138 133 207 197 144 141 131 125 153

LYB-H56A 126
76 84 90 60 58 80 99 107 130 103 152 85 97 97 107 146 152 192 97 129
181 114 62 114 75 102 103 77 75 100 64 55 61 37 31 96 97 100 105 80
71 61 31 40 89 83 63 81 89 57 67 59 66 60 52 70 88 56 37 37
36 47 54 74 63 49 46 55 44 41 32 52 72 60 62 46 45 38 47 35
41 55 79 71 60 54 50 52 60 63 89 57 57 55 52 52 69 87 61 65
119 159 150 166 160 118 167 124 202 227 123 164 123 112 111 128 120 195 157 140
151 138 108 181 239 297

LYB-H56B 126
89 74 103 57 58 83 93 104 141 91 156 92 87 105 106 139 150 197 102 131
188 102 71 104 87 95 106 76 76 95 70 52 63 41 27 97 103 100 99 81
69 52 39 37 88 91 68 74 84 62 66 45 53 70 41 75 95 56 45 41
30 49 60 55 53 53 49 55 62 41 28 45 69 53 53 43 44 54 55 55
56 51 78 78 60 67 45 59 75 56 85 61 58 52 46 62 64 89 67 61
115 164 149 171 156 124 169 123 202 230 127 145 118 106 108 115 121 173 157 126
154 133 101 185 248 302

LYB-H57A 155
112 98 119 135 165 138 132 132 90 102 96 99 98 54 92 120 86 68 41 24
23 29 38 43 31 20 45 37 27 28 31 43 49 46 38 27 34 39 29 40
41 73 66 46 48 54 41 46 62 71 43 54 41 36 47 53 51 41 41 64
127 108 97 99 94 125 89 77 110 54 63 63 51 43 66 56 72 110 114 74
76 51 126 125 180 150 166 120 101 100 112 118 129 148 157 154 140 147 113 127
156 193 210 160 99 77 85 65 58 77 124 108 125 120 101 133 143 154 123 168
157 141 84 71 65 63 99 120 93 109 68 82 94 115 140 124 134 176 147 97
80 103 111 150 147 171 181 144 117 127 138 188 183 167 176

LYB-H57B 155
126 105 119 134 160 141 129 139 76 111 103 91 84 60 79 134 80 76 35 25
34 33 43 29 24 26 34 33 23 24 35 49 48 36 34 32 38 45 36 33
55 65 61 54 53 52 44 51 51 69 45 37 34 43 60 60 57 37 29 71
110 106 86 77 98 111 91 68 118 53 62 72 53 47 52 57 80 105 105 80
84 53 119 120 181 153 172 126 99 95 113 121 112 158 140 156 137 149 124 122
162 189 203 159 101 72 84 75 49 71 136 113 132 118 98 128 140 155 126 165
158 145 83 65 61 64 99 121 96 108 69 81 100 117 136 129 131 176 148 102
61 91 119 151 148 162 187 146 121 138 134 186 176 171 179

LYB-H58A 133
129 142 134 92 68 82 83 107 111 85 61 65 73 94 45 67 112 112 89 77
84 80 65 67 59 63 70 125 116 69 75 55 76 74 73 105 75 52 55 79
89 82 102 65 50 86 138 145 126 122 106 135 81 89 140 70 54 68 67 54
76 85 127 149 112 114 74 64 102 150 180 148 196 137 93 135 142 156 191 182
176 156 154 132 112 132 130 179 192 162 87 99 82 82 73 75 91 106 143 124
118 149 147 139 136 126 125 116 105 134 108 93 164 166 112 115 93 99 133 113
172 131 154 205 209 114 106 121 141 149 147 153 179

LYB-H58B 133
126 134 147 90 74 80 79 112 115 95 58 62 58 76 70 54 95 117 111 77
88 82 68 64 55 73 62 125 108 75 69 65 70 67 80 103 75 56 61 72
85 89 111 57 48 89 112 148 129 122 94 140 89 91 141 61 62 63 64 65
72 87 120 163 107 111 85 57 110 141 183 144 199 136 95 131 151 145 171 187
180 161 150 135 110 131 139 185 191 178 80 92 86 82 76 70 105 104 149 112
123 142 146 141 137 123 123 118 107 136 106 98 166 168 106 125 86 96 138 125
159 129 160 214 211 108 107 126 159 138 142 151 180

LYB-H59A 129
84 64 75 58 69 85 140 108 107 86 82 91 108 92 142 103 75 61 93 125
142 122 102 59 117 160 146 188 140 142 224 127 186 180 124 105 120 98 69 94
111 187 154 153 147 114 56 137 176 192 138 217 160 133 130 156 193 208 163 222
161 163 159 148 133 174 218 227 185 141 127 99 101 100 119 133 117 171 144 131
152 166 188 170 139 153 97 97 118 101 79 134 142 115 113 92 81 112 109 147
122 147 191 142 83 87 100 108 126 119 138 128 106 88 97 119 133 140 112 109
110 87 118 119 89 82 77 79 78

LYB-H59B 129
79 76 60 55 69 79 156 108 86 100 76 94 95 114 137 92 85 67 93 109
131 148 76 67 103 156 151 174 158 141 209 127 174 195 130 101 132 91 74 102
106 192 162 147 157 108 58 121 160 196 128 228 137 112 126 157 187 221 172 217
174 159 158 144 162 171 224 224 181 145 117 96 95 105 116 139 120 182 141 123
159 172 189 183 132 150 100 104 105 100 97 139 150 111 122 94 75 110 107 152
118 150 188 148 90 88 101 104 128 129 139 120 123 86 95 129 130 128 105 122
100 100 114 119 97 70 76 85 86

LYB-H60A 94
39 31 35 43 42 54 46 40 40 41 51 46 40 61 62 71 111 69 79 74
95 74 100 103 142 150 224 181 138 89 53 54 65 57 75 116 133 101 133 153
180 166 131 127 166 152 133 126 127 154 157 100 83 117 107 169 151 131 137 173
197 163 110 92 54 47 40 40 41 38 37 40 56 68 105 123 123 63 61 50
61 92 103 102 93 102 92 138 91 169 159 138 152 123

LYB-H60B 94
36 22 30 47 51 42 49 46 53 33 47 56 30 52 57 70 103 70 69 82
88 77 93 111 136 108 172 177 136 87 60 36 60 66 68 111 127 107 129 155
168 165 131 121 175 148 140 117 130 146 147 118 81 121 104 156 132 135 138 168
200 162 110 112 58 44 51 46 37 43 35 46 44 73 101 102 131 70 57 63
68 106 115 111 112 98 81 132 99 163 159 133 151 121

LYB-H61A 101
664 478 489 485 474 422 400 268 387 445 446 350 348 191 269 248 203 170 251 268
190 217 177 178 188 170 434 373 309 459 330 203 180 267 292 304 178 341 443 235
255 210 264 247 191 236 186 236 232 248 208 129 115 180 227 258 211 239 190 200
159 217 154 152 121 160 192 196 93 146 124 151 184 156 259 136 197 179 137 151
186 229 173 141 176 267 260 271 236 184 192 214 189 273 235 210 191 230 158 159
201

LYB-H61B 101
605 481 493 471 477 413 401 275 391 445 440 351 338 198 249 259 204 171 229 269
161 217 203 157 180 190 418 368 309 445 336 193 180 280 281 298 176 338 446 220
264 198 268 249 207 238 188 256 240 212 198 125 103 189 244 295 222 240 196 182
168 212 171 136 113 175 189 181 106 136 126 154 174 169 246 152 178 183 139 153
197 219 172 141 187 264 228 262 238 171 205 217 209 281 231 222 186 221 172 180
197

LYB-H62A 62
417 369 415 319 188 187 195 289 214 218 172 147 180 297 346 332 299 368 380 263
295 322 366 376 230 320 390 191 310 211 277 252 286 336 225 313 273 263 282 200
133 204 204 255 249 262 213 216 191 234 199 189 169 187 190 217 124 175 135 186
219 205

LYB-H62B 62
425 335 400 307 180 193 182 284 203 213 176 139 188 298 354 331 297 368 363 260
293 351 359 391 233 324 385 192 303 212 281 234 293 356 232 295 264 279 243 198
154 175 215 267 229 262 218 222 204 231 231 200 160 189 181 210 135 178 149 161
233 189

LYB-H63A 90
139 190 193 164 291 211 205 197 169 166 204 158 154 144 188 210 173 179 127 144
112 203 151 178 163 168 154 125 72 108 107 186 126 137 213 178 106 112 185 174
182 162 159 209 159 134 126 155 134 117 118 178 233 189 226 180 121 113 110 131
148 159 119 144 133 93 121 114 124 113 82 109 112 117 111 143 116 156 184 144
107 112 133 98 79 89 133 191 171 109

LYB-H63B 90
135 186 209 153 302 198 201 209 163 163 196 151 126 129 187 220 174 182 125 147
129 197 154 152 165 182 159 125 80 96 124 170 139 155 238 170 110 98 180 188
175 164 167 222 147 140 128 158 135 117 128 164 220 201 236 174 122 120 108 140
143 151 136 139 124 107 121 114 119 129 87 106 110 123 111 141 121 147 161 148
123 109 128 108 91 92 112 192 173 111

LYB-H64A 94
135 192 244 210 215 296 262 202 440 360 239 219 143 146 70 44 30 38 45 42
44 54 45 32 41 52 52 47 61 65 68 65 65 61 52 60 53 44 44 36
51 54 45 41 44 57 49 55 60 71 61 53 41 58 65 85 60 65 73 96
67 78 91 75 92 84 58 47 37 41 38 45 50 52 75 64 39 48 65 70
46 55 49 69 52 44 63 60 46 57 54 63 68 88

LYB-H64B 94
152 182 238 225 210 295 273 186 448 360 227 215 151 144 69 53 26 40 45 48
38 49 50 31 39 48 50 59 47 70 73 59 62 66 49 61 53 42 47 47
50 54 38 42 46 62 55 54 60 82 55 42 53 60 65 101 67 77 80 94

67 92 88 90 81 81 59 59 51 39 40 53 55 40 72 66 44 54 66 54
60 55 47 64 52 48 66 58 51 60 49 66 68 87

LYB-H65A 90
311 458 314 351 253 227 306 260 235 319 76 104 97 153 133 165 134 67 66 97
150 164 123 85 101 133 125 104 108 122 136 182 106 144 115 125 134 224 133 96
133 120 73 130 142 119 117 95 108 172 163 82 76 85 112 123 86 91 97 124
67 74 71 123 112 114 96 109 101 104 116 127 182 157 156 105 112 152 98 118
104 82 77 88 104 122 128 125 93 105

LYB-H65B 90
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64 83 69 120 106 100 102 106 103 99 107 149 188 157 142 127 117 163 100 112
118 72 74 84 105 119 132 120 105 112

LYB-H66A 94
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150 198 201 192 193 220 166 173 161 321 222 255 148 115 109 148 143 124 122 136
172 95 84 82 152 105 118 135 131 110 146 184 215 213 217 189 149 151 212 105
128 126 119 140 139 141 201 217 214 291 235 333 280 236

LYB-H66B 94
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LYB-H67A 73
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213 214 302 236 215 279 308 257 271 223 202 300 266

LYB-H67B 73
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LYB-H68A 76
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LYB-H69A 150
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190 150 110 130 170 170 190 150 190 160 120 200 180 150 140 130 180 150 130 150
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110 100 130 130 100 120 150 140 110 120 130 130 140 150 110 120 150 130 150 120
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LYB-H70A 103
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120 220 210 180 210 190 140 170 120 160 180 190 160 150 150 140 150 240 200 150
140 180 130 120 170 140 150 150 130 140 120 150 120 130 170 150 150 160 170 160
130 170 150

LYB-H71A 99
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150 140 130 130 130 150 150 160 150 180 150 120 180 150 140 120 130 170 190 200
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200 170 140 150 120 150 150 160 150 160 160 120 150 100 130 130 150 130 120

LYB-H72A 73
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150 120 140 200 150 200 150 180 160 180 120 140 170 230 200 150 160 150 160 160
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LYB-H73A 115
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120 110 130 120 110 150 130 140 130 120 110 170 150 120 130 110 120 140 110 100
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LYB-H74A 189
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90 170 130 130 90 110 90 100 130 140 120 90 80 110 100 100 90 130 140 150
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130 110 180 110 120 110 90 130 110 140 100 170 110 110 100 80 100 130 120 130
120 70 120 110 100 100 80 100 100 80 130 110 110 130 90 120 100 110 110 120
140 130 120 110 90 140 130 140 150

LYB-H75A 95
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200 230 150 140 190 270 140 100 150 100 100 120 150 150 250 150 170 150 120 90
150 110 110 140 150 180 150 150 130 140 150 130 140 120 130

LYB-H76A 80
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90 80 90 70 90 100 70 60 100 50 50 60 60 50 60 60 80 110 100 170

LYB-H77A 116
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80 110 90 110 100 90 80 60 100 100 100 90 130 110 80 90 100 100 90 110
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LYB-H78A 118
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LYB-H79A 137
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LYB-H80A 96
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100 80 70 70 60 80 80 70 60 70 60 70 100 80 80 70 60 60 70 80
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LYB-H81A 144
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110 100 110 110 110 170 100 140 120 150 100 120 100 110 100 120 110 120 130 130
130 100 100 100 150 150 150 140 150 110 120 150 140 130 110 100 90 80 70 100
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130 140 140 130 120 120 100 110 130 130 130 130 100 90 80 110 90 70 80 70
70 80 70 60

LYB-H82A 121
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110

LYB-H83A 288
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90 100 90 80 70 70 60 80

LYB-H84A 147
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LYB-H85A 160
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100 120 90 100 130 90 90 100 100 70 80 60 50 100 110 90 100 90 100 80
90 150 80 100 90 70 80 100 80 60 70 70 100 80 80 70 70 40 50 40
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110 120 140 100 110 120 80 120 90 60 100 80 90 80 50 80 70 60 90 60
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LYB-H86A 85
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120 110 120 90 100 130 100 90 100 100 100 100 100 120 90 110 100 90 80 50
70 80 70 50 80

LYB-H87A 284
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80 70 70 80 90 80 80 70 90 110 100 80 70 80 80 100 100 70 90 90
100 80 100 80 110 60 80 80 70 60 70 80 80 70 70 80 60 70 70 80
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90 80 100 80 90 80 80 120 80 90 90 80 70 90 70 70 80 80 70 60
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70 100 100 90 80 100 90 80 60 80 60 70 70 70 60 90 70 80 60 50
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70 80 90 100

LYB-H88A 132
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90 100 80 70 80 90 100 60 100 80 90 70 60 80 100 80 90 70 100 70
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50 60 60 70 70 80 100 100 90 80 90 100 120 70 70 70 60 100 110 80
100 100 100 80 100 90 80 90 80 90 150 100 110 120 80 100 80 90 70 80
80 100 80 90 100 70 80 60 80 70 80 60

LYB-H90A 55
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288 302 264 215 176 209 191 170 233 215 174 218 158 220 233

LYB-H90B 55
212 295 265 303 326 210 175 240 208 197 235 304 227 166 242 242 275 206 225 303
276 307 321 327 291 203 229 253 273 189 208 198 146 155 363 225 180 198 303 222
294 282 278 223 168 219 171 173 251 217 178 217 145 199 234

LYB-H91A 55
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519 452 330 394 374 331 201 287 343 244 386 215 273 270 195 251 215 303 306 198
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LYB-H91B 55
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178 184 206 162 162 220 197 142 223 235 273 251 251 160 269

LYB-H92A 54
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255 178 202 264 274 238 319 303 266 264 265 182 319 350

LYB-H92B 54
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244 339 308 295 198 271 305 225 351 227 310 330 228 272 199 266 288 274 173 255
244 183 197 264 282 234 315 300 284 267 269 201 303 355

LYB-H93A 76
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71 138 198 112 116 105 143 166 201 205 101 158 161 172 220 271 260 204 202 171
184 242 216 226 243 196 151 90 155 214 134 99 134 212 155 148

LYB-H93B 76
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237 181 201 153 144 102 102 92 195 148 156 157 219 137 158 169 210 209 271 157
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188 253 215 229 250 193 143 86 152 208 127 99 132 204 165 141

LYB-H94A 54
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329 343 372 456 353 266 224 305 272 236 289 259 275 271 200 225 171 178 241 295
299 310 226 231 274 295 217 160 129 152 156 169 212 156

LYB-H94B 54
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327 338 380 443 350 278 214 303 264 245 299 256 246 284 193 231 161 188 240 301
286 327 217 238 274 293 222 158 131 151 151 168 212 161

LYB-H95A 66
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249 258 180 328 309 353 297 388 366 434 264 212 201 262 218 188 209 198 281 252
215 195 164 170 163 155 115 155 109 126 187 176 146 140 136 123 157 118 196 142
165 150 128 153 136 134

LYB-H95B 66
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248 240 192 336 317 349 294 387 362 440 264 206 216 247 223 180 215 209 286 256
210 184 168 156 159 159 131 153 120 134 191 197 139 138 134 139 151 119 198 152
155 158 130 140 133 86

LYB-H96A 94
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105 96 114 138 119 185 186 295 336 246 241 194 110 92 138 133 153 164 125 292
300 167 147 239 227 242 173 114 138 88 89 72 60 67 108 158 87 131 132 123
225 254 171 189 144 144 221 177 209 203 143 121 174 133

LYB-H96B 94
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88 121 186 165 131 150 141 121 86 50 55 83 199 160 108 90 75 69 99 92
95 99 116 130 107 200 179 282 328 229 252 189 115 90 135 138 155 169 128 308
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229 246 181 188 141 136 217 171 213 202 155 132 167 106

LYB-H98A 54
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290 221 204 245 246 240 184 279 410 275 412 412 378 291 312 345 266 362 327 316
380 307 323 327 266 371 291 324 268 431 291 204 222 227

LYB-H98B 54
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LYB-H99A 55
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LYB-H99B 55
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445 398 350 371 342 511 546 573 292 354 268 439 387 354 252

LYBH100A 52
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225 265 264 204 208 129 166 182 179 383 265 244

LYBH100B 52
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229 258 275 200 208 118 174 178 165 387 287 214

LYBH101A 74
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LYBH101B 74
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LYBH103A 61
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152

LYBH103B 61
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156

LYBH104A 54
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LYBH104B 54
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LYBH107A 56
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LYBH107B 56
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LYBH108A 76
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63 105 63 81 84 139 135 76 80 134 74 112 125 69 132 142 136 172 110 124
100 73 71 102 63 124 113 139 120 114 157 129 62 107 77 95

LYBH108B 76
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90 63 66 111 59 119 113 141 121 121 140 120 60 93 70 96

LYBH109A 57
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239 203 143 121 135 175 146 332 112 109 172 227 190 154 221 390 221

LYBH109B 57
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237 194 133 145 126 165 158 325 108 115 194 220 183 147 216 397 208

LYBH110A 69
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166 217 201 244 280 234 166 124 221

LYBH110B 69
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175 210 225 244 259 253 138 136 228

LYBH111A 59
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LYBH111B 59
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LYBH112A 115
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78 102 104 107 94 105 134 159 82 89 58 84 154 152 135

LYBH112B 115
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81 75 67 98 81 95 138 173 148 190 169 192 121 168 134 122 211 140 95 87
85 88 95 109 96 116 115 155 95 78 50 110 150 176 125

LYBH113A 65
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133 156 200 167 199

LYBH113B 65
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216 195 125 228 242 186 168 129 166 173 79 141 122 326 328 185 131 82 77 98
144 170 230 162 142 134 195 216 199 173 162 147 175 214 164 104 121 93 86 115
132 154 205 174 200

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	

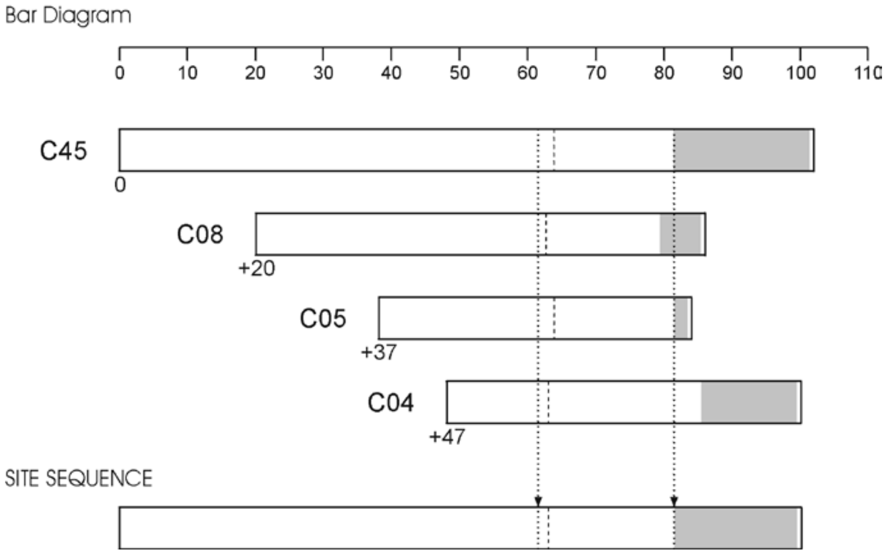


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

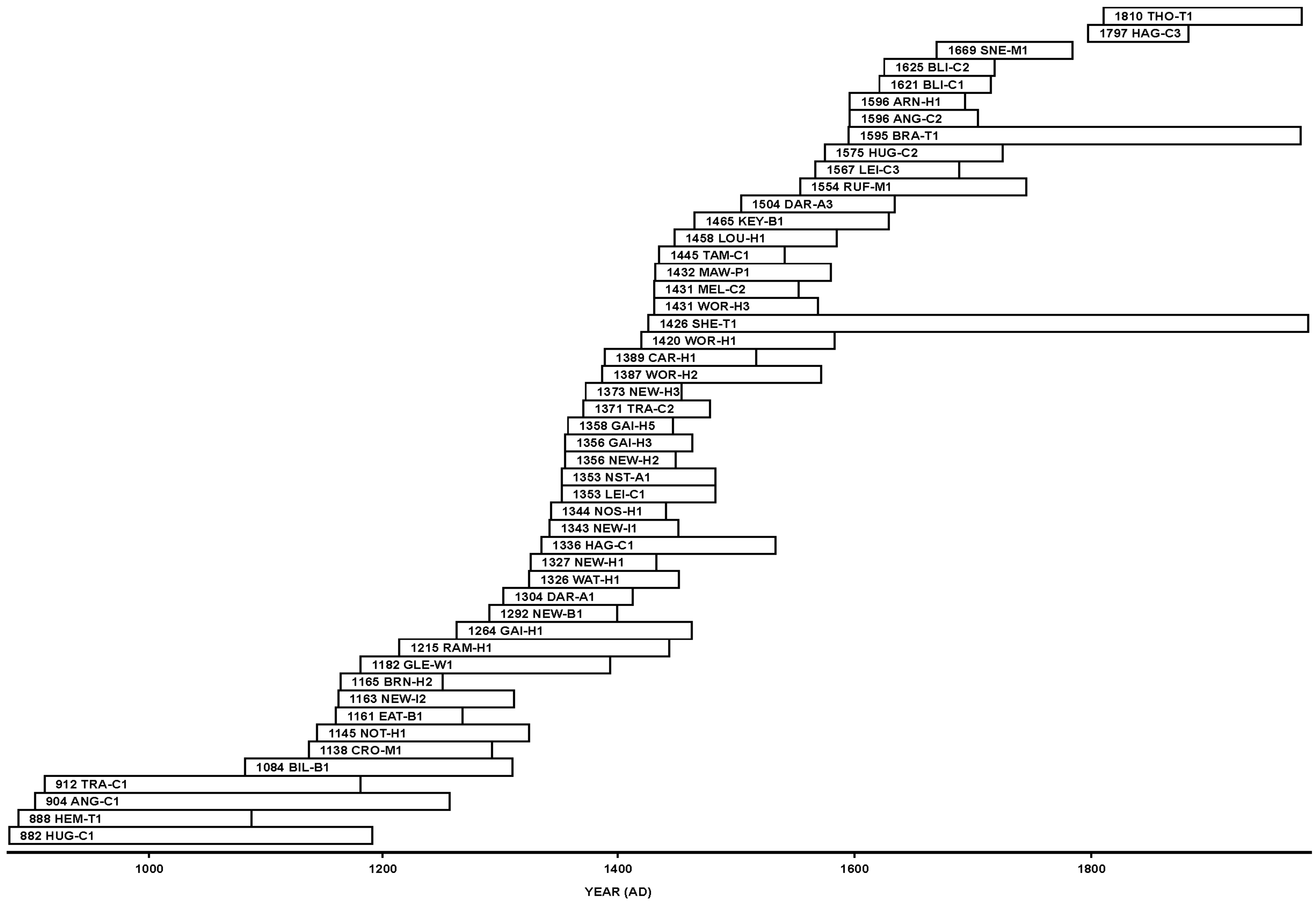
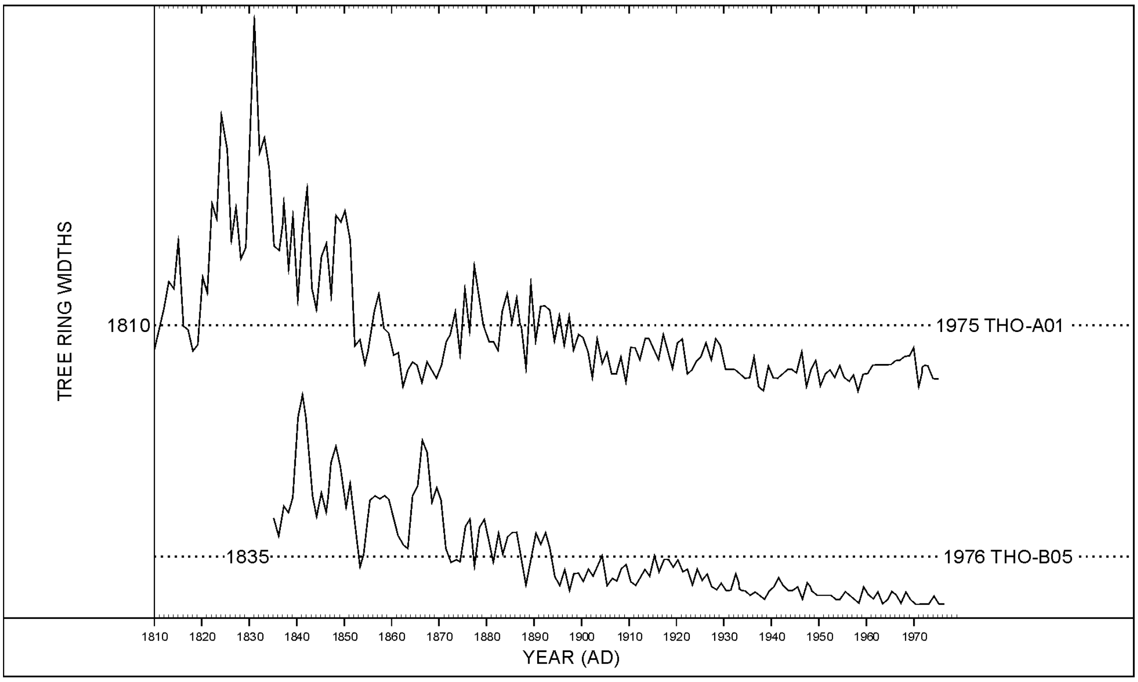


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

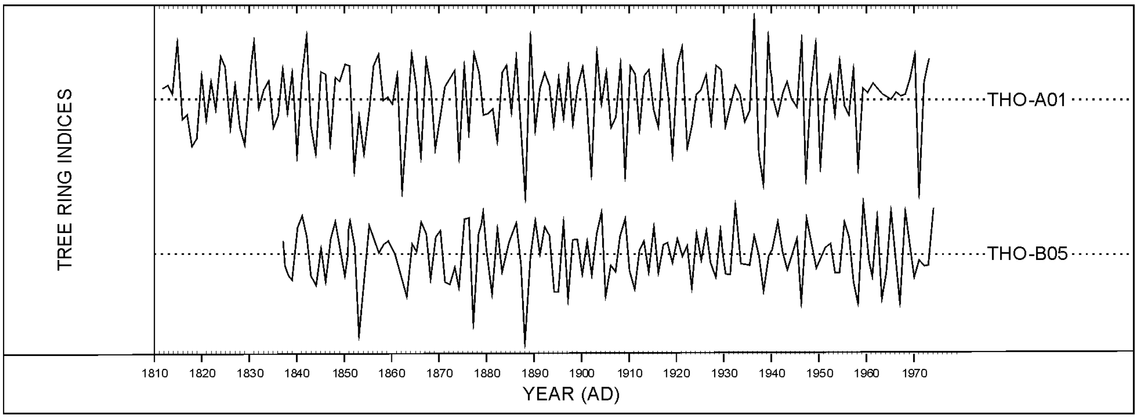


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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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