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Summary

Fifty samples were obtained from the roofs of the north and south aisles of the Lady Chapel, and the south aisle of the Choir at Worcester Cathedral. These samples were analysed in conjunction with 143 obtained previously, producing four site chronologies, WORCSQ01-04, that included new samples; one sample dated individually. These new chronologies replace those produced during earlier analysis.

The site chronologies comprise 23, six, four, and two new samples, being 289, 191, 131 and 90 rings long. Three of these dated spanning AD 1484 - AD 1772, AD 1095 - 1285, and AD 1294 - AD 1424.

The latest work, from the north aisle of the Lady Chapel, uses timber felled in AD 1772. Some work in the south aisle possibly dates to this time too.

The Choir south aisle roof contains timber felled in AD 1742, with a brace structure here being made of timber felled in AD 1727 and between AD 1733 - 68.

The Lady Chapel roofs and the Choir south aisle roof also contain probable early to mid-seventeenth century timber, and probable early to mid-fifteenth century timber.

The north aisle of the Lady Chapel also contains probable early to mid-thirteenth century timber. Several timbers are of indeterminate date.

Keywords

Dendrochronology
Standing Building

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Frontispiece: Worcester Cathedral from the south-west, across the River Severn.
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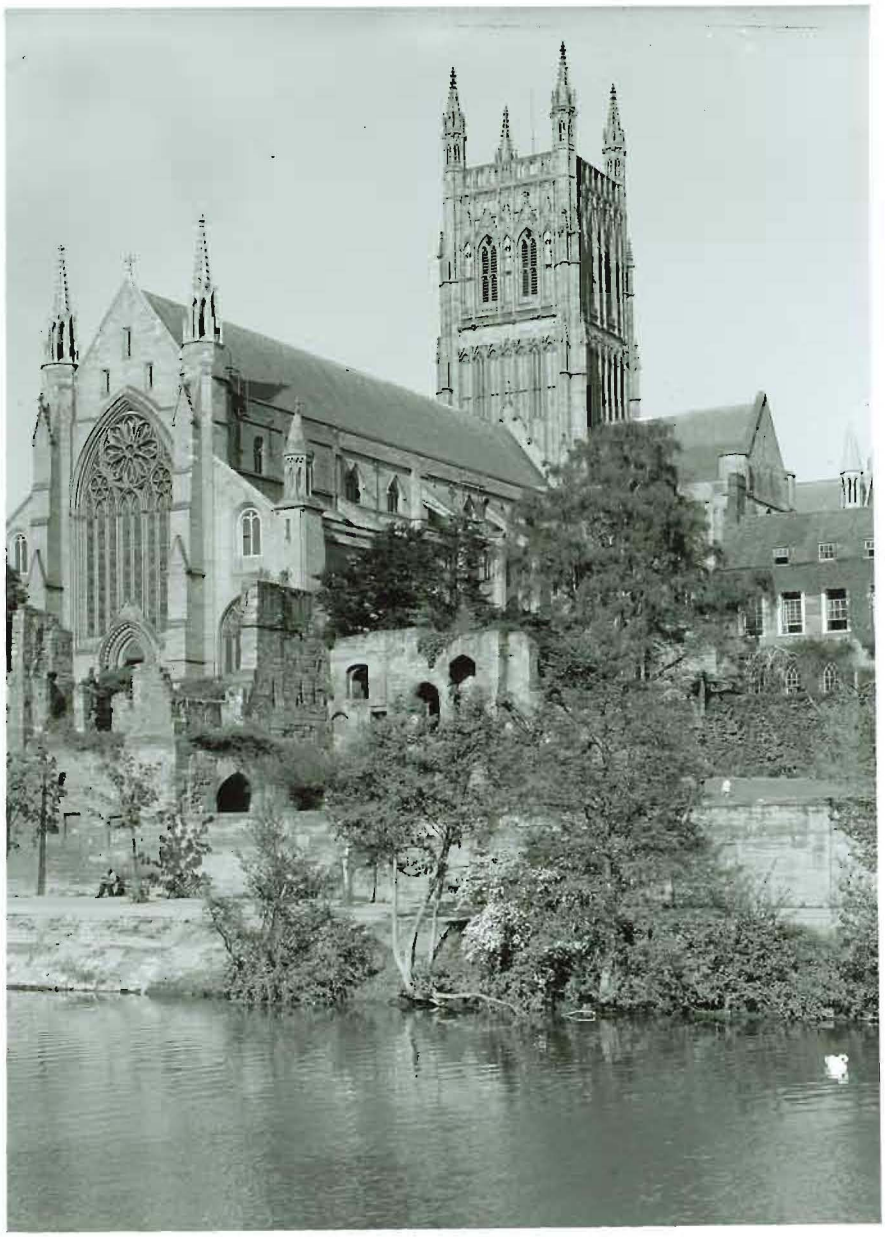

Introduction

Worcester Cathedral (frontispiece), standing in a prominent position on the east bank of the River Severn (SO 850 545; Fig 1) has a long history. The bishopric was founded in the seventh century and the first Cathedral was dedicated to St Peter. Oswald, who was made bishop in AD 961, built a new cathedral, dedicated to St Mary. The presbytery of St Peter's was rebuilt following a Danish raid in AD 1041. Both early cathedrals appear to have been demolished around the time St Wulfstan started the present cathedral in AD 1084 (although the current hypothesis is that the Chapter House is a remodeling of a late Anglo-Saxon rotunda).

Surviving work of St Wulfstan's period includes the crypt, western transepts, cloisters, and Chapter House. In AD 1175 the crossing tower fell down and was rebuilt (Guy 1994). It was rebuilt again in the AD 1370s. In AD 1224 the construction of a new east end was started under bishop William of Blois. Much of the existing decorated architecture at the east end belongs to this phase, with additional work in the perpendicular style dating from the late-fourteenth or early-fifteenth century. There was also a considerable amount of rebuilding activity in the nineteenth century.

A modest amount of sampling for tree-ring analysis has been undertaken from timbers of the nave roof. This was commissioned by the Dean and Chapter of Worcester Cathedral in AD 1993, the work being funded by English Heritage (Howard *et al* 1995). The AD 1993 analysis indicated that, although a significant number of samples could not be dated, a certain amount of timber was felled in the early-seventeenth century, for repair work undertaken at that time. That programme of sampling showed that some earlier timbers were reused.

A much larger programme of sampling for tree-ring analysis, funded by English Heritage, has been undertaken from timbers of the choir, the north-east and south-east transepts, and the crossing between them in AD 1999 (Howard *et al* 2000). A further programme of tree-ring analysis was undertaken of the timbers of the roof of St John Chapel, and of the roof connecting the Chapel to the Chapter House (Howard *et al* 2001).

The work reported upon here concerns three areas of roofing, that of the north and the south aisles of Lady Chapel, and the south aisle of the Choir. A plan of the Cathedral showing the areas under consideration in this report is shown in Figure 2. The purpose of this work, also funded by English Heritage, was to inform the current (AD 2003) process of repair to these roofs by establishing felling dates for the timbers within. The repairs required the lifting of the lead covering and the late nineteenth or early twentieth-century softwood boards beneath. Normally clear access to these roofs, though not impossible, is difficult. The removal of the lead and boards allowed for clear and uninterrupted access to all timbers, and made it less difficult to obtain samples with complete sapwood, or with the heartwood/sapwood boundary. Access to such elements of the timber is often obstructed by the roof covering.

The Laboratory would like to take this opportunity to thank all those who assisted with the sampling of the timbers. In particular thanks are due to the Dean and Chapter of Worcester Cathedral, the Clerk of Works, and to the Vergers' Office, whose staff assisted with access to the roof. The Laboratory would also like to thank Mr Christopher Guy, the Cathedral Archaeologist, who made a detailed study of the roof, produced and provided the drawings and

photograph used in this report, and who assisted with the descriptive introduction to the site given above.

The roofs

For the purposes of this programme of analysis the Laboratory was asked to sample three areas of roofing; the north and south aisles of the Lady Chapel, and the south aisle of the Choir.

Structurally, the roofs of all three areas are very similar. Each is formed in a lean-to fashion against the main walls of the Lady Chapel or the Choir. The roofs of the Lady Chapel aisles consists of principal rafter frames with tiebeams fixed at their inner ends into the wall of the chapel, and wall posts, There are four principal rafter frames in the north aisle, and two in the south. The principal rafters carry double purlins, which in turn carry slightly smaller common rafters. The north aisle is thus divided up into five bays of varying width, the south aisle into three bays of equal width. At various intervals within these roofs are to be found paired struts, a lower one running from the foot of the wall posts where it meets the tiebeam to the lower purlin, and an upper one from about half way up the wall posts to the upper purlin. An illustration of a typical frame from the Choir south aisle roof is given in Figure 3.

The Choir south aisle is also constructed of principal rafter frames, in this case six, again with tiebeams fixed into the wall, and wall posts. These frames, which divide the roof up into seven equal bays carry triple purlins, the common rafters here being noticeably smaller than the principals.

The timbers in all three roof areas appear to be of mixed age. Judging from the evidence of empty mortices, redundant tennons, and peg holes, it is believed that many of the beams are reused. Such timbers appear to be poorly carpentered and are now well worn and eroded, giving the impression of being of some antiquity.

On the other hand there are timbers which show no signs of reuse, are well carpentered, and squarely cut. Such timbers show surface evidence of sawing, possibly with a mechanical circular blade. These timbers are very sound and show no evidence of being degraded.

The roofs also contain modern softwood timbers which are known to date to the repairs of the AD 1960s, or believed to belong to other minor earlier twentieth-century repairs of indeterminate date. No formal record of these works was ever made. Drawings of these roofs, showing the possible phasing interpretation are given in Figures 4a-c.

At the east end of the Choir south aisle roof is found an unusual bracing structure, laid horizontally on the floor of the roof void (the upper side of the aisle ceiling). This is formed almost as a roof truss, with principal rafters, a tiebeam, king post and struts. It appears to hold the east gable end wall plate in place. Its date is completely unknown though a comparison with other timbers in the roof suggests it might be of eighteenth century date. A photograph of this structure is given in Figure 5.

The Choir also contains a small number of "random" individual timbers, inserted as blocks or

beams in the walls, with no apparent structural significance. In some cases these timbers appear to have had a previous use, judging by the evidence of redundant mortices etc. Some of these timbers appear to have been pulled out of their sockets in the wall and are *ex situ*, that is, they have been moved and are no longer in their original positions.

Thus, on the basis of this physical appearance of the timbers, on the documentary evidence, and upon the basis of previous tree-ring analysis, it is believed that two or three, and possibly more, phases of oak timber might be present. It is believed that the reused timbers might date from the thirteenth century, while the later timber is probably of eighteenth or nineteenth century date. It is believed that there may be other timbers of different dates.

Sampling

After discussion with Chris Guy on the possible phasing of the timbers, and in conjunction with the brief provided by English Heritage, a total of 50 core samples was obtained. Each sample was given the code WOR-C (for Worcester Cathedral). Given that the last sample from previous programmes of work was numbered WOR-C143, the samples obtained for this analysis run from WOR-C144 to C193.

An attempt was made to obtain approximately equal numbers of samples from each of the three roofs, with samples within each roof spread between what appeared to be reused timbers and those that were believed to be later. Of course, such a selection is based on the subjective examination of the timbers and in the past this has not always been correct. Some timbers which were originally thought to be later on the basis of their appearance subsequently turn out not to be and vice-versa. In particular the timbers of the Lady Chapel south aisle were less easy to categorise than those of the other roofs. Samples were also obtained from some of the random timbers in the Choir, and from the horizontal brace structure here.

This sampling information given above is summarised below:

Sample area	Number of samples	Sample numbers
Lady Chapel north aisle - later timbers	6	WOR-C144 – 149
Lady Chapel north aisle - reused timbers	9	WOR-C150 – 158
Lady Chapel south aisle all timbers	17	WOR-C159 – 175
Choir south aisle - reused timbers	7	WOR-C176 – 182
Choir south aisle - later timbers	6	WOR-C183 – 188
Choir south aisle - horizontal brace	5	WOR-C189 – 193

The positions of the timbers cored were recorded at the time of sampling on the timber survey plans produced and provided by Christopher Guy, Figures 4a - c. It should be pointed out that not all the timbers in the roof are illustrated in these drawings, so that in some cases, the horizontal brace structure or the wall plates for example, the position of some individual

timbers is not shown. Details of the samples are given in Table 1. When referring to frames, bays, and timbers, this report follows the numbering convention used in the drawings provided.

Analysis

Each sample was prepared by sanding and polishing, and the growth-ring widths of all 50 were measured; the data of these measurements are given at the end of the report. For the purposes of analysis, the 50 samples obtained in this programme of work, WOR-C144 – C193, were compared with each other by the Litton/Zainodin grouping procedure (see appendix) in conjunction with all other samples of at least 54 rings obtained during previous campaigns, samples WOR-C01 – C143.

At a minimum *t*-value of 4.5 two larger groups, and two smaller groups, which included cross-matching samples from the most recently acquired material, could be formed, these newly formed groups replacing those of any previous analysis. The largest of these groups contains a total of 79 samples, 56 samples obtained previously plus 23 newly acquired. All 79 samples were combined at their indicated relative off-set positions to form site chronology WORCSQ01, with a combined overall length 289 rings. Site chronology WORCSQ01 was compared with a large number of reference chronologies for oak indicating a series of very high *t*-value cross-matches when the date of its first ring is AD 1484 and the date of its last ring is AD 1772. Evidence for this dating is given in the *t*-values of Table 2.

The next major group comprises a total of 40 samples, 34 obtained previously plus six samples newly acquired. These 40 samples were combined at their indicated relative off-set positions to form site chronology WORCSQ02, with a combined overall length 229 rings. Site chronology WORCSQ02 was also compared to a large number of reference chronologies for oak indicating a series of satisfactory *t*-value cross-matches when the date of its first ring is AD 1057 and the date of its last ring is AD 1285. Evidence for this dating is given in the *t*-values of Table 3.

The third group comprises eight samples, four from the previous work and four newly obtained. These eight samples were combined at their indicated relative off-set positions to form site chronology WORCSQ03, with a combined overall length 139 rings. Site chronology WORCSQ03 was also compared to a large number of reference chronologies for oak indicating a series of satisfactory *t*-value cross-matches when the date of its first ring is AD 1286 and the date of its last ring is AD 1424. Evidence for this dating is given in the *t*-values of Table 4.

A fourth and final group, consisting of only two new samples, could also be formed, WORCSQ04, of combined overall length 90 rings. Although compared to a large number of reference chronologies, there was no cross-matching and site chronology WORCSQ04 remains undated.

The relative positions of only the 35 newly acquired cross-matching samples of each of the four groups (any previously obtained cross-matching samples being omitted) are shown in bar diagrams Figures 6, 7, 8, and 9. In these bar diagrams the samples are shown in simple last

measured ring position, but are colour coded to show the area from which samples have been taken, blue for the Lady Chapel, and red for the Choir.

In addition to the main groups of samples, other small groups which included previously and newly obtained samples were also indicated. However, there was usually only one new sample in each group. An attempt was made to date these groups by comparison with the reference chronologies, but no consistent satisfactory cross-matching was indicated. These groups were not made into site chronologies and are thus not illustrated, the newly obtained samples being now treated as singletons.

Each of the four new site sequences thus created, WORCSQ01 – C04, was then compared with all the remaining newly acquired but ungrouped samples, and the samples which had cross-matched with the previously acquired material but were still undated. There was, however, no further satisfactory cross-matching. All the remaining newly acquired samples were then compared individually with the full range of reference chronologies. This process indicated satisfactory cross-matching and dating for only one further sample, WOR-C169, dated as spanning AD 1682 – AD 1754. Evidence for this dating is given in the *t*-values of Table 5.

Brief details of these four site chronologies thus created are sumarised below, showing the number of new samples obtained, and the combined number of rings and date span of only these newly acquired samples.

Site chronology	**Sample area (new samples only)**	**Number of new samples**	**Number of rings**	**Date span (new samples)**
WORCSQ01	Lady Chapel, north/south aisles (including horizontal brace)	23	289	AD 1484 – 1772
WORCSQ02	Lady Chapel, north aisle	6	191	AD 1095 – 1285
WORCSQ03	Lady Chapel, south aisle Choir, south aisle	4	131	AD 1294 – 1424
WORCSQ04	Lady Chapel, south aisle	2	90	undated
WOR-C169	Lady Chapel, south aisle	1	73	AD 1682 – 1754

Interpretation

The Lady Chapel - north aisle

Five of the dated samples from the north aisle of the Lady Chapel, WOR-C144, C145, C146, C151, and C153, retain complete sapwood, that is, they have the last growth-ring produced by the tree before it was felled. On all five such samples the last measured complete sapwood

ring date is the same, AD 1772. This is thus the felling date of the trees represented. The relative position of the heartwood/sapwood boundary on a sixth sample from this area of the roof, WOR-C149, would strongly suggest that this represents a tree felled at this time too.

The north aisle, however, also contains timbers which were felled centuries earlier, an illustration of the relative position and dates of each group of samples from within this roof being shown in Figure 10. Three samples, WOR-C150, C154, and C156 have heartwood/sapwood boundary dates of AD 1218, AD 1204, and AD 1211 respectively. The average heartwood/sapwood boundary date of these three is AD 1211. Using a 95% confidence limit for the amount of sapwood on mature oaks in this part of England of 15 – 50 rings would give the timbers represented by these three samples an estimated felling date in the range AD 1226 – 61.

It should be stressed, however, that it is not certain that the trees represented by these three samples were felled at exactly the same time. The spread of the relative position of the heartwood/sapwood boundary on each, ranging from AD 1204 to AD 1218, is perhaps a little wider than might be expected on timbers with an identical felling date. Whilst all three timbers were certainly felled in the early to mid-thirteenth centuries, it is possible that they were felled at slightly different times. It is possible, for example, that the timber represented by sample WOR-C154 was felled as early as AD 1219 whilst that represented by sample WOR-C150 was felled as late as AD 1268.

This possibility is emphasised by the fact that another timber from the north aisle of the Lady Chapel, though early, was almost certainly felled later than the three timbers discussed above. This later timber is represented by sample WOR-C152. This sample has a last measured ring date of AD 1285. It does not, though, have a heartwood/sapwood boundary, and thus its felling date cannot be estimated. It is unlikely, however, to have been felled before AD 1300, some 32 years or so at least after the latest possible felling of any of the above mentioned timbers.

Two other apparently early timbers, represented by samples WOR-C155 and C158, are also without a heartwood/sapwood boundary and their felling dates cannot be reliably estimated. It is unlikely that the timbers they represent were felled before AD 1188 and AD 1211 respectively.

The Lady Chapel - south aisle

The south aisle of the Lady Chapel also contains timbers with a variety of felling dates. The latest felling is represented by sample WOR-C169. This has a heartwood/sapwood boundary date of AD 1751. Using a 95% confidence limit for the amount of sapwood on mature oaks in this part of England of 15 – 50 rings would give the timber represented by this sample an estimated felling date in the range AD 1766 to AD 1801. It is perhaps most likely that this timber has a felling date very similar, if not identical, to that of the latest timbers of the north aisle, that is, AD 1772.

Other, apparently reused, timbers from the south aisle are earlier. Probably the earliest dated timbers are represented by samples WOR-C160 and C163 These have almost identical

heartwood/sapwood boundary dates, AD 1398 and AD 1399, and probably represent a single phase of felling. Using the same sapwood estimates as above would give the timbers represented an estimated felling date in the range AD 1413 - 48.

The felling dates of the timbers represented by samples WOR-C162 and WOR-C166 on the other hand cannot be reliably estimated because neither of them have a heartwood/sapwood boundary. It is unlikely, however, that they were felled earlier than AD 1593 and AD 1611 respectively.

The last two dated timbers from the south aisle of the Lady Chapel are represented by samples WOR-C168 and C171. These have similar heartwood/sapwood boundary dates, AD 1605 and AD 1609 respectively, and again probably represent timbers of a single phase of felling. Using the usual sapwood estimate for this region would give the timbers represented an estimated felling date in the range AD 1622 - 57.

Choir, south aisle

Like the north and south aisles of the Lady Chapel the south aisle of the Choir has timbers of different felling dates, the relationship of these again being shown in Figure 10. The earliest material found in this analysis is that represented by sample WOR-C177. This sample has a heartwood/sapwood boundary date of AD 1406, and retains 18 sapwood rings. Given that its last measured ring date is AD 1424, this would give an estimated felling date in the range AD 1425 – 56, using a 95% confidence limit for the amount of sapwood on mature oaks in this part of England of 15 – 50 rings

It is likely that the timbers represented by samples WOR-C179 and WOR-C180 are of a single phase of felling, such an interpretation being based on the fact that the relative position of the heartwood/sapwood boundary on each sample is very close to each other, varying by only one year. The average heartwood/sapwood boundary date of these two is AD 1610. Using a 95% confidence limit for the amount of sapwood on mature oaks in this part of England is 15 – 50 rings again would give the timbers represented by these an estimated felling date in the range AD 1625 – 60.

The latest certain felling is represented by samples WOR-C186 and C188. Both of these samples have complete sapwood, the last ring dates of both being the same at AD 1742. This is thus the felling date of the timbers represented. Other samples in this group, WOR-C181, C182, C184, and C185 have their heartwood/sapwood boundary in relative positions consistent with all these timbers being felled in, or very close to, AD 1742 also.

Less easy to determine is the felling date, or dates, of a number of timbers from the horizontal bracing structure. One of the samples from this structure, WOR-C192, retains complete sapwood, with a last measured ring date of AD 1727, this being the felling date of the timber. This sample, however, has only 13 sapwood rings, less than the 95% confidence limit of 15 – 50 rings used here. It also has the earliest heartwood/sapwood boundary date, AD 1714, of any sample from the bracing structure. If the other samples from the bracing structure were to have been felled in AD 1727 too, they would have to have even fewer sapwood rings. While this is not beyond the bounds of possibility it would be unusual.

The average heartwood/sapwood boundary date of those four samples from the bracing structure without complete sapwood, WOR-C189, C190, C191, and C193, is AD 1718. Using the same sapwood estimate as above would give a felling date range of AD 1733 – 68. It is thus probable that the brace structure uses timber felled some time within this date range as well as a piece felled in AD 1727.

The latest possible material may be represented by the individually dated sample WOR-C169. This has a heartwood sapwood boundary date of AD 1751. Using the same sapwood estimate as above would give the timber represented an estimated felling date in the range AD 1766 to AD 1801. Given that there is no other evidence for work after the early AD 1770s it is more probable that this timber was felled at about this time rather than later.

The felling date of the final dated timber, represented by WOR-C187, cannot be estimated because it does not have the heartwood/sapwood boundary. However, given that its last measured ring date is AD 1387, it is unlikely to have been felled before AD 1402.

This preceding interpretation may be summarised below:

Sample area (Lady Chapel)	**Sample numbers**	**Felling date or estimated felling date range**
north aisle	C144, C145, C146, C149, C151, C153	AD 1772
south aisle	C169	AD 1766 – AD 1801
south aisle	C168, C171	AD 1622 – 57
south aisle	C166	not before AD 1611
south aisle	C162	not before AD 1593
south aisle	C160, C163	AD 1413 – 48
north aisle	C152	not before AD 1300
north aisle	C150, C154, C156	AD 1226 – 61
north aisle	C158	not before AD 1211
north aisle	C155	not before AD 1188

Sample area (Choir)	**Sample numbers**	**Felling date or estimated felling date range**
south aisle	C181, C182, C184, C185, C188	AD 1742
brace structure	C189, C190, C191, C192, C193	AD 1727 and AD 1733 – 68
south aisle	C179, C180	AD 1625 – 60
south aisle	C177	AD 1425 – 56
south aisle	C187	not before AD 1402

Conclusion

Analysis by tree-ring dating has produced three site chronologies, WORCSQ01 – 03, comprising a total of 33 dated samples, with one further sample being dated individually, plus one undated site chronology of two samples, WORCSQ04. This has provided felling dates, or estimated felling date ranges, for timbers from the north and south aisles of the Lady Chapel, and the south aisle of the Choir. As suspected on carpentry and structural ground, tree-ring analysis has shown that these timbers have a wide range of felling dates and, along with a terminal date for works, indicate the extensive reuse of earlier timber. An attempt to show the relationship between the dated timbers found in these roofs is shown in Figure 11.

The latest firmly dated material is that from the north aisle of the Lady Chapel, these timbers being felled in AD 1772. This appears to represent some of the latest repair work at Worcester Cathedral identified by tree-ring dating. It is possible that a small amount of material from the south aisle of the Lady Chapel is of this date too. The dating of the timber in this roof to the AD 1770s, in conjunction with other similarly dated material analysed earlier suggests that a large and extensive programme of roof repairs was undertaken at Worcester throughout the eighteenth century.

Some work had been undertaken on the roof of south aisle of the Choir, using timbers felled prior to that discussed above, in AD 1742. It is possible that the horizontal brace structure was put in place at this time, using one piece that had already been felled, in AD 1727, though it is possible that the brace structure is later and more closely associated with the AD 1770s work to the roof

An earlier phase of felling is represented by small groups of samples, WOR-C179 and C180, from the south aisle of the Choir, and WOR-C162, C166, C168, and C171, from the south aisle of the Lady Chapel. While the felling date of two of these cannot be reliably estimated, the group appears to represent the felling of timbers in the early to mid-seventeenth century.

There is then a further group of timbers, represented by WOR-C177 and C187, from the south aisle of the Choir, and WOR-C160 and C163, from the south aisle of the Lady Chapel. Again, while the felling date of one of these cannot be reliably estimated, the group probably represents the felling of timbers in the early to mid-fifteenth century.

It is not possible to estimate the felling date of the timber represented by sample WOR-C152, except to say that it is unlikely to have been felled before AD 1300.

The earliest phase of felling detected in this analysis is represented by samples WOR-C150, C154, C155, C156, and C158. Again the felling date of all the timbers represented by this group of samples is not certain, but they appear to indicate the cutting of timber in the early to mid thirteenth century. These conclusions may be summarised over page.

Sampling area	Sample numbers	Felling date
Lady Chapel, north aisle	C144, C145, C146, C149, C151, C153	AD 1772
Lady Chapel, south aisle	C169	probably no later than AD 1770s
Choir, south aisle	C181, C182, C184, C185, C188	AD 1742
Choir, brace structure	C189, C190, C191, C192, C193	AD 1727 and AD 1733 – 68
Lady Chapel, south aisle	C162, C166, C168, C171	probably early to mid-seventeenth century
Choir, south aisle	C179, C180	
Lady Chapel, south aisle	C160, C163	probably early to mid-fifteenth century
Choir, south aisle	C177, C187	
Lady Chapel, north aisle	C152	not before AD 1300
Lady Chapel, north aisle	C150, C154, C156, C158, C155	probably early to mid thirteenth century

The dating of the timbers from the Choir and Lady Chapel aisle roofs is highly consistent with that obtained for the other roofs at Worcester that have been analysed using dendrochronology. For example, the St John Chapel roof and the connecting roof use timbers felled in the early to mid AD 1740s, a date very similar to that of the material used in the Choir south aisle. The St John Chapel roof also contains timber felled in the mid-seventeenth, and early- to mid-fifteenth centuries.

Analysis of timbers from the high roofs at Worcester Cathedral have also produced felling dates in the AD 1720s, the mid-seventeenth century, and the mid- to late- thirteenth century. All such felling dates are echoed in the results obtained in the material from the aisle roofs undertaken here.

Some observations may now be made of this analysis. It is perhaps noticeable from Table 1 that most of the main structure of the Lady Chapel north aisle roof, the principal rafters, tiebeams, purlin, post, is made of the timber felled in AD 1772. Only one late timber is used as a common rafter, most of these being made of earlier timber reused.

On the other hand, on the basis of tree-ring dating, the south aisle of the Lady Chapel appears to have less late material in it than the other roofs. This roof appears to be made up largely of reused material. Such an interpretation appears to be consistent with the timber survey (see Fig 4b).

Turning to the principal timbers of the south aisle of the Choir these are again also made from later timbers, this roof appearing to have only a small amount of reused material in it.

The dating of the timber in the aisle roofs to the AD 1770s, in conjunction with other similarly dated material analysed earlier suggests that a large and extensive programme of roof repairs was undertaken at Worcester throughout the eighteenth century. In these repairs new timber appears to have been felled specifically for the principal structural timbers, with the older material being used for the lesser members.

Ungrouped and undated samples account for 14 of the 50 cores obtained. Half of these 14 undated individual samples have between 54 and 60 rings which is just about a sufficient number for satisfactory analysis. Other ungrouped and undated individuals samples are longer, the longest being WOR-C178 with 77 rings. Some of these undated samples, WOR-C148 for example, might have slight distortions to their rings, a feature which might account for their not cross-matching and dating. None of the other undated samples appear to have any problems which might make dating difficult. Given the extensive reuse of timbers in these roofs it is possible that some of the undated samples represent singletons of diverse date. Singletons are often difficult to date, particularly when they have lower numbers of growth-rings.

Eight of the 14 ungrouped and undated samples come from the south aisle of the Lady Chapel, a roof which contains a lot of reused material with different felling dates. Two other undated samples (WOR-C167 and C175) come from *ex situ* timbers in this roof, and it is likely, given their *t*-value cross-match, that they are from the same tree.

Using this analysis it may be possible to refine the tree-ring dates obtained with further documentary research into the repair or modification of the roofs. This may aid in the identification of the source roof, or roofs, of the reused material. The documentary sources may also provide information about the woodland sources of this timber.

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Table 1: Details of samples from the Lady Chapel north and south aisles, and the Choir south aisle, Worcester Cathedral

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Lady Chapel north aisle - later timbers					
WOR-C144	Lower purlin, east gable to P1	80	20C	AD 1693	AD 1752	AD 1772
WOR-C145	Post, P2	82	18C	AD 1691	AD 1754	AD 1772
WOR-C146	Principal rafter, P2	100	23C	AD 1673	AD 1749	AD 1772
WOR-C147	Tiebeam, P3	55	10	------	------	------
WOR-C148	Upper strut, P4	67	18C	------	------	------
WOR-C149	Post, P4	64	10	AD 1697	AD 1750	AD 1760
	Lady Chapel north aisle - reused timbers					
WOR-C150	Common rafter no 4 (from east end)	110	h/s	AD 1109	AD 1218	AD 1218
WOR-C151	Common rafter no 5	64	20C	AD 1709	AD 1752	AD 1772
WOR-C152	Common rafter no 6	143	no h/s	AD 1143	------	AD 1285
WOR-C153	Common rafter no 7	54	17C	AD 1719	AD 1755	AD 1772
WOR-C154	Common rafter no 11	54	h/s	AD 1151	AD 1204	AD 1204
WOR-C155	Common rafter no 13	79	no h/s	AD 1095	------	AD 1173
WOR-C156	Common rafter no 15	64	h/s	AD 1148	AD 1211	AD 1211
WOR-C157	Common rafter no 17	54	h/s	------	------	------
WOR-C158	Common rafter no 19	98	no h/s	AD 1099	------	AD 1196

Table 1: continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Lady Chapel south aisle - reused timbers					
WOR-C159	Tiebeam, P1	67	h/s	------	------	------
WOR-C160	Principal rafter, P1	84	h/s	AD 1315	AD 1398	AD 1398
WOR-C161	Wall plate, P1 – P2	67	h/s	------	------	------
WOR-C162	Lower purlin, P1 – P2	95	no h/s	AD 1484	------	AD 1578
WOR-C163	Principal rafter, P2	106	h/s	AD 1294	AD 1399	AD 1399
WOR-C164	Lower purlin, P2 to east gable wall	55	h/s	------	------	------
WOR-C165	Common rafter no 7	72	23	------	------	------
WOR-C166	Lower purlin, P1 to west gable wall	75	no h/s	AD 1522	------	AD 1596
WOR-C167	Ex-situ horizontal wall timber	90	h/s	------	------	------
WOR-C168	Common rafter no 6	54	15	AD 1567	AD 1605	AD 1620
WOR-C169	Strut at rafter 6	73	3	AD 1682	AD 1751	AD 1754
WOR-C170	Common rafter 8	56	15	------	------	------
WOR-C171	Common rafter 15	73	15	AD 1552	AD 1609	AD 1624
WOR-C172	Common rafter 16	54	h/s	------	------	------
WOR-C173	Common rafter 18	57	20C	------	------	------
WOR-C174	Ex situ timber	64	12C	------	------	------
WOR-C175	Ex situ timber	60	no h/s	------	------	------

Table 1: continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Choir south aisle - reused timbers					
WOR-C176	Tiebeam, P4	54	13	------	------	------
WOR-C177	Tiebeam, P5	68	18	AD 1357	AD 1406	AD 1424
WOR-C178	Common rafter 8	77	h/s	------	------	------
WOR-C179	Common rafter 6	78	12	AD 1546	AD 1611	AD 1623
WOR-C180	Lower purlin, P1 – P2	93	20	AD 1538	AD 1610	AD 1630
WOR-C181	Tiebeam, P1	69	18	AD 1671	AD 1721	AD 1739
WOR-C182	Tiebeam, P3	63	13	AD 1677	AD 1726	AD 1739
	Choir south aisle - later timbers					
WOR-C183	Wall post, P4	60	11	------	------	------
WOR-C184	Principal rafter, P4	55	15	AD 1685	AD 1724	AD 1739
WOR-C185	Principal rafter, P5	54	12	AD 1686	AD 1727	AD 1739
WOR-C186	Wall post, P6	54	12C	------	------	------
WOR-C187	Strut, wall post – purlin, P1	84	no h/s	AD 1304	------	AD 1387
WOR-C188	Principal rafter, P3	62	16C	AD 1681	AD 1726	AD 1742

Table 1: continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Choir south aisle - horizontal brace structure at east end					
WOR-C189	North strut	54	h/s	AD 1663	AD 1716	AD 1716
WOR-C190	North brace	57	6	AD 1666	AD 1716	AD 1722
WOR-C191	King post	69	h/s	AD 1653	AD 1721	AD 1721
WOR-C192	South brace	98	13C	AD 1630	AD 1714	AD 1727
WOR-C193	South strut	55	h/s	AD 1665	AD 1719	AD 1719

*h/s = the heartwood/sapwood boundary is the last ring on the sample
C = complete sapwood on sample, last measured ring date is felling date of the timber

Table 2: Results of the cross-matching of site chronology WORCSQ01 and relevant reference chronologies when first ring date is AD 1484 and last ring date is AD 1772

Reference chronology	Span of chronology	*t*-value	
East Midlands	AD 882 – 1981	13.6	(Laxton and Litton 1988)
England	AD 401 – 1981	11.3	(Baillie and Pilcher 1982 unpubl)
Quenby Hall	AD 1575 – 1724	10.6	(Howard *et al* 1993)
St Hugh's Choir, Lincoln Cathedral	AD 1575 – 1724	10.5	(Laxton and Litton 1988)
Bolsover Castle, Derby (Riding house)	AD 1494 – 1744	10.2	(Howard *et al* forthcoming)
England, London	AD 413 – 1728	9.6	(Tyers 1999 unpubl)
26 Westgate Street, Gloucester	AD 1399 – 1622	9.6	(Howard *et al* 1998)
Wales and West Midlands	AD 1341 – 1636	9.0	(Siebenlist-Kerner 1978)

Table 3: Results of the cross-matching of site chronology WORCSQ02 and relevant reference chronologies when first ring date is AD 1057 and last ring date is AD 1285

Reference chronology	Span of chronology	*t*-value	
Salisbury Cathedral, Wilts	AD 1155 – 1228	7.1	(Howard *et al* 1991)
Angel Choir, Lincoln Cathedral	AD 912 – 1248	6.9	(Howard *et al* 1985)
East Midlands	AD 882 – 1981	6.2	(Laxton and Litton 1988)
Brecon Cathedral, Powys	AD 996 – 1227	6.2	(Howard *et al* 1994)
England	AD 401 – 1981	6.0	(Baillie and Pilcher 1982 unpubl)
England, London	AD 413 – 1728	5.9	(Tyers 1999 unpubl)
Southern England	AD 1083 – 1589	5.8	(Bridge 1988)

Table 4: Results of the cross-matching of site chronology WORCSQ03 and relevant reference chronologies when first ring date is AD 1294 and last ring date is AD 1424

Reference chronology	Span of chronology	*t*-value	
The Post Office, Oxhill Warwick	AD 1322 – 1447	8.5	(Alcock *et al* 1989)
Stratford-upon-Avon, Warwicks	AD 1319 – 1462	8.5	(Alcock *et al* 1991)
East Midlands	AD 882 – 1981	8.3	(Laxton and Litton 1988)
Mercers Hall, Gloucester	AD 1289 – 1541	8.1	(Howard *et al* 1997)
Sinai Park, Burton on Trent, Staffs	AD 1227 – 1750	7.3	(Tyers 1997)
Southern England	AD 1083 – 1589	7.0	(Bridge 1988)
England	AD 401 – 1981	6.9	(Baillie and Pilcher 1982 unpubl)
England, London	AD 413 – 1728	6.9	(Tyers 1999 unpubl)

Table 5: Results of the cross-matching of sample WOR-C169 and relevant reference chronologies when first ring date is AD 1682 and last ring date is AD 1754

Reference chronology	Span of chronology	*t*-value	
Catholme, Staffs	AD 1649 – 1750	7.2	(Howard *et al* 1992 unpubl)
Stoneleigh Abbey, Warwicks	AD 1646 – 1813	6.2	(Howard *et al* 2000)
East Midlands	AD 882 – 1981	5.8	(Laxton and Litton 1988)
Grimston Bell-frame, Grimstone, Leics	AD 1674 – 1754	5.0	(Arnold *et al* forthcoming)
Bolsover Castle, Derby (Riding house)	AD 1494 – 1744	4.8	(Howard *et al* forthcoming)

Figure 1: Map to show general location of Worcester Cathedral

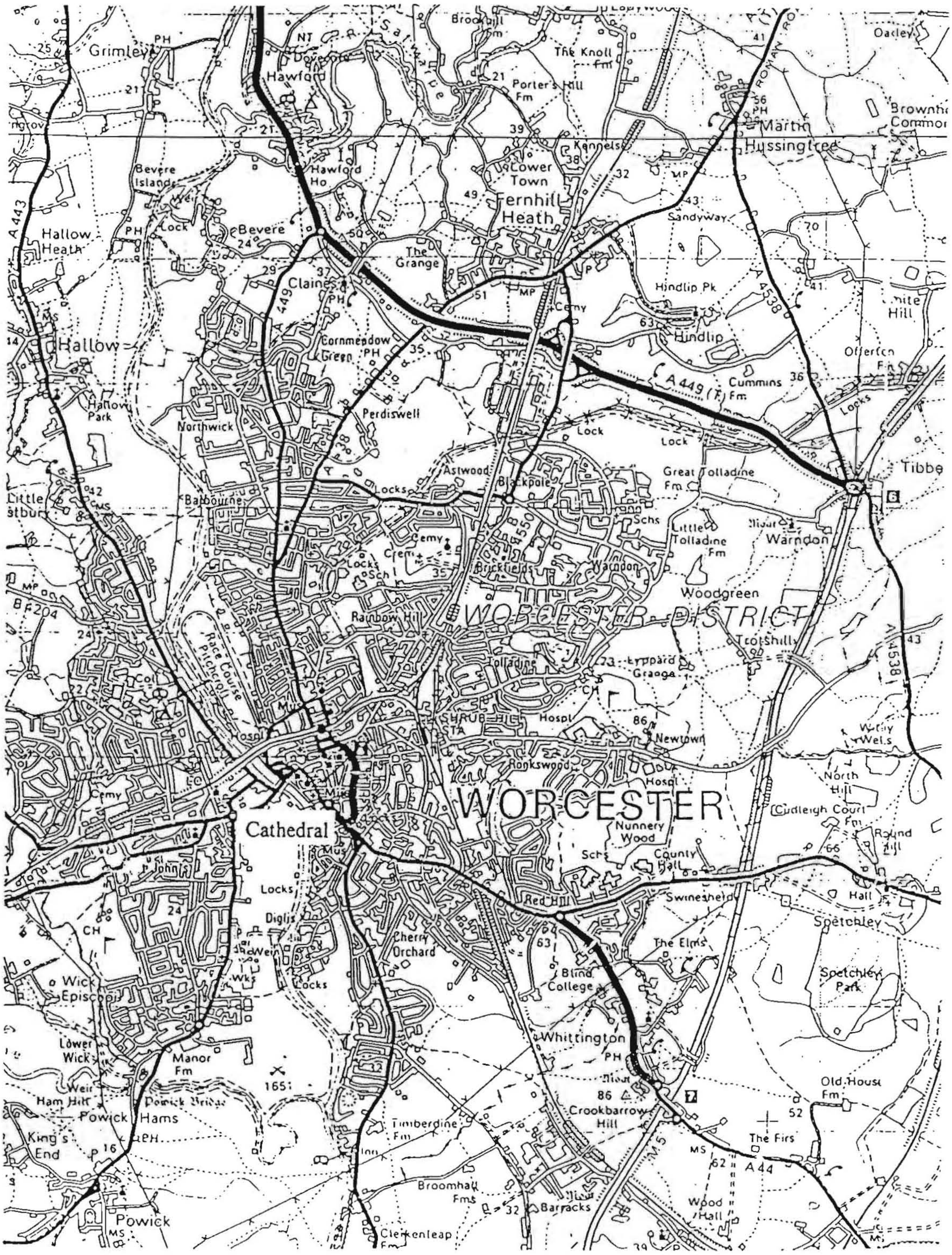


Figure 2: General plan of Worcester Cathedral to show areas of sampling

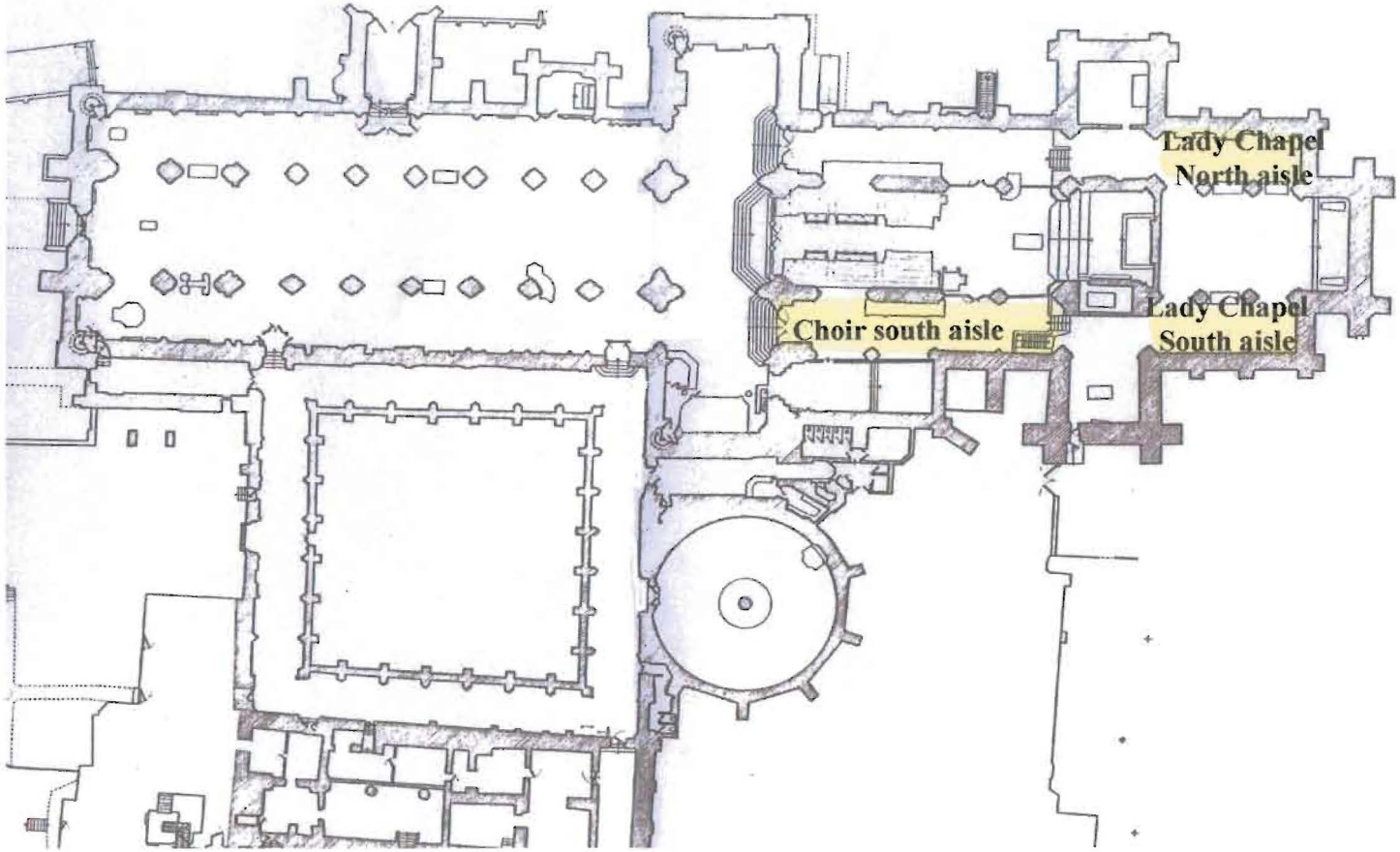


Figure 3: Illustration of a typical truss from the Choir south aisle roof

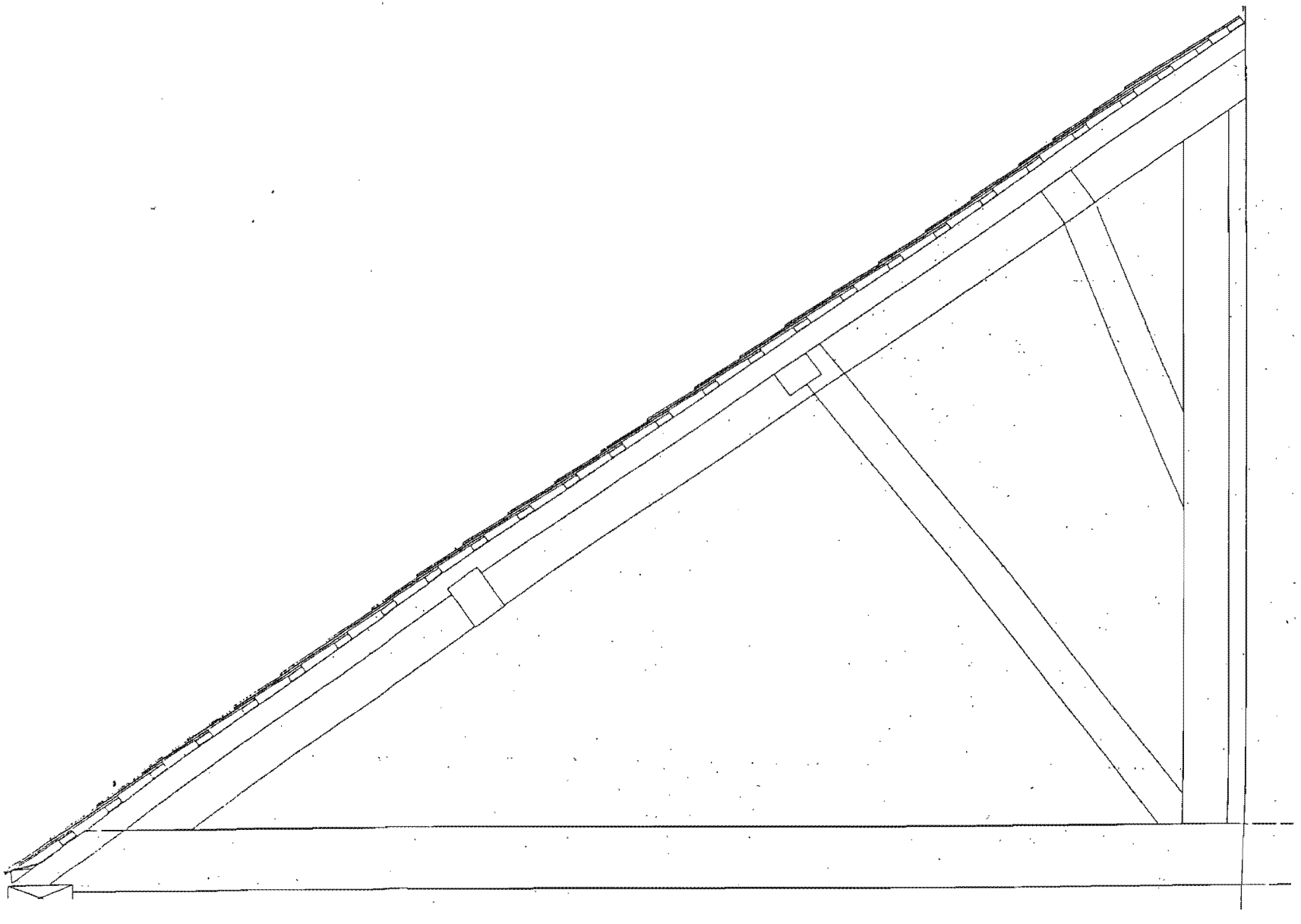


Figure 4a: Long-section of Lady Chapel north aisle roof to show probable phasing of timbers and location of timbers sampled (viewed from the north looking south)

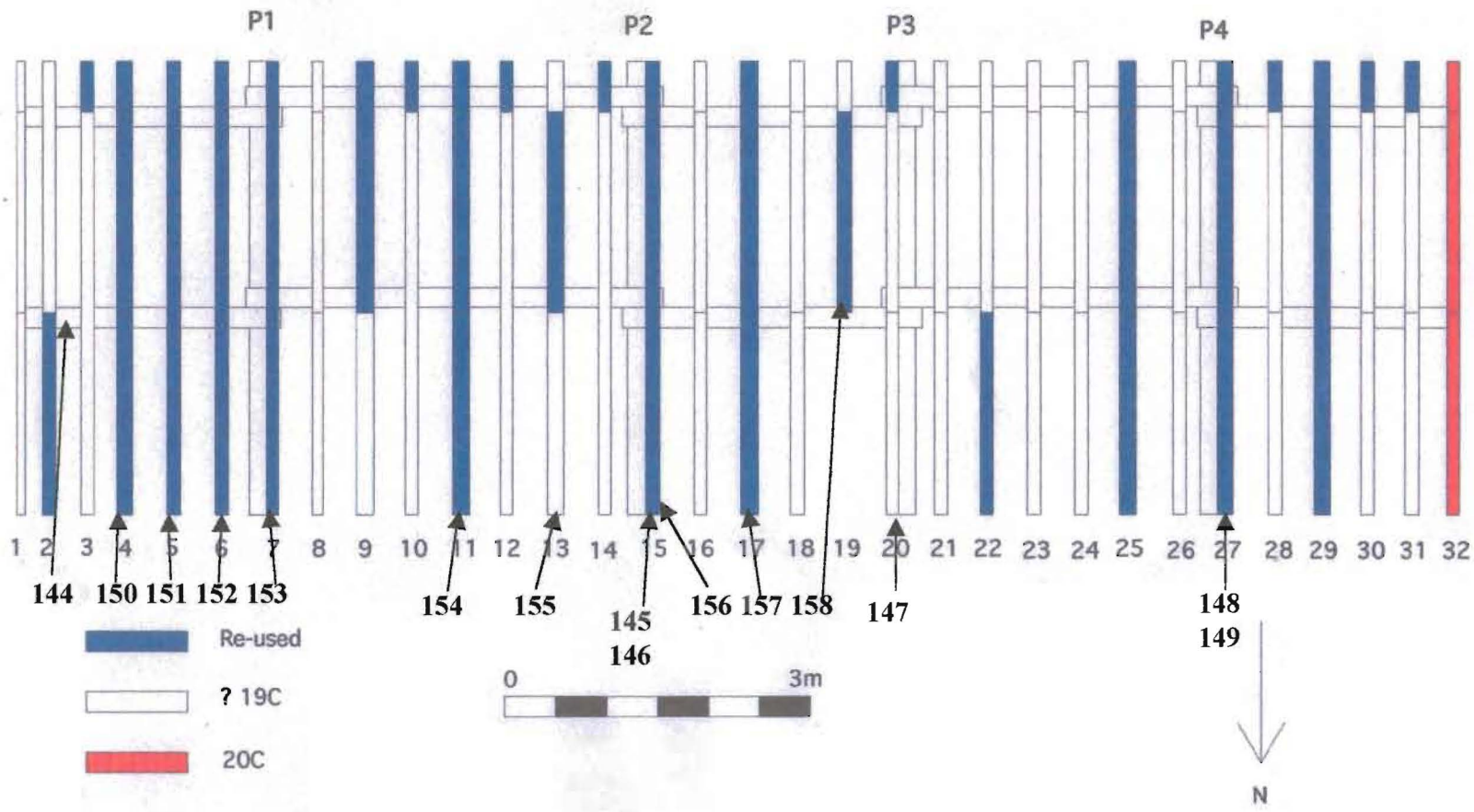


Figure 4b:Long-section of the Lady Chapel south aisle roof to show possible phasing of timbers and position of timbers sampled (viewed from the south looking north)

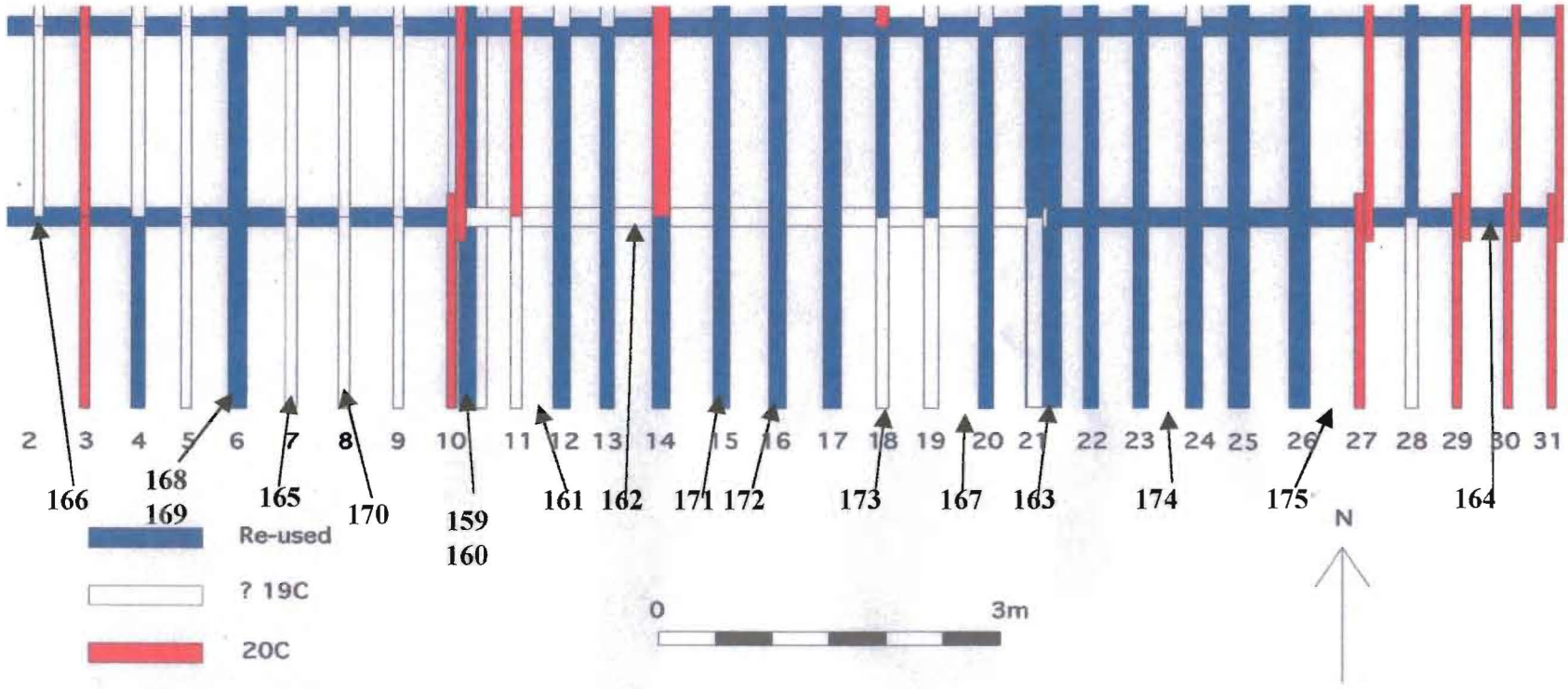


Figure 4c: Long-section of the Choir south aisle roof to show probable phasing of timbers and location of timbers sampled (viewed from the south looking north)

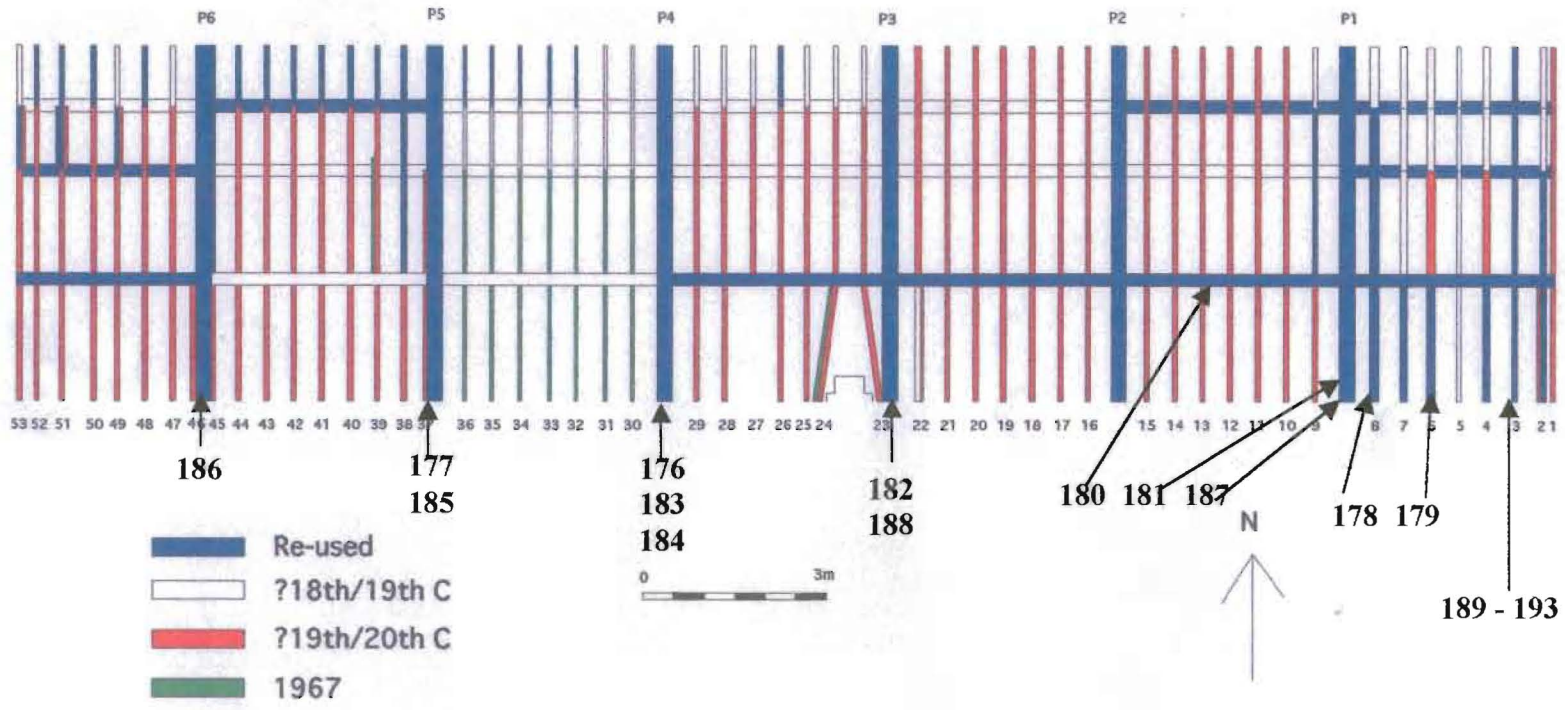
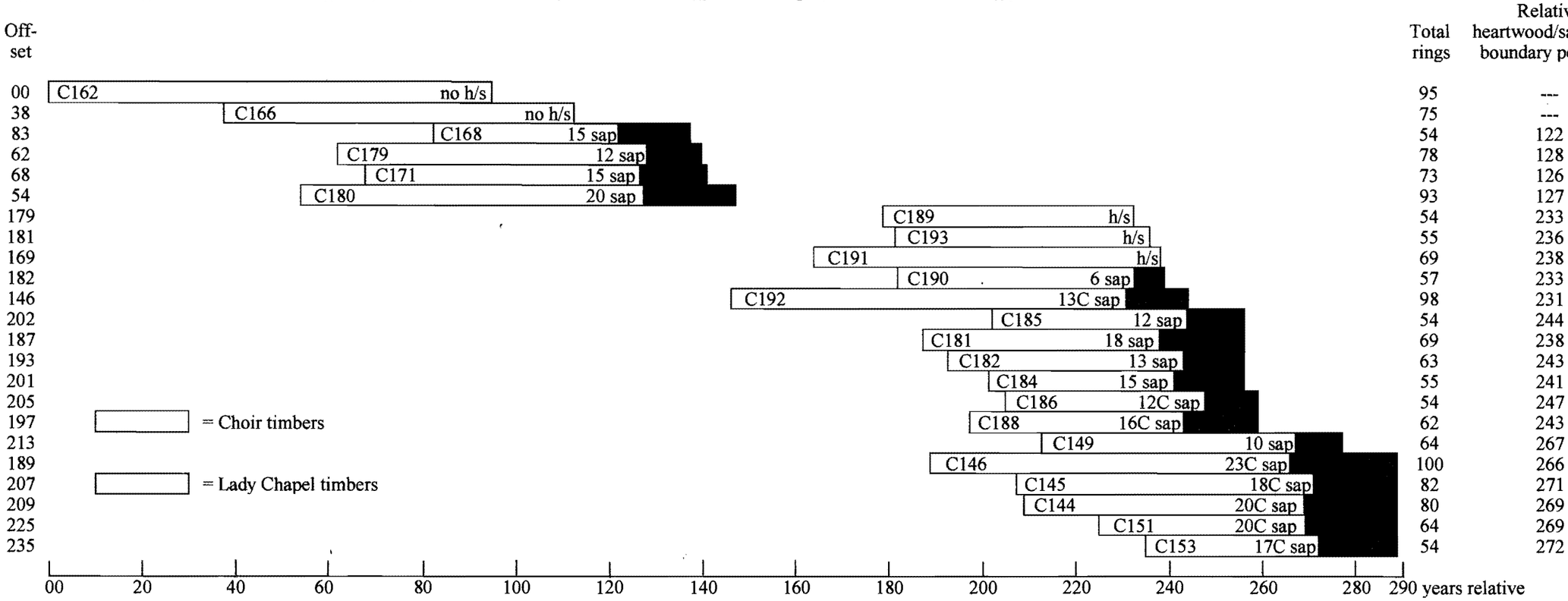


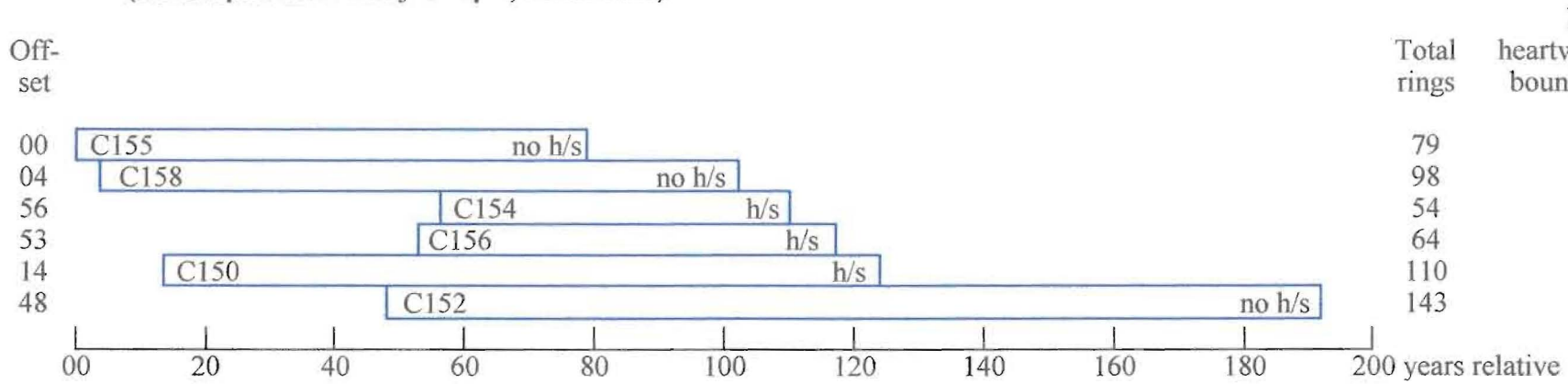
Figure 5: Photograph of the horizontal brace structure at the east end of the Choir south aisle roof

Figure 6: Bar diagram of cross-matching samples (WOR-C144 – 193) in site chronology WORCSQ01, in last measured ring position



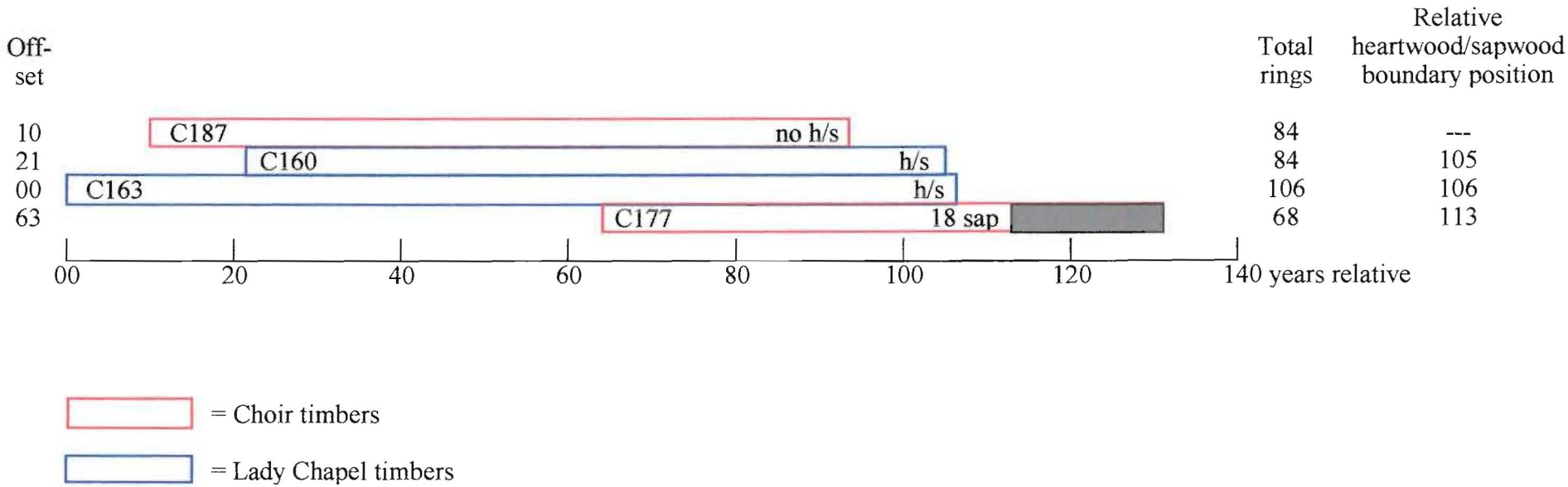
white bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample
C = complete sapwood retained on sample, the last measured ring date is the felling date of the timber

Figure 7: Bar diagram of cross-matching samples (WOR-C144 – 193) in site chronology WORCSQ02, in last measured ring position (all samples from Lady Chapel, north aisle)



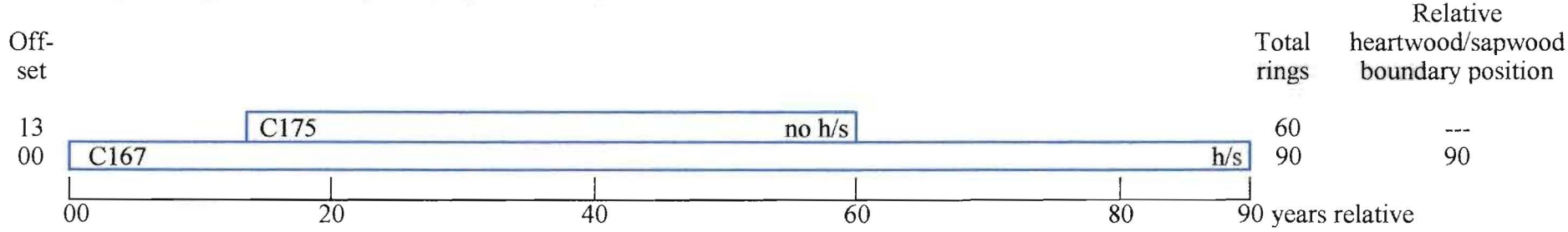
white bars = heartwood rings
h/s = heartwood/sapwood boundary is last ring on sample

Figure 8: Bar diagram of cross-matching samples (WOR-C144 – 193) in site chronology WORCSQ03, in last measured ring order



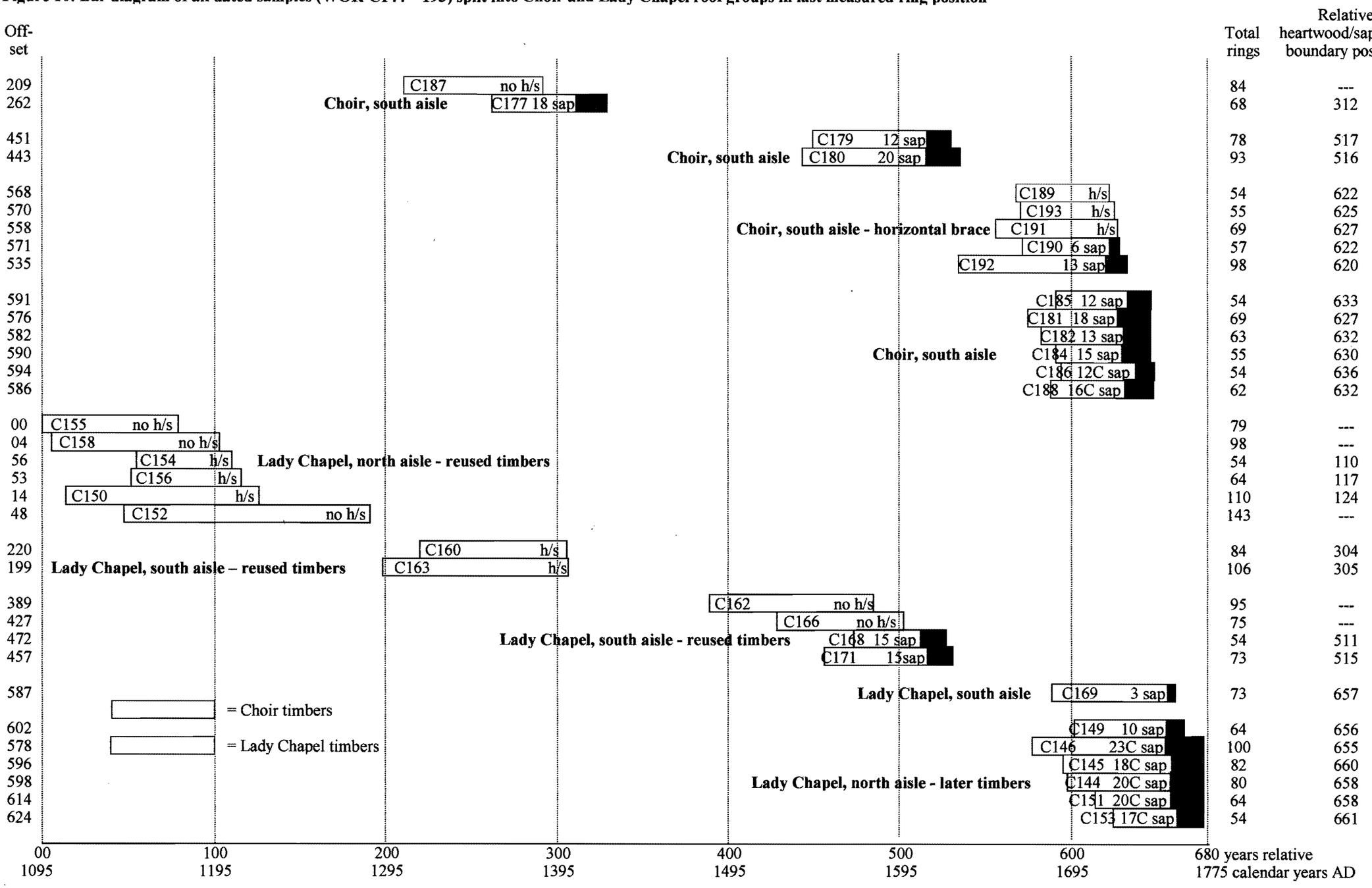
white bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample

Figure 9: Bar diagram of cross-matching samples (WOR-C144 – 193) in site chronology WORCSQ04, in last measured ring position (all samples from Lady Chapel, north aisle, ex-situ timbers)



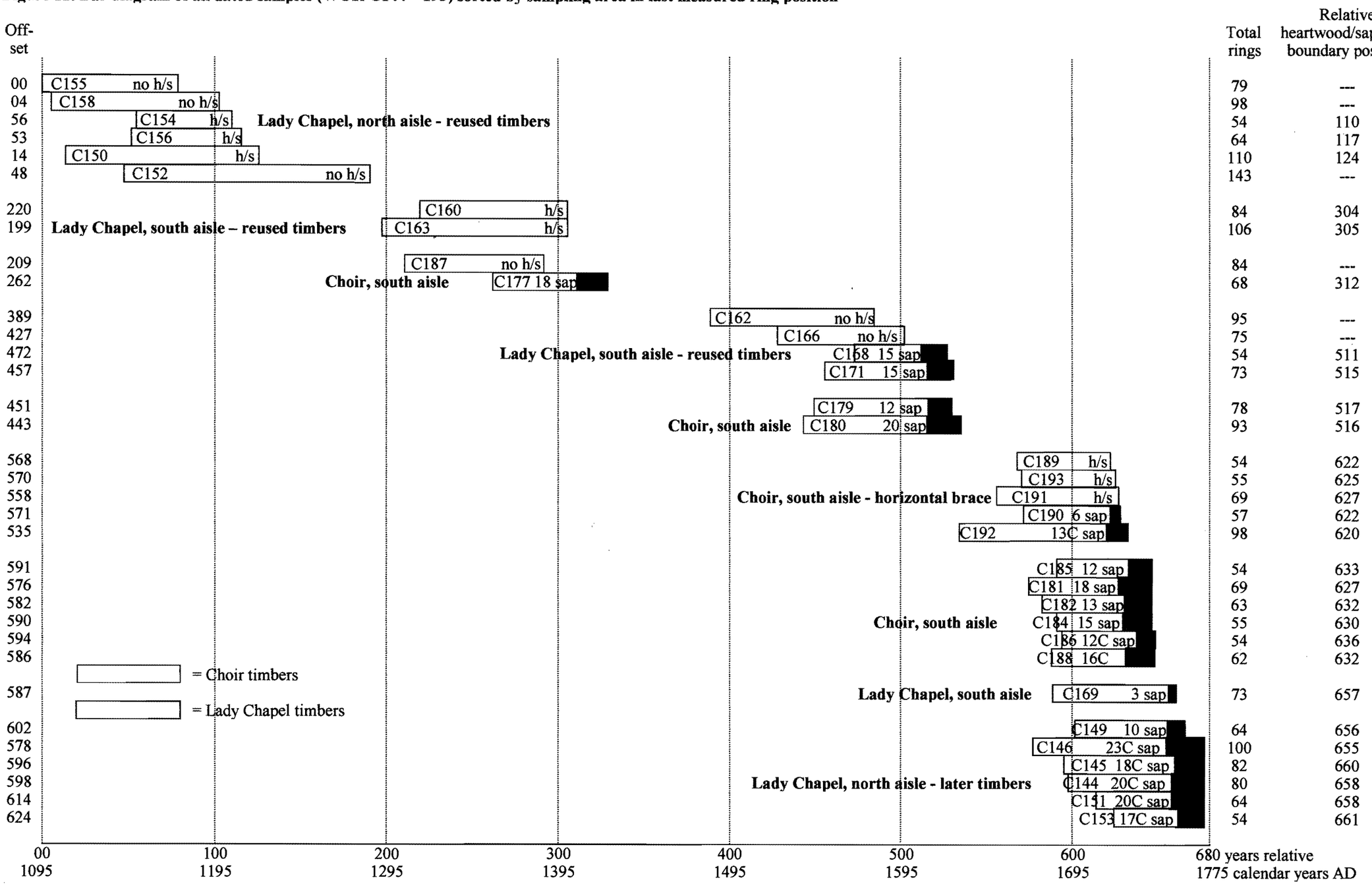
white bars = heartwood rings
h/s = heartwood/sapwood boundary is last ring on sample

Figure 10: Bar diagram of all dated samples (WOR-C144 – 193) split into Choir and Lady Chapel roof groups in last measured ring position



white bars = heartwood rings, shaded area = sapwood rings. h/s = heartwood/sapwood boundary is last ring on sample
C = complete sapwood retained on sample, the last measured ring date is the felling date of the timber

Figure 11: Bar diagram of all dated samples (WOR-C144 – 193) sorted by sampling area in last measured ring position



white bars = heartwood rings, shaded area = sapwood rings. h/s = heartwood/sapwood boundary is last ring on sample
C = complete sapwood retained on sample, the last measured ring date is the felling date of the timber

Data of measured samples - measurements in 0.01 mm units

WORC144A 80
480 422 266 307 306 286 180 316 359 249 260 282 187 279 256 272 212 142 155 157
171 124 114 145 144 107 146 177 207 207 155 262 289 283 176 239 198 229 194 335
256 308 375 324 197 315 321 177 191 128 308 254 164 304 269 207 272 228 211 237
235 325 216 299 274 278 367 275 223 164 243 267 212 230 263 476 294 345 224 356
WORC144B 80
487 431 274 340 289 302 220 354 405 207 294 328 196 298 264 214 241 153 162 160
196 129 125 162 139 131 99 184 239 214 161 271 287 277 172 230 187 230 206 320
291 301 353 324 203 310 323 176 220 117 279 265 150 312 269 208 273 248 195 226
232 328 225 305 243 285 358 271 226 181 260 260 204 276 254 450 285 344 257 318
WORC145A 82
595 393 444 418 334 331 337 355 284 328 359 349 394 369 206 265 244 222 258 251
352 371 445 300 344 310 338 224 314 278 347 239 188 275 207 244 214 238 210 213
261 363 328 357 453 303 188 259 235 168 124 86 163 113 81 174 175 190 197 215
238 226 332 246 252 229 176 311 184 197 182 174 280 274 292 224 224 278 193 204
152 199
WORC145B 79
588 382 440 422 319 347 342 352 287 341 353 339 393 355 196 269 255 230 242 271
349 363 427 328 331 309 349 214 323 253 358 237 198 277 197 226 223 252 201 217
262 350 324 368 454 304 178 255 236 162 129 93 165 125 88 149 165 179 195 189
246 230 319 245 244 243 169 305 206 201 180 167 270 270 295 213 254 280 136
WORC146A 100
217 147 160 97 151 99 219 282 284 314 282 187 145 130 134 143 157 208 254 190
170 150 138 156 129 131 113 109 122 103 104 188 151 149 175 199 191 69 65 161
191 184 258 247 219 240 224 186 247 199 213 300 224 236 187 137 113 141 171 204
184 187 195 216 156 180 161 162 179 145 195 187 214 244 217 136 127 137 173 177
164 226 127 128 148 166 154 106 90 73 187 206 158 174 126 148 108 136 116 154
WORC146B 100
211 145 158 93 144 113 178 327 273 297 269 210 151 123 145 157 159 207 254 206
162 143 132 158 138 142 109 100 127 97 118 192 140 147 187 208 180 61 77 135
203 199 238 247 237 230 232 184 239 202 196 320 226 234 188 130 115 144 175 205
195 189 200 227 151 179 159 158 176 136 203 198 220 231 211 145 137 135 164 170
172 213 128 117 144 185 156 111 79 96 179 202 174 160 126 144 108 146 107 136
WORC147A 55
436 550 364 504 468 389 314 330 352 395 362 333 393 375 449 325 312 345 344 311
315 271 320 382 363 253 315 369 259 245 177 178 159 155 232 276 238 294 239 280
292 258 329 248 247 185 197 127 102 179 268 262 235 204 243
WORC147B 55
383 557 354 493 441 406 337 307 363 393 348 297 401 405 410 307 332 341 355 241
322 256 306 399 372 278 329 360 244 252 180 178 158 161 248 274 234 294 236 293
300 247 333 236 246 199 196 119 98 195 258 268 225 183 251
WORC148A 67
201 178 175 163 167 202 252 247 215 249 236 231 327 270 282 290 273 314 307 301
351 384 275 362 361 246 270 352 216 212 234 293 322 270 318 290 184 274 224 257
246 207 177 224 233 154 175 203 200 168 176 167 152 149 127 182 194 236 196 225
281 218 216 154 183 168 150
WORC148B 67
178 219 168 185 158 182 270 245 208 252 232 242 322 277 282 273 268 302 297 305
348 375 279 380 345 249 247 359 217 209 241 297 325 273 323 292 190 272 218 255
247 194 189 235 235 153 169 197 201 184 196 172 142 155 123 172 190 238 170 208
290 212 182 159 183 165 152

WORC149A 64
278 518 345 298 394 332 380 432 242 294 386 445 374 299 330 385 457 266 323 385
372 300 311 260 302 219 282 401 311 351 363 272 315 299 353 273 253 299 391 378
321 282 245 211 243 226 245 290 197 222 271 272 285 182 188 183 207 210 153 116
163 214 188 227
WORC149B 64
294 497 332 308 390 318 376 411 223 293 392 422 372 291 351 401 444 277 378 320
361 300 308 261 297 240 255 417 264 355 365 296 316 273 364 258 273 292 491 268
302 290 260 201 238 214 274 267 188 247 256 276 250 195 181 207 200 195 170 106
169 216 184 260
WORC150A 110
107 126 101 99 218 222 215 145 120 95 106 166 183 258 270 200 204 206 168 151
69 126 166 150 144 98 80 52 109 59 74 67 134 101 63 59 40 79 98 122
172 147 180 189 190 103 107 121 174 185 192 217 133 154 144 102 164 161 228 236
200 185 146 76 97 109 134 182 138 128 86 48 60 118 142 92 111 114 153 83
114 101 69 66 52 101 86 135 123 96 65 53 52 33 95 69 99 64 72 60
75 84 47 58 39 64 64 94 80 108
WORC150B 110
109 124 97 116 193 248 202 145 125 86 101 167 187 257 240 205 208 214 161 140
71 146 171 147 144 103 69 56 108 62 73 64 130 104 74 67 45 82 116 134
167 171 179 188 197 92 136 101 176 174 176 227 136 150 131 129 143 165 211 236
210 197 136 80 91 111 153 181 138 113 101 47 58 126 143 96 110 112 165 76
124 86 85 57 49 102 90 124 130 107 63 46 51 39 88 74 88 76 65 64
81 73 58 56 37 76 67 76 99 114
WORC151A 64
354 282 368 401 509 403 370 379 356 228 355 247 245 256 212 308 286 297 210 244
198 217 214 270 191 186 221 338 275 249 252 274 239 197 186 184 141 150 126 138
159 175 158 166 135 159 125 99 113 114 95 97 95 96 148 131 93 100 84 127
132 118 156 148
WORC151B 64
347 294 362 397 512 402 371 357 350 235 332 269 238 241 213 308 273 307 222 231
202 226 201 284 190 199 196 349 242 278 250 263 244 201 182 176 167 148 131 139
174 174 163 153 150 155 119 117 98 118 101 99 103 91 138 131 91 101 82 128
133 127 147 160
WORC152A 142
52 62 106 93 101 139 132 114 190 124 100 110 136 157 154 177 178 167 168 106
116 169 194 186 178 247 250 218 120 132 151 154 145 106 99 58 55 84 104 140
78 95 99 127 79 77 87 64 53 62 119 112 144 125 126 105 96 83 100 125
114 92 90 83 67 84 88 50 64 54 64 75 93 78 60 68 75 58 38 70
85 76 81 84 87 86 75 43 44 41 36 68 49 67 58 42 49 54 51 69
63 75 42 63 50 46 41 40 55 52 62 77 74 56 39 46 52 77 55 47
65 51 46 55 47 43 101 116 103 98 96 78 52 50 61 74 98 91 108 88
122 159
WORC152B 143
46 52 63 107 94 100 137 132 123 196 110 115 108 133 171 141 181 184 164 174
104 124 150 204 190 170 250 250 209 100 134 141 147 137 104 96 68 52 65 129
140 83 99 71 140 94 78 96 65 55 63 106 124 130 122 142 99 93 90 90
133 100 113 89 76 76 94 81 74 50 51 61 72 88 89 64 64 71 47 55
67 81 79 76 95 73 85 78 42 46 46 31 60 56 71 58 43 50 53 53
66 57 86 56 63 46 43 39 53 51 47 62 74 71 61 40 43 54 81 56
59 55 52 38 54 45 56 94 120 103 95 111 75 50 56 68 74 105 72 114
90 115 165

WORC153A 54
231 210 294 221 214 287 336 281 243 231 237 296 273 303 289 263 296 339 310 272
266 236 237 220 230 220 191 230 204 237 301 228 224 229 208 220 189 187 158 143
199 176 168 125 244 242 188 171 166 247 213 191 180 160
WORC153B 54
245 205 300 280 201 301 328 288 241 238 235 298 270 313 276 266 292 352 268 292
269 228 242 214 227 207 186 239 212 230 301 218 229 234 205 224 190 190 159 136
194 175 170 133 216 256 210 167 164 236 211 194 171 169
WORC154A 54
283 320 237 256 232 160 320 256 248 288 275 245 339 503 525 417 341 425 524 371
509 402 356 344 314 335 228 356 320 268 245 306 284 219 363 242 328 185 263 273
290 189 206 193 237 274 226 198 182 209 184 207 126 166
WORC154B 54
288 318 247 263 216 170 317 249 252 299 249 269 315 494 535 424 333 413 520 381
525 381 372 337 300 340 221 357 311 276 230 341 285 222 354 224 333 176 264 290
289 183 193 203 236 260 247 193 183 197 203 192 172 164
WORC155A 79
169 330 386 150 171 191 329 317 388 209 251 290 237 291 187 110 74 88 157 190
162 91 96 80 165 197 146 228 228 160 173 170 148 111 98 166 142 129 142 110
82 91 247 196 136 119 118 74 61 59 72 90 132 149 210 157 183 237 242 157
222 178 248 293 262 245 177 194 162 135 182 242 187 234 249 191 199 108 97
WORC155B 79
191 325 362 150 158 202 330 317 399 212 258 299 233 286 181 108 83 87 159 192
160 95 88 82 174 179 151 200 227 145 179 161 135 126 90 168 135 145 156 98
99 92 233 212 134 120 116 95 55 53 61 92 137 158 196 150 200 236 254 172
213 172 247 279 272 236 182 183 160 149 174 242 185 230 234 214 190 111 107
WORC156A 64
299 282 179 405 193 275 192 234 217 238 208 186 250 201 202 211 251 291 256 206
240 310 225 304 205 193 230 158 183 147 188 294 217 284 248 201 148 228 235 256
143 177 250 219 157 221 206 236 263 237 211 193 202 145 141 152 193 191 255 125
250 222 235 228
WORC156B 64
313 291 162 502 179 276 200 223 263 249 206 190 248 198 222 193 266 276 250 236
253 299 230 318 202 186 245 146 201 121 205 293 199 277 233 208 146 234 220 266
145 180 256 196 167 205 211 227 270 241 219 174 184 139 159 146 194 196 259 113
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WORC157A 54
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