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Summary

A total of 56 samples was obtained from five different areas of Dacre Hall. The analysis of 52 of these produced five site chronologies. The first, LCPASQ01, comprises 29 samples of combined length 155 rings. This site chronology is dated as spanning AD 1350 to AD 1504. The second site chronology LCPASQ02, comprises six samples of combined length 280 rings, these spanning AD 977 to AD 1256. Three other site chronologies comprising a total of seven further samples cannot be dated.

Interpretation of the sapwood on the dated samples suggests that a number of timbers, possibly originally felled in the thirteenth century, have been reused in the roof.

Some principal roof timbers, particularly at the northern end, were felled in AD 1465. Other timbers of the hall roof, particularly those of the southern trusses have an estimated felling date in the range AD 1502 to AD 1527.

Many of the timbers of the first floor frame appear to have been felled *c* AD 1507. It is possible that this work, and that to the southern trusses occurred at the same time.

No timber from the immediate post-Dissolution period has been found.

Keywords

Dendrochronology

Standing Buildings

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Introduction

What is now Dacre Hall is all that remains substantially above ground of the late twelfth-century cloistral buildings of the Augustinian Priory at Lanercost, Cumbria (NY 556 637; Figs 1 and 2). The Priory was originally founded in AD 1166, at the behest of, and with a generous endowment from, Robert de Vaux. Building work began almost immediately, with the church and a large compliment of other priory buildings being largely complete by AD 1220. A plan of the site is given in Figure 3. It is believed that Lanercost was settled by Cannons from the Priory of Pentney in Norfolk, and became one of 165 other Augustinian sites in England, other nearby communities being established at Carlisle and Hexham.

However, given its position in the disputed Border country with Scotland, life at Lanercost, with its various religious, political, and military visitations, was not as tranquil as might be expected of a monastic establishment. In AD 1280 King Edward I and Queen Eleanor visited Lanercost on their way to Newcastle. In AD 1296 the Scots overran the region and Lanercost, along with Hexham, sustained some damage to its cloisters. Further harm was sustained in AD 1297 during a raid by William Wallace. Edward I visited once more in AD 1300, and again, for a longer period due to illness, in AD 1306 -7. Lanercost was ransacked and desecrated for the last time in AD 1346, by raiders led by King David of Scotland.

At the Dissolution in AD 1536 the Priory buildings were possessed for the Crown and subsequently sold to Sir Thomas Dacre. It is not known exactly when the sale took place but Sir Thomas is known to have taken up residence in AD 1559, having, it is believed, made substantial alterations, particularly to the west range of the cloisters. It is from his family that the Hall takes its present name. These alterations to the west range may have included the removal of the stone vaulted first floor and its replacement in timber, and the division of the north-most bay of the Hall from the southern six bays with a solid stone wall.

Other elements of the site were allowed to fall into gradual decay, with stone and timber being removed, it is believed, to construct other nearby buildings. The site remained with the Dacre family until the early eighteenth century, during which time, on the basis of documentary and structural evidence, it is believed that many other smaller modifications were undertaken. These works may have included the blocking of doors and windows. With the demise of the Lanercost Dacres the priory site eventually passed to the Crown, again, being subsequently bought by the Earl of Carlisle in AD 1869. The property came in to the hands of the Department of the Environment during the twentieth century.

Thus, apart from the still-standing Dacre Hall itself, the site in general now consists of a most impressive parish church, and the stone foundations and semi-subterranean stone remains of the former priory buildings. There is no timber to be seen in any of these features. The upper floor of Dacre Hall, apart from the north-most bay, which is known as the Scriptorium and which belongs with the church, is managed by the Dacre Hall committee, and is used for meetings, talks, and a wide variety of other public functions. It is thus with Dacre Hall, the western range of the former cloisters, that this programme of analysis is concerned.

Hall roof

The date of the present hall roof is unknown, but it is unlikely to be the first one, the probable line of the original being shown by a more steeply pitched scar above the present covering on the southern side of the church. It is possible that the present roof is a pre-Dissolution one, but it is believed that it may belong to the mid-sixteenth century works undertaken by Sir Thomas. It is also considered possible that the roof might be a seventeenth century replacement.

As currently built the roof, including the roof above the scriptorium, consists of eight king post trusses forming seven bays. The trusses have diagonal struts from tiebeams to principal rafters and carry double purlins, which in turn carry smaller common rafters. There are slightly curved braces from the king posts to the ridge beam. An illustration of a typical truss is given in Figure 4.

Apart from one instance, a diagonal strut in truss 4, there is little obvious indication, by way of redundant mortices, tennons, or peg holes, that the main beams of the principal trusses are of other than a single phase of felling. There is, however, a noticeable difference in the grain and pattern of some of the timbers, with some of the tiebeams, for example, appearing to be made from fast grown timber. Also the main timbers of truss 8, the south-most truss, appear to be slightly larger and more squarely cut than those of any other truss. The braces to the ridge here are also of a slightly different size to those seen on the other trusses.

The mixed nature of the timber is perhaps most clearly seen in the purlins. Although individual lengths again showed no obvious signs of reuse, no more than three or four of them appeared to be the same shape, or size, or to be from the same type of timber and have a similar grain patina. They appear to be quite different from the timbers of the trusses and give the impression of representing material of potentially different phases of felling or from different sources.

There are, furthermore, clearly reused timbers amongst the common rafters. In particular a considerable number of individuals show one, and sometimes two empty lap-mortices or joint beds, many of these being notched-lap type joints.

Related to this roof, but possibly of a different date, and possibly belonging to the original roof of the hall, is a wall plate. This is found on the east wall, between trusses 1 and 2, at the far north end of the hall, in the Scriptorium.

The first-floor frame

The frame of the first floor is made up of seven large east-west bridging beams, which carry close-set joists in half-trenched mortices. The large bridging beams have mortices on one of their side faces and shallow groove-mortices in the other to allow boards to be inserted into them to form a wooden ceiling. The date of this floor is unknown. It is believed to be possibly original, but may also represent a pre- or post-Dissolution alteration. As in the roof of the Hall, the timber comprising the common joists of the floor shows some variety in its shape, size and patina, though the timbers here do not appear to be as varied as those in the roof. It is thus possible that timbers of different felling dates are used here also.

Other timbers

Within the Hall are some isolated single timbers or other small structures. One of these is represented by the lintel of a blocked window on the ground floor. The timber is buried deep in the stone work, and is again believed to possibly date from the original structure.

On the first floor, at the far south end is a group of three timbers, with two upright posts from floor to ceiling, connected by a single cross-beam. This is shown in Figure 5. The date of this structure is unknown, as is its function. Local tradition has it that this is the remains of a feeding stall, though, being at first floor, this is perhaps unlikely.

Sampling

Sampling and analysis by tree-ring dating were commissioned by English Heritage, this being requested to help refine the dating of Dacre Hall in the post-Dissolution period. The dendrochronological brief covered five different areas of the hall representing, it is believed, possibly three different main phases of construction, plus reused material of varied and indeterminate date.

The primary area of sampling lay in the roof timbers of the hall, with the second area of sampling being from the main east-west bridging beams and the common joists of the first-floor frame. It was believed that these two together represented one main phase of construction. Samples were initially to be obtained from only the main timbers of the principal trusses but given the apparent variety of timbers seen here, the number of samples was increased and sampling was extended to include reused material.

The third area of sampling was that of a single wall plate on the east side at the far north end of the Hall, above the Scriptorium, this timber possibly representing another phase of felling.

A fourth area of sampling in this upper floor area of the hall was a group of two upright timbers and a single cross-timber, known as the "stall" at the far southern end of the Hall. The fifth and final area of sampling comprised a single lintel of a blocked window on the ground floor. The dates of both these features were unknown, but it was believed that they may represent a third phase of felling.

Sampling was restricted to a set number of cores from these areas and their constituent timbers by nature of the site being a scheduled ancient monument for which consent to sample had to be obtained. Thus from within these five areas 56 different timbers were sampled by coring, this being the maximum number allowed. Each sample was given the code LCP-A (for Lanercost Priory, site "A"), and numbered 01 - 56.

A total of 29 samples, LCP-A01 - A15, and A44 - A56) was obtained from the main elements of the principal trusses. One sample, LCP-A16, was taken from the east wall plate at the far north end. A further eight samples, LCP-A31 - A38 were obtained from the common rafters, most of them, but not all, showing clear evidence of reuse.

A total of 15 samples, LCP-A17 - 26 and A39 - 43, was obtained from the beams of the first-floor framing, with five samples coming from the main beams and 10 from the common joists. Three samples, LCP-A27 - A29, were taken from the "stall" structure, with the final sample, LCP-A30, being taken from the lintel of the blocked window on the ground floor.

Where possible the positions of the cores obtained were recorded at the time of sampling on drawings made by Peter Ryder and provided by English Heritage, these being reproduced here as Figures 6 - 8. Details of the samples are given in Table 1 and can be used in conjunction with the drawing to locate timbers sampled. In this report the bays and the roof and floor-frame timbers are numbered and described on a north to south, or east to west basis, as appropriate.

The Laboratory would like to take this opportunity to thank Mr and Mrs Robinson, key holders for Dacre Hall, who were most helpful in gaining access to the site and who were most interested in the project. We would also like to thank the Reverend Cannon Christopher Morris for his enthusiasm and help during sampling. We would also like to thank Peter Ryder for his knowledgeable expertise on site, for providing drawings and for his help with the introduction and description given above.

<u>Analysis</u>

Each of the 56 samples obtained was prepared by sanding and polishing. It was seen at this point that four samples, LCP-A27, A28, and A29, all from the "stall" structure, and LCP-A31 from a roof timber, had too few rings, that is less than 54, for satisfactory analysis, and these were rejected. The annual growth-ring widths of the remaining 52 samples were measured, the data of these being given at the end of the report.

These data were then compared with each other by the Litton/Zainodin grouping procedure (see appendix). At a minimum *t*-value of 4.5 five site chronologies could be formed. The first site chronology, LCPASQ01, consists of 29 samples and has a combined overall length of 155 rings. The relative positions of the cross-matching samples are shown in the bar diagram, Figure 9.

Site chronology LCPASQ01 was compared with an extensive range of reference chronologies indicating a satisfactory cross-match with a number of these when the date of its first ring is AD 1350, and the date of its last ring is AD 1504. Evidence for the dating of this site chronology is given in the *t*-values of Table 2.

The second site chronology, LCPASQ02, consists of six samples and has a combined overall length of 280 rings. The relative positions of the cross-matching samples in this site chronology are shown in the bar diagram, Figure 10. Site chronology LCPASQ02 was also compared with an extensive range of reference chronologies indicating a satisfactory cross-match when the date of its first ring is AD 977, and the date of its last ring is AD 1256. Evidence for the dating of this site chronology is given in the *t*-values of Table 3.

The third site chronology, LCPASQ03, consists of three samples and has a combined overall length of 68 rings. The relative positions of the cross-matching samples in this site chronology are shown in the bar diagram, Figure 11. Site chronology LCPASQ03 was compared with an extensive range of reference chronologies, but there was no satisfactory cross-matching at any position, and these samples must remain undated.

The fourth site chronology, LCPASQ04, consists of two samples which also have a combined overall length of 68 rings. The relative positions of the two cross-matching samples are shown in the bar diagram, Figure 12. Site chronology LCPASQ04 was compared with an extensive range of reference chronologies, but again there was no satisfactory cross-matching at any position, and these samples are also undated.

The fifth and final site chronology, LCPASQ05, also consists of two samples which have a combined overall length of 126 rings. The relative positions of the two cross-matching samples are shown in the bar diagram, Figure 13. Site chronology LCPASQ05 was compared with an extensive range of reference chronologies, but again there was no satisfactory cross-matching at any position, and these samples are also undated.

In the cases of site chronologies LCPASQ03 – SQ05, those site chronologies with two and three samples, an attempt at dating constituent samples individually was also made. There was no satisfactory cross-matching indicated.

The five site chronologies thus created, LCPASQ01 - ASQ05, were also compared with each other and with the 10 remaining measured but ungrouped samples. There was, however, no further satisfactory cross-matching. Each of the 10 ungrouped samples was then compared individually with an extensive range of reference chronologies. There was, however, no further satisfactory cross-matching.

Interpretation

Analysis by dendrochronology has produced five site chronologies of 29, six, three, two, and two samples respectively. The earliest material detected in this programme of analysis is found in site chronology LCPASQ02 (Fig 10), represented by samples LCP-A06, A12, A34, A36, A38, and A44, these being from diagonal struts and common rafters, all but two, LCP-A06 and A12, showing clear signs of reuse. This site chronology has a last measured ring date of AD 1256.

Unfortunately, only one sample in this group, LCP-A44, appears to have the heartwood/sapwood boundary and it is thus not possible to say that all the samples represent timbers felled at the same time. However, using a 95% confidence limit of 15 to 40 sapwood rings on mature oaks from this part of England, would give a felling date range of AD 1271 to AD 1296, for the timber represented by sample LCP-A44, and thus indicate a possible felling date range for the other timbers in this group. It is equally possible, however, that some timbers were felled earlier or indeed later. It is particularly difficult to be more certain given that they represent reused material and are therefore potentially a very mixed collection of timbers.

The next latest material is represented in site chronology, LCPASQ01 (Fig 9), which comprises 29 samples with a combined overall length of 155 rings. These rings are dated as spanning the period AD 1350 to AD 1504. At least two phases of felling are represented by this material. An attempt to illustrate this is given in the bar diagram Figure 14, where the samples are sorted into roof or floor timbers, and in Figure 15 where the samples from the roof are sorted according to truss.

Four samples from trusses 1, 2 and 3, LCP-A51, A52, A53, and A54, retain complete sapwood. This means that they each sample has the last ring produced by the trees they represent before those trees were cut down. In each case the last measured complete sapwood ring date is the same, AD 1465. This is thus the felling date of the timber.

A further sample from truss 3, LCP-A03, also retained complete sapwood. Unfortunately, due to decay, the sapwood rings could not be reliably measured. The number of sapwood rings was, however, estimated at 30 - 35. Given that the last measured, heartwood ring on sample LCP-A03 is dated to AD 1434, this would again suggest a probable felling date of AD 1465.

The relative positions of the heartwood/sapwood boundaries on a number of other samples from these trusses in site chronology LCPASQ01, and also on a sample from truss 6, LCP-A11, all lie relatively close to each other. Such a relative closeness is consistent with the trees they represent being felled in AD 1465 too. This point is illustrated in Figure 15, where the dated samples from the roof in site chronology LCPASQ01 are shown sorted by truss number.

Figure 15 will also illustrate, however, that other timbers from the hall roof, particularly timbers from trusses 5 and 7, samples LCP-A09, A46, and A50, were certainly felled later. Two of these samples, LCP-A46 and A50, retain some sapwood or the heartwood sapwood boundary, the average last heartwood ring date of these being AD 1481. A further sample, LCP-A09, has last measured heartwood rings which approach the heartwood/sapwood boundary (the last 8 – 10 rings being unmeasurable due to compaction). Given that this sample's last heartwood ring date is AD 1484, this would give the sample a heartwood/sapwood boundary date of no later than AD 1494. Taken together is estimated that these sample represent trees with an estimated felling date in the range AD 1502 to AD 1527.

The floor beams and joists may have been felled at about this time too. A number of these timbers provided samples that retained complete sapwood but in no instance was it possible to measure all these sapwood rings due to decay. However, it has been possible to estimate the likely number of unmeasured sapwood rings, or estimate the likely number of sapwood rings lost during coring from timbers where the sapwood was complete.

It is estimated, for example, that the floor timber sample with the latest dated sapwood ring, AD 1504 on LCP-A26, has lost only two or three sapwood rings at the most.

Such a loss would give an estimated felling date of AD 1507 at the latest for the timber represented. The estimated loss from, or estimated number of sapwood rings on the other samples with complete sapwood, and the relative positions of the heartwood/sapwood boundaries on the other dated samples, are highly consistent with *c* AD 1507 being the felling date of these timbers too.

The dated material in site chronologies LCPASQ01 and SQ02 thus represent timbers from only two of the four areas sampled and analysed (those from the "stall structure" having been rejected), the hall roof and the first-floor frame.

The remaining three site chronologies, LCPASQ03 – SQ05, with two or three samples, and having combined sequences of 68 or 126 rings, have not cross-matched with any reference chronologies, and thus none of the material analysed has dated. However, it might be noticed that some of the samples in each site chronology represent particular beam types.

Two of the samples in site chronology LCPASQ03, LCP-A45 and A56 are purlins. Samples LCP-A33 and A37 in site chronology LCPASQ04 are both from common rafters. This might suggest that these timbers were felled for these particular purposes at different times to the other timbers.

Conclusion

Analysis by dendrochronology has produced dates for 35 of the 52 samples analysed. The interpretation of the sapwood on the dated samples indicates that the roof contains timbers with different felling dates, an impression intimated at the time of sampling by differences in their appearance. The earliest material found is that of the reused common rafters, some of which could have been felled in the early thirteenth century. It is believed that the Priory complex was largely complete by AD 1220 and the rafters could represent timber reused from the original Hall roof, or perhaps from one of the other Priory buildings of this date. Other reused timbers, struts from trusses 4 and 6, were perhaps not felled until later in the thirteenth century, and may, in their original locations, represent episodes of repair following periods of destruction, or simply be material reused from other Priory buildings.

Another group of timbers, particularly those in trusses 1, 2, and 3, was certainly felled in AD 1465, this probably representing a major and extensive re-roofing of the Hall. Other roof timbers, particularly those used in trusses 5 and 7, were, however, probably not felled until the early part of the sixteenth century. The work on these trusses may be contemporary with work on the first-floor frame, the timbers of which appear to have been felled in *c* AD 1507. It is perhaps noticeable too that the majority of undated samples are from timbers at this southern end, trusses 5 – 7, again suggesting the possibility that more extensive alterations have been made at this end, perhaps using timbers with different felling dates.

So, while there appears to be some possible variation in the felling date of the early material which has been reused, there appears to be two phases of felling in the main trusses. One phase dates to AD 1465, and tends to be found in the timbers of the northern trusses, the other dates to the early sixteenth century, and appears to be confined to the southern most trusses, possibly being connected with the floor timbers felled, it is estimated, *c* AD 1507. All the dated timber appears to be of pre-Dissolution date, with nothing detected that certainly dates to the time of Sir Thomas Dacre's supposed alterations before his arrival in AD 1559. Perhaps his work was confined more to the partitioning of internal spaces, the blocking of some openings, and the opening of others, particularly for windows.

Of the remaining seventeen samples analysed, seven are combined in one of three undated site chronologies, whilst a further 10 remain ungrouped and undated. It is possible, though it cannot be proven by tree-ring dating, that some of these site chronologies or individual samples, represents timbers of yet other phases of felling. It is noticeable for example, that the timbers represented by site chronology LCPASQ03, LCP-A10, A45, and A56, are all similar in grain and patina to each other, but different to many of the other dated timbers. None of the purlins are dated, and some common rafters are undated. None of these undated timbers show evidence for reuse.

Some of the samples may not represent timbers of the same felling date, samples LCP-A08 and A32 in site chronology LCPASQ05 for example (Fig 13). Sample LCP-A08 has a heartwood/sapwood boundary at relative position 108, whilst the last ring on sample LCP-A32, at relative position 126 does not include the heartwood/sapwood boundary.

Some of the ungrouped and undated samples do show some bands of narrow or compressed rings. This may be brought about by stress during growth, muting the climatic input, and thus making the samples difficult to cross-match and date. Other ungrouped and undated samples however, show no such problems. It is again possible that these represent timbers with different felling date and are, in effect singletons, such samples often being more difficult to cross-matching and date.

It is possible that the climatic influence on the growth of the undated timbers used in this roof might have been disrupted by stressful local growing conditions, this being indicated by bands of narrow and slightly distorted growth-rings on some of the samples. A further contributory factor to the difficulty in cross-matching and dating of some samples might be that a number of them, though having at least the minimum of 54 rings necessary for reliable analysis, are close to this limit.

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Table 1a: Details of samples from Dacre Hall, Lanercost Priory, Brampton, Cumbria

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Roof timbers					
LCP-A01	King post, truss 2	69	5	AD 1374	AD 1437	AD 1442
LCP-A02	Tiebeam, truss 3	76	2	AD 1376	AD 1449	AD 1451
LCP-A03	East diagonal strut, truss 3	73+30nm	h/s+30nm	AD 1362	AD 1434	AD 1434
LCP-A04	West diagonal strut, truss 3	67	h/s	AD 1362	AD 1428	AD 1428
LCP-A05	Tiebeam, truss 4	62	h/s	AD 1389	AD 1450	AD 1450
LCP-A06	East diagonal strut, truss 4	164	no h/s	AD 1058	------	AD 1221
LCP-A07	Tiebeam, truss 5	79	h/s	------	------	------
LCP-A08	King post, truss 5	58	17	------	------	------
LCP-A09	East diagonal strut, truss 5	75+8-10nm	no h/s	AD 1410	------	AD 1484
LCP-A10	Tiebeam, truss 6	61	6	------	------	------
LCP-A11	King post, truss 6	62	h/s	AD 1378	------	AD 1439
LCP-A12	East diagonal strut, truss 6	145	no h/s	AD 1003	------	AD 1147
LCP-A13	Tiebeam, truss 7	55	h/s	------	------	------
LCP-A14	North brace, king post – collar, truss 7	96	h/s	------	------	------
LCP-A15	West diagonal, truss 2	54	h/s	AD 1375	AD 1428	AD 1428
LCP-A16	East wall plate, truss a – b	65	h/s	------	------	------
	First-floor frame					
LCP-A17	Main floor beam number 1	123	7	AD 1369	AD 1484	AD 1491
LCP-A18	Main floor beam number 2	104	14c	AD 1386	AD 1475	AD 1489
LCP-A19	Main floor beam number 3	86	h/s	AD 1394	AD 1479	AD 1479
LCP-A20	Main floor beam number 4	70	h/s	------	------	------

Table 1a: Continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	First-floor frame continued					
LCP-A21	Main floor beam number 5	71	h/s	AD 1409	AD 1479	AD 1479
LCP-A22	Joist 7, bay 2	110	19c	AD 1392	AD 1482	AD 1501
LCP-A23	Joist 3, bay 4	54	17	AD 1443	AD 1479	AD 1496
LCP-A24	Joist 5, bay 4	67	no h/s	AD 1358	------	AD 1424
LCP-A25	Joist 7, bay 4	118	h/s	AD 1364	AD 1481	AD 1481
LCP-A26	Joist 2, bay 5	73	30c	AD 1432	AD 1474	AD 1504
	Other timbers					
LCP-A27	North "stall" upright post	nm	---	------	------	------
LCP-A28	South "stall" upright post	nm	---	------	------	------
LCP-A29	Cross-beam	nm	---	------	------	------
LCP-A30	Blocked ground-floor window lintel	68	no h/s	------	------	------
	Roof timbers					
LCP-A31	East common rafter 9, bay 2	nm	no h/s	------	------	------
LCP-A32	East common rafter 10, bay 2	126	no h/s	------	------	------
LCP-A33	East common rafter 6, bay 3	66	2	------	------	------
LCP-A34	East common rafter 7, bay 3	130	no h/s	AD 1059	------	AD 1188
LCP-A35	East common rafter 6, bay 5	68	no h/s	AD 1350	------	AD 1417
LCP-A36	West common rafter 2, bay 6	127	no h/s	AD 977	------	AD 1103
LCP-A37	East common rafter 8, bay 3	67	h/s	------	------	------
LCP-A38	East common rafter 9, bay 3	86	no h/s	AD 1120	------	AD 1205

Table 1a: continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	First-floor frame					
LCP-A39	Joist 3, bay 3	83	h/sc	AD 1399	AD 1481	AD 1481
LCP-A40	Joist 6, bay 1	120	4c	AD 1365	AD 1480	AD 1484
LCP-A41	Joist 5, bay 3	83	h/s	AD 1395	AD 1477	AD 1477
LCP-A42	Joist 5, bay 5	72	21c	AD 1428	AD 1478	AD 1499
LCP-A43	Joist 8, bay 5	76	no h/s	AD 1396	------	AD 1471
	Roof timbers					
LCP-A44	West diagonal strut, truss 4	155	h/s	AD 1102	AD 1256	AD 1256
LCP-A45	East upper purlin, truss 4 – 5	56	7	------	------	------
LCP-A46	East principal rafter, truss 5	114	4	AD 1370	AD 1479	AD 1483
LCP-A47	West principal rafter, truss 6	54	h/s	------	------	------
LCP-A48	West diagonal strut, truss 5	68	h/s	------	------	------
LCP-A49	East principal rafter, truss 7	57	h/s	------	------	------
LCP-A50	West principal rafter, truss 7	70	h/s	AD 1414	AD 1483	AD 1483
LCP-A51	West principal rafter, truss 1	69	16C	AD 1397	AD 1449	AD 1465
LCP-A52	East principal rafter, truss 2	78	18C	AD 1388	AD 1447	AD 1465
LCP-A53	West principal rafter, truss 2	60	16C	AD 1406	AD 1449	AD 1465
LCP-A54	West principal rafter, truss 3	69	20C	AD 1397	AD 1445	AD 1465
LCP-A55	West upper purlin, truss 3 – 4	97	8	------	------	------
LCP-A56	West upper purlin, truss 4 – 5	62	h/s	------	------	------

*h/s = the heartwood/sapwood boundary is the last ring on the sample. nm = rings not measured
C = complete sapwood retained on the sample, the last measured ring date is the felling date of the timber
c = complete sapwood on sample. All or part of sapwood lost from core during sampling

Table 1b: Details of samples from Dacre Hall, Lanercost Priory, Brampton, Cumbria, sorted by sample location

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Roof timbers					
LCP-A51	West principal rafter, truss 1	69	16C	AD 1397	AD 1449	AD 1465
LCP-A01	King post, truss 2	69	5	AD 1374	AD 1437	AD 1442
LCP-A15	West diagonal, truss 2	65	h/s	AD 1364	AD 1428	AD 1428
LCP-A52	East principal rafter, truss 2	78	18C	AD 1388	AD 1447	AD 1465
LCP-A53	West principal rafter, truss 2	60	16C	AD 1406	AD 1449	AD 1465
LCP-A02	Tiebeam, truss 3	76	2	AD 1376	AD 1449	AD 1451
LCP-A03	East diagonal strut, truss 3	73+30nm	h/s+30nm	AD 1362	AD 1434	AD 1434
LCP-A04	West diagonal strut, truss 3	67	h/s	AD 1362	AD 1428	AD 1428
LCP-A54	West principal rafter, truss 3	69	20C	AD 1397	AD 1445	AD 1465
LCP-A55	West upper purlin, truss 3 – 4	97	8	------	------	------
LCP-A05	Tiebeam, truss 4	62	h/s	AD 1389	AD 1450	AD 1450
LCP-A06	East diagonal strut, truss 4	164	no h/s	AD 1058	------	AD 1221
LCP-A44	West diagonal strut, truss 4	155	h/s	AD 1102	AD 1256	AD 1256
LCP-A45	East upper purlin, truss 4 – 5	56	7	------	------	------
LCP-A56	West upper purlin, truss 4 – 5	62	h/s	------	------	------
LCP-A07	Tiebeam, truss 5	79	h/s	------	------	------
LCP-A08	King post, truss 5	58	17C	------	------	------
LCP-A46	East principal rafter, truss 5	113	4	AD 1370	AD 1479	AD 1483

Table 1b: continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Roof timbers					
LCP-A48	West diagonal strut, truss 5	68	h/s	------	------	------
LCP-A09	East diagonal strut, truss 5 8-10 nm	75+8-10nm	no h/s	AD 1410	------	AD 1484
LCP-A10	Tiebeam, truss 6	60	6	------	------	------
LCP-A11	King post, truss 6	62	h/s	AD 1378	AD 1439	AD 1439
LCP-A12	East diagonal strut, truss 6	145	no h/s	AD 1003	------	AD 1147
LCP-A47	West principal rafter, truss 6	56	h/s	------	------	------
LCP-A13	Tiebeam, truss 7	55	h/s	------	------	------
LCP-A14	North brace, king post – collar, truss 7	96	h/s	------	------	------
LCP-A49	East principal rafter, truss 7	57	h/s	------	------	------
LCP-A50	West principal rafter, truss 7	70	h/s	AD 1414	AD 1483	AD 1483
LCP-A16	East wall plate, truss a – 1	65	h/s	------	------	------
LCP-A31	East common rafter 9, bay 2	40	no h/s	------	------	------
LCP-A32	East common rafter 10, bay 2	126	no h/s	------	------	------
LCP-A33	East common rafter 6, bay 3	65	2	------	------	------
LCP-A34	East common rafter 7, bay 3	130	no h/s	AD 1059	------	AD 1188
LCP-A37	East common rafter 8, bay 3	54	h/s	------	------	------
LCP-A38	East common rafter 9, bay 3	86	no h/s	AD 1120	------	AD 1205
LCP-A35	East common rafter 6, bay 5	68	no h/s	AD 1350	------	AD 1417
LCP-A36	West common rafter 2, bay 6	127	no h/s	AD 977	------	AD 1103

Table 1b: continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Floor-frame timbers					
LCP-A17	Main floor beam number 1	123	7	AD 1369	AD 1484	AD 1491
LCP-A18	Main floor beam number 2	104	14c	AD 1386	AD 1475	AD 1489
LCP-A19	Main floor beam number 3	86	h/s	AD 1394	AD 1479	AD 1479
LCP-A20	Main floor beam number 4	70	h/s	------	------	------
LCP-A21	Main floor beam number 5	71	h/s	AD 1409	AD 1479	AD 1479
LCP-A40	Joist 6, bay 1	120	4c	AD 1365	AD 1480	AD 1484
LCP-A22	Joist 7, bay 2	110	19c	AD 1392	AD 1482	AD 1501
LCP-A39	Joist 3, bay 3	83	h/sc	AD 1399	AD 1481	AD 1481
LCP-A41	Joist 5, bay 3	83	h/s	AD 1395	AD 1477	AD 1477
LCP-A23	Joist 3, bay 4	54	17	AD 1443	AD 1479	AD 1496
LCP-A24	Joist 5, bay 4	67	no h/s	AD 1358	------	AD 1424
LCP-A25	Joist 7, bay 4	118	h/s	AD 1364	AD 1481	AD 1481
LCP-A26	Joist 2, bay 5	73	30c	AD 1432	AD 1474	AD 1504
LCP-A42	Joist 5, bay 5	72	21c	AD 1426	AD 1478	AD 1499
LCP-A43	Joist 8, bay 5	76	no h/s	AD 1396	------	AD 1471
	Other timbers					
LCP-A27	North "stall" upright post	nm	---	------	------	------
LCP-A28	South "stall" upright post	nm	---	------	------	------
LCP-A29	Cross-beam	nm	---	------	------	------
LCP-A30	Blocked ground-floor window lintel	68	no h/s	------	------	------

Table 2: Results of the cross-matching of chronology LCPASQ01 and relevant reference chronologies when the date of the first ring is AD 1350 and the last ring date is AD 1504

Reference chronology	Span of chronology	*t*-value	
Shield Barn, Longburgh, Cumbria	AD 1476 -1596	5.5	(Howard *et al* 1998)
Hitchins Onset, Scaleby, nr Carlisle, Cumbria	AD 1364 -1491	7.6	(Howard *et al* 1997)
Witton Hall Barn, Witton Gilbert, Tyne and Wear	AD 1342 -1441	7.1	(Howard *et al* 1996)
Askerton Castle, Kirkcambeck, Cumbria	AD 1324 -1493	7.8	(Esling *et al* 1990)
North transept, Durham Cathedral	AD 1320 -1457	7.1	(Howard *et al* 1992)
Choir roof, Durham Cathedral	AD 1346 -1458	5.3	(Howard *et al* 1992)
Kepier Hospital, Durham	AD 1304 -1522	5.5	(Howard *et al* 1996)
Scotland	AD 946 -1975	5.4	(Baillie 1977)
East Midlands	AD 882 -1981	4.5	(Laxton and Litton 1988)
England	AD 401 -1981	5.8	(Baillie and Pilcher 1982 unpubl)

Table 3: Results of the cross-matching of sample LCP-A12 and relevant reference chronologies when the date of the first ring is AD 977 and the last ring date is AD 1256

Reference chronology	Span of chronology	*t*-value	
East range, Carlisle Guildhall, Cumbria	AD 976 -1382	6.2	(Howard *et al* 1994)
Carlisle Castle, Carlisle, Cumbria	AD 968 -1446	7.3	(Arnold *et al* forthcoming)
Carlisle Cathedral, Carlisle, Cumbria	AD 961 -1374	8.4	(Howard *et al* 2001)
Scotland	AD 946 -1975	6.2	(Baillie 1977)
East Midlands	AD 882 -1981	7.2	(Laxton and Litton 1988)
St Hugh's Choir, Lincoln Cathedral	AD 882 -1191	7.5	(Laxton and Litton 1988)
The Rigging Loft, Newcastle upon Tyne	AD 950 -1183	4.7	(Howard *et al* 2002)

Figure 1: Map to show general location of Lanercost Priory

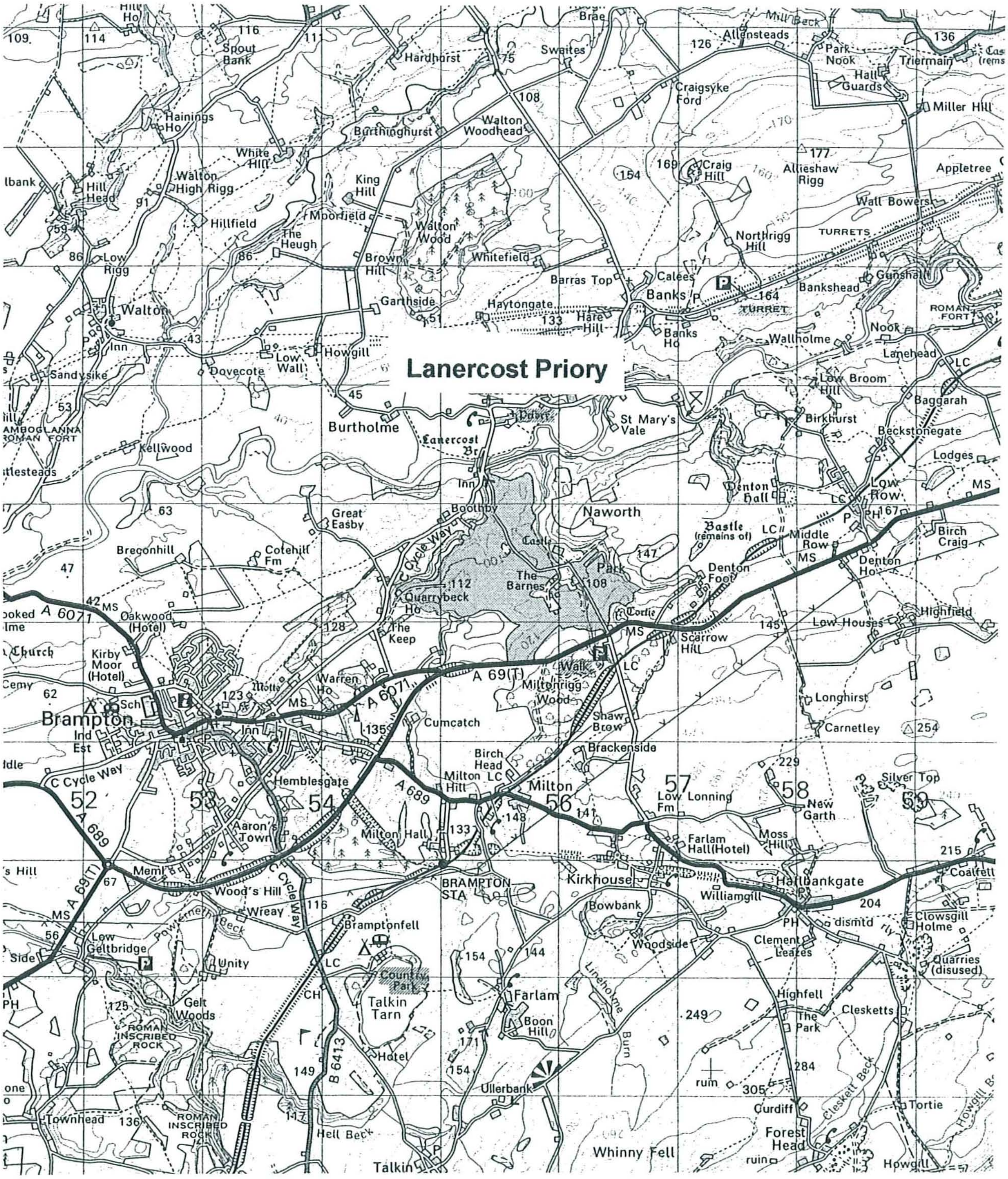


Figure 2: Map to show specific location of Lanercost Priory

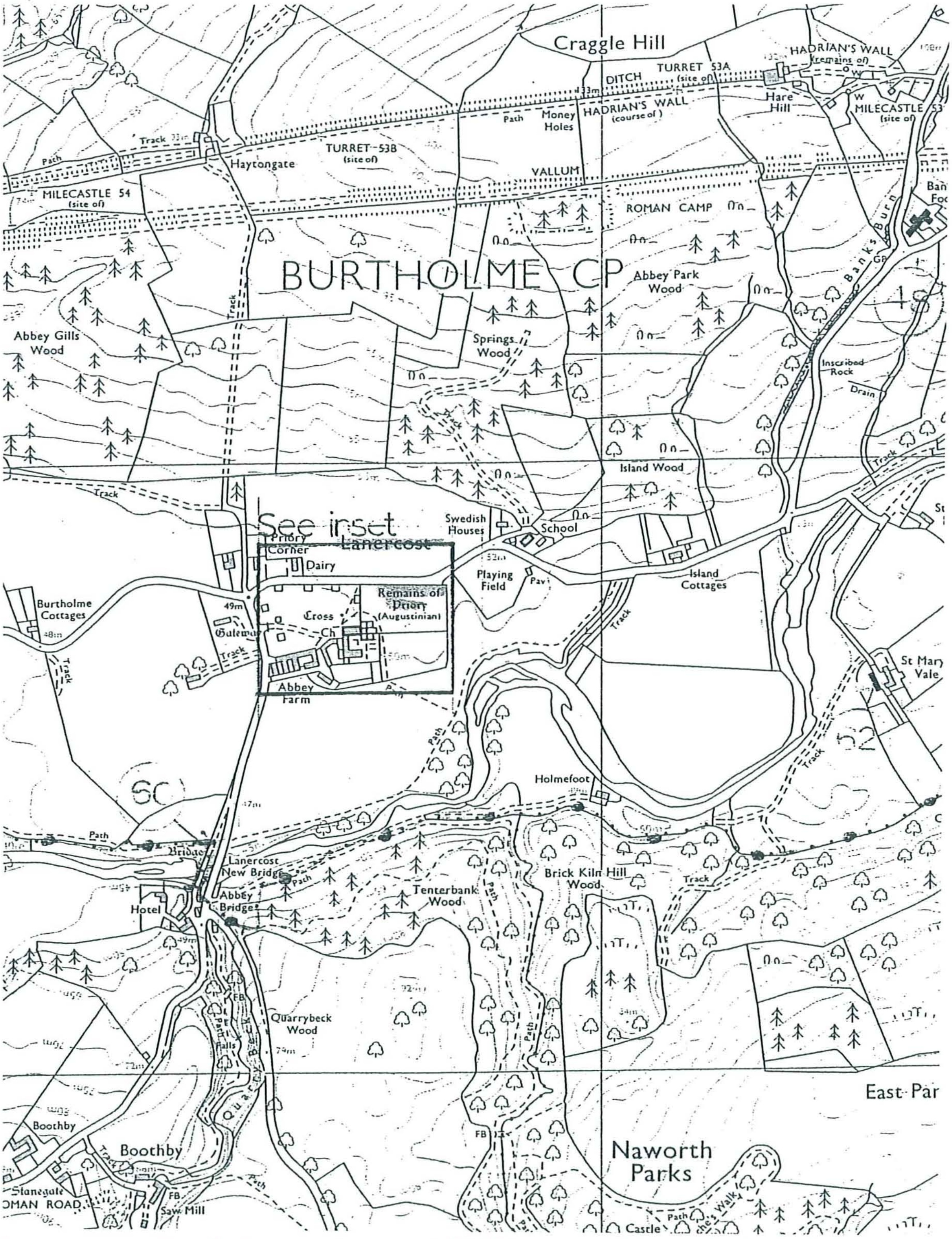


Figure 3: Plan to show layout of Lanercost Priory (from the guidebook by John R. H. Moorman)

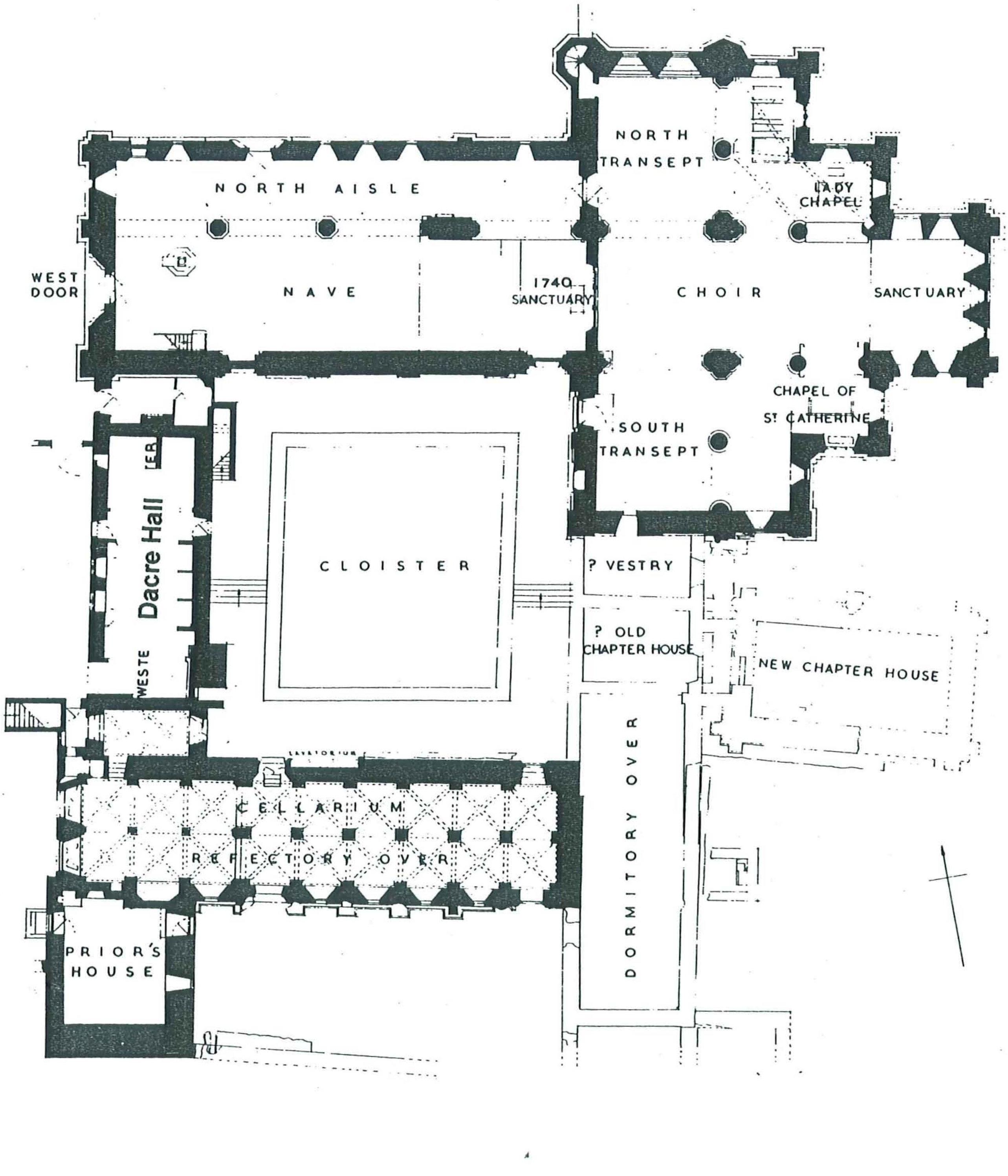


Figure 4: Illustration of a typical roof truss from Dacre Hall

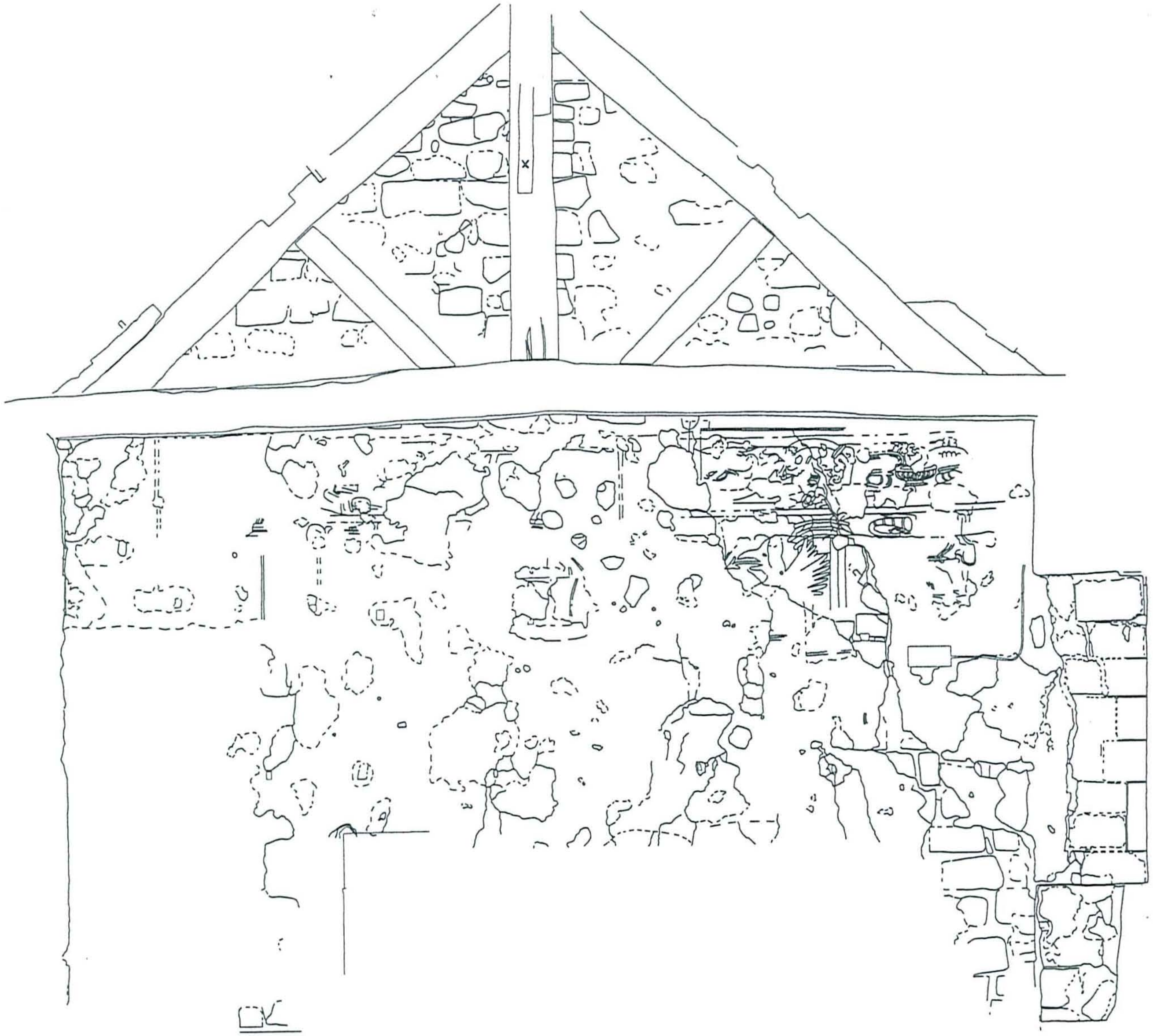


**Figure 5: 'Stall' structure
(viewed from the west)**

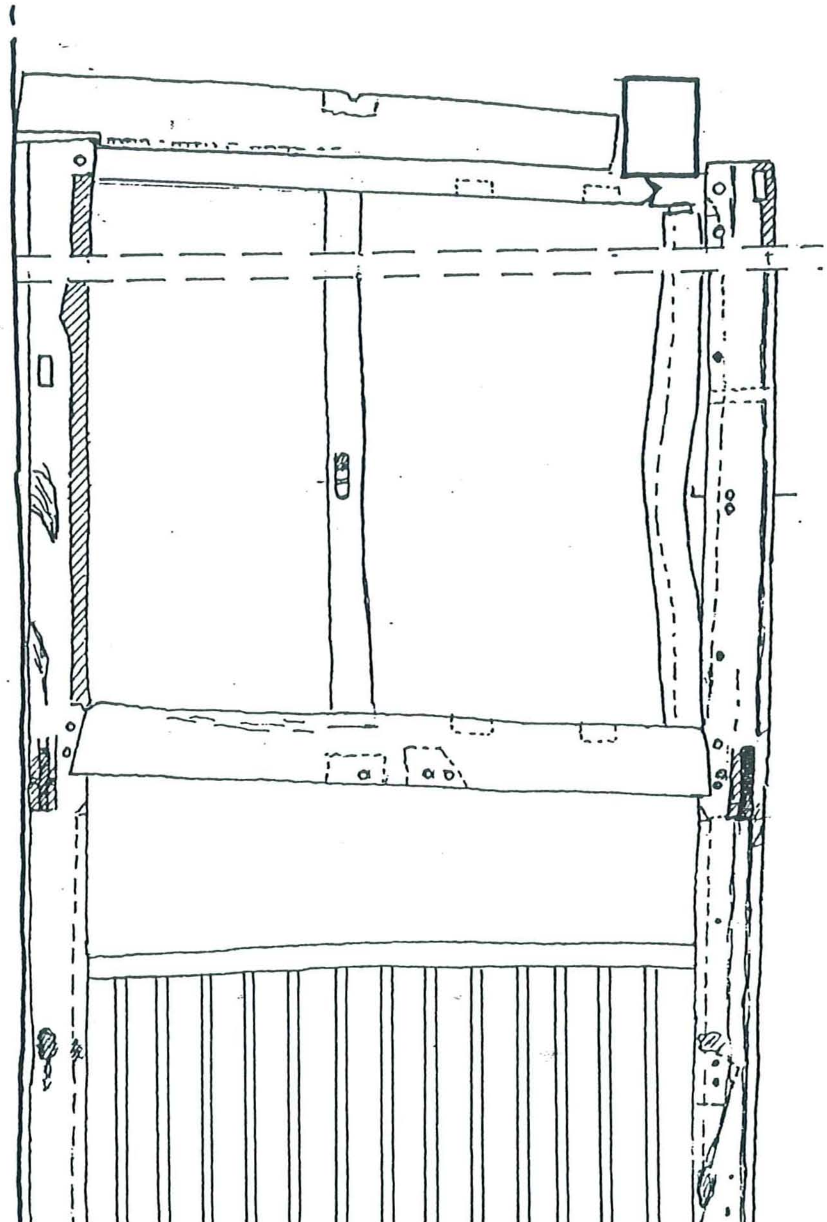


Figure 6: Plan to show location of samples from the first-floor frame

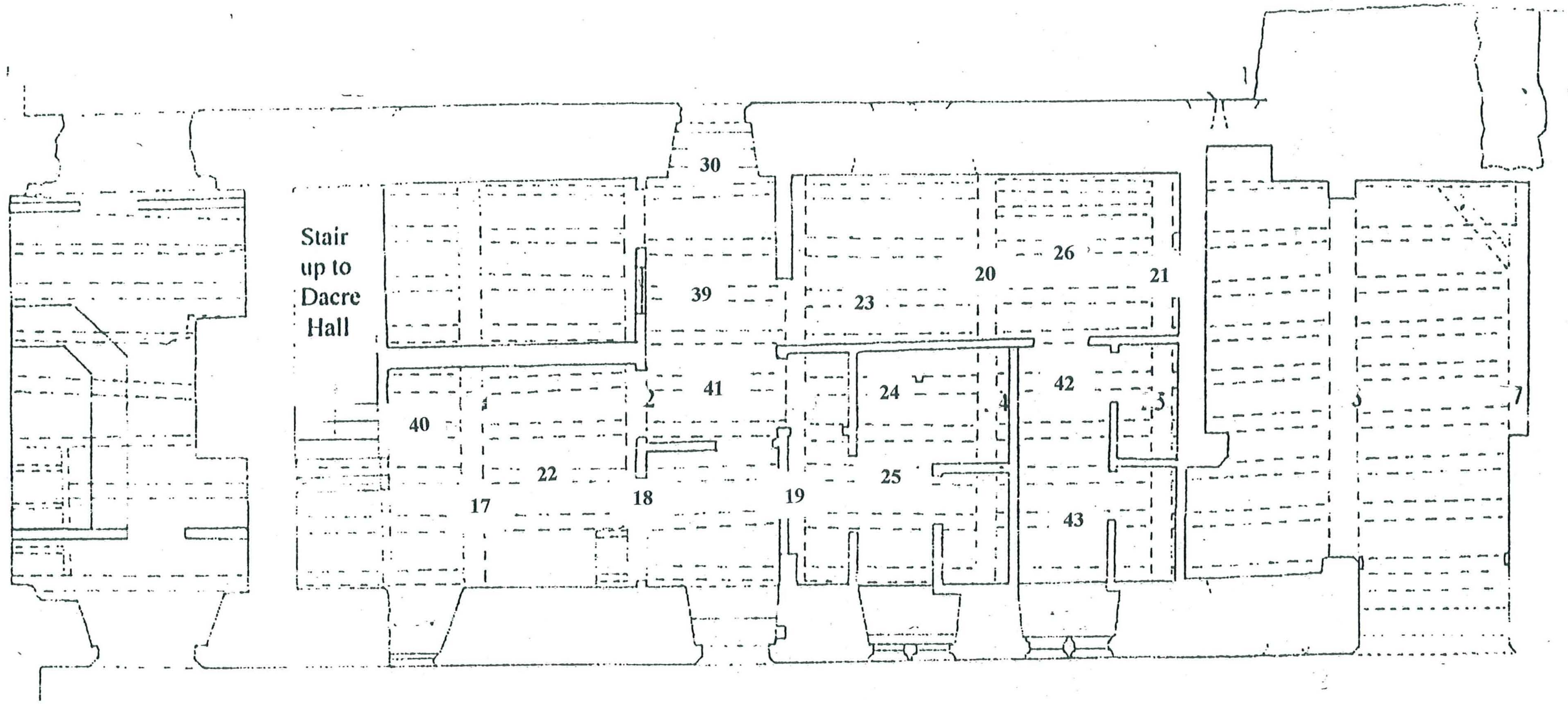


Figure 7: Plan to show location of samples from the roof timbers

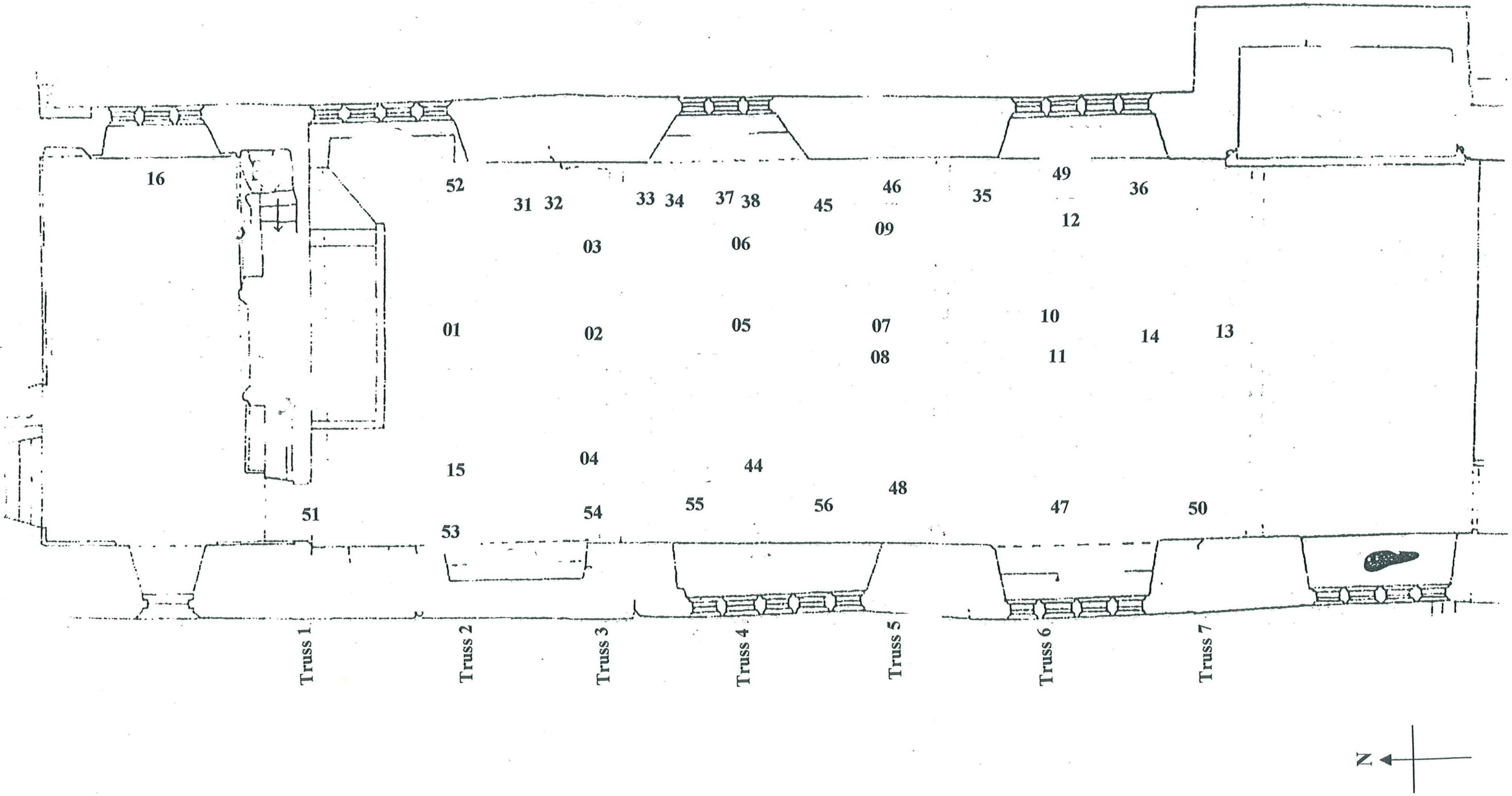


Figure 8: Drawing to show location of samples from the 'stall'

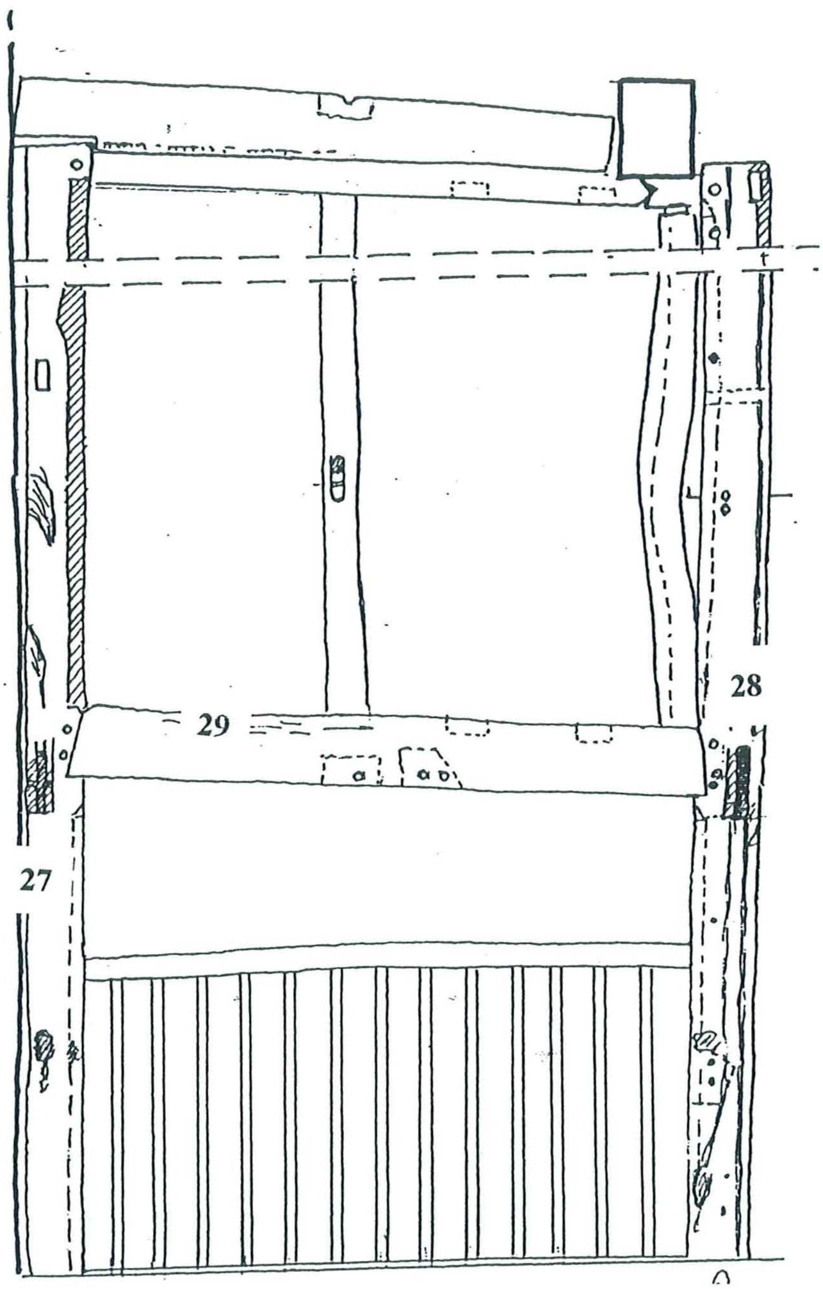
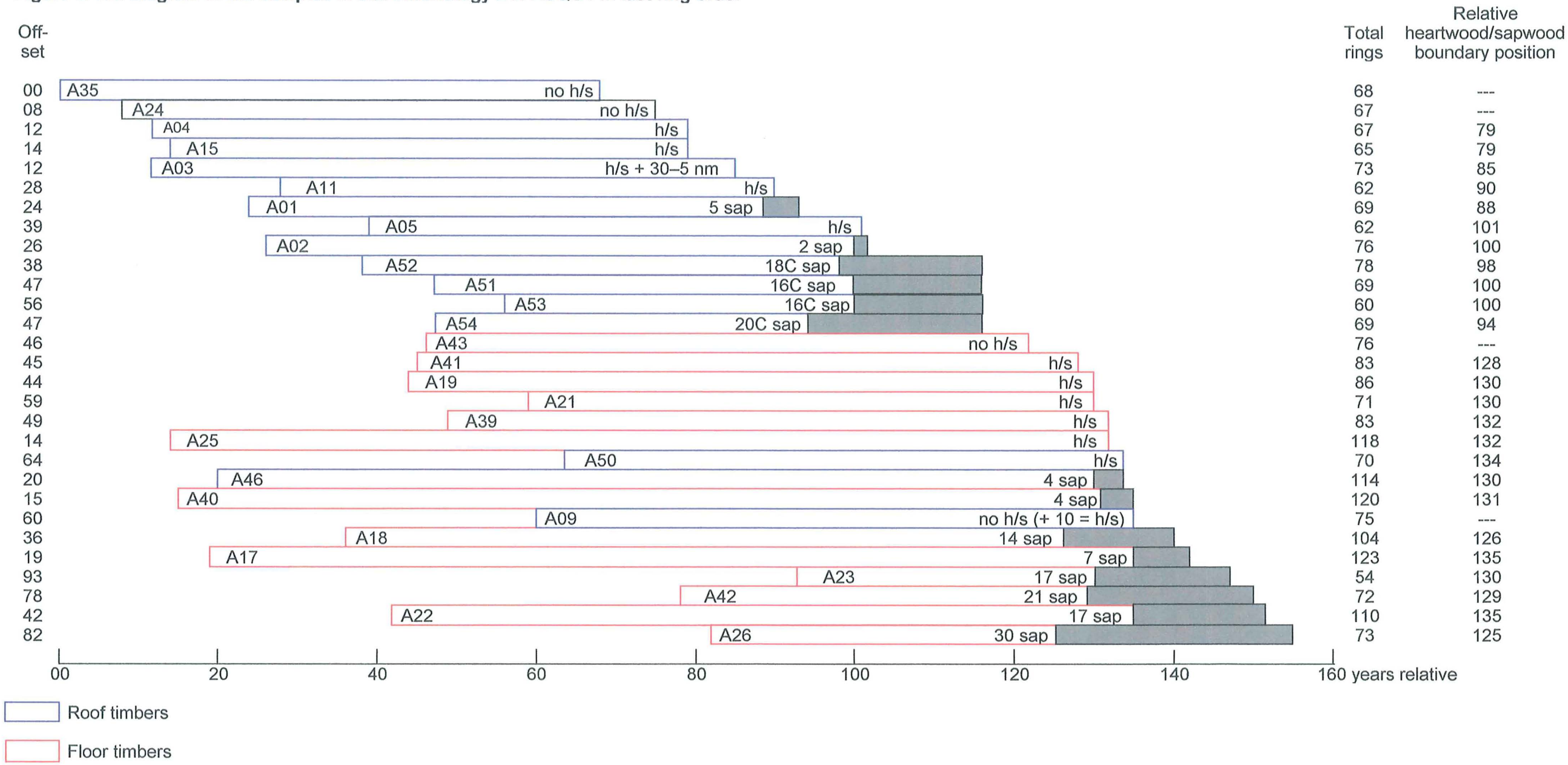


Figure 9: Bar diagram of the samples in site chronology LCPASQO1 in last ring order



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
c = complete sapwood on sample, all or part lost during sampling

Figure 10: Bar diagram of the samples in site chronology LCPASQ02

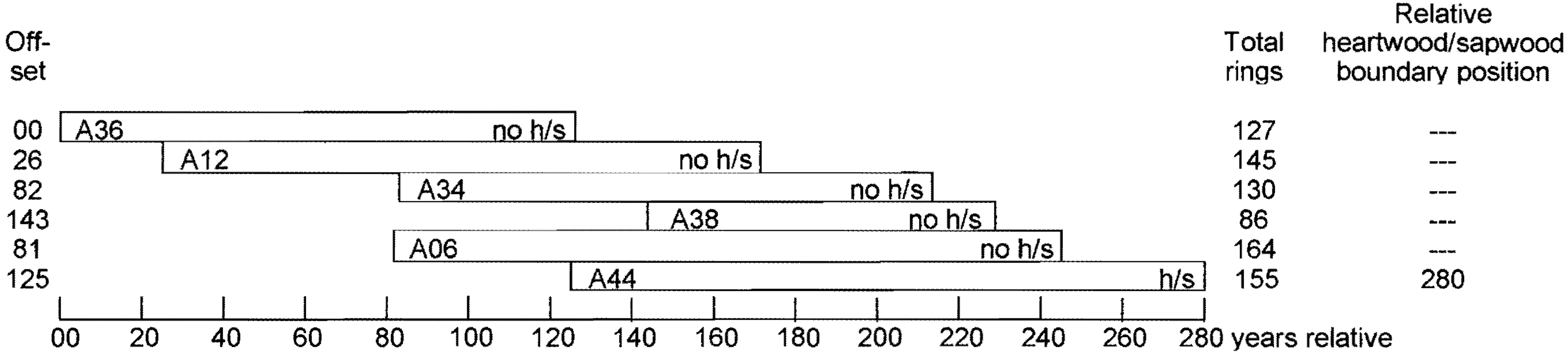
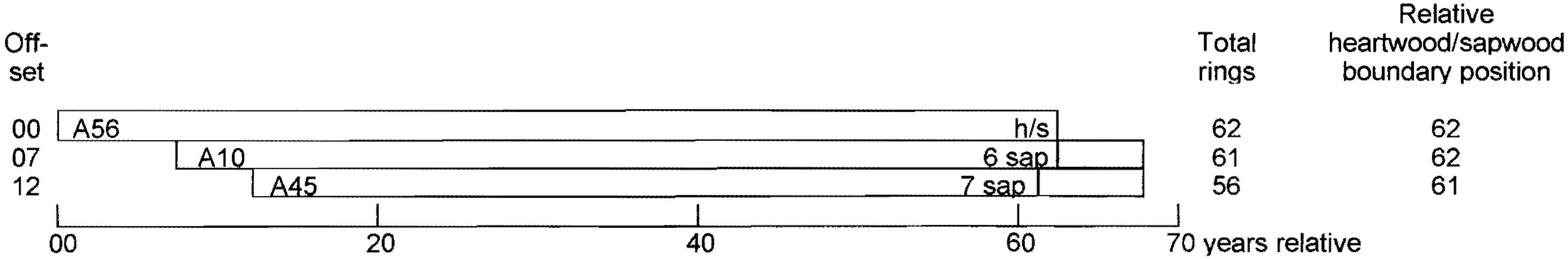


Figure 11: Bar diagram of the samples in site chronology LCPASQ03



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

Figure 12: Bar diagram of the samples in site chronology LCPASQ04

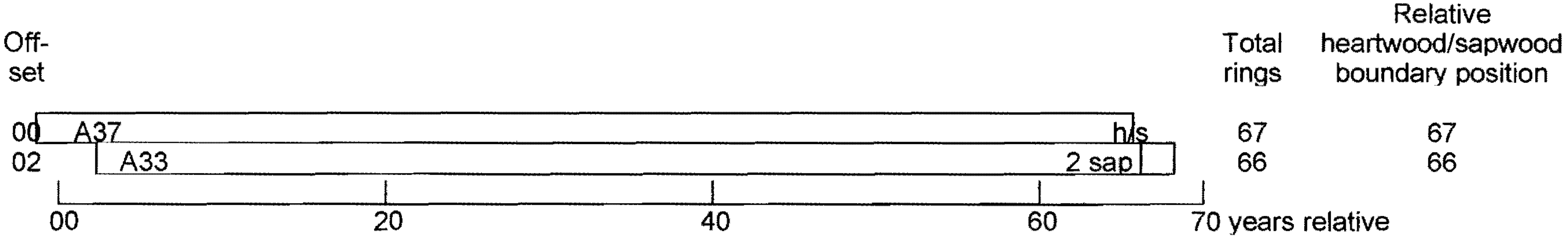
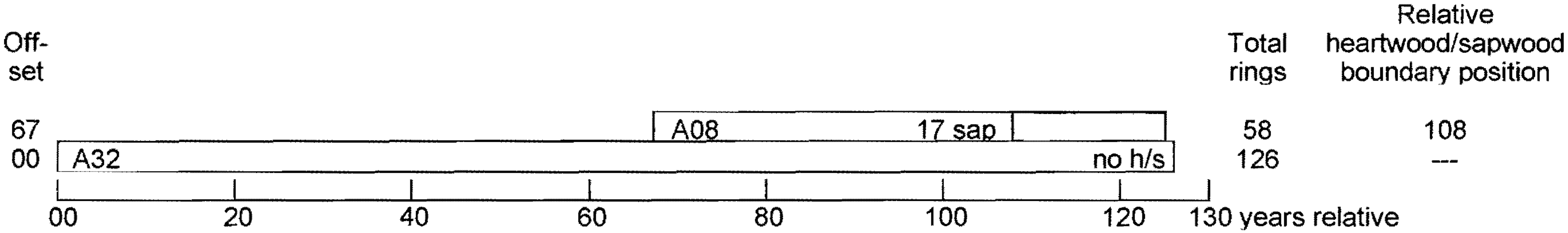
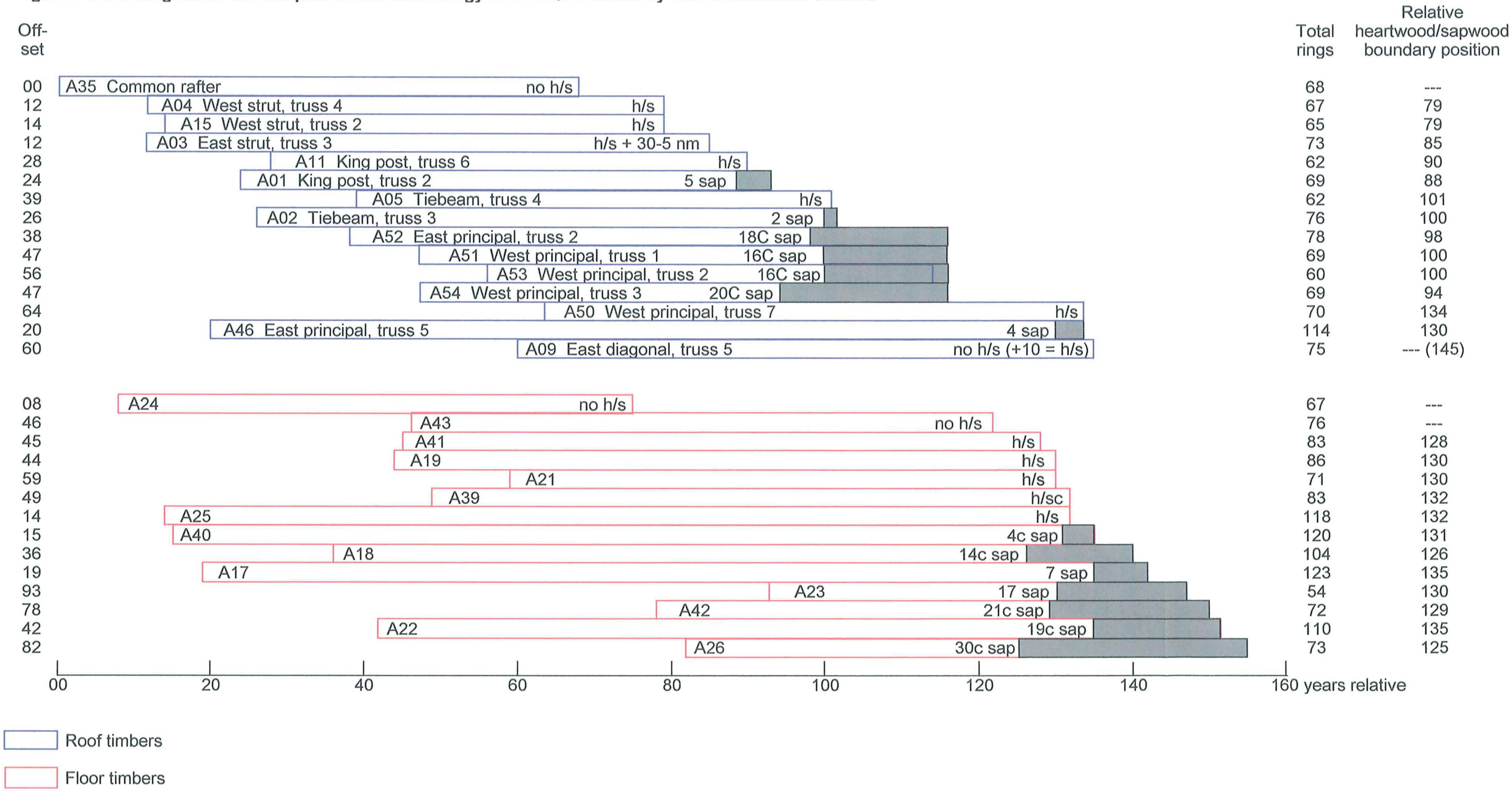


Figure 13: Bar diagram of the samples in site chronology LCPASQ05



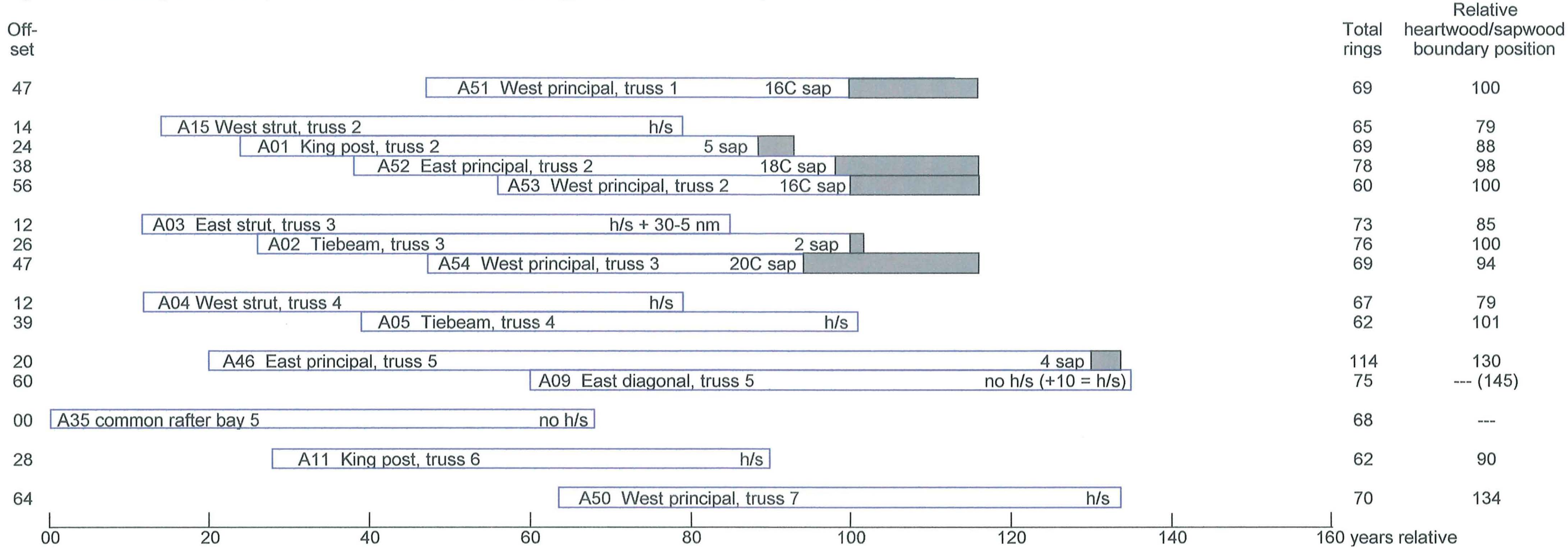
white bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample

Figure 14: Bar diagram of the samples in site chronology LCPASQO1 sorted by roof or first-floor timbers



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
c = complete sapwood on sample, all or part lost during sampling

Figure 15: Bar diagram of samples from the roof in site chronology LCPASQO1 sorted by truss number



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
c = complete sapwood on sample, all or part lost during sampling

Data of measured samples – measurements in 0.01mm units

LCP-A01A 69
361 280 280 171 167 159 221 186 281 340 395 278 362 276 242 188 208 191 206 196
197 183 199 203 186 159 171 194 188 236 176 178 201 203 150 164 177 141 115 154
159 129 74 100 108 102 99 99 98 138 156 87 58 70 72 81 90 97 140 89
122 102 96 137 136 118 137 113 137
LCP-A01B 69
353 297 276 166 164 176 215 177 301 351 363 353 418 298 243 224 207 187 194 207
201 189 186 212 194 160 182 179 183 239 178 168 211 199 158 161 161 138 135 176
150 112 80 96 107 95 105 111 98 127 146 91 67 58 78 86 90 88 135 123
107 99 97 114 135 152 123 119 136
LCP-A02A 76
245 192 263 273 292 344 246 217 230 176 342 309 299 248 235 184 200 245 248 242
352 220 291 250 335 332 320 287 300 245 217 329 328 289 401 325 243 280 226 332
224 287 282 263 377 184 199 211 277 123 87 107 165 270 312 367 344 346 291 237
203 217 301 137 134 125 98 105 197 135 101 105 119 201 166 171
LCP-A02B 76
249 191 275 264 306 354 255 233 228 174 351 333 276 261 229 185 188 278 252 215
364 213 307 235 336 336 308 301 281 234 218 326 368 301 425 324 232 298 209 293
246 276 298 252 452 176 213 207 265 136 81 138 146 274 300 368 343 337 306 229
213 220 294 133 131 143 87 105 194 127 97 108 133 226 179 151
LCP-A03A 73
476 356 408 346 282 333 281 328 195 212 331 313 329 406 364 292 291 329 359 257
263 274 310 224 239 211 192 174 160 144 153 179 159 170 217 212 177 176 244 220
199 197 166 104 97 149 77 58 49 61 51 40 38 51 29 40 62 58 71 67
52 70 103 65 46 48 49 52 57 60 95 77 91
LCP-A03B 73
398 378 370 340 332 312 276 331 193 223 295 345 343 412 365 270 299 311 364 251
292 229 338 203 237 210 190 182 155 160 146 164 193 156 201 216 172 170 241 234
199 198 166 98 98 160 91 55 44 53 51 43 33 38 38 46 63 56 68 66
59 61 103 63 58 43 41 53 53 67 88 76 70
LCP-A04A 67
316 425 337 327 318 286 204 383 233 191 290 220 274 247 181 179 217 211 220 219
245 209 228 156 172 152 207 189 149 146 121 126 158 146 173 130 124 161 176 159
124 182 137 82 113 124 94 116 126 108 101 131 86 96 86 73 95 80 109 100
125 122 135 105 75 98 123
LCP-A04B 67
256 407 379 343 254 265 210 335 225 168 295 228 274 239 179 171 204 210 205 238
232 215 229 160 171 163 196 201 145 143 131 118 164 146 165 143 139 136 179 173
117 175 145 77 108 116 89 120 129 103 111 121 106 94 71 99 74 73 105 103
126 135 115 132 73 96 127
LCP-A05A 62
423 362 454 283 437 373 372 396 400 348 327 321 427 322 375 376 322 298 354 295
255 308 274 236 269 191 302 182 177 179 165 261 246 208 227 204 186 152 180 216
272 204 185 237 204 301 196 159 184 284 195 160 148 122 174 257 175 147 195 160
202 208
LCP-A05B 62
403 369 448 319 409 373 373 396 367 367 342 319 439 314 378 395 304 324 325 317
242 330 264 262 272 197 293 169 186 186 148 291 233 198 245 210 188 143 167 234
273 202 177 231 202 269 202 202 185 286 190 160 159 128 179 232 192 139 193 152
213 209

LCP-A06A 164
60 84 79 103 92 94 99 68 81 103 72 89 77 61 55 46 77 57 63 80
71 87 96 100 90 107 112 109 82 97 103 103 93 131 88 83 82 93 86 82
79 84 71 77 55 79 78 87 75 90 53 85 63 89 48 79 81 86 88 83
89 68 94 66 80 67 65 75 59 87 75 46 56 87 87 98 111 102 55 70
79 76 83 104 86 71 80 66 62 83 71 64 66 58 62 69 73 77 67 70
64 86 81 72 74 84 69 72 53 81 73 72 51 79 72 71 62 43 36 36
55 74 66 74 77 59 78 94 81 82 77 81 96 84 87 98 116 126 125 113
117 92 89 100 79 77 76 71 74 78 93 95 103 87 97 88 139 124 115 121
88 88 126 139
LCP-A06B 164
96 72 86 99 88 95 93 69 92 94 77 77 82 59 59 39 55 81 73 72
76 91 101 88 93 105 110 106 84 93 103 110 80 143 96 72 81 99 81 93
73 87 75 61 68 87 78 78 84 73 63 87 74 74 44 75 70 88 83 84
86 75 86 70 84 61 63 84 61 85 71 45 65 86 82 105 105 104 54 70
71 78 86 93 95 77 74 70 64 80 69 69 66 53 65 70 72 80 58 71
68 85 82 74 73 66 88 68 61 74 71 51 68 72 70 78 69 46 52 57
49 84 58 66 82 61 75 93 86 82 81 72 86 103 80 110 111 115 116 121
116 90 86 96 74 76 74 67 74 76 84 89 102 90 93 98 139 125 112 108
85 92 135 140
LCP-A07A 79
282 250 257 317 222 289 315 275 339 345 331 350 302 291 226 312 331 189 279 239
296 208 207 177 196 266 196 225 226 205 176 198 217 203 199 195 169 243 307 280
249 200 249 119 220 260 363 271 249 192 157 168 193 140 181 180 213 245 158 160
239 129 138 126 195 238 260 132 244 242 147 122 110 169 201 207 194 247 205
LCP-A07B 79
313 256 262 308 222 290 299 299 341 353 322 312 316 288 260 352 373 184 253 218
316 215 207 208 194 278 178 227 219 206 187 212 216 203 226 184 167 278 287 250
271 207 254 139 201 275 348 264 239 196 151 156 184 176 159 173 228 241 153 169
232 127 126 140 206 240 254 142 235 234 175 126 119 149 187 186 194 240 198
LCP-A08A 58
422 289 314 260 379 230 183 234 223 257 308 288 308 206 344 253 171 173 173 175
245 254 161 186 200 181 407 287 237 287 265 368 436 335 242 375 242 248 223 144
264 194 224 260 146 156 161 181 132 121 141 141 165 169 149 171 195 229
LCP-A08B 58
417 286 320 305 385 225 180 238 232 263 305 283 318 213 333 260 171 174 166 182
254 236 164 177 205 190 385 301 265 301 294 336 414 310 237 387 257 253 220 156
264 206 228 229 174 134 148 168 107 141 147 145 165 163 148 166 205 210
LCP-A09A 75
339 277 298 251 183 213 159 186 206 109 227 211 268 260 240 170 126 140 225 233
192 209 257 153 128 136 156 184 134 141 142 178 107 118 137 138 81 112 123 112
63 99 103 107 118 111 112 115 84 81 107 82 88 67 69 51 82 59 86 99
73 68 64 92 84 97 97 92 84 67 87 73 47 67 93
LCP-A09B 75
304 269 277 264 177 207 156 195 188 145 220 212 269 266 231 177 122 140 236 233
192 206 256 155 137 134 144 175 150 130 130 185 106 114 145 124 82 115 120 114
80 107 101 105 121 107 107 113 78 96 100 85 87 75 61 59 67 68 82 106
83 62 69 79 89 95 112 91 83 59 80 77 46 58 77
LCP-A10A 61
379 388 410 271 212 250 212 241 407 364 481 446 457 188 236 203 384 261 195 167
122 121 168 212 254 261 316 288 263 244 203 245 338 269 305 276 309 324 197 120
178 144 158 140 186 207 229 166 132 127 186 123 133 118 107 188 193 178 166 160
166

LCP-A10B 61
432 390 421 257 223 240 210 242 388 376 497 452 454 193 209 224 369 250 189 185
131 126 152 206 260 272 304 294 256 227 209 265 346 258 310 268 296 299 213 137
161 143 167 130 185 204 228 148 140 119 173 135 143 108 108 178 184 202 163 157
170
LCP-A11A 62
210 244 242 219 183 171 263 298 319 281 274 315 203 108 180 247 299 265 316 259
288 286 272 178 147 217 230 236 278 210 179 219 177 177 154 200 158 159 116 131
118 109 152 150 174 179 195 171 128 140 132 161 176 171 192 148 143 141 99 111
116 143
LCP-A11B 62
175 273 218 211 192 158 287 314 292 287 305 288 154 123 172 260 291 280 312 237
279 285 279 177 133 224 233 264 249 240 176 225 156 166 185 194 161 151 100 114
117 95 131 156 176 167 209 203 135 123 140 155 186 152 185 141 152 141 109 108
121 143
LCP-A12A 145
101 41 31 93 91 69 103 35 83 161 79 38 71 49 80 72 62 56 89 70
100 61 57 65 79 102 118 135 128 116 87 43 50 36 106 73 64 81 54 108
42 49 32 33 35 56 92 103 81 51 42 33 26 22 41 53 44 89 75 105
77 86 60 90 92 81 66 113 76 91 26 50 127 129 122 106 133 160 128 198
187 119 164 148 136 116 75 53 63 27 36 37 65 43 34 50 64 43 40 44
42 59 55 51 54 86 91 71 82 41 54 56 71 100 94 98 84 67 58 87
92 89 83 60 70 68 55 39 79 110 87 108 74 83 78 52 78 76 106 112
69 88 89 124 110
LCP-A12B 145
109 30 37 101 76 84 84 44 83 166 77 51 67 53 93 65 81 50 91 72
111 65 54 77 85 111 88 138 137 101 104 34 61 41 114 73 52 80 55 99
47 40 27 29 49 60 82 96 66 70 32 24 22 30 50 53 33 98 67 103
59 117 58 108 101 85 75 131 66 85 27 58 117 137 113 119 122 164 127 187
196 116 166 157 131 110 83 51 58 32 28 34 58 36 43 41 64 37 39 43
49 71 56 48 55 88 88 78 91 40 50 73 70 106 94 116 83 66 68 82
91 74 76 80 63 64 72 25 72 104 75 115 83 89 73 56 75 73 115 101
80 83 97 114 118
LCP-A13A 55
288 322 306 277 305 247 261 241 188 241 204 179 132 178 215 183 180 166 216 297
247 249 261 227 237 180 187 198 299 235 213 176 193 165 215 246 208 190 190 183
171 169 173 207 171 160 105 140 166 170 143 154 159 183 167
LCP-A13B 55
261 344 264 229 325 239 239 223 185 232 207 188 131 162 217 214 185 185 200 291
258 232 238 233 264 178 190 224 288 231 216 185 196 171 202 259 195 203 182 190
172 164 165 195 169 158 102 137 172 172 148 154 155 192 185
LCP-A14A 96
155 211 231 205 167 139 172 145 158 159 142 185 158 175 162 101 103 98 155 102
98 112 120 74 94 63 95 108 102 60 100 99 78 62 51 75 64 78 89 77
63 59 86 85 56 58 53 82 61 84 82 75 81 58 84 65 68 67 74 83
69 72 69 74 56 68 66 56 55 76 68 57 61 60 78 79 72 60 58 63
77 70 73 58 80 69 80 64 67 72 75 78 79 83 107 108
LCP-A14B 96
135 225 226 215 179 135 175 140 160 145 123 170 154 177 182 100 94 95 146 105
100 104 107 81 98 69 89 104 95 72 87 86 86 61 38 77 55 69 93 81
69 59 92 70 64 51 46 60 73 72 86 70 82 76 61 76 55 73 76 75
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65 79 62 63 84 63 77 66 73 75 61 90 73 87 99 103

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93 142 75 125

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56 64 55 46 58 59
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LCP-A34B 130
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97 162 139 95 102 107
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LCP-A41B 83
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LCP-A45A 56
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LCP-A55B 97
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LCP-A56A 62
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119 152
LCP-A56B 62
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151 181 198 285 242 206 193 213 187 173 235 309 227 237 264 257 397 262 243 284
226 353 304 339 310 232 131 189 130 145 135 184 219 227 186 152 150 184 128 135
125 163

APPENDIX

Tree-Ring Dating

The Principles of Tree-Ring Dating
Tree-ring dating, or *dendrochronology* as it is known, is discussed in some detail in the Laboratory's Monograph, '*An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Building*' (Laxton and Litton 1988) and, *Dendrochronology; Guidelines on Producing and Interpreting Dendrochronological Dates* (English Heritage 1988). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The *width* of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure 1 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 1, 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 University of 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 2 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 to 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.

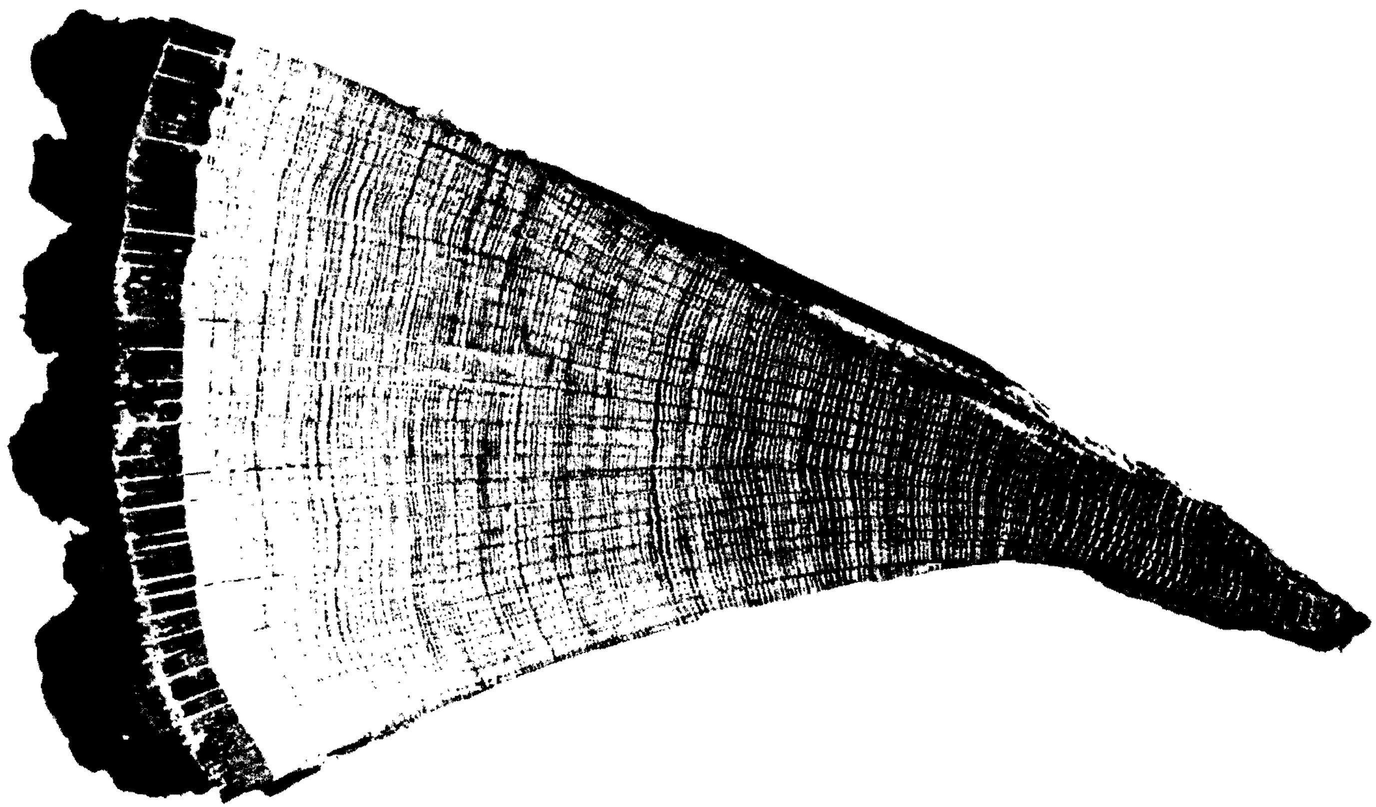


Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can determined by counting back from the outside ring, which grew in 1976.

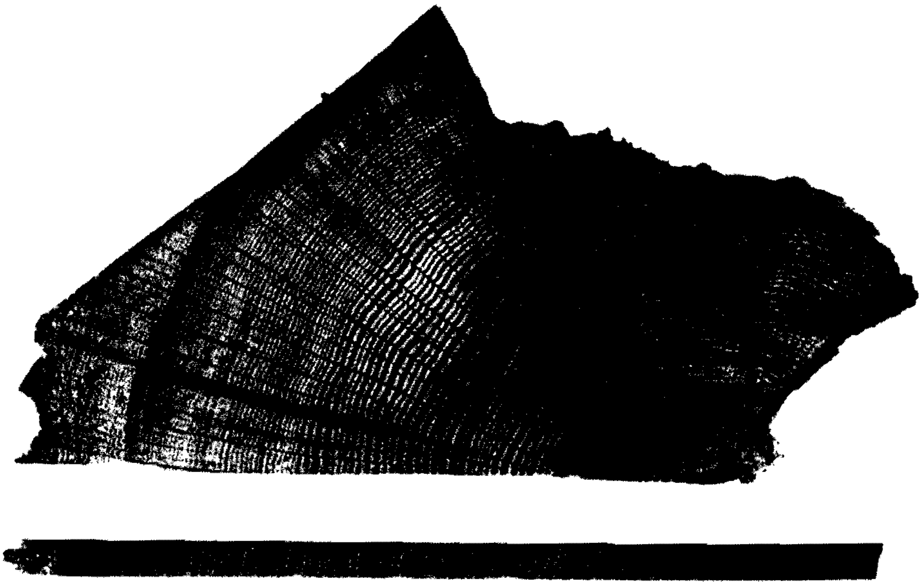


Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the left hand corner, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

Fig. 3 Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measure 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.

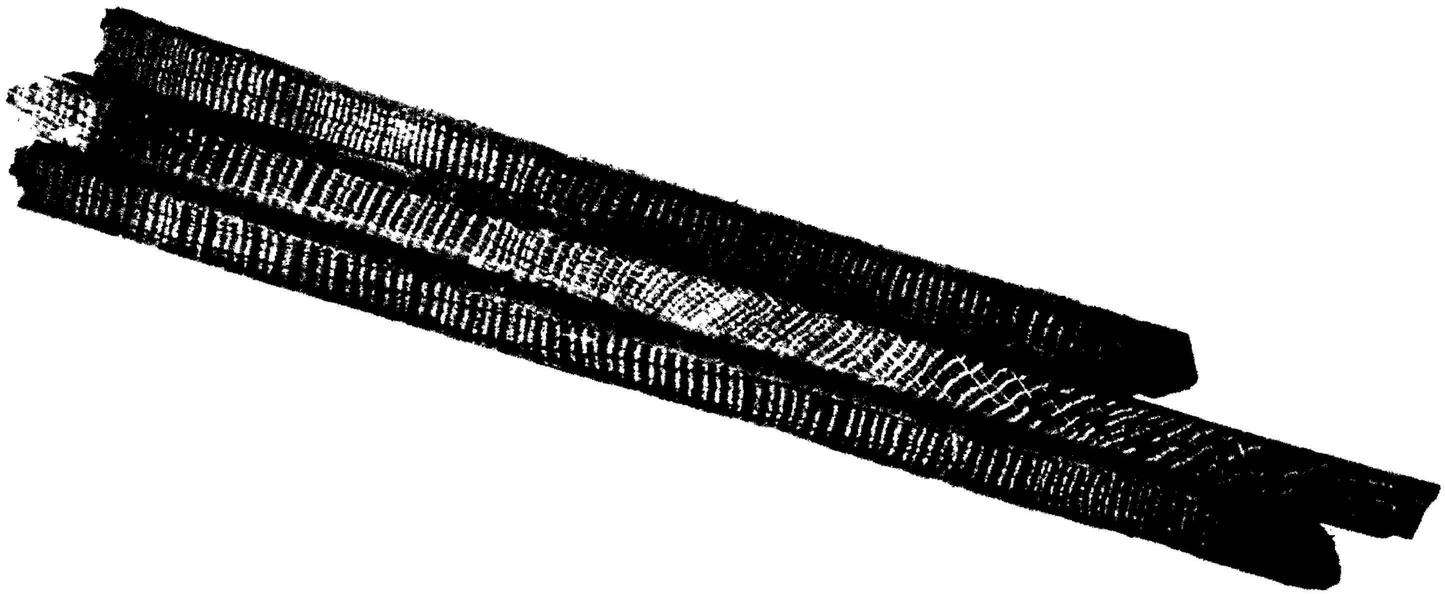


Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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 2; it is about 15cm long and 1cm 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.

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 2. 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 3).

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 4). 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 Fig 5 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 Fig 5. 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 5 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 straight forward 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. Actually it could be the year after if it had been felled in the first three months 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 2, 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 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 2 was taken still had complete sapwood but that none of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 2 cm, 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

t-value/offset Matrix

	C45	C08	C05	C04
C45		+20	+37	+47
C08	5.6		+17	+27
C05	5.2	10.4		+10
C04	5.9	3.7	5.1	

Bar Diagram

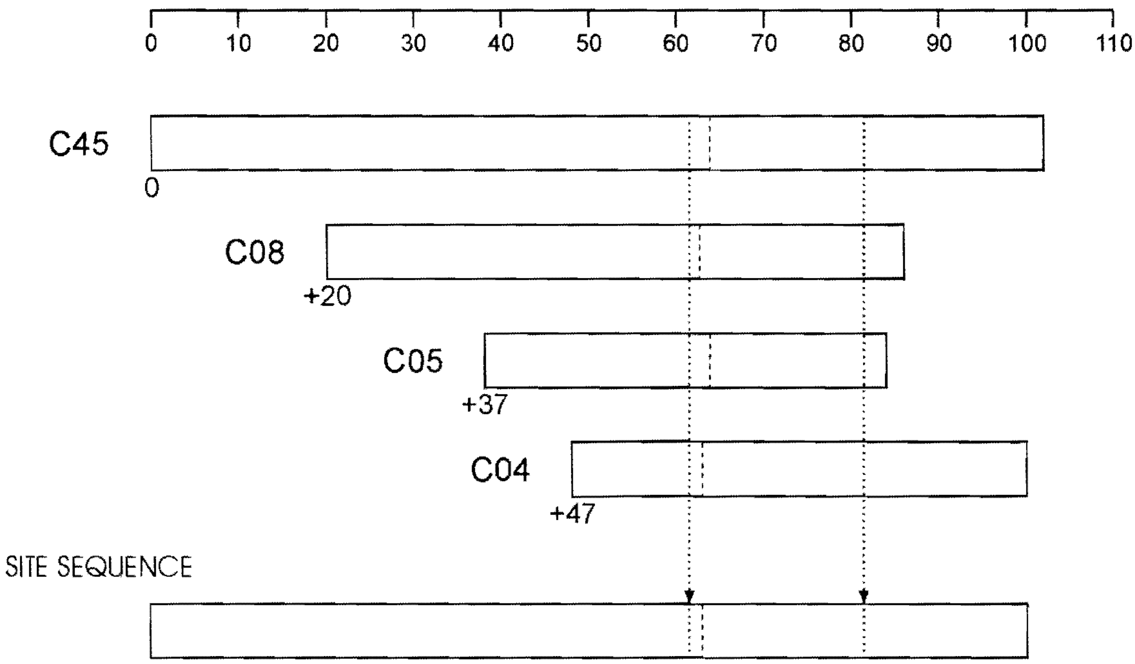


Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

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.

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 and Miles 1997, 50-55). Hence provided 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, figure 8 and pages 34-5 where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storing 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 Fig 6 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 Fig 6. 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 Fig 7. 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 phenomena 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.

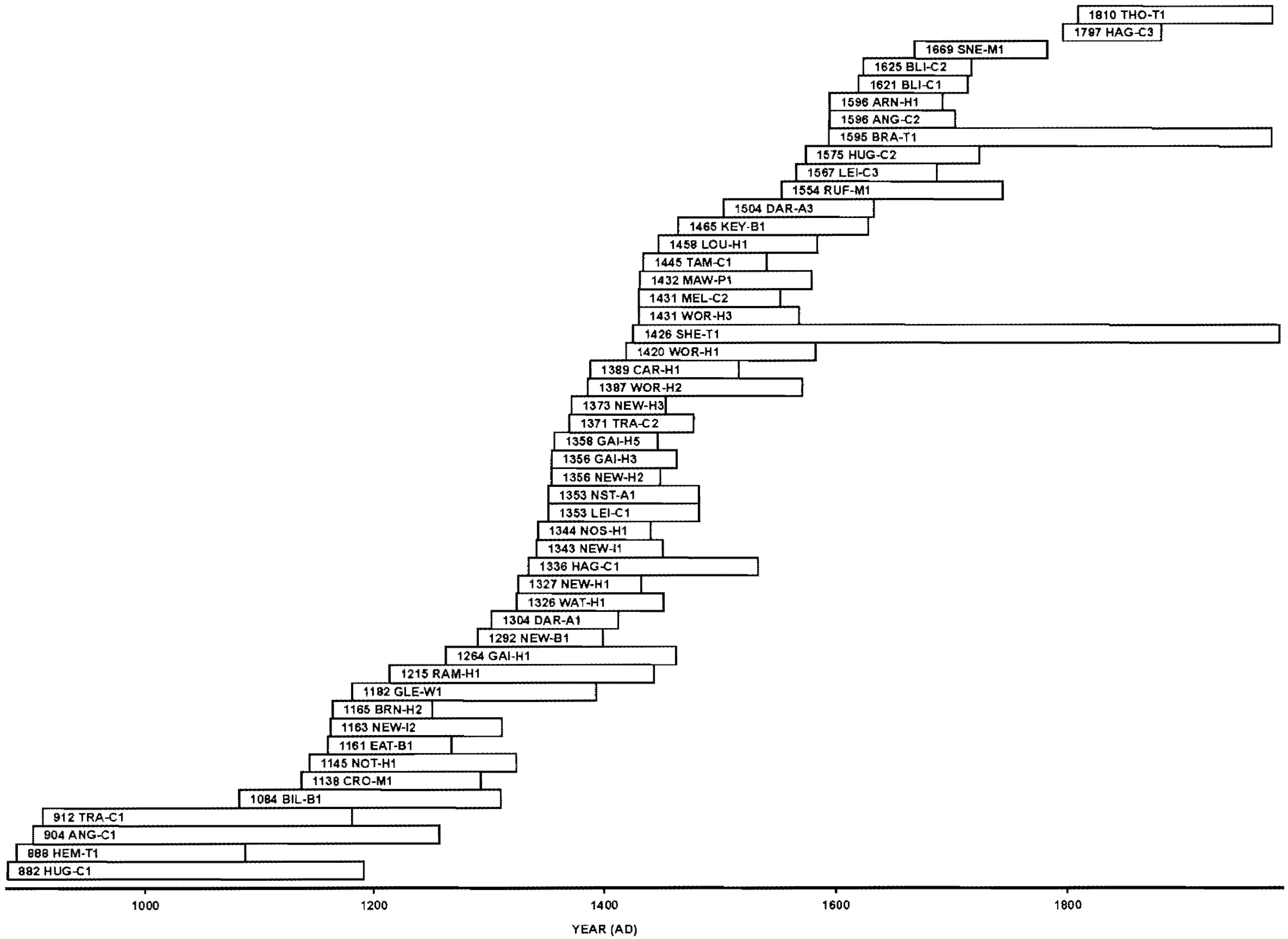
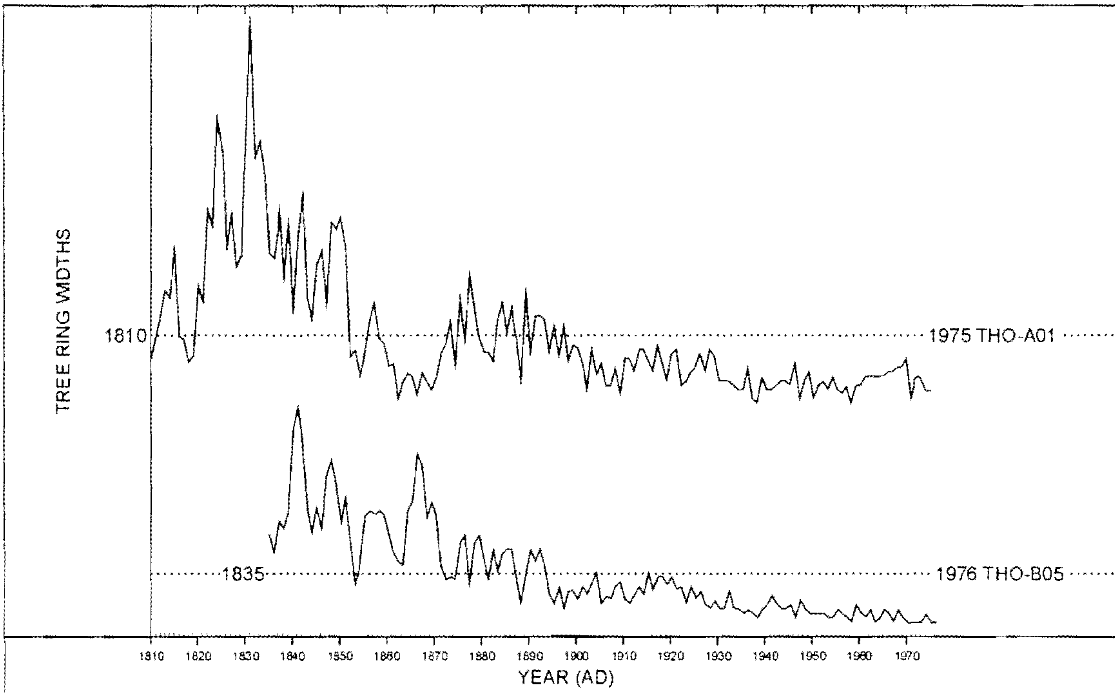


Fig. 6 Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

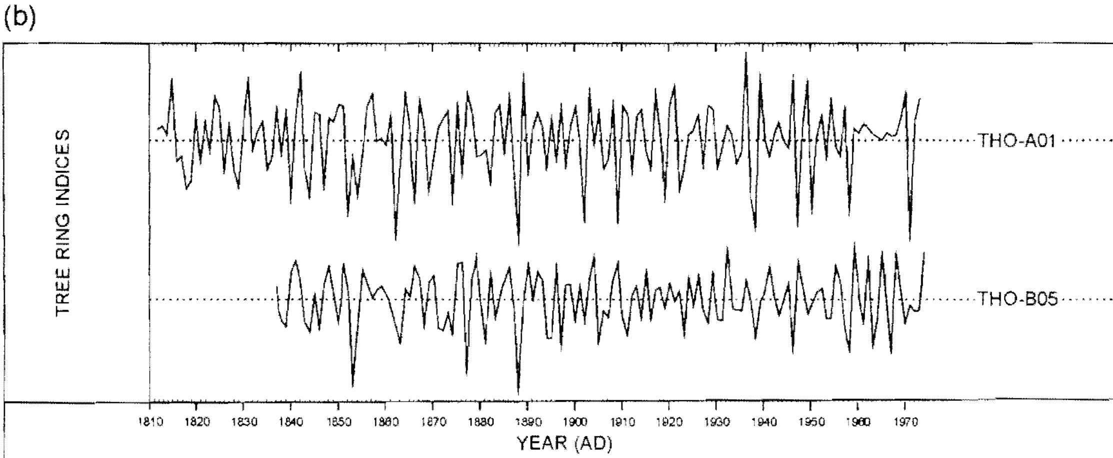


Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree are wider than the later ones of the older tree in both sequences.

Fig 7. (b) The *Baillie-Pilcher* indices of the above widths. The growth-trends have been removed completely.

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