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TREE-RING ANALYSIS OF TIMBERS FROM THE BARN AND COTTAGE, ABBEY FARM, THETFORD, NORFOLK

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Summary

Eighty-one samples obtained from the timbers of Abbey Farm barn and cottage were analysed by tree-ring dating. This analysis produced four site chronologies. The first site chronology consists of thirty-one samples that are all from the eastern half of the barn except for one sample from the cottage. This site chronology has 205 rings spanning the period AD 1332 - AD 1536. Interpretation of the sapwood on the samples would indicate that all the dated timbers in this group were probably felled in the period AD 1533 - 6. The second site chronology also consists of thirty-one samples, having 192 rings spanning the period AD 1237 - AD 1428. The majority of samples in this site chronology come from the western half of the barn and also from the cottage, although some do come from the eastern half of the barn. Interpretation of the sapwood on the samples in the second site chronology suggests that the timbers used in the cottage have an estimated felling date in the range AD 1405 - 30. The timbers used for the western end of the barn have an estimated felling date in the range AD 1414 - 39. The third site chronology consists of three samples, having 73 rings spanning the period AD 1556 - AD 1628. Interpretation of the sapwood on these samples would indicate that the timbers in this group, all from the east gable and replaced roof of the barn, were felled in AD 1628. The fourth and final site chronology also consists of three samples, having 74 rings. This site chronology failed to date.

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Introduction

The Priory of Our Lady of Thetford (TL 865835; Figs 1 and 2) belonged to the Order of Cluny, and was founded in AD 1103 – 4 by Roger Bigod, the old soldier, friend, and counsellor of William the Conqueror. The original twelve monks came from the Priory of Lewes, the first Cluniac House of England which had been founded some ten years before by William de Warenne. The original priory was in the town of Thetford, and took over the church of St Mary which had been the cathedral of the diocese until the see was translated to Norwich in AD 1094 by Bishop Herbert de Losinga. The urban site, however, soon proved too cramped for a convent of twenty monks - the normal number - and within a very few years the second prior, Stephen, obtained from old Roger Bigod authority to move to the site on which the ruins now stand. On 1 September AD 1107, work was begun, Bigod himself and the prior laying the foundation stones.

Building work proceeded from that time until approximately AD 1140. Later additions included the construction of the Lady Chapel in the early-thirteenth century and the lengthening of chancel in the later-thirteenth century; a gatehouse was built in the fourteenth century. The priory was disolved and surrendered to the King in AD 1540.

Abbey Farm is situated towards the north-west corner of the former precinct of the Priory and consists of a range of buildings set round a rectangular farmyard. To the north-east of the farmyard stands an open-fronted store while to the north-west stands an L-shaped building used until recently as garages and offices.

On the south-western and the south-eastern side of the farmyard respectively stand Abbey Farm barn and Abbey Farm cottage.

Abbey Farm barn

Abbey Farm barn is a long, rectangular building aligned east – west and situated on the south side of the former farmyard. The building lies immediately to the west of Abbey Farm cottage. Most of the building is encased in flint with gault brick dressings and a corrugated asbestos roof.

The building is divided into two storeys. Internally, the exterior walls appear to have been completely rebuilt up to first-floor level, probably at some time during the nineteenth century. For the purpose of this report, the roof trusses have been numbered 1 to 9 from west to east, starting at the west gable and ending at the east gable. A ground-floor plan of the building showing the trusses is given in Figure 3. The first floor is open to a crown-post roof that extends the entire length of the building. The roof is divided by seven crown-post trusses into eight bays. In addition, there is a gable truss at each end. Cross-sections showing two typical trusses are provided in Figures 4 and 5

The present eight-bay structure comprises two separate major phases of construction. The western half of the building pre-dates the eastern half and contains the shell of an original four-bay timber-framed building believed to date from around the middle of the fifteenth century whereas the eastern section is though to be post-dissolution. A long section of the western bays is shown in Figure 6, with a reconstruction shown in Figure 7.

The original mid fifteenth-century building forming the present western half of the building was a two-storey, timber-framed structure, with a high-quality crown-post roof. The building was jettied at first-floor level on its south side (ie the side facing the main Conventual buildings). Behind the exterior flint wall cladding the first-floor wall framing is largely intact, preserving such evidence as the original window positions and shutter arrangements. The roof itself is almost completely intact, with the rafters still arranged in their original sequence according to the pattern of carpenter's marks present on the timbers. At first-floor level, the building appears originally to have been divided into two, with one very large chamber occupying the westernmost three bays and

a much smaller chamber at the east end. The central section of the tie beam of the former cross frame partition (truss 4) has been cut away and new tie-beam braces inserted, yet it preserves evidence of a possible door opening at its south end. The roof trusses above tie-beam level are numbered 1 to 3 from east to west. The tie-beam braces are numbered 1 to 3 from west to east along the north side of the building, and 4 to 6 from east to west along the south side (with braces 3 and 4 from truss 4 now missing and having been replaced).

It would appear that in the phase 1 construction at the western end, there were originally no braces in the former eastern gable (removed following the construction of the phase 2 addition). Again, this observation is based on the sequence of carpenter's marks found on the tie beams and braces, and the fact that the numbering is complete, even though the end tie beam is now missing. Indeed, the same is also true of the present western gable, where, although there is a tie beam, there are no carpenters marks present at either end (or indeed, pegs/peg holes) to indicate there were ever any tie beam braces.

The eastern half represents a four-bay extension of the earlier building and is believed to date from the mid sixteenth-century. Included within the frame of the eastern addition and forming an integral part of the work is a large group of re-used elements from an earlier, high-quality, building of probable fifteenth-century date.

Within the phase 2 four-bay eastern addition, the tie beams and their braces are numbered in similar fashion to the numbering system adopted in the phase 1 western end of the building. The beams and braces and numbered at each end of the tie beam, the numbering running from 1 to 4 from east to west along the north side of the building, and 5 to 8 from west to east along the south side. The numbering sequence extends up to the tie beam of the eastern gable (where there is a number 8 at its south end), suggesting that the gable, although now a masonry wall, was originally timber-framed, with braces between the wall posts and tie beam.

A particular feature of interest is the eastern gable end of the original fifteenth-century building, which was deliberately built with a skew. The tie beam has been removed yet the dovetail mortises and the partially surviving crown post show that it was built out of alignment. This indicates that the present structure may have had to take account of a pre-existing building. The roof of the present east end of the barn appears to have been hipped when it was built. Some time later the east end was altered, part of the roof being replaced, and the end finished with a gable.

The present structure clearly held a certain status above its more recent use as a barn and store. The high quality of construction, particularly the crown-post roof of the western four bays, the jetty facing the priory church, are all indicative of attention to more than the purely functional. The absence of heating shows that the building was not domestic and the layout suggests that it was used for formal meetings of some sort. The small private vestibule at the eastern end suggests that it may have been a courthouse with a retiring room for a judge. As yet no document from the priory archives has come to light which could help us to understand further the function of this.

A mid fifteenth-century date for the western bays has been proposed on stylistic and constructional grounds. The heavy scantling, the crown-post truss with massive downward braces, and the splayed scarf joints are indicative of a fourteenth-century date as a general rule. The use of a jetty and the associated expanded feet to the principal posts is a sophistication which is not normally seen in buildings earlier than the fifteenth century. The absence in the area of dated buildings with similar characteristics renders any attempt at greater precision unwise. On the basis of the quantity of reused timber and the variation in timber, and what appears to have been a conversion of the building to agricultural use, it has been proposed that the four easternmost bays post-date the dissolution.

Abbey Farm Barn was the subject of an earlier programme of dendrochronology undertaken by the Sheffield Laboratory. This more limited programme produced a felling date of *c* AD 1532 – 40 for the tiebeams of the eastern bays (Groves and Hillam 1993). Although there are documents which relate to the expenditure of the Priory between AD 1482 and AD 1540, none of the entries appear to relate to the construction or alteration of a building that might be the barn.

Abbey Farm cottage

Also on the south side of the farmyard, and to the east of the main barn stands a second timber-framed aisled barn encased in flint and brick. This is generally referred to as Abbey Farm cottage, a ground-floor plan of which is provided in Figure 8. The interior of the building is sub-divided into four bays of approximately equal size by three transverse partition walls. The partition walls contain the remains of a series of three timber-framed aisle trusses that survive from an earlier building on the site. Illustrations of two of the trusses, plus a long section are shown in Figures 9, 10, and 11.

Each cross frame included a pair of vertical arcade posts joined together at their tops by a horizontal tie beam. To judge from the few remaining carpenter's marks to be seen on the timbers, it would appear that the cross frames were originally numbered from east to west. That is, with the easternmost cross frame between bays 1 and 2 being marked number one, and the westernmost cross frame, between bays 3 and 4, marked number three.

Cross frames 2 and 3 are linked by a set of lower/inner and upper/outer arcade plates. The lower/inner plates are housed between the posts and tie beams in the usual manner, whilst the upper/outer plates sit over the ends of the tie beams, which project outwards beyond the line of the arcade posts. The plates were connected to the posts by a series of curved arcade braces, which divided the interior space into a central nave and a flanking aisle on either side. Along the south side of the roof only, the upper plate is braced to the tie beams at each end with curved angle ties. Both cross frames carry a queen-post roof truss above the tie beam.

The trusses are comprised of a pair of queen posts that rise up vertically from the tie beam and a horizontal collar. The posts have jowled heads and are linked to the collar with curved braces. The posts carry square-set purlins, which are housed between the posts and collar. The purlins are linked to the queen posts with straight windbraces. It is interesting to note that at cross frame 2 (cross frame 3 is presently encased inside a later flint render to above tie-beam level) the mortice and tenon joint between the feet of the queen posts and tie beam is unpegged. This suggests that the roof trusses might not be original to the building, but introduced at some later date. Similarly, it may be significant that the windbraces are not pegged to the purlins, but are simply halved over their inner faces and nailed.

Encased inside the present partition wall between bays 1 and 2 are the remains of two arcade posts which originally formed part of the easternmost of the three aisled cross frames, cross frame 1. The easternmost bay, bay 1, is currently inaccessible, and it is not known whether the face of the truss is exposed on this side or not. On the western side of the partition wall, the brickwork has been built flush with the sides of the timbers, so that the original configuration of the cross frame can still be made out. Of the original cross frame all that can now be seen are the two arcade posts, and the post stud and sill beam on the northern side. It is possible that the southern post stud and sill beam may also survive behind the existing cement render at the southern end of the partition wall.

From an analysis of the surviving timbers, it is possible to obtain a fairly clear idea of the original appearance of the easternmost cross frame, at least up to tie-beam level. From a design point of view, the cross frame was characterised by the use of angled, or cranked, arcade posts, and the inclusion of short vertical basal timbers (referred to here as 'post studs') which linked the posts to the sill beams, and transferred the loading from the roof, via the arcade posts, directly to the ground. The plain butt joint used to connect the post stud to the arcade post, although unpegged, was extremely well cut and remains tight and secure, and in itself gives no cause to suspect the timber being a later addition, in fact rather the contrary. The post stud was tenoned and pegged to the inner end of the aisle sill beam, and this would have been sufficient to ensure that the timber was held in an upright position, in line with the arcade post. A diagram of the joint is shown in Figure 12. At present it is not clear whether the post stud stood directly on the floor surface, or was set some distance into the ground.

The southern arcade post of cross frame 1 includes a halving for a former passing brace, at the very top of the timber, close to the point at which the post was truncated. The halving is on the western side of the post, a short distance above the point of intersection of the former arcade brace. The northern arcade post was truncated at a lower level, roughly at a point in line with the bottom of the arcade brace mortice, and therefore all evidence of the passing brace on this side of the cross frame has been lost. In the outer face of each arcade post, (ie the side

facing the external side walls of the building) at a distance of some 620mm below the arcade brace is a vertical mortice indicating the position of the two former aisle tie beams, which originally would have linked the posts with the tops of the aisle walls.

The very heavy scantling, the aisled construction, and the splayed scarf joints all indicate unequivocally a pre-Dissolution date, possibly in the range AD 1200 to AD 1400, with indications that the timber frame may have been substantially remodeled perhaps, like the barn, around the time of the Dissolution. An isometric illustration of the cottage is given in Figure 13.

Sampling and analysis by tree-ring dating were commissioned by English Heritage. The purpose of this was to assist with decision making concerning acquisition or guardianship of the site and to inform potential restoration and conservation of the buildings.

The Laboratory would like to take this opportunity to thank Mr Paul Rudkin and his colleagues of Breckland District Council. At all times they were extremely helpful in providing access to the site and in assisting in its sampling. The Laboratory would also like to thank Richard Bond of English Heritage who undertook a particularly thoroughgoing and productive survey of the buildings and provided extensive material for the introductory remarks. Acknowledgement and thanks are due to Stephen Heywood who wrote the original survey report on the barn and cottage and to Robert Smith who produced the drawings to accompany it, some of which are used in this report.

Sampling

A preliminary survey of the two buildings was undertaken by Richard Bond of English Heritage. This revealed that they appeared to contain at least five distinct areas or groups of timbers. Each of these five groups was sampled with a total of eighty-one different timbers being cored. Each sample was given the code THT-A (for Thetford site "A") and numbered 01 – 81. Some of the areas or groups were sampled at different times so that the samples from the same group or area do not always run in consecutive numerical order. A summary of the sampling is given below, with greater details of the individual samples being given in Table 1. The locations of the samples are shown in Figures 14, 15, and 16.

Sampling area/group	Sample numbers
Barn – eastern 4 bays	THT-A01 – 20
	THT-A30 – 40
	THT-A49 – 55
Barn – western 4 bays	THT-A21 – 29
Barn – western 2 bays – first-floor framing	THT-A41 – 48
Barn – east gable wall and replacement roof	THT-A56 – 68
Cottage – trusses at east and west ends	THT-A69 – 81

Analysis

Each sample was prepared by sanding and polishing and the growth-ring widths of all eighty-one were measured; the data of these measurements are given at the end of the report. The growth-ring widths of all samples were compared with each other allowing four groups of samples to be produced.

The thirty-one samples of the first group cross-match with each other at relative off-sets as shown in the bar diagram of Figure 17. The growth-ring widths of these thirty-one samples were combined with each other, at their cross-matching positions, to form THTASQ01, a site chronology of 205 rings. Site chronology THTASQ01

was compared with a series of relevant reference chronologies for oak, giving it a first ring date of AD 1332 and a last measured ring date of AD 1536. Evidence for this dating is given in the *t*-values of Table 2.

The thirty-one samples of the second group cross-match with each other at relative off-sets as shown in the bar diagram of Figure 18. The growth-ring widths of these samples were combined with each other, at their cross-matching positions, to form THTASQ02, a site chronology of 191 rings. Site chronology THTASQ02 was compared with a series of relevant reference chronologies for oak, giving it a first ring date of AD 1237 and a last measured ring date of AD 1428. Evidence for this dating is given in the *t*-values of Table 3.

The third group is made up of three samples, cross-matching with each other at relative off-sets as shown in the bar diagram of Figure 19. The growth-ring widths of these three samples were combined with each other, at their cross-matching positions, to form THTASQ03, a site chronology of 73 rings. Site chronology THTASQ03 was compared with a series of relevant reference chronologies for oak, giving it a first ring date of AD 1556 and a last measured ring date of AD 1628. Evidence for this dating is given in the *t*-values of Table 4.

The fourth and final group is also made up of three samples. These cross-match with each other at the relative off-sets shown in the bar diagram of Figure 20. The growth-ring widths of these three samples were combined with each other, at their cross-matching positions, to form THTASQ04, a site chronology of 74 rings. Site chronology THTASQ04 was compared with a series of relevant reference chronologies for oak, but there was no satisfactory cross-matching, and these samples remain undated.

Each site chronology was compared with the remaining ungrouped samples, There was, however, no further satisfactory cross-matching. Each of the ungrouped samples was, therefore, compared individually with a full range of reference chronologies. Again, there was no satisfactory cross-matching.

Interpretation

Site chronology THTASQ01

Apart from one sample, THT-A71 from the cottage, site chronology THTASQ01 (AD 1332 – AD 1536) is made up exclusively of samples from the eastern four bays of the barn. It contains five samples that retain complete sapwood, THT-A01, A17, A33, A49, and A50, these samples having last measured complete sapwood rings dates of AD 1533, AD 1533, AD 1534, AD 1533, and AD 1536 respectively. Given that the relative positions of the heartwood/sapwood boundaries on the other samples in this site chronology, where it exists, is indicative of a single phase of felling, this would suggest that all the timbers represented by this site chronology were felled between AD 1533 and AD 1536. Given the size of the building it is perhaps not unexpected that the construction, and thus the felling of the timbers, is spread over a few years.

Two samples in site chronology THTASQ01, THT-A60 and A61, come from timbers of the east gable of the barn. Given that other timbers from this gable have a later felling date (see below) it is probable that these samples represent re-used timbers.

Site chronology THTASQ02

The locations from which the samples in site chronology THTASQ02 (AD 1237 – AD 1428) come are more varied and thus it might perhaps be expected that so too would be the felling dates. Eight dated samples are from the floor frame of the west end of the barn, with a further nine samples coming from the upper timbers at the west end. Site chronology THTASQ02 also contains seven samples from the eastern four bays of the barn, plus seven samples from the cottage. None of the samples retain complete, or indeed very much, sapwood.

It is possible, however, to make some interpretation as to likely felling dates. If each of the sample groups/areas is taken separately it is possible to show that the average last heartwood ring date of the seven dated samples

from the cottage in site chronology THTASQ02 is AD 1390. Using a 95% confidence limit for the amount of sapwood of 15 – 40 rings would give these timbers an estimated felling date in the range AD 1405 – 30.

The average last heartwood ring date of the nine dated samples from the upper timbers of the western four bays of the barn and the eight samples from the first-floor frame is slightly later at AD 1399. Using the same confidence limit for the amount of sapwood as above would give the timbers an estimated felling date in the range AD 1414 – 39.

Site chronology THTASQ02 contains seven samples from timbers in the eastern bays of the barn which, as we have seen from the analysis above, is built of timber felled in AD 1533 - 36. Three of these samples, THT-A11, A12, and A32 do not have the heartwood/sapwood boundary and their felling dates cannot be reliably estimated. The latest dated ring on any of these three is AD 1428, on sample THT-A32. The timber which this sample represents is unlikely to have been felled before AD 1443.

The four remaining samples from the eastern bays of the barn in site chronology THTASQ02 that do have the boundaries, that is samples THT-A07, A30, A31 and A55, give an average last heartwood/sapwood date of AD 1382. Using a 95% confidence limit for the amount of sapwood of 15 – 40 rings would give the timbers represented by these an estimated felling date in the range AD 1397 – AD 1422.

Site chronology THTASQ03

The samples seen in site chronology THTASQ03, THT-A58, A66, and A67 are all from the east gable and the replaced portion of the roof of the barn. Although all three dated samples in this site chronology come from timbers that had complete sapwood, it is retained complete on only one sample, THT-A67. This sample has a last measured complete sapwood ring date of AD 1628. The other two samples lost only small portions of the sapwood, which fragmented during coring, and it is almost certain that the timbers represented by these were felled in AD 1628 also.

Conclusion

Following analysis by tree-ring dating it has been possible to obtain dates for all parts of the site. It is possible that the cottage and the western part of the barn are both to be seen as a single building project using timber felled in the early fifteenth century. However, the relative positions of the heartwood/sapwood boundaries on the samples from the cottage are consistently slightly earlier than those on the samples from the barn. This might indicate that the timbers used in the cottage were felled first.

On the basis of the analysis, therefore, it is suggested that the oldest building of the Abbey Farm complex is indeed the cottage, being constructed of timbers with an estimated felling date in the range AD 1405 – 30.

Shortly after this what is now the western part of the barn was built using timbers with an estimated felling date in the range AD 1414 – 39.

To this first part of the barn were added the eastern four bays. These were built using timbers felled between AD 1533 – 6.

The present east gable of the barn and the replacement roof at the east end were constructed using timber felled in AD 1628.

Apart from the western four bays of the barn, where there appeared to be no such timbers, all other areas of the barn contain reused timbers. The eastern bays of the barn, though built using timber felled in AD 1533 - 36, contains timbers that were felled earlier, as represented by samples THT-A07, A30, A31, and A55 for example. All the reused timbers are represented by samples found in site chronology THTASQ02, these probably being

felled in the early fifteenth century.

The east gable wall of the barn also contains at least two reused timbers, samples THT-A60 and A61, which have last measured ring dates of AD 1521 and AD 1488 respectively. It is possible that these timbers belonged to the original hipped roof of the sixteenth-century building and were reused in the early seventeenth-century alteration.

The cottage contains reused and inserted timber too. This is in part represented by timbers which show evidence for this by way of redundant mortices etc, sample THT-A76, for example. While the cottage contains a quantity of timber felled in the early fifteenth century sample, THT-A71 has a last measured ring date of AD 1431. The timber does not have the heartwood/sapwood boundary and its felling date cannot be estimated, except to say that it is unlikely to be before about AD 1445.

A noticeable feature of the site chronologies is the difference in the level of crossmatching between them and the reference chronologies, as measured by the *t*-values. Although they are both about the same length and contain the same number of samples, it will be seen from Tables 2 and 3 that site chronology THTASQ02 cross-matches against the references with higher *t*-values than does site chronology THTASQ01. There is no immediate explanation of this though one possibility is that the timbers represented in THTASQ2 come from a more discreet climatic niche which is not represented by any of the other chronologies.

Thirteen of the 81 samples failed to group satisfactorily with each other and to cross-match any of the site chronologies and date. The longest ungrouped and undated sample, THT-A79, has only 70 rings, with several others having fewer than 60 rings. Samples with fewer rings are often more difficult to cross-match and date. There appears to be no other difficulty with these samples that might make cross-matching difficult.

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Table 1: Details of samples from the barn and cottage, Abbey Farm, Thetford, Norfolk

Sample no.	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Barn – eastern 4 bays					
THT-A01	Arch-brace, south wall-post, truss 6	80	19C	AD 1454	AD 1514	AD 1533
THT-A02	Arch-brace, north wall-post, truss 6	100	h/s	AD 1409	AD 1508	AD 1508
THT-A03	Arch-brace, north wall-post, truss 5	100	no h/s	AD 1390	------	AD 1489
THT-A04	Tiebeam, truss 5 (north part)	73	13	AD 1456	AD 1515	AD 1528
THT-A05	Tiebeam, truss 5 (south part)	66	14	AD 1458	AD 1509	AD 1523
THT-A06	North wall-post, truss 5	155	15	AD 1367	AD 1506	AD 1521
THT-A07	North wall-plate, truss 5 – 6 (reused)	56	no h/s	AD 1346	------	AD 1401
THT-A08	South wall-post, truss 5	146	h/s	AD 1352	AD 1497	AD 1497
THT-A09	Arch-brace, south wall-post, truss 5	82	h/s	AD 1423	AD 1504	AD 1504
THT-A10	Tiebeam, truss 4	54	h/s	------	------	------
THT-A11	North wall-post, truss 4	130	no h/s	AD 1265	------	AD 1394
THT-A12	North wall-plate, truss 4 – 5	100	no h/s	AD 1237	------	AD 1336
THT-A13	North wall-post, truss 8	126	no h/s	AD 1332	------	AD 1457
THT-A14	Arch-brace, north wall-post, truss 8	97	3	AD 1415	AD 1508	AD 1511
THT-A15	North stud post, truss 8 – 9	133	h/s?	AD 1369	AD 1501	AD 1501
THT-A16	North wall-plate, truss 8 – 9	108	6	AD 1418	AD 1519	AD 1525
THT-A17	Arch-brace, south wall-post, truss 8	82	21C	AD 1452	AD 1512	AD 1533
THT-A18	South wall-post, truss 8	55	no h/s	------	------	------
THT-A19	South wall-plate, truss 8 – 9	96	6	AD 1428	AD 1517	AD 1523
THT-A20	South wall-plate, truss 6 – 7	54	no h/s	------	------	------

Table 1: continued

Sample no.	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood Ring date	Last measured Ring date
	Barn – western 4 bays					
THT-A21	Brace to north wall-post, truss 3	84	no h/s	AD 1262	------	AD 1345
THT-A22	Brace to north wall-post, truss 2	76	no h/s	AD 1265	------	AD 1340
THT-A23	Brace to south wall-post, truss 3	119	h/s	AD 1285	AD 1403	AD 1403
THT-A24	South wall-post, truss 3	130	7	AD 1270	AD 1392	AD 1399
THT-A25	South brace to crown-post, truss 2	112	h/s	AD 1285	AD 1396	AD 1396
THT-A26	North brace to crown post, truss 3	129	h/s	AD 1270	AD 1398	AD 1398
THT-A27	South brace to crown post, truss 3	83	h/s	AD 1314	AD 1396	AD 1396
THT-A28	East brace to collar purlin, truss 3	122	h/s	AD 1273	AD 1394	AD 1394
THT-A29	North brace to crown post, truss 2	63	h/s	AD 1336	AD 1398	AD 1398
	Barn – eastern 4 bays					
THT-A30	West brace to collar purlin, truss 6 (reused)	77	13	AD 1323	AD 1386	AD 1399
THT-A31	East brace to collar purlin, truss 6 (reused)	91	h/s	AD 1296	AD 1386	AD 1386
THT-A32	Crown post, truss 6	83	no h/s	AD 1346	------	AD 1428
THT-A33	East brace to collar purlin, truss 8	164	25C	AD 1371	AD 1509	AD 1534
THT-A34	Collar purlin, truss 8 – 9	118	h/s	AD 1378	AD 1495	AD 1495
THT-A35	Collar, frame 52	126	h/s	AD 1381	AD 1506	AD 1506
THT-A36	Collar, frame 51	82	h/s	AD 1423	AD 1504	AD 1504
THT-A37	Collar purlin, truss 7 – 8	140	h/s	AD 1372	AD 1511	AD 1511
THT-A38	Collar, frame 47, bay 2	87	h/s	AD 1426	AD 1512	AD 1512
THT-A39	North common rafter, frame 39	81	h/s	AD 1430	AD 1510	AD 1510
THT-A40	North common rafter, frame 33	73	10	AD 1451	AD 1513	AD 1523

Table 1: continued

Sample no.	Sample location	Total rings	*Sapwood Rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Barn – western 2 bays floor framing					
THT-A41	Main east – west bridging beam	116	h/s	AD 1290	AD 1405	AD 1405
THT-A42	South joist 12	117	h/s	AD 1281	AD 1397	AD 1397
THT-A43	South joist 11	112	h/s	AD 1293	AD 1404	AD 1404
THT-A44	South joist 9	129	h/s	AD 1268	AD 1396	AD 1396
THT-A45	South joist 5	147	2	AD 1257	AD 1401	AD 1403
THT-A46	North joist 3	96	2	AD 1312	AD 1405	AD 1407
THT-A47	North joist 4	98	no h/s	AD 1242	------	AD 1339
THT-A48	Wall-plate to south-west	54	h/s	AD 1345	AD 1398	AD 1398
	Barn – eastern 4 bays					
THT-A49	Collar purlin, truss 5 – 6	116	19C	AD 1418	AD 1514	AD 1533
THT-A50	North common rafter, frame 38	57	26C	AD 1480	AD 1510	AD 1536
THT-A51	North common rafter, frame 34	86	h/s	AD 1420	AD 1505	AD 1505
THT-A52	Collar, frame 33	141	no h/s	AD 1352	------	AD 1492
THT-A53	Collar, frame 34	91	no h/s	AD 1395	------	AD 1485
THT-A54	Collar, frame 35	66	no h/s	AD 1359	------	AD 1424
THT-A55	East brace to crown post, truss 5 (reused)	98	no h/s	AD 1289	------	AD 1386
	Barn – east gable and replacement roof					
THT-A56	Lower north purlin	52	h/s	------	------	------
THT-A57	Upper north purlin	42	2	------	------	------
THT-A58	North common rafter 5 (from east end)	55	18c	AD 1571	AD 1607	AD 1625
THT-A59	King stud of east gable wall	48	no h/s	------	------	------
THT-A60	Collar, east gable wall	57	8	AD 1473	AD 1521	AD 1529

Table 1: continued

Sample no.	Sample location	Total rings	*Sapwood Rings	First measured ring date	Last heartwood Ring date	Last measured Ring date
	east gable and replacement roof cont..					
THT-A61	Stud 1 from north, east gable wall	64	no h/s	AD 1425	------	AD 1488
THT-A62	Stud 6 from north, east gable wall	58	h/s	------	------	------
THT-A63	Stud 7 from north, east gable wall	49	h/s	------	------	------
THT-A64	Tiebeam, east gable wall	54	h/s	------	------	------
THT-A65	South common rafter 2 (from east end)	63	20C	------	------	------
THT-A66	South common rafter 3 (from east end)	71	22c	AD 1556	AD 1604	AD 1626
THT-A67	South common rafter 4 (from east end)	60	19C	AD 1569	AD 1609	AD 1628
THT-A68	Upper south purlin	51	h/s	------	------	------
	Cottage					
THT-A69	South arcade post, east aisle truss	50	h/s	AD 1342	AD 1391	AD 1391
THT-A70	North "post stud", arcade post, east aisle truss	57	no h/s	------	------	------
THT-A71	North sill beam, east aisle truss (inserted timber)	61	no h/s	AD 1371	------	AD 1431
THT-A72	North queen post, west roof truss	65	h/s	------	------	------
THT-A73	Collar, west roof truss	68	11	------	------	------
THT-A74	South queen post, west roof truss	50	4	------	------	------
THT-A75	South brace to tiebeam from north post, central aisle truss	67	h/s	AD 1327	AD 1393	AD 1393
THT-A76	Timber re-used as purlin from east aisle truss to gable wall, south side (reused timber)	48	h/s	AD 1346	AD 1393	AD 1393
THT-A77	North post to central aisle truss	60	h/s	AD 1324	AD 1383	AD 1383
THT-A78	Lower south arcade plate	78	h/s	AD 1315	AD 1392	AD 1392
THT-A79	Upper south arcade plate	70	h/s	------	------	------
THT-A80	South arcade post to west aisle truss	69	h/s	AD 1321	AD 1389	AD 1389
THT-A81	South sill beam to west aisle truss	49	h/s	AD 1341	AD 1389	AD 1389

*h/s = the heartwood/sapwood boundary is the last ring on the sample
c = complete sapwood on timber, part or all lost from core in sampling
C = sapwood complete on sample

Table 2: Results of the cross-matching of site chronology THTASQ01 and relevant reference chronologies when first ring date is AD 1332 and last ring date is AD 1536

Reference chronology	Span of chronology	t-value	
East Midlands	AD 882 – 1981	5.9	(Laxton and Litton 1988)
England, East Anglia	AD 781 – 1899	7.5	(Tyers and Groves, 1999a unpubl)
Chicksands Priory, Beds	AD 1175 – 1541	6.7	(Howard *et al* 1998)
Kings Lynn, Norfolk	AD 1310 – 1583	6.1	(Tyers 1999)
Fore Street, Ipswich, Suffolk	AD 1420 – 1635	5.3	(Bridge 1999)
Little Totham, Essex	AD 1380 – 1517	5.7	(Tyers 1996)

Table 3: Results of the cross-matching of site chronology THTASQ02 and relevant reference chronologies when first ring date is AD 1237 and last ring date is AD 1428

Reference chronology	Span of chronology	t-value	
East Midlands	AD 882 – 1981	7.1	(Laxton and Litton 1988)
England, East Anglia	AD 781 – 1899	10.2	(Tyers and Groves, 1999a unpubl)
Castle Acre Priory, Norfolk	AD 1237 – 1356	6.8	(Tyers forthcoming)
Chicksands Priory, Beds	AD 1175 – 1541	6.6	(Howard *et al* 1998)
Dragon Hall, Norwich	AD 1289 – 1426	6.5	(Tyers 1998)
Fyfield Hall, Essex	AD 1293 – 1388	6.3	(Bridge 1998)

Table 3: Results of the cross-matching of site chronology THTASQ03 and relevant reference chronologies when first ring date is AD 1556 and last ring date is AD 1628

Reference chronology	Span of chronology	t-value	
East Midlands	AD 882 – 1981	4.9	(Laxton and Litton 1988)
England, East Anglia	AD 781 – 1899	6.2	(Tyers and Groves, 1999a unpubl)
England, Yorkshire	AD 440 – 1823	5.3	(Tyers and Groves 1999b unpubl)
Chicksands Priory, Beds	AD 1175 – 1541	4.5	(Howard *et al* 1998)
Cressing Temple, Essex	AD 1560 – 1633	6.0	(Tyers 1997)
Sutton-in-the-Isle, Cambs	AD 1508 – 1615	5.3	(Tyers 1995)

Figure 1: Map to show general location of Abbey Farm

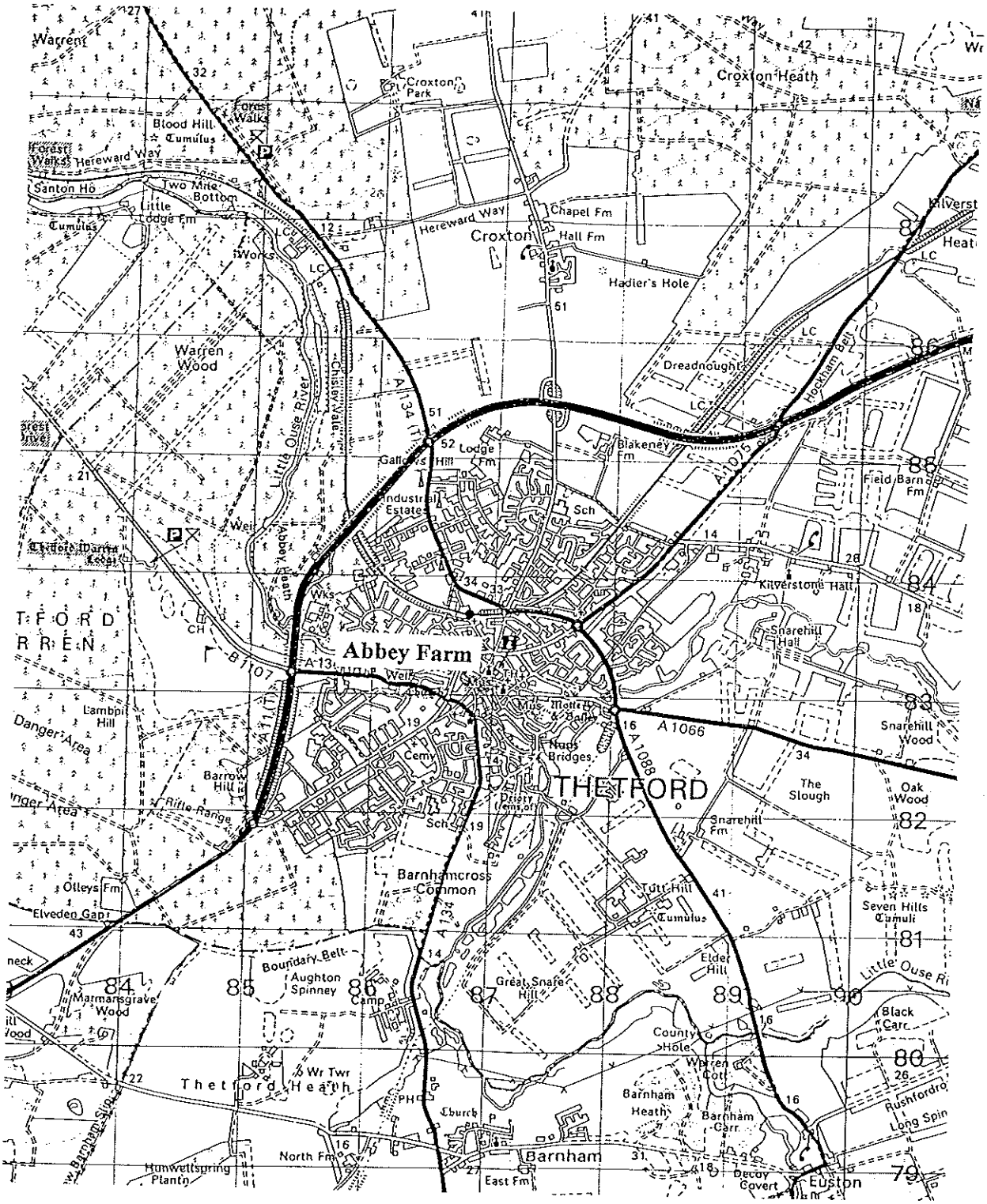


Figure 2: Map to show location of buildings at Abbey Farm

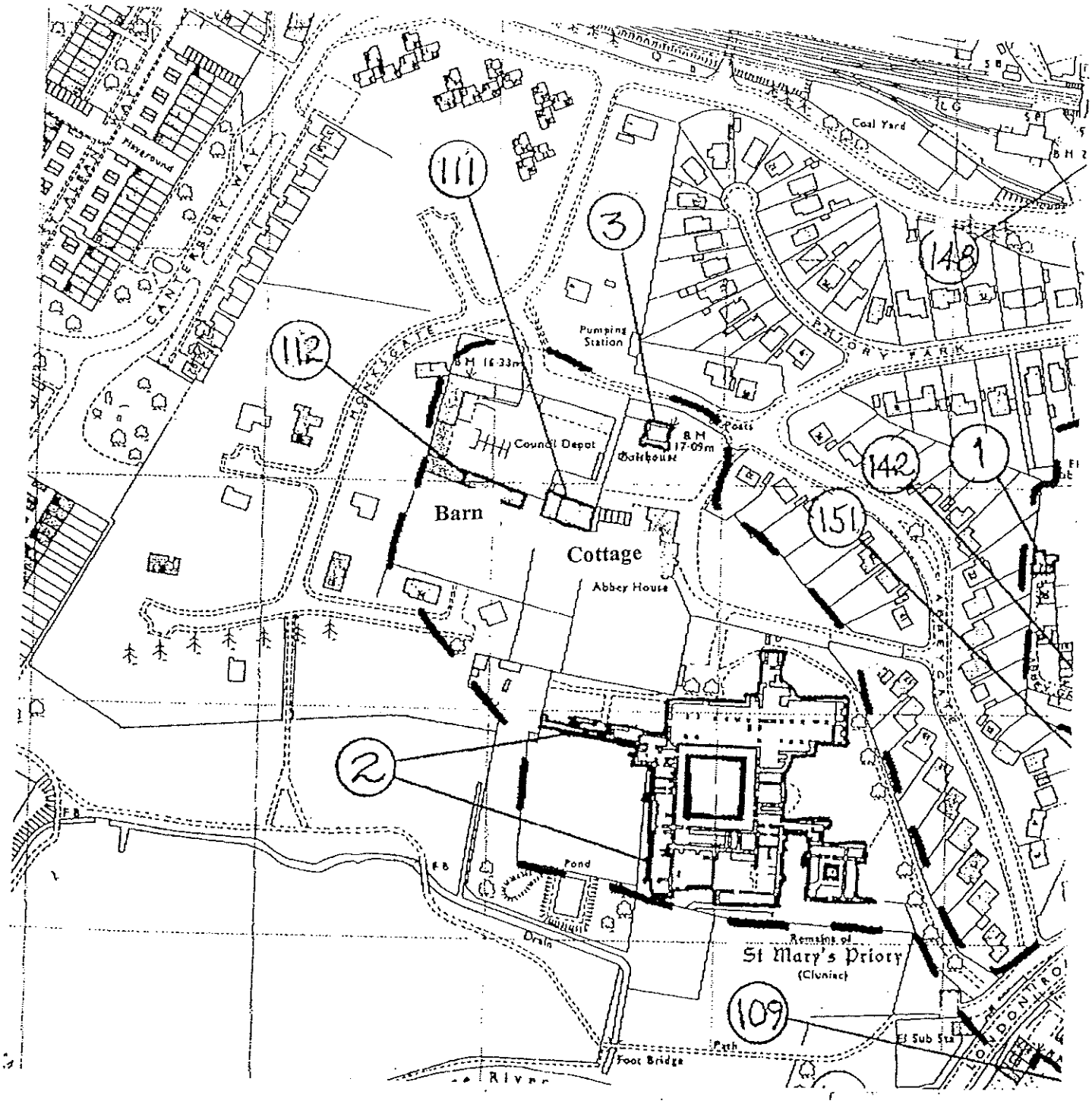


Figure 3: Plan to show position of trusses in Abbey Farm barn

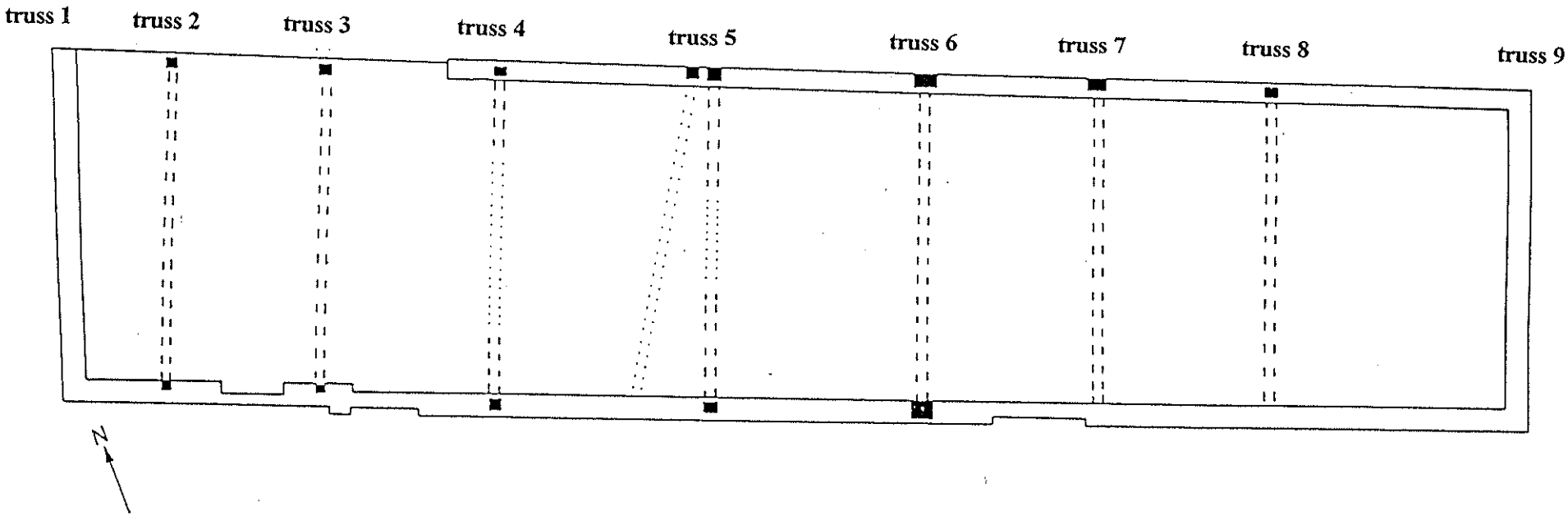


Figure 4: Illustrative example of truss from the western half of Abbey Farm barn (viewed from the west looking east)

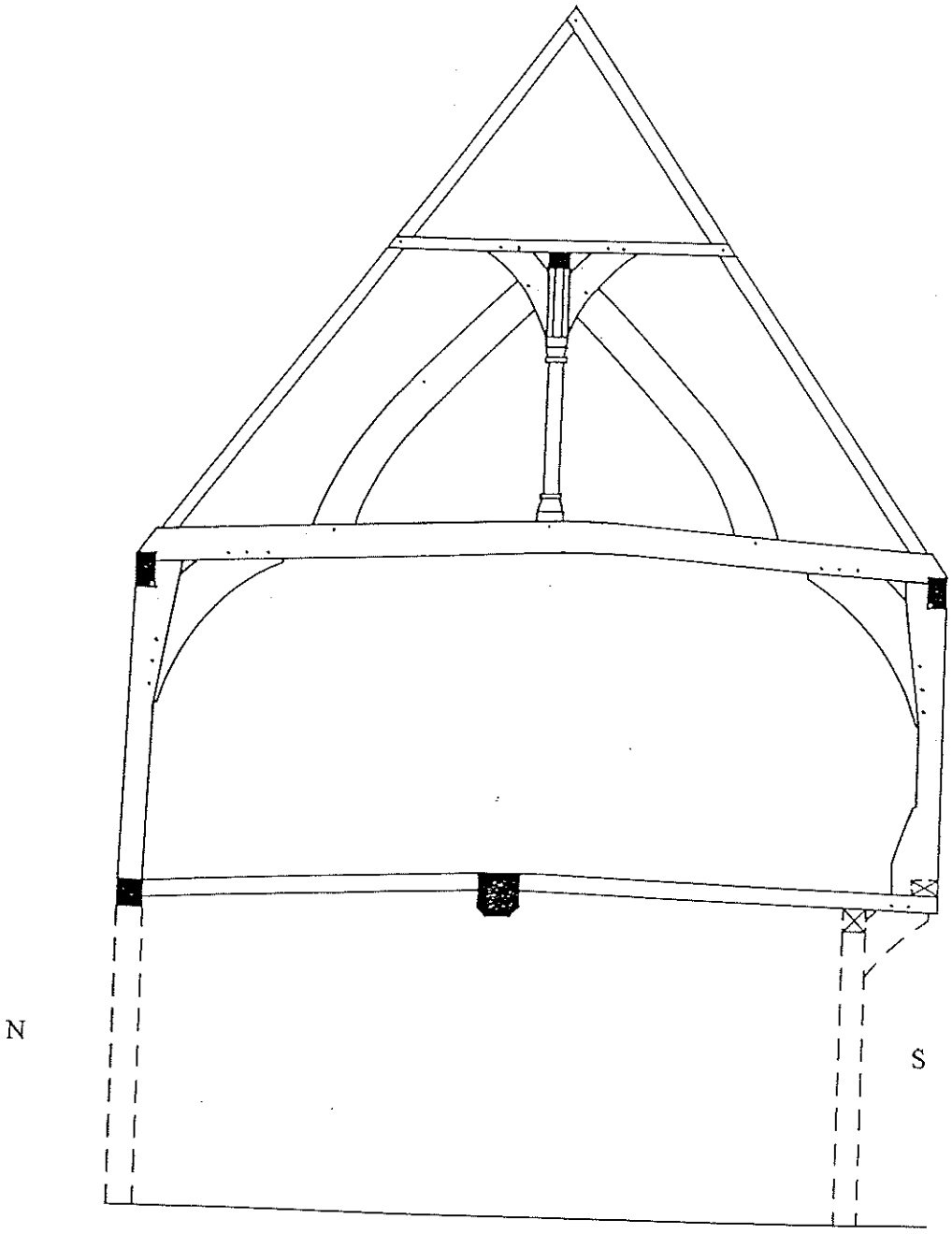


Figure 5: Illustrative example of truss from the eastern half of Abbey Farm barn (viewed from the west looking east)

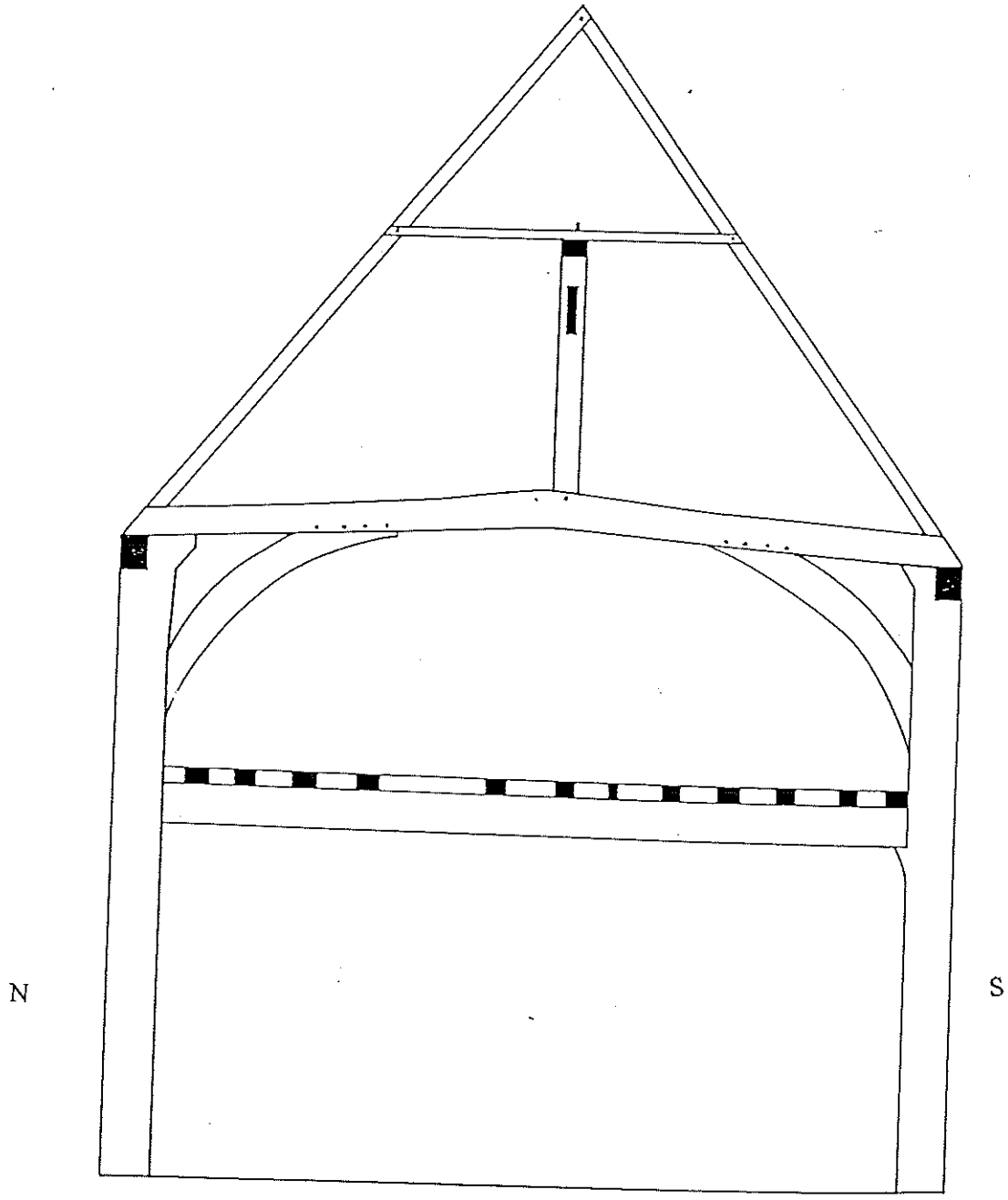


Figure 6: Drawing to show long section of the western end of Abbey Farm barn (viewed from the north looking south)

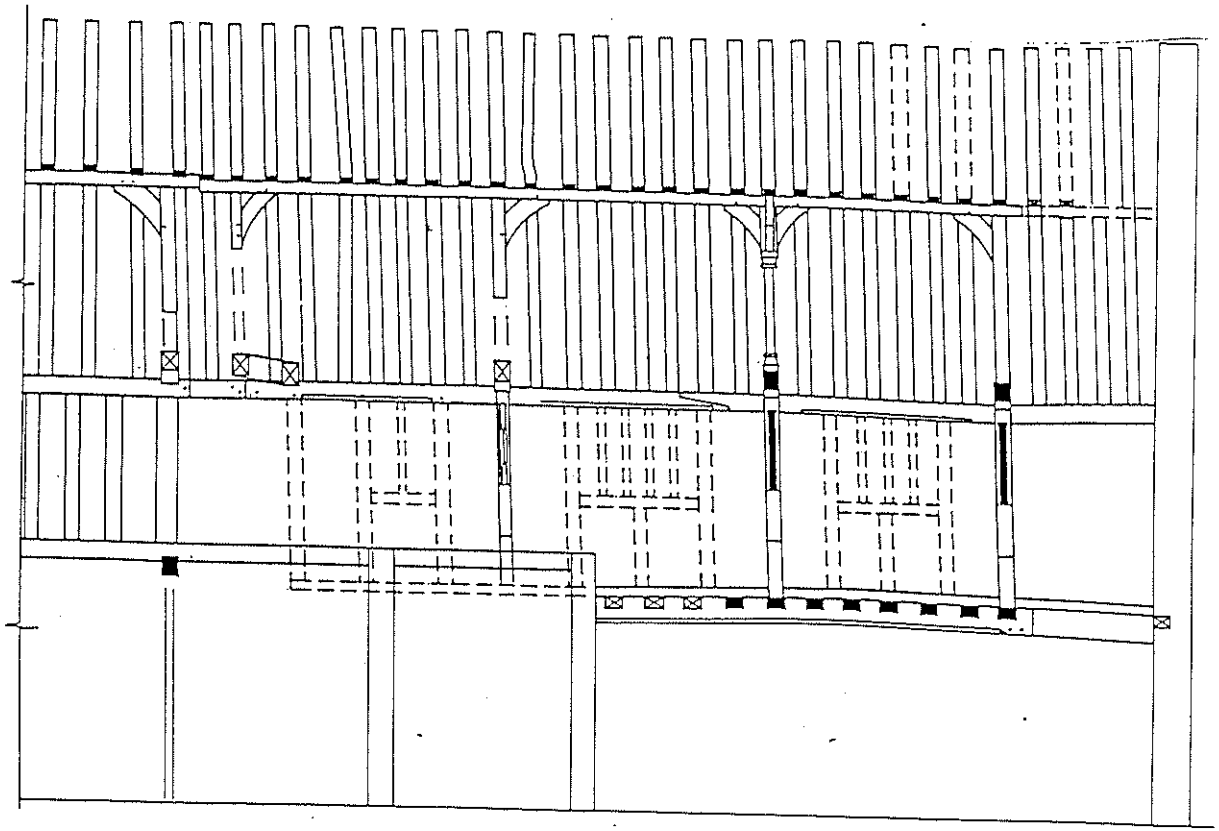


Figure 7: Reconstruction of the western end of Abbey Farm barn (viewed from the south-west)

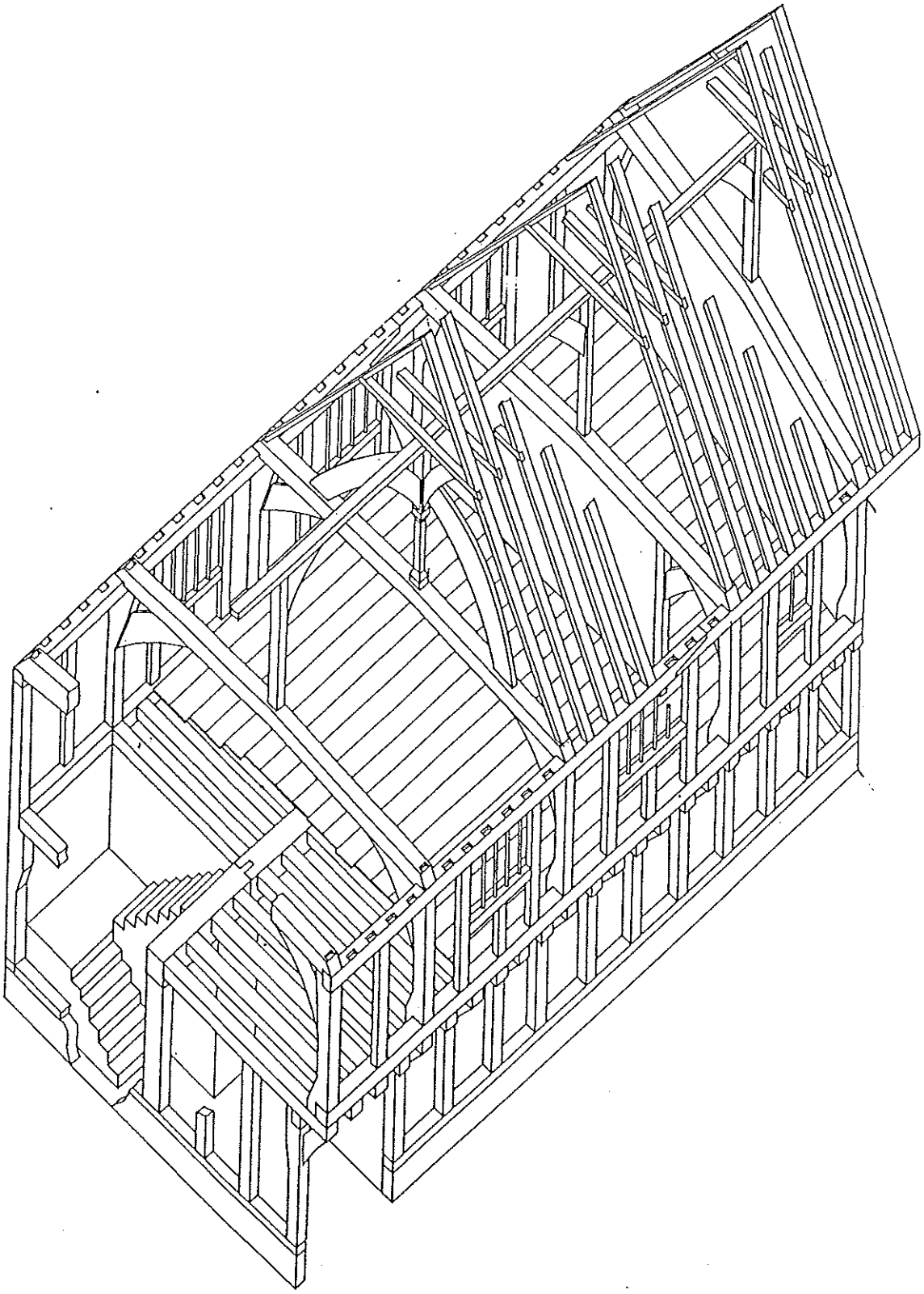


Figure 8: Ground-floor plan of Abbey Farm cottage
(drawn by Robert Smith)

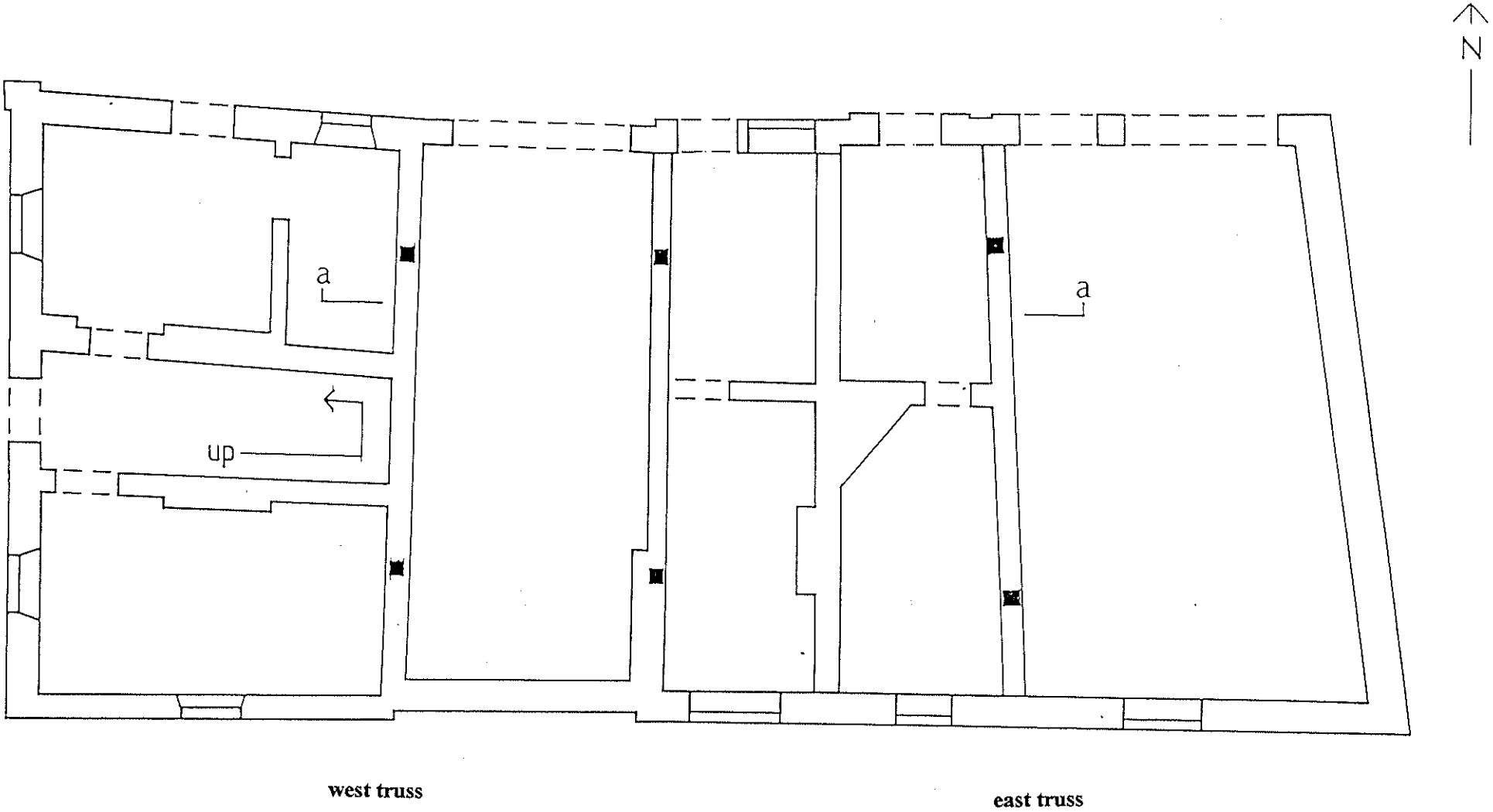


Figure 9: Drawing to show long section a – a of Abbey Farm cottage (viewed from the south looking north)

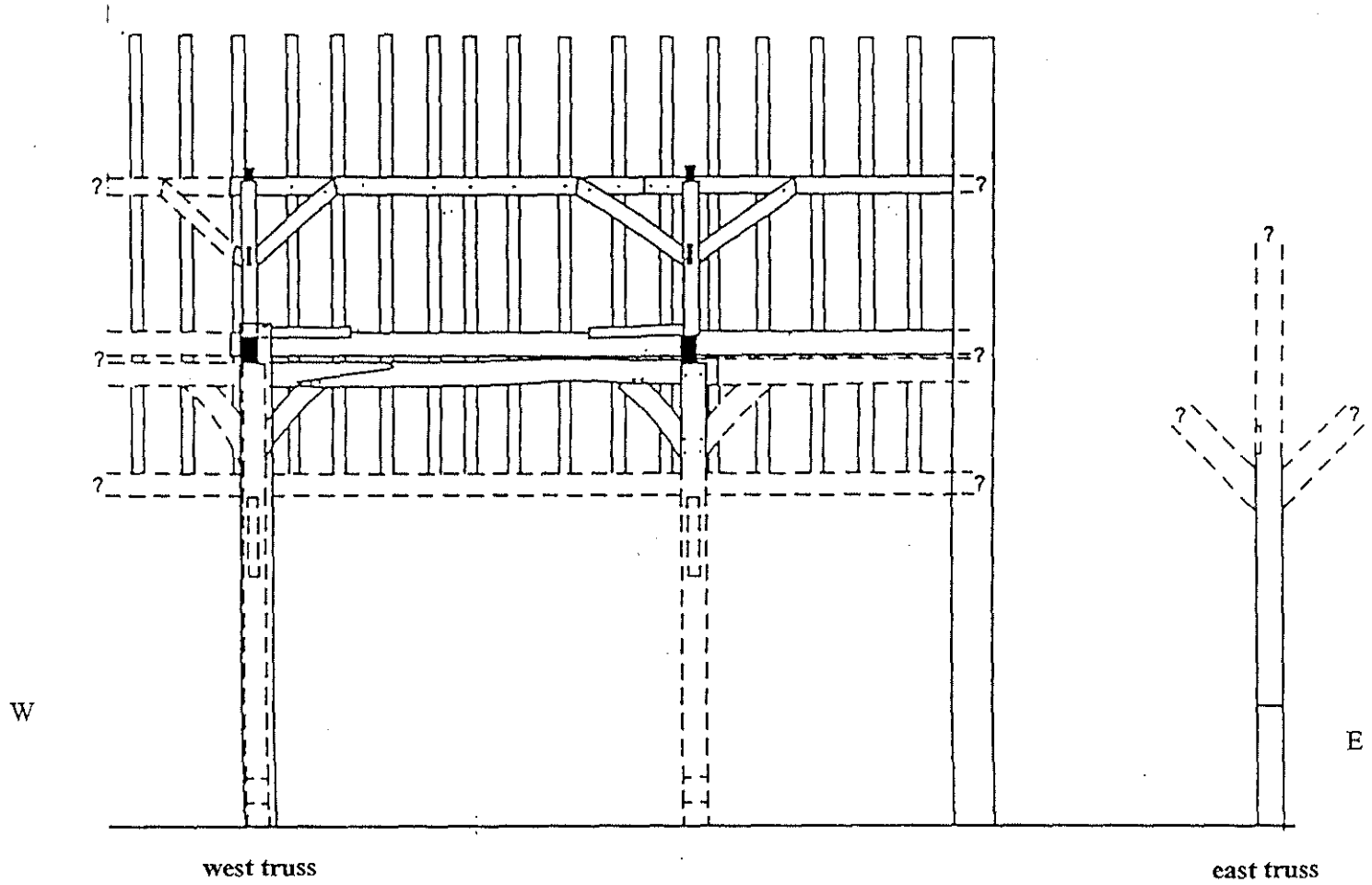


Figure 10: Drawing to show west end truss of Abbey Farm cottage (viewed from the west looking east)

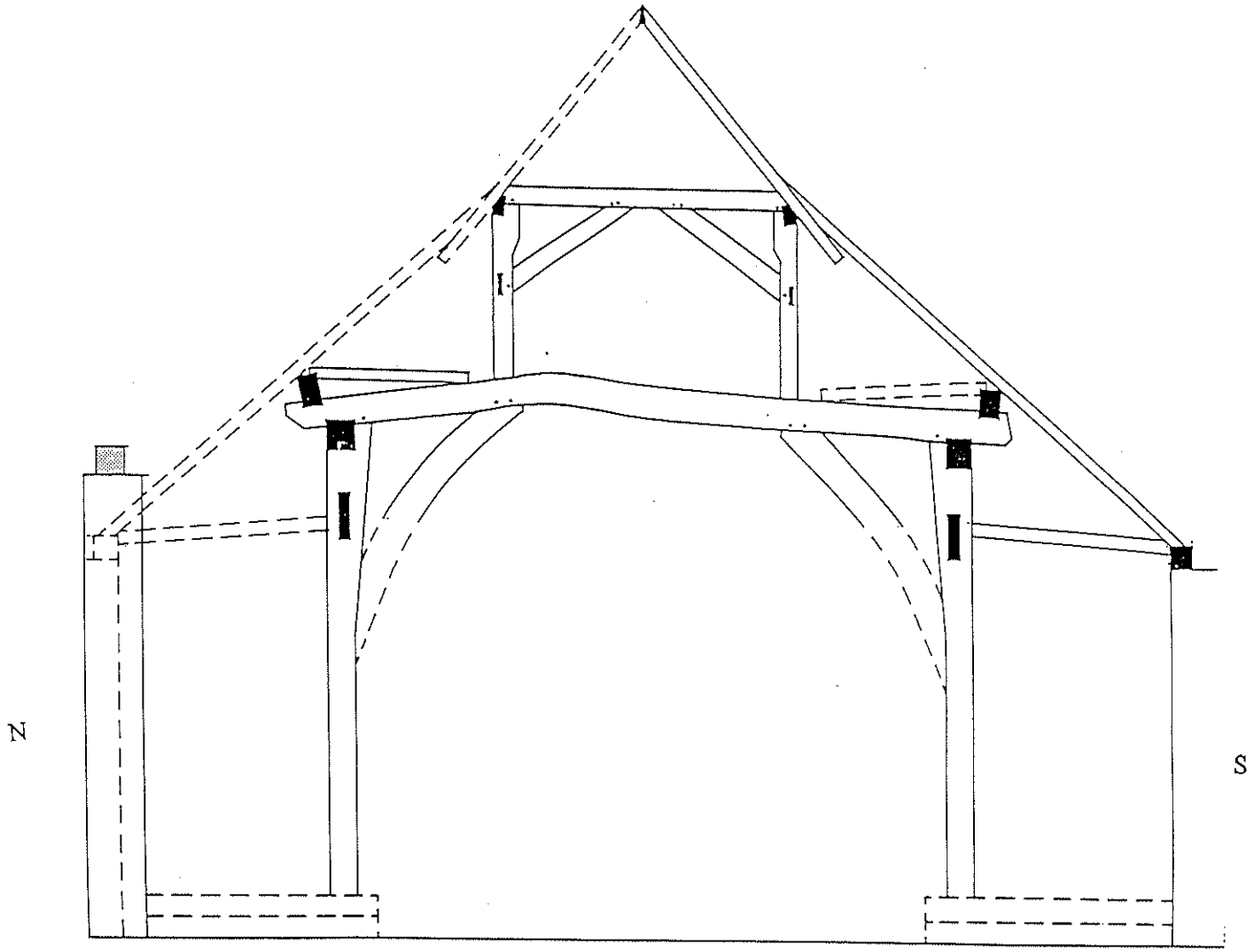


Figure 11: Drawing to show east end truss of Abbey Farm cottage (viewed from the west looking east)

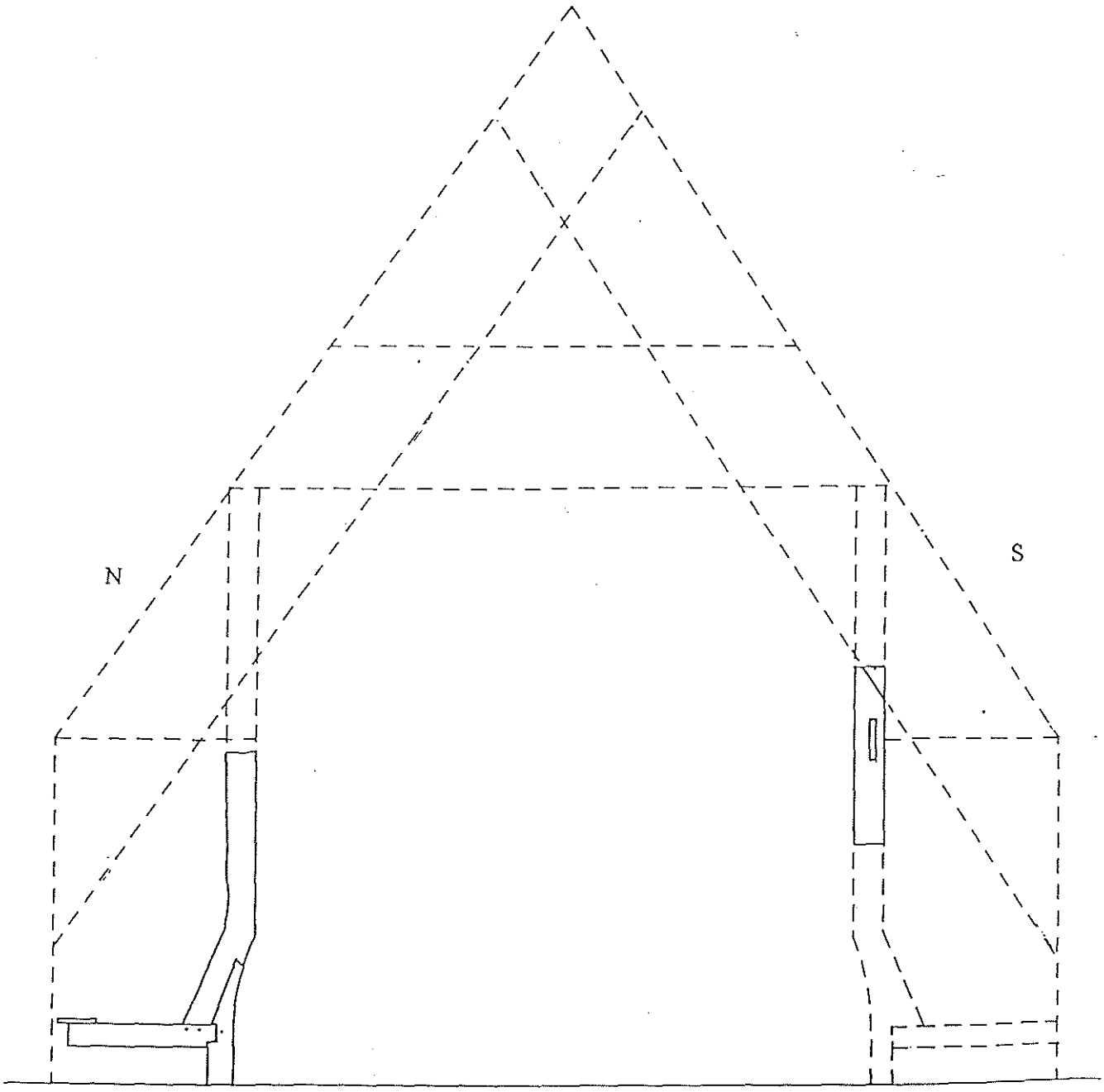


Figure 12: Abbey Farm cottage, north end of east cross frame (viewed from the west – survey drawing by Richard Bond)

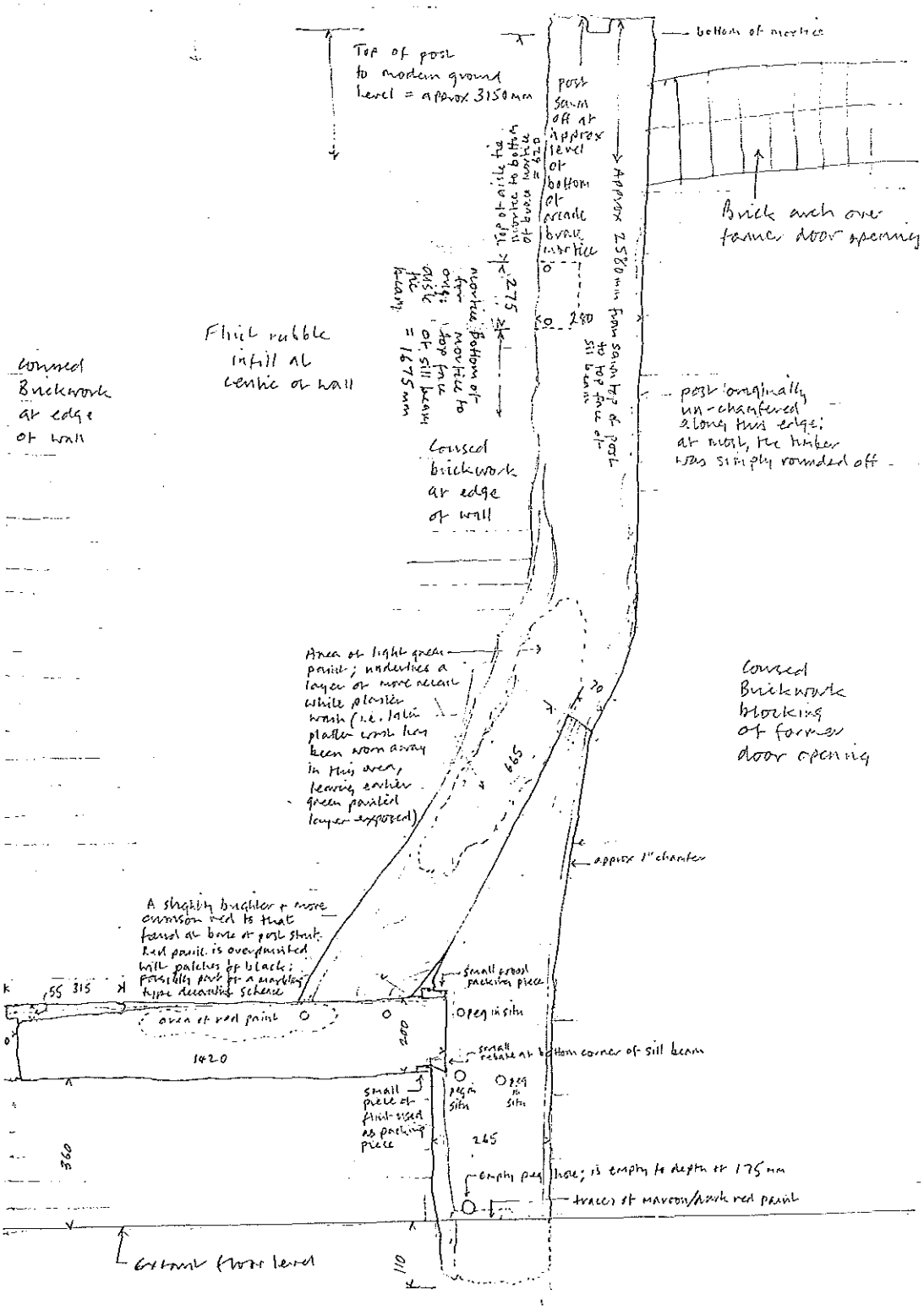
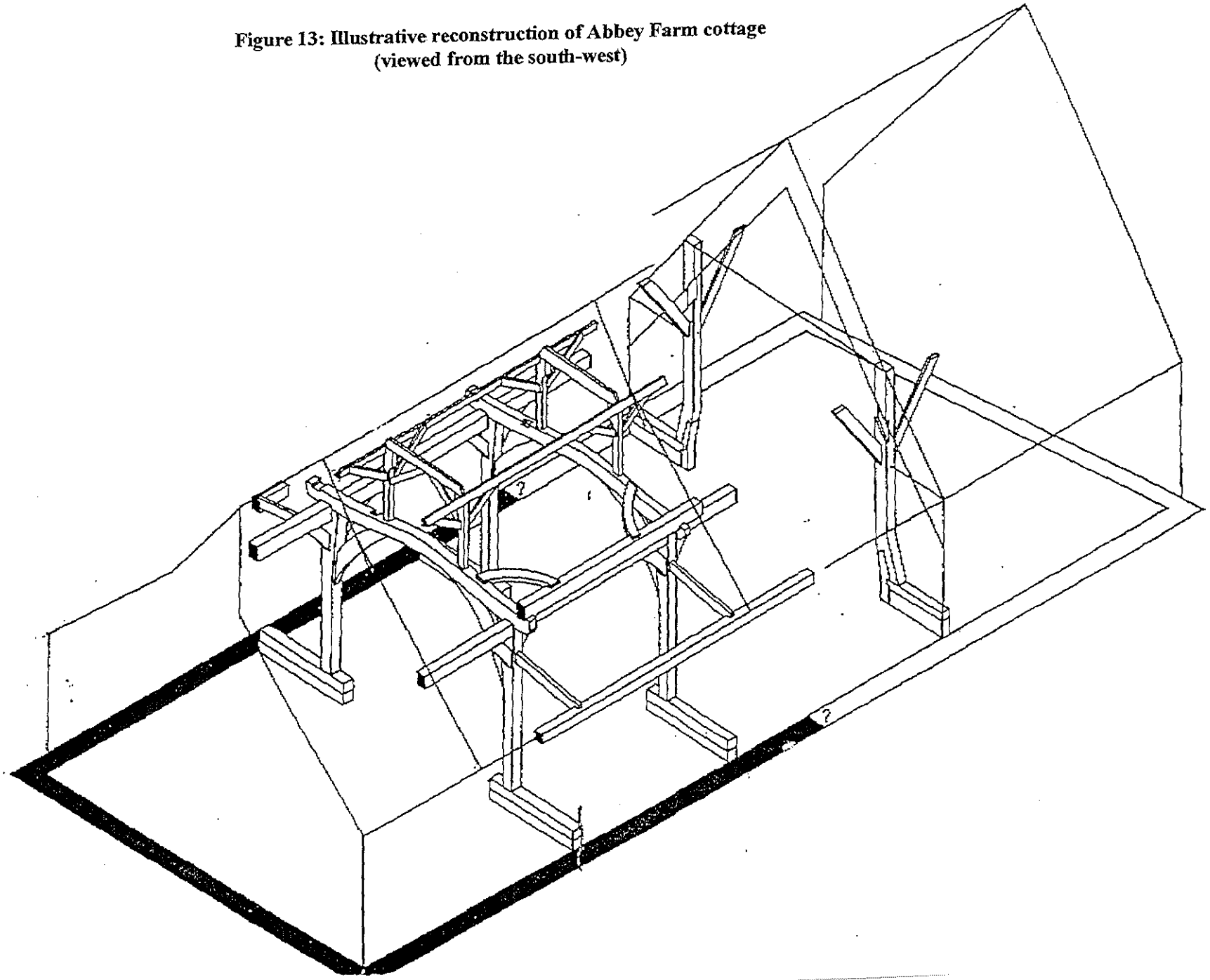


Figure 13: Illustrative reconstruction of Abbey Farm cottage (viewed from the south-west)



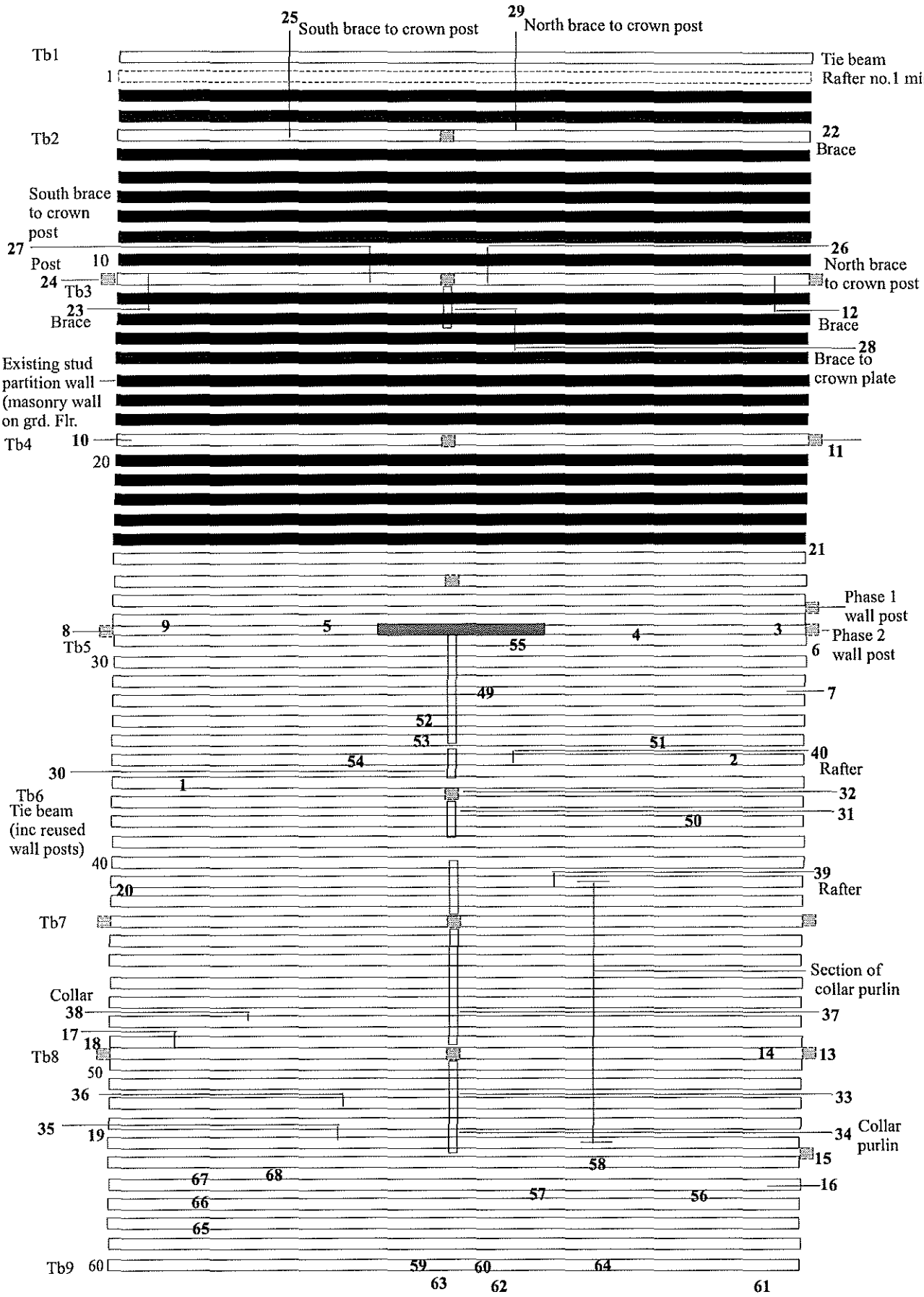


Figure 14: Plan to show location of samples from Abbey Farm barn (samples THT-A01 – A40 and A49 – 68)

Figure 15: Plan to show location of samples from western 2 bays of floor framing at Abbey Farm barn (samples THT-A41 – A48)

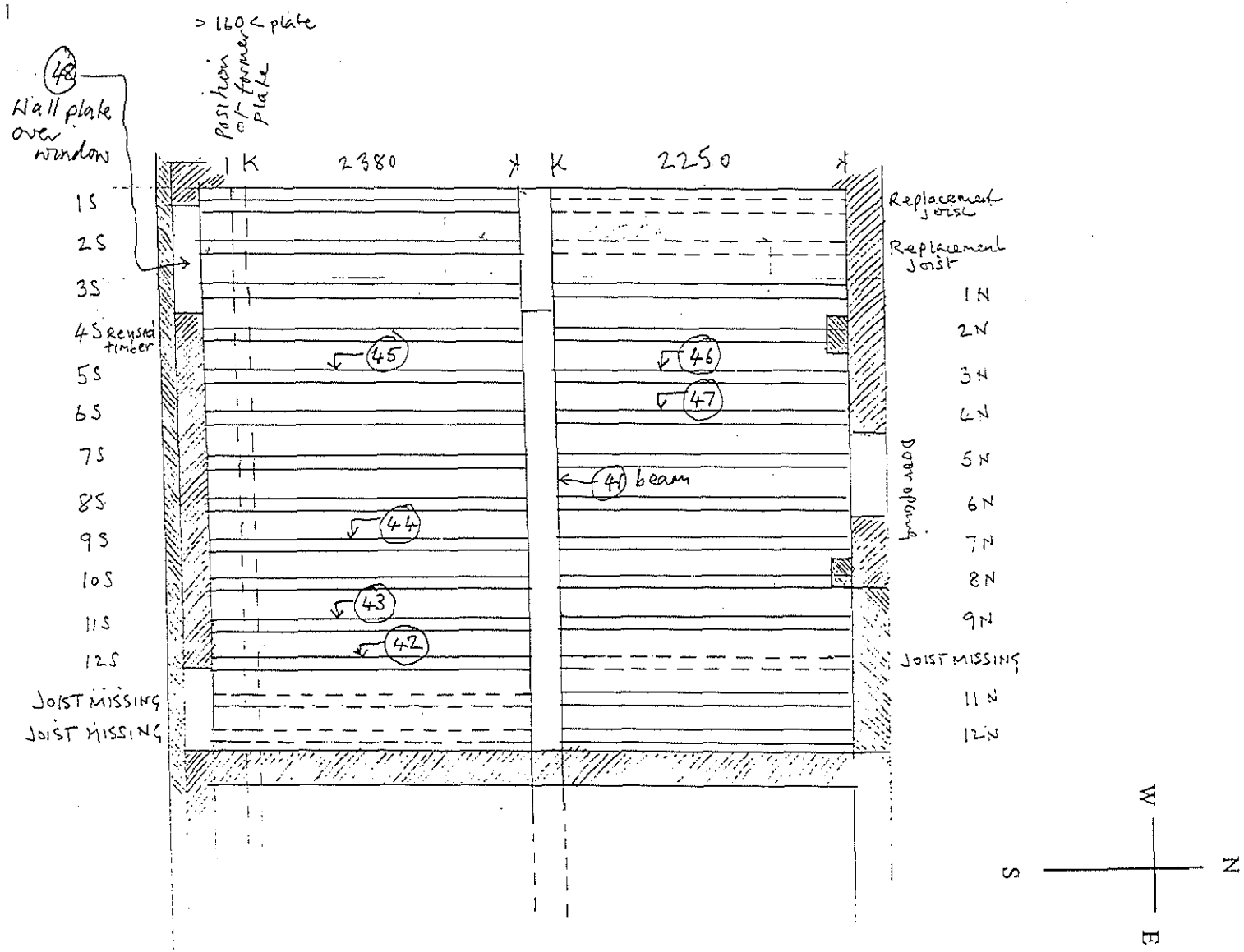


Figure 16: Drawing to show location of samples from Abbey Farm cottage (samples THT-A69 – A81)

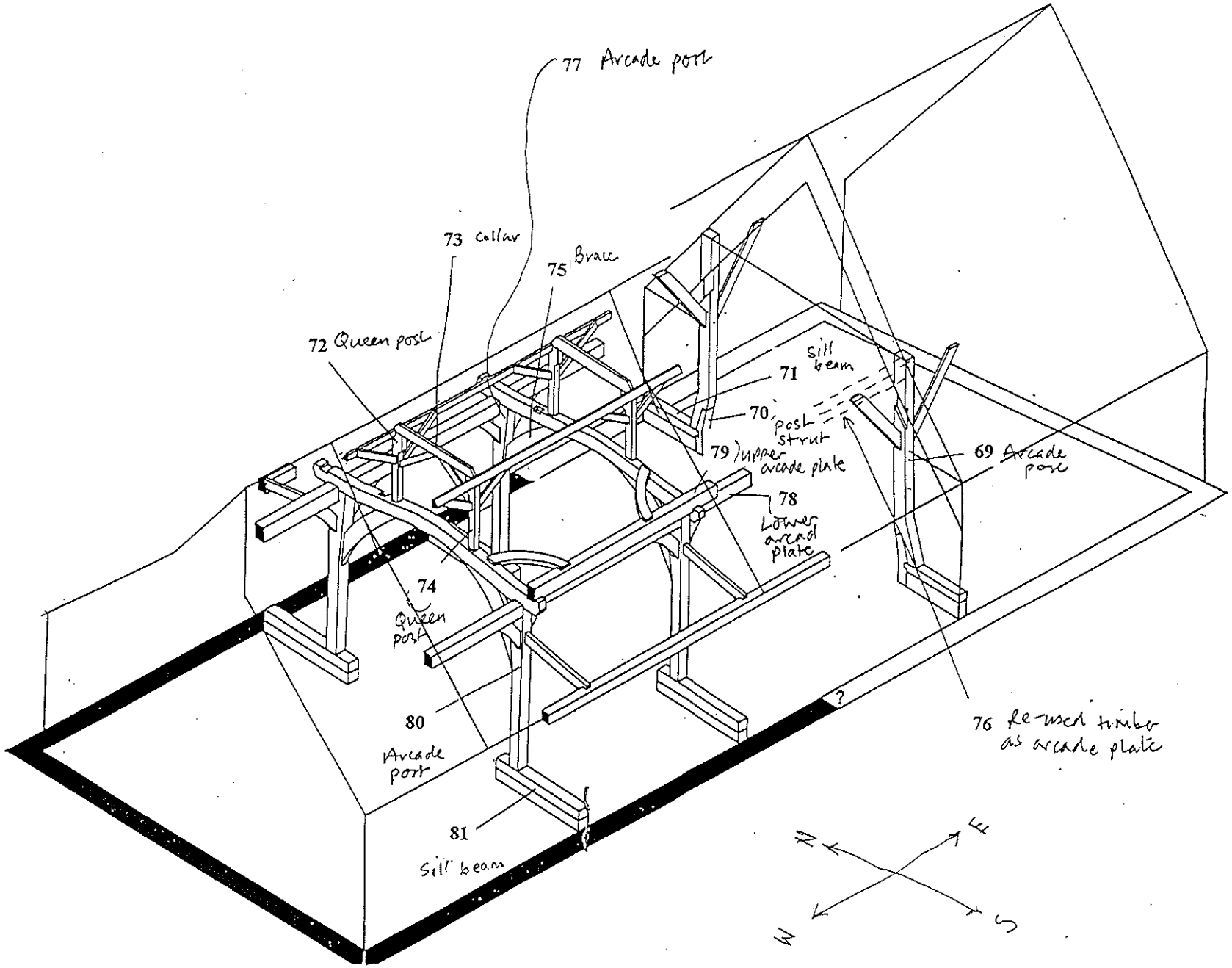


Figure 17: Bar diagram of samples in site chronology THTASQ01

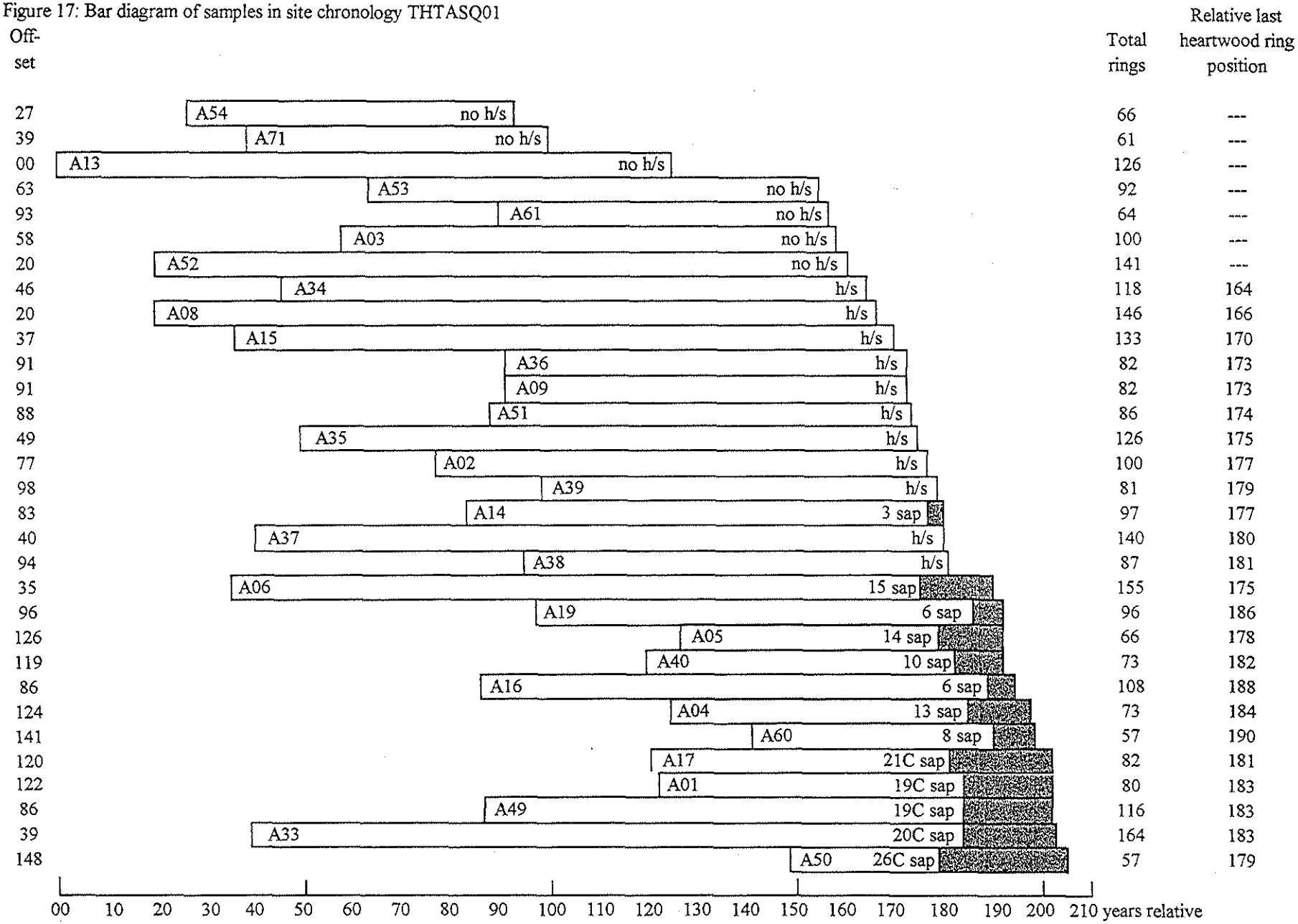


Figure 18: Bar diagram of samples in site chronology THTASQ02

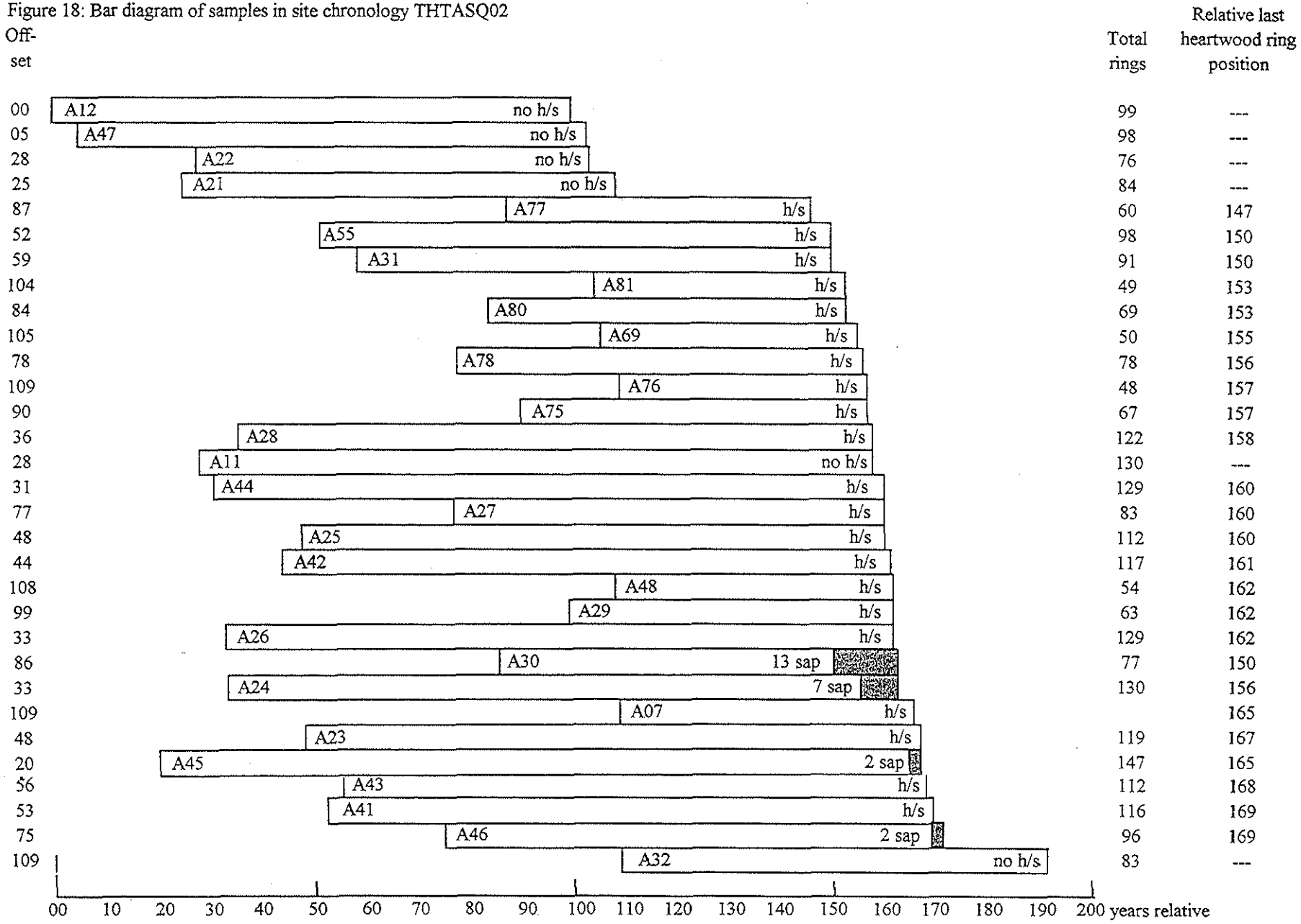


Figure 19: Bar diagram of samples in site chronology THTASQ03

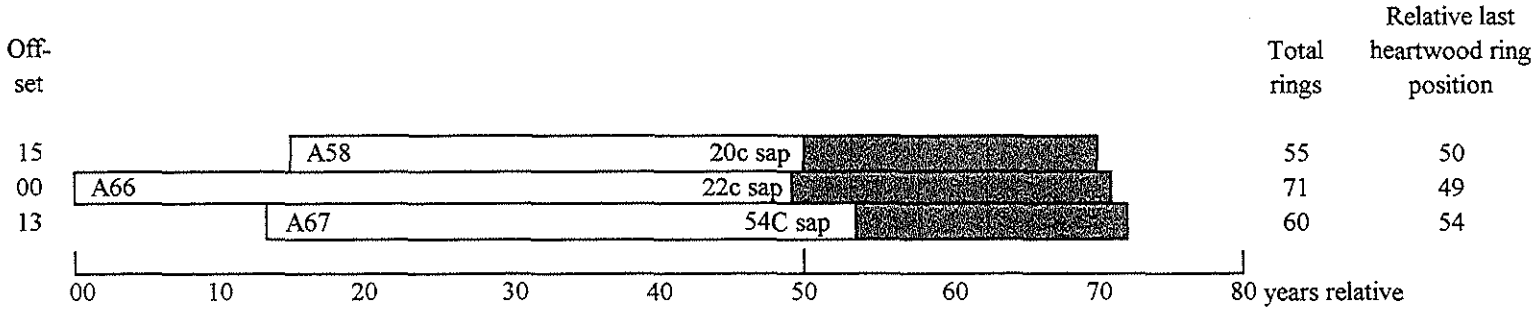
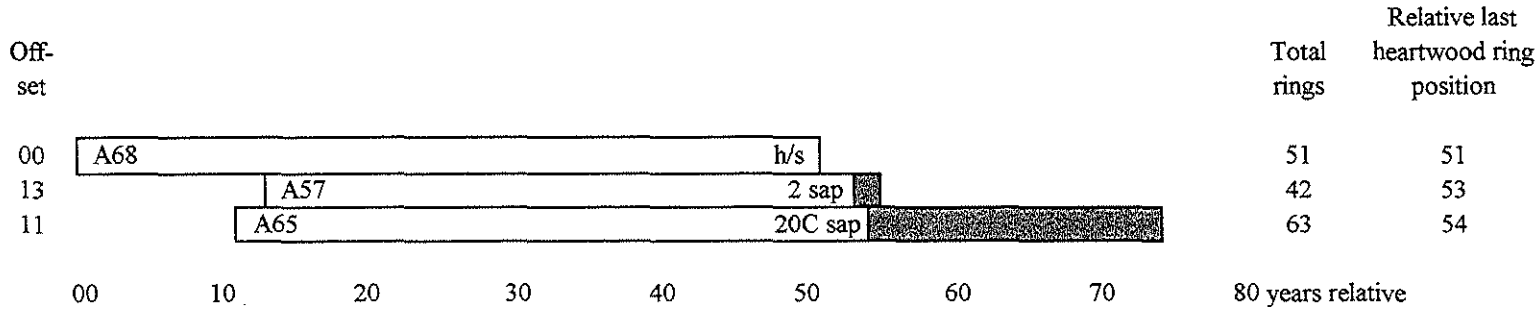


Figure 20: Bar diagram of samples in site chronology THTASQ04



White bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample
C = sapwood is retained complete on sample

Data of measured samples – measurements in 0.01 mm units

THT-A01A 57
240 270 366 241 216 183 156 171 184 151 135 121 147 133 266 257 182 159 155 130
152 163 168 96 201 245 207 224 208 133 117 115 223 336 290 212 173 150 99 77
90 140 161 123 93 57 70 101 149 102 103 147 145 140 89 91 137
THT-A01B 53
233 216 145 139 126 191 292 217 169 163 142 119 101 95 134 194 151 92 76 77
143 191 113 114 192 161 147 118 131 183 186 164 116 134 147 231 93 169 157 121
218 253 178 170 109 210 215 214 171 164 177 119 181
THT-A02A 94
117 87 147 157 192 119 157 218 198 210 159 142 130 97 91 97 94 100 115 89
145 115 119 126 125 83 119 136 190 166 131 138 147 154 165 66 83 110 164 73
114 86 64 67 74 94 92 184 140 134 83 98 89 126 74 64 85 53 42 56
80 90 67 53 77 77 64 57 46 78 95 112 104 81 43 47 47 51 82 43
79 39 52 50 53 58 63 127 89 54 44 50 42 106
THT-A02B 56
125 153 126 195 171 158 154 110 108 136 92 102 129 101 100 105 149 146 133 117
177 172 153 156 129 149 182 172 187 137 110 77 68 81 146 82 114 74 97 72
66 85 100 145 85 55 60 58 58 80 63 66 46 50 54 72
THT-A03A 100
257 185 133 192 184 229 327 421 423 366 309 257 215 161 206 177 192 141 115 151
77 121 157 225 82 152 230 258 293 266 314 270 200 208 134 119 118 113 101 152
113 139 170 188 95 124 101 116 110 90 98 80 121 87 44 54 76 88 57 80
77 63 65 85 125 135 252 197 167 113 133 138 113 60 62 64 44 43 51 58
65 60 47 52 51 53 34 44 57 59 51 65 34 61 34 35 36 44 46 48
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78 114 158 239 90 156 233 251 295 271 319 275 219 206 125 133 115 110 104 141
117 128 169 175 89 120 113 135 100 89 84 95 110 91 46 54 73 81 57 80
75 73 69 79 124 140 258 203 182 108 136 133 120 72 47 57 48 36 43 65
86 54 44 52 43 47 32 49 53 30 48 51 64 40 44 28 55 60 45 62
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198 211 268 451 443 345 351 233 184 125 146 297 246 292 200 125 84 84 148 133
311 164 90 105 151 144 284 213 179 134 213 171 95 119 100 73 134 82 75 123
70 59 135 125 142 111 127 131 149 124 144 169 177
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316 145 103 106 155 138 305 195 195 140 200 153 116 141 97 84 142 97 75 110
87 54 132 134 140 104 129 139 163 84 135 175 207
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621 368 328 209 285 231 165 250 199 185 135 74 63 61 84 72 128 235 185 262
170 197 357 224 274 223 190 125 153 286 192 241 191 92 65 57 102 126 250 123
77 77 93 109 206 156 149 96 197 121 82 76 84 66 95 69 60 118 122 136
73 85 97 93 108 124

THT-A05B 66
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168 225 363 219 267 213 184 125 153 291 177 257 192 98 57 63 105 126 242 121
79 72 94 102 210 163 144 98 194 114 90 74 81 67 100 71 59 110 124 148
75 68 114 124 117 110
THT-A06A 155
75 124 118 128 93 116 88 105 154 120 80 103 93 151 132 120 104 78 113 118
126 155 141 128 134 139 142 160 163 157 127 104 144 178 171 178 158 179 163 175
137 119 139 162 151 137 233 180 175 171 159 182 182 164 257 191 148 169 145 126
137 151 187 162 118 166 112 106 111 117 113 113 152 174 92 89 94 79 91 79
105 87 90 69 82 104 109 116 106 138 127 91 83 79 115 135 128 136 156 136
138 166 120 156 145 125 172 115 122 107 91 128 174 196 192 125 95 97 79 108
166 138 147 134 95 78 72 104 121 139 134 87 85 68 139 124 175 162 140 170
184 157 135 105 117 152 135 151 122 178 141 132 126 98 135
THT-A06B 155
92 96 121 139 95 111 90 108 155 105 78 104 102 151 133 115 101 81 108 119
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145 105 150 157 138 144 231 180 168 202 161 175 177 169 254 198 151 173 131 142
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131 161 138 158 208 142 103 182 143 125 99 89 112 85 79 101
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246 239 308 406 290 343 252 239 125 265 226 359 419 390 337 105 162 300 206 227
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140 141 136 162 210 139 106 192 132 128 102 84 102 84 90 103
THT-A08A 146
314 268 266 368 394 490 436 323 355 320 425 475 497 416 181 58 70 87 106 99
128 70 83 123 67 77 104 137 149 190 137 145 92 142 145 135 173 125 135 169
162 157 164 147 155 166 132 125 172 249 215 157 209 197 226 181 143 189 177 183
169 218 179 164 168 204 229 260 191 199 187 175 184 136 177 135 158 192 196 163
212 132 129 123 119 119 130 129 152 154 154 109 88 83 85 80 93 73 70 53
75 104 114 134 146 119 83 98 91 100 130 110 138 148 106 100 116 98 139 135
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77 61 67 75 99 124
THT-A08B 146
331 257 261 376 396 491 444 323 379 334 437 493 512 436 174 64 72 82 104 104
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205 137 118 122 113 129 135 135 142 154 165 116 87 87 75 80 86 74 72 57
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126 159 101 116 103 112 111 116 128 158 96 76 78 66 100 138 93 105 95 105
70 62 62 79 101 96

THT-A09A 82
140 165 179 114 132 114 153 108 124 179 182 94 162 182 186 187 142 201 218 266
266 123 138 208 303 207 303 273 181 177 187 143 137 211 137 148 93 120 111 132
106 97 111 79 78 55 87 74 85 73 75 93 86 77 68 82 120 152 208 237
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81 119
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162 181 171 113 136 106 164 106 139 191 169 94 178 165 173 179 139 207 220 275
256 126 133 204 306 191 281 275 168 170 164 143 130 186 139 138 93 116 114 126
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90 99
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199 360 533 291 385 447 393 425 375 314 253 315 229 304
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190 363 513 284 372 467 408 461 395 335 249 329 205 233
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252 298 328 309 313 286 249 248 247 180 182 175 279 193 199 304 268 274 217 193
169 103 73 60 113 133 102 196 241 202 178 205 159 124 146 150 214 124 93 95
70 114 92 91 102 91 59 70 86 110 139 120 106 95 88 90 141 110 80 74
58 41 55 61 73 46 51 51 47 46 68 64 59 76 100 67 88 102 71 84
132 66 71 91 124 150 131 76 78 97 55 106 107 148 121 120 39 57 111 100
77 96 87 64 68 64 57 104 64 138 121 124 88 99 101 123 122 99 83 40
48 65 77 85 68 54 64 54 49 55
THT-A11B 130
257 291 306 320 267 274 291 242 247 176 161 144 257 192 208 311 289 271 220 213
174 108 64 73 112 134 107 199 239 199 151 216 161 133 154 140 219 144 79 100
71 118 101 98 105 71 63 64 77 107 128 124 99 83 96 99 124 107 77 74
62 41 49 64 85 54 50 54 44 54 59 61 59 85 83 71 83 97 69 99
120 67 65 97 123 153 121 92 66 99 62 94 115 154 98 109 39 34 131 88
75 108 90 72 53 71 58 97 63 142 107 121 81 99 104 115 120 98 88 48
43 58 85 85 58 60 58 59 47 55
THT-A12A 78
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THT-A13B 126
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THT-A13C 64
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THT-A15B 133
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THT-A20B 54
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THT-A30A 77
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THT-A35B 126
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88 95 106 94 97 101 123 121 111 75 73 114 84 86 93 74 99 79 93 89
104 71 69 75 59 105 150 166 144 129 111 92 92 111 61 40 35 45 76 78
52 105 72 81 86 75 69 53 38 68 79 81 83 94 102 82 97 85 99 103
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370 313 221 258 318 281 278 291 252 219 199 297 221 176 226 235 323 260 251 164
243 186 203 257 287 260 302 231 180 56 23 34 43 66 66 102 163 103 72 123
85 104 114 117 123 97 53 49 32 48 61 70 87 41 53 56 74 109 132 109
92 55 63 72 84 98 77 82 34 37 54 75 108 63 51 69 41 61 101 74
93 89 121 84 108 103 135 125 127 76 73 110 85 82 84 79 86 73 98 86
104 74 65 78 63 96 156 175 136 133 116 78 85 114 61 47 30 59 64 90
57 83 76 85 84 78 63 53 42 70 75 87 90 84 102 81 102 82 99 106
89 114 127 136 125 160 152

THT-A46A 96
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113 79 98 93 116 157 120 98 118 58 96 169 171 115 119 142 138 166 159 106
57 41 67 46 55 39 63 60 63 53 75 71 55 56 69 97 112 79 85 112
98 79 79 97 161 119 125 146 141 163 124 210 310 234 181 205
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101 78 73 100 165 115 127 144 154 147 129 200 315 221 221 207
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204 177 145 157 144 213 237 199 151 176 190 234 192 183 133 201 159 139 161 198
154 193 179 176 170 73 71 84 109 68 115 118 108 85 95 73 85 64 65 94
96 81 77 60 77 92 105 114 110 72 75 59 88 164 166 115 80 88 82 117
139 110 75 64 53 95 98 139 114 68 97 61 120 145 81 101 95 149
THT-A47B 98
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207 178 139 151 136 211 244 196 150 172 194 238 186 183 128 197 157 143 157 198
175 187 179 159 193 70 68 88 103 64 114 129 102 85 91 79 85 69 64 91
107 76 77 59 80 89 104 112 110 72 70 60 90 158 147 124 81 79 75 116
134 108 77 59 59 88 102 137 113 72 93 61 126 138 86 92 98 142
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110 102 113 164 126 133 166 117 120 126 124 147 127 172
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150 198 175 257 197 219 175 201 198 175 231 188 171 199 94 133 170 181 189 94
112 105 105 169 133 132 187 107 107 121 107 149 124 193
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60 60 42 48 84 95 97 75 45 45 42 39 47 50 55 55 38 51 45 64
63 100 79 110 74 60 43 50 65 126 132 130 129 80 63 48 68 109 155 117
86 93 64 47 59 51 53 61 55 45 47 46 73 90 114 129 110 115 120 65
93 81 63 50 78 82 65 60 72 103 88 52 42 77 76 88
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93 110 141 71 100 90 53 56 53 57 63 69 67 61 57 77 85 91 96 73
60 54 43 54 81 96 100 62 45 40 44 39 44 55 62 53 35 50 41 55
74 99 75 107 78 50 47 48 64 128 127 134 129 79 69 50 71 106 162 121
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170 175 217 133 144 117 161 141 122 101 50 52 66 66 44 86 91

THT-A50B 57
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90 64 64 68 49 33
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61 59 67 51 66 67 86 87 75 66 33 42 47 38 34 45 50 52 46 46
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61
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172 230 207 286 191 221 155 151 166 108 138 126 151 73 64 45 59 42 50 86
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85 74 63 57 62 55 75 80 66 119 62 41 57 50 80 108 82 86 67 75
56
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101 91 90 108 144 138 136 92 100 94 68 56 85 99 77 91 76 92 75 44
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123 124 107 144 154 137 208 110 88 63 84
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117 125 104 145 147 137 201 104 93 56 62
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90 74 73 45 56 48

THT-A54B 66
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91 128 133 145 136 115 97 131 142 110 99 117 104 116 109 132 123 109 73 82
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113 116 129 140 105 85 138 138 156 150 194 178
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80 91
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188 135 139 166 171 167 183 198 131 134 109 100 131 103 102 111 128 213 82 65
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182 135 141 169 175 162 182 196 137 131 122 96 130 104 100 115 125 204 74 75
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166 148 141 167 131 168 216 177 130 99 164 114 211 195 200 229 221 131
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208 241 217 151 240 197 238 271 263
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153 279 345 301 307 270 291 341 344 383 230 327 296 317 330 338 258 305 165 191
209 250 213 152 248 201 236 279 278

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 Buildings*' (Laxton and Litton 1988b) and, for example, in *Tree-Ring Dating and Archaeology* (Baillie 1982) or *A Slice Through Time* (Baillie 1995). 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 Figure1 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, 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 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. 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 we inspect the timbers in a building 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. Similarly the core has just over 100 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.

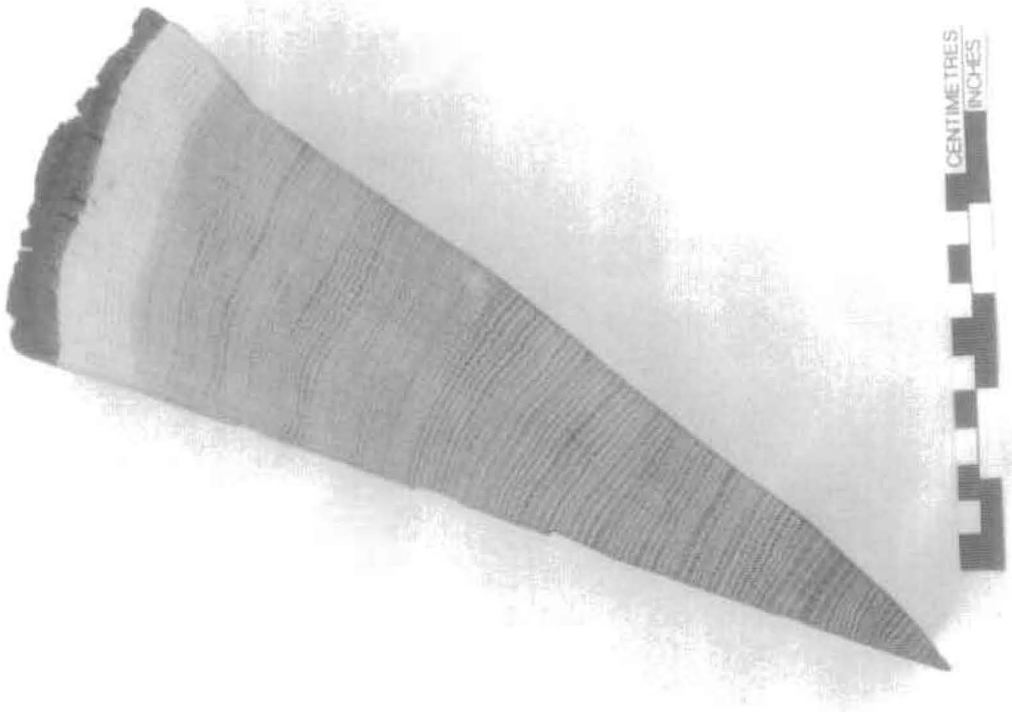

Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

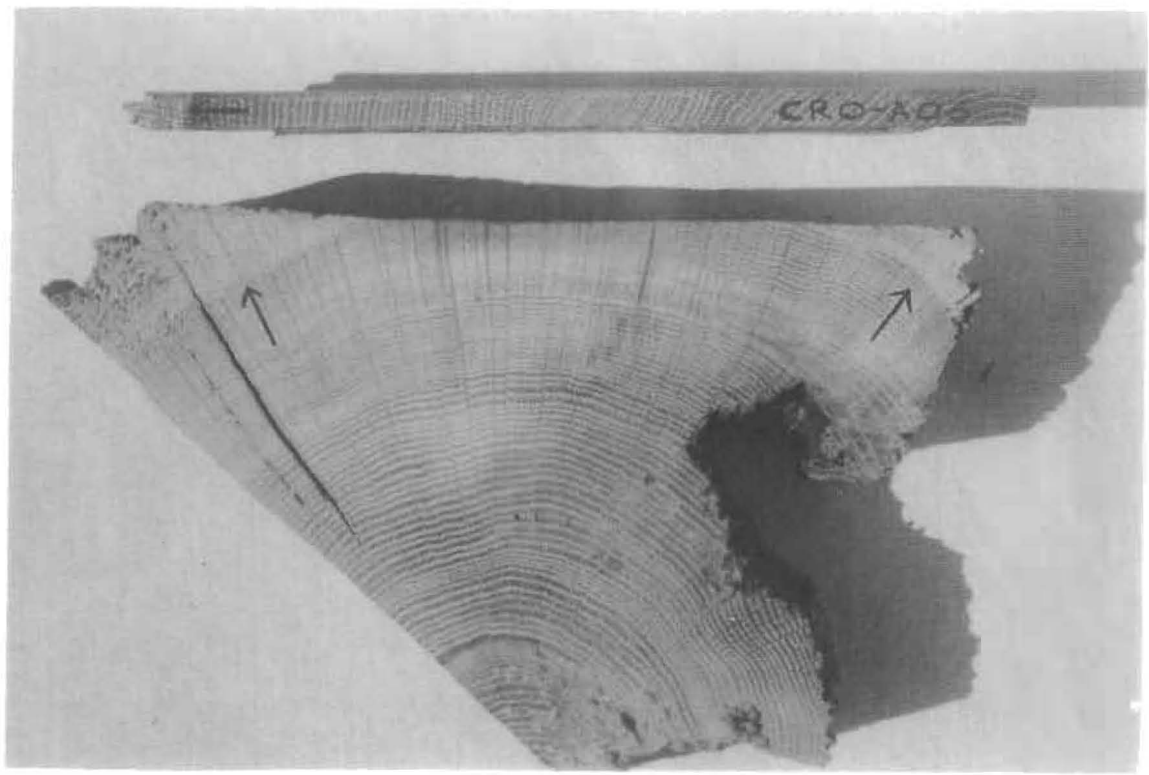

Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

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 measured twice to ensure that an error has not been made. This type of apparatus is needed to process a large number of samples on a regular basis.

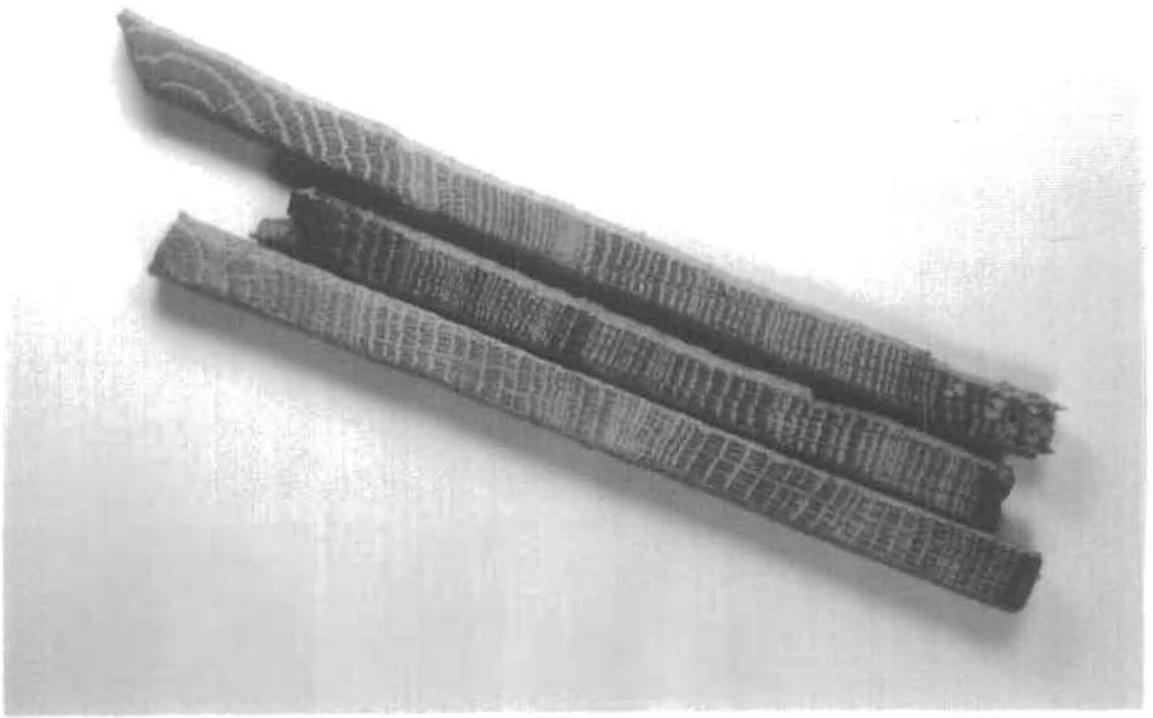

Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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 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 inspecton 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 is insured with the CBA.

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 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton *et al* 1988a,b; 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. C08 matches C45 best when it is at a position starting 20 rings after the first ring of 45, 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 between these two whatever the position of one sequence relative to the other.

It is standard practice in our Laboratory first to cross-match as many as possible of the 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 from 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. 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.

average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

This 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'. This was developed and tested in the Laboratory and has been published (Litton and Zainodin 1991; Laxton *et al* 1988a). To illustrate the difference between the two approaches with the above example, consider sequences C08 and C05. They are the most similar pair with a t-value of 10.4. Therefore, these two are first averaged with the first ring of C05 at +17 rings relative to C08 (the offset at which they match each other). This average sequence is then used in place of the individual sequences C08 and C05. The cross-matching continues in this way gradually building up averages at each stage eventually to form the site sequence.

4. ***Estimating the Felling Date.*** 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, they can be seen in two upper corners of the rafter and at the outer end of the core in Figure 2. 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 for 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. Thus in these circumstances the date of the present last ring is at least close to the date of the original last ring on the tree, and so to the date of felling.

   Various estimates have been made for the average number of sapwood rings in a mature oak. One estimate is 30 rings, based on data from living oaks. So, in the case of the core in Figure 2 where 9 sapwood rings remain, this would give an estimate for the felling date of 21 (= 30 - 9) years later than of the date of the last ring on the core. Actually, it is better in these situations to give an estimated range for the felling date. Another estimate is that in 95% of mature oaks there are between 15 and 50 sapwood rings. So in this example this would mean that the felling took place between 6 (= 15 - 9) and 41 (= 50 - 9) years after the date of the last ring on the core and is expected to be right in at least 95% of the cases (Hughes *et al* 1981; see also Hillam *et al* 1987).

   Data from the Laboratory has shown that when sequences are considered together in groups, rather than separately, the estimates for the number of sapwood can be put at between 15 and 40 rings in 95% of the cases with the expected number being 25 rings. We would use these estimates, for example, in calculating the range for the common felling date of the four sequences from Lincoln Cathedral using the average position of the heartwood/sapwood boundary (Fig 5). These new estimates are now used by us in all our publications except for timbers from Kent and Nottinghamshire where 25 and between 15 to 35 sapwood rings, respectively, is used instead (Pearson 1995).

   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. Sapwood rings were only lost in coring, because of their softness. By measuring in the timber the depth of sapwood lost, say 2 cm., a reasonable estimate can be made of the number of sapwood rings missing from the core, 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 40 years later we would have estimated without this observation.

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

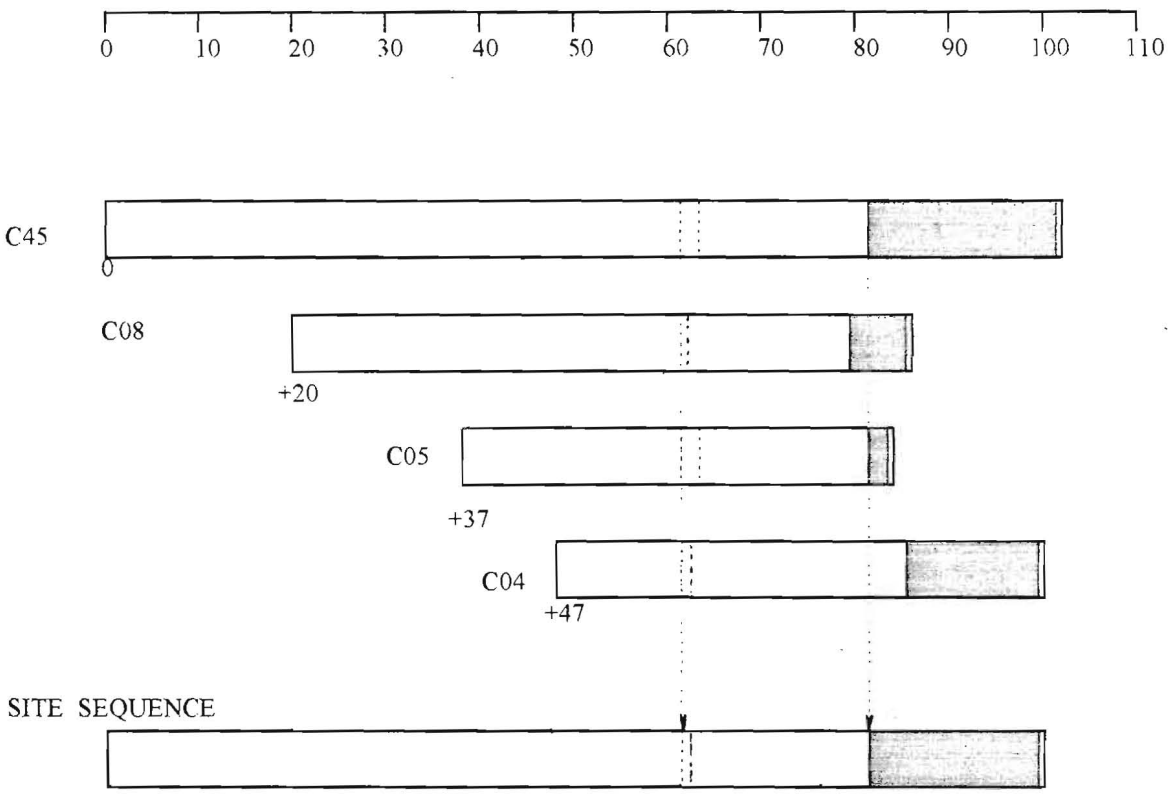

Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.
The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set 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.

Even if all the sapwood rings are missing on all the timbers sampled, an estimate of the felling date is still possible in certain cases. For provided the original last heartwood ring of the tree, called the heartwood/sapwood boundary (H/S), is still on some of the samples, an estimate for the felling date of the group of trees can be obtained by adding on the full 25 years, or 15 to 40 for the range of felling dates.

If none of the timbers have their heartwood/sapwood boundaries, then only a *post quem* date for felling is possible.

5. ***Estimating the Date of Construction.*** There is a considerable body of evidence in the data collected by the Laboratory that the oak timbers used in vernacular buildings, at least, were used 'green' (see also Rackham (1976)). Hence provided the samples are taken *in situ*, and several dated with the same estimated common felling date, then this felling date will give an estimated date for the construction of the building, or for the phase of construction. If for some reason or other we are rather restricted in what samples we can take, then an estimated common felling date may not be such a precise estimate of the date of construction. More sampling may be needed 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 1988b, 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* 1988a). 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 (1988b) 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 (a), the generally large early growth after 1810 is very apparent as is the smaller generally later growth from about 1900 onwards. A similar difference can be observed in the lower sequence 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, hopefully corresponding to good and poor growing seasons, respectively. The two corresponding sequences of Baillie-Pilcher indices are plotted in (b) where the differences in the early and late growths have been removed and only the rapidly changing peaks and troughs remain only associated with the common climatic signal and so make cross-matching easier.

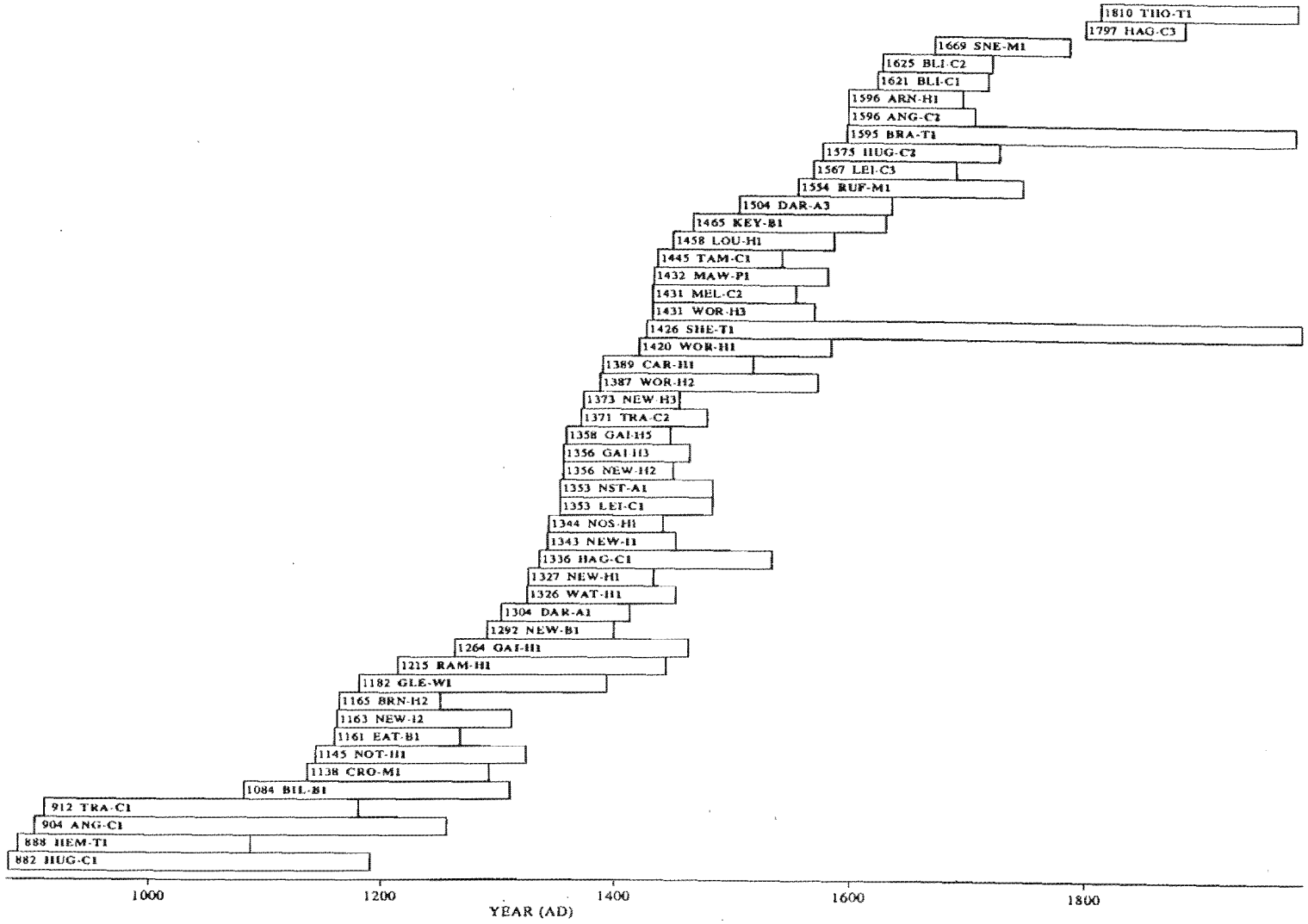

Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

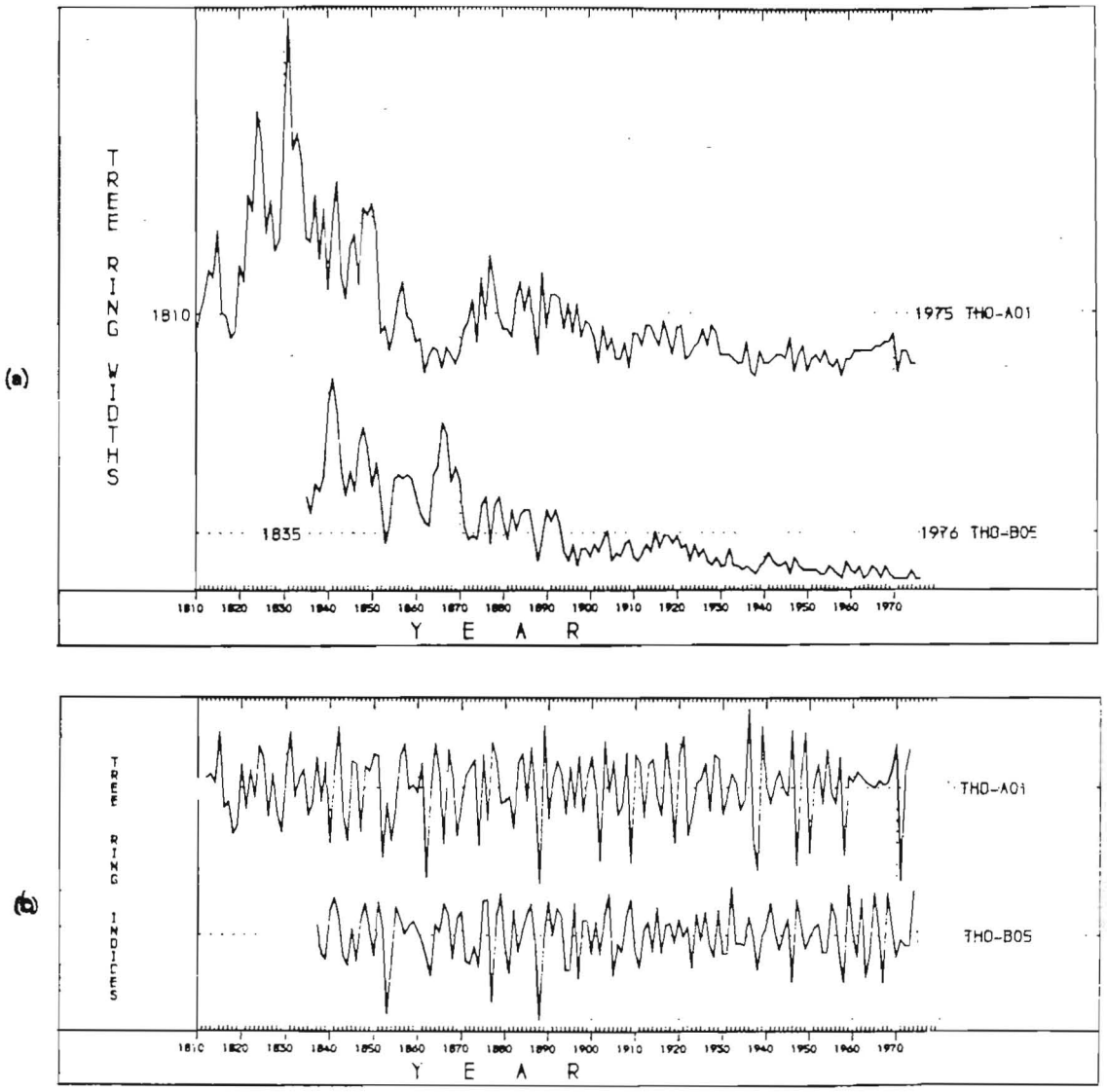

Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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

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

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