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# OAK HOUSE, OAK ROAD, WEST BROMWICH, SANDWELL, WEST MIDLANDS
# TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

ARCHAEOLOGICAL SCIENCE

ENGLISH HERITAGE

# OAK HOUSE, OAK ROAD, WEST BROMWICH, SANDWELL, WEST MIDLANDS

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## SUMMARY

Analysis of 53 measured samples from a wide range of locations at the Oak House, West Bromwich has resulted in the production of five site chronologies. Three of these site chronologies, accounting for 39 samples, can be dated, whilst two further site chronologies, accounting for a total of four samples, remain undated. Ten measured samples remain ungrouped and undated.

Interpretation of the sapwood and the heartwood/sapwood boundaries on these dated samples indicates that the Oak House is constructed of timbers which were cut as part of series of indistinguishable felling phases in the late sixteenth and/or early seventeenth centuries. There appears to be no appreciable difference in the felling dates of the timbers from the hall range, from either wing, or from the ground floor, strongly suggesting that the Oak House is substantially of a single phase of construction, dating to the late-sixteenth/early-seventeenth century.

A small group of timbers date to the mid- to third-quarter of the seventeenth century, and probably relate to alterations and modifications made at that time.

## CONTRIBUTORS

Alison Arnold and Robert Howard

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## ARCHIVE LOCATION

Sandwell Sites & Monuments Record
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# INTRODUCTION

The first documentary reference to Oak House (SO 992 913, Figs 1 and 2) is found in AD 1634, when John Turton bought the house from his brother, Thomas, and sold it just over six months later to his own son, also named John. The Turtons lived at Oak House until AD 1768, when the property passed to the illegitimate son of the last Turton, who took the name William Whyley, after his mother's family. After AD 1837, the Oak House passed to the Piercy family of Warley Hall, and various tenants and agents lived in it until Alderman Reuben Farley, first Mayor of West Bromwich, bought it in AD 1894. Mayor Farley then began restoring the house, and presented it to the town as a museum, for which purpose it served for the next fifty years. After being closed for a number of years the Oak House opened again in AD 1951, furnished in the style of the Turton family period. The house is maintained as a museum to the present time.

## The phases of the house

According to a brief note on the Oak House, prepared by Nicholas Molyneux, Historic Building Inspector for English Heritage, following a visit in 2008 (Molyneux pers comm) from which much of this information is taken, the interpretation of the phasing of The Oak House has been a puzzle for many years, a number of different versions of its development having been put forward. The *Victoria County History* (Baggs 1976) took the view that the present building was originally constructed in the sixteenth century on an L-shaped plan, with a hall to one range and a parlour to the cross-wing. Subsequently, according to this interpretation, *c* AD 1600, a new parlour range was added (the original parlour becoming the service wing), and the porch and brick service stack were added. A brick stair turret was then built in the seventeenth century.

Also in 1976, Stephen Price (Price 1976 unpubl), historic building consultant, suggested that, on the basis of stylistic similarity, the timber framing was all of one phase. He argued for a date at the very end of the sixteenth century, with the porch probably being contemporary. Most recently Birmingham Archaeology (Lobb 2006) has offered a third and more complex history. Lobb follows the Victoria County History schema with an initial L-plan, but then argues for the hall range, an in-line service room, and the parlour cross-wing as the first phase, followed by the room behind the service wing, then the new chimney in the kitchen, and the porch in an early-seventeenth century third phase. In this interpretation, the stair turret is also the final addition, this dating to the mid-seventeenth century. A view of the north façade is given in Figure 3.

The recent re-assessment of the building by Nicholas Molyneux favoured the simpler interpretation of the development of the building. The heart of the house is the hall range (Fig 4) comprising a two-bay chamber between trusses 4–6 (the central truss, truss 5, only surviving in fragmentary form visible in front of the inserted belvedere). The trusses at each end of the hall have their upper, or 'best', face into the hall so that they might be seen. These trusses, however, do not have independent tiebeams, these being formed by the wall plates of the parlour and service cross-wings. The corner posts in the rear angle of the hall and each cross-wing, furthermore, serve to support the wall plates of the two cross-wings as well as the rear wall plate of the hall at the same time; their jowls run along the back wall of the hall. Such an arrangement argues strongly for both cross-wings and hall range being coeval.

It would appear, therefore from this most recent re-examination, that the primary phase comprises a U-shaped building of a hall range with a parlour cross-wing at one end and a shorter service cross-wing at the other. The framing style is consistent with this, and other stylistic indicators, such as chamfer stops, point to this all being of one late sixteenth or early seventeenth century phase.

In structural terms, it is clear that the porch is a later addition, in that it is planted over the framing of the hall range. The framing of the porch is also stylistically different, since it has decorative bracing of a kind not seen elsewhere in the house. However, other elements, such as the chamfer stops and the jetty moulding, suggest that it may be contemporary. The gable to its left, sitting on the wall plate of the hall, is positioned to respect the porch, and so is contemporary with it.

The next alteration was the addition of the belvedere on the roof, which cut through the central hall truss, perhaps in the second quarter of the seventeenth century.

Finally, there are the brick alterations and additions. A substantial brick stack to the east side of the service end provides a large kitchen fireplace. This has undergone further significant internal alteration. There is also a stair turret in the south-west corner of the addition to the rear (with underlying cellar) and associated contemporary brickwork wrapping around the back of the parlour cross-wing. With the shaped gable of the stair turret, these alterations date to the mid- to late-seventeenth century, which would be an acceptable stylistic date for the staircase.

## SAMPLING

Sampling and analysis by tree-ring dating of timbers within The Oak House, West Bromwich, was requested by Alan Taylor, Historic Buildings Inspector at English Heritage's Birmingham office. The purpose of this was to inform statutory advice to supplement information for possible 'opening-up' works on the building, prior to the completion of a bid for lottery funds for a re-presentation of the site. It was hoped that dating the timbers would confirm their age and inform an understanding of the development of the building which has, in the past, generated some controversy (see above).

Thus, from the timbers available, a total of 62 samples was obtained by coring, each sample being given the code OAK-H (for Oak House) and numbered 01–62. An attempt was made to distribute the samples as widely as possible about the house, yet remain consistent with the need to obtain groups of coeval timbers. The samples were therefore spread over the cellar in the later addition to the rear, the ground floor, the first floor, and the attic spaces of the three ranges of the building, that is the hall, and the east and west cross-wings. In theory other timbers were available for sampling at the Oak House, such as those from the porch, the belvedere and the stairs. It was seen however, that these timbers were derived from fast-grown trees and as such, unlikely to provide samples with sufficient rings, ie at least 54, for reliable analysis. Such timbers were note sampled therefore.

The positions of these cores were marked at the time of sampling on drawings made by Birmingham Archaeology and kindly provided by Sandwell Metropolitan Borough Council or on photographs. These are reproduced here as Figures 5a–9d. Details of the samples are given in Table 1. In this Table all the rooms are identified following the schema of the drawings provided. The trusses, beams, and other timbers have been further identified and numbered on an east-west or north-south basis as appropriate.

## ANALYSIS

Each of the 62 samples obtained was prepared by sanding and polishing. It was seen at this time that nine samples had less than 54 rings, the minimum number necessary for reliable dating, and these were rejected from this programme of analysis. The widths of the annual growth rings on the remaining 53 samples were, however, measured, the data of these measurements being given at the end of this report. The data were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix) and, at a minimum value of $t$=4.0, five groups of cross-matching samples could be formed.

The first group comprises 19 samples, the samples cross-matching with each other at the positions shown in the bar diagram, Figure 10. The 19 samples were combined at these positions to form site chronology OAKHSQ01, with an overall length of 186 rings. This site chronology was then compared with an extensive corpus of reference chronologies for oak, cross-matching consistently with a number of these when the date of its first ring is AD 1405 and the date of its last ring is AD 1590. The evidence for this dating is given in Table 2.

The second group comprises 15 samples; these samples cross-match with each other at the positions shown in the bar diagram, Figure 11. The 15 samples were combined at these positions to form site chronology OAKHSQ02, with an overall length of 144 rings. Site chronology OAKHSQ02 was also compared with an extensive corpus of reference chronologies for oak cross-matching consistently with a number of these when the date of its first ring is AD 1456 and the date of its last ring is AD 1599. The evidence for this dating is given in Table 3.

The third group comprises five samples, cross-matching with each other at the positions shown in the bar diagram, Figure 12. The five samples were combined at their indicated positions to form site chronology OAKHSQ03, with an overall length of 86 rings. Site chronology OAKHSQ03 was also compared with an extensive corpus of reference chronologies for oak, cross-matching consistently with a number of these when the date of its first ring is AD 1553 and the date of its last ring is AD 1638. The evidence for this dating is given in Table 4.

The fourth and fifth groups both comprises two samples each, the samples cross-matching with each other at the positions shown in the bar diagrams, Figures 13 and 14. The samples of each group were combined at their indicated positions to form site chronologies OAKHSQ04 and OAKHSQ05, with overall lengths of 93 and 102 rings respectively. Both site chronologies were compared with the full range of reference material for oak, but there was no satisfactory cross-matching at any position, and all these samples must remain undated.

The five site chronologies thus created were then compared with each other, but despite at least three of them having overlapping date spans, there was no satisfactory cross-matching between them. Each of the five site chronologies was also compared with the 10 remaining measured but ungrouped samples. Again, there was no further satisfactory cross-matching.

The 10 remaining measured but ungrouped samples were then compared individually with the reference chronologies, but again there was no cross-matching and all 10 individuals must remain undated.

This analysis can be summarised as follows:

| Site chronology | Number of samples | Number of rings | Date span (where dated) |
|---|---|---|---|
| OAKHSQ01 | 19 | 186 | AD 1405–1590 |
| OAKHSQ02 | 15 | 144 | AD 1456–1599 |
| OAKHSQ03 | 5 | 86 | AD 1553–1638 |
| OAKHSQ04 | 2 | 93 | undated |
| OAKHSQ05 | 2 | 102 | undated |
| | | | |
| singles | 10 | --- | undated |
| unmeasured | 9 | --- | undated |

## INTERPRETATION

Analysis by tree-ring dating has thus created two dated site sequences, OAKHSQ01 and SQ02, both of which contain samples from the Hall range, the east and west cross-wings, and the ground and first floor ceilings. Taking these two site sequences, OAKHSQ01 and SQ02, as separate groups, it is noticeable that there is some difference in their average heartwood/sapwood boundary date. The average date for the boundary of site sequence OAKHSQ01 is AD 1565, while the average date for the boundary of OAKHSQ02 is AD 1578, a difference of 13 years. This could be taken as evidence that the trees used for one group of timbers were felled at a different time to those forming another group.

There is, however, an even greater range within the respective individual samples of these two site chronologies. The earliest heartwood/sapwood boundary date of any sample in site chronology OAKHSQ01 is AD 1554 (OAK-H52), while the latest heartwood/sapwood boundary is at AD 1577, on sample OAK-H09, a difference of 23 years. The dates of the respective earliest and latest boundaries in site chronology OAKHSQ02 are AD 1561 (OAK-H55) and AD 1589 (OAK-H07 and H53), a variation of 28 years. This could be taken as further evidence that the timbers even within each site chronology were cut over a period of time, rather than as part of a single felling.

An attempt to illustrate this is given in the bar diagram, Figure 15, where all 39 dated samples in site chronologies OAKHSQ01, SQ02, and SQ03 are shown, sorted by sample location, in last measured ring date order. As may be seen from this, as well as from Table 1, there is a significant overall variation in the relative position/date of the earliest and latest heartwood/sapwood boundary. This ranges from as early as relative position 150/AD 1554, on sample OAK-H52, a ceiling beam in room G4, to as late as relative position 185/AD 1589 on samples OAK-H06, from the roof of the west wing, and OAK-H53 from a ground-floor ceiling beam, a difference of 35 years.

Based on a 95% probability of 15–40 rings for the amount of sapwood the trees might have had, the former sample represents a timber with an estimated felling date in the range AD 1569–94, with the latter samples representing timbers with estimated felling dates in the range AD 1604–29. These two estimated felling date ranges do not overlap, and it is thus most likely that they represent timbers felled at slightly different dates. Indeed, the broad range of the heartwood/sapwood boundary dates make it feasible that felling was undertaken gradually over a number of years. More likely, however, is the possibility that timbers were cut in periodic batches over a relatively short period of years, as work on the building progressed and timbers were seen to be required.

The felling date of one timber, from the roof of the east cross-wing and represented by sample OAK-H08 in dated site chronology OAKHSQ02, is known precisely. This sample retains complete sapwood, meaning that it has the last ring produced by the tree represented before it was cut down, this last, complete, sapwood, ring, and thus the felling of the tree, being dated to AD 1599. It is very likely, based on the interpretation of the amount of sapwood, and of the position of the heartwood/sapwood boundary, on a number of other samples, that they too represent timbers felled at or about this time in the late-sixteenth century, or possibly in the early-seventeenth century

This phenomenon, timbers being cut over a period of time and showing little date-specific distinction, is seen in different parts of the house, and there appears to be no clear distinction between the dates of the roofs to the hall range or either cross-wing or to the timbers of the first and ground floors. Samples OAK-H38, H52, and H55, for example, from ceiling beams and a partition wall stud, have heartwood/sapwood boundary dates suggesting a felling date into the late-sixteenth century. Other similar beams, represented by samples OAK-H32, H46, and H53, are unlikely to have been felled before the early-seventeenth century. A very slightly shorter range of possible felling dates is found amongst the roof timbers, where timbers possibly felled in the late-sixteenth to early-seventeenth century are also found.

Whilst the bulk of dated material from throughout the complex is of late sixteenth or early seventeenth century date, a small group of five timbers were clearly felled in the mid- to third quarter of the seventeenth century. These timbers include a strut associated with the belvedere, two timbers associated with rooms F1/F9, and ceiling beams from the cellar. These appear likely to represent repairs or alterations, perhaps related to the building of the stair turret and the belvedere.

## DISCUSSION AND CONCLUSION

It would thus appear that the majority of dated timbers from the Oak House were felled, possibly in batches over a period of time rather than in a single felling, in the late sixteenth and early seventeenth centuries. There appears, however, to be no difference in the use of such timbers in the various parts of the Oak House, that is the Hall range, from either wing, or from the ground and first floors, with timbers apparently felled at different times being mixed together and used in the same part of the building. This strongly suggests the Oak House is substantially of a single phase of construction, originating as the simpler U-shaped building proposed rather than having the more complex alternative development sometimes put forward. The small group of later timbers identified probably relate to alterations and modifications made during the mid- to third-quarter of the seventeenth century.

However, although of a single phase of construction, it would appear that the timber used in the primary phase of construction has come from at least two different sources. Although not unknown in tree-ring analysis, it is unusual, as in this analysis, to find groups of coeval timbers, as in the case of site chronologies OAKHSQ01 (AD 1405–1590) and OAKHSQ02 (AD 1456–1599), which do not cross-match with each other. These two site chronologies share a common overlapping growth period of 134 years (AD 1456–1590), quite sufficient, in theory, for satisfactory cross-matching. Although sharing a common growth period, it is possible that the lack of cross-matching is a result of the trees represented by each site chronology growing in different locations. The lack of cross-matching between either of these two site chronologies and the third dated site chronology, OAKHSQ03, is more easily explicable by the fact that the maximum overlap between them is only 46 years , slightly too short for reliability.

The dichotomy between the trees represented by the three site chronologies is further evidenced in the growth regime seen in the relevant samples. It is noticeable that the samples in site chronology OAKHSQ01 tend to represent slower-grown, longer-lived, trees than those in site chronology OAKHSQ02 (this is highlighted to a degree in Fig 15). This difference could be taken to further suggest different sources as well as potentially slightly different felling dates for the timbers of each group. The trees represented by site chronology OAKHSQ03 also appear to be derived from relatively young and relatively fast- grown trees.

Where these source woodlands were cannot be determined precisely by tree-ring analysis. However, judging by the *t*-values of Table 2–4, which shows the relevant reference chronologies against which the site chronologies have been dated, the best matches for site chronology OAKHSQ01 occur with references made up of material from other sites to the west of West Bromwich, with Gloucestershire, Oxfordshire, and Warwickshire being seen, while site chronologies OAKHSQ02 and SQ03 match best with a more widely dispersed set of reference data.

Wherever the source of the timbers, and its exact felling date, it may finally be of interest to note that, given the high number of samples obtained from this site, and therefore the number of trees potentially represented, there is surprisingly little cross-matching between samples high enough to indicate timbers derived from the same tree. The best cross-matching, with *t*-values ranging from 10.1 to 13.2, is found between samples OAK-H18 and H19, from the west wing roof, and sample OAK-H22 from the Hall range roof. Further high *t*-values are found between samples OAK-H13 and H14, both from purlins of the west wing roof ($t$=11.0), OAK-H25 and H26, purlins of the Hall range roof ($t$=12.7) and between OAK-H46 and H56, both ground-floor ceiling beams ($t$=11.2), these being the only evidence of same-tree sources. It may also be noted that, with the exception of one group (samples OAK-H18/19 and H22), there is little evidence of timbers derived from the same tree being used in different parts of the building.

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# TABLES

*Table 1: Details of tree-ring samples from the Oak House, West Bromwich*

| Sample number | Sample location | Total rings | Sapwood rings* | First measured ring date | Last heartwood ring date | Last measured ring date |
|---|---|---|---|---|---|---|
| | East wing roof | | | | | |
| OAK-H01 | East principal rafter, truss 1 | 58 | no h/s | AD 1475 | ------ | AD 1532 |
| OAK-H02 | West principal rafter, truss 1 | 117 | no h/s | AD 1410 | ------ | AD 1526 |
| OAK-H03 | East purlin, truss 1 – 2 | 68 | 8 | ------ | ------ | ------ |
| OAK-H04 | West purlin, truss 1 – 2 | nm | --- | ------ | ------ | ------ |
| OAK-H05 | East principal rafter, truss 2 | 73 | h/s | ------ | ------ | ------ |
| OAK-H06 | West principal rafter, truss 2 | 61 | 9 | AD 1538 | AD 1589 | AD 1598 |
| OAK-H07 | East purlin, truss 2 – 3 | 75 | h/s | AD 1505 | AD 1579 | AD 1579 |
| OAK-H08 | West purlin, truss 2 – 3 | 99 | 19C | AD 1501 | AD 1580 | AD 1599 |
| OAK-H09 | East principal rafter, truss 3 | 74 | h/s | AD 1504 | AD 1577 | AD 1577 |
| OAK-H10 | West principal rafter, truss 3 | 155 | 22 | AD 1434 | AD 1566 | AD 1588 |
| | | | | | | |
| | | | | | | |
| | West wing roof | | | | | |
| OAK-H11 | West principal rafter, truss 7 | 80 | no h/s | AD 1421 | ------ | AD 1500 |
| OAK-H12 | Middle stud below lower collar, truss 7 | 63 | 3 | ------ | ------ | ------ |
| OAK-H13 | East purlin truss 7 – 8 | 62 | no h/s | AD 1447 | ------ | AD 1508 |
| OAK-H14 | West purlin, truss 7 – 8 | 58 | no h/s | AD 1450 | ------ | AD 1507 |
| OAK-H15 | East principal rafter, truss 8 | 98 | h/s | AD 1482 | AD 1579 | AD 1579 |
| OAK-H16 | West principal rafter, truss 8 | 89 | 19 | AD 1495 | AD 1564 | AD 1583 |
| OAK-H17 | Collar, truss 8 | 102 | h/s | ------ | ------ | ------ |
| OAK-H18 | East principal rafter, truss 9 | 84 | no h/s | AD 1446 | ------ | AD 1529 |
| OAK-H19 | West principal rafter, truss 9 | 156 | h/s | AD 1412 | AD 1567 | AD 1567 |
| OAK-H20 | Collar, truss 9 | 70 | no h/s | ------ | ------ | ------ |
| OAK-H21 | West purlin, truss 9 – '10' | nm | --- | ------ | ------ | ------ |
| | | | | | | |

*Table 1: continued*

| Sample number | Sample location | Total rings | Sapwood rings* | First measured ring date | Last heartwood ring date | Last measured ring date |
|---|---|---|---|---|---|---|
| | Hall range roof | | | | | |
| OAK-H22 | West principal rafter, north gable truss | 119 | h/s | AD 1450 | AD 1568 | AD 1568 |
| OAK-H23 | Upper central stud post, north gable truss | 71 | 5 | AD 1509 | AD 1574 | AD 1579 |
| OAK-H24 | East principal rafter, north gable truss | 79 | 20 | AD 1507 | AD 1565 | AD 1585 |
| OAK-H25 | Lower north purlin, | 116 | 5 | AD 1456 | AD 1566 | AD 1571 |
| OAK-H26 | Upper north purlin | 110 | 26 | AD 1486 | AD 1569 | AD 1595 |
| OAK-H27 | North principal rafter, truss 6 | 90 | h/s | ------ | ------ | ------ |
| OAK-H28 | Collar truss 6 | 125 | no h/s | AD 1435 | ------ | AD 1559 |
| OAK-H29 | Diagonal strut to east of belvedere tower | 61 | h/s | AD 1573 | AD 1633 | AD 1633 |
| | | | | | | |
| | | | | | | |
| | First-floor timbers | | | | | |
| | | | | | | |
| OAK-H30 | Tiebeam to south gable wall, room F8 | 140 | 25 | AD 1451 | AD 1565 | AD 1590 |
| OAK-H31 | Main south-west wall post, room F8 | 88 | no h/s | AD 1452 | ------ | AD 1539 |
| OAK-H32 | Partition wall beam, rooms F8/9 | 76 | h/s | AD 1512 | AD 1587 | AD 1587 |
| OAK-H33 | Tiebeam to north wall room F6 | 92 | no h/s | AD 1436 | ------ | AD 1527 |
| OAK-H34 | Partition wall beam, rooms F4/7 | 122 | no h/s | AD 1413 | ------ | AD 1534 |
| OAK-H35 | Mid-rail 5, party wall, rooms F2/12 | 75 | no h/s | ------ | ------ | ------ |
| OAK-H36 | Main partition wall beam, rooms F2/12 | nm | --- | ------ | ------ | ------ |
| OAK-H37 | North brace, party wall, rooms F2/12 | 56 | no h/s | ------ | ------ | ------ |
| OAK-H38 | Stud post 3, party wall, rooms F2/12 | 164 | 10 | AD 1405 | AD 1558 | AD 1568 |
| OAK-H39 | Stud post 2, party wall, rooms F2/12 | nm | --- | ------ | ------ | ------ |
| OAK-H40 | North-south ceiling beam, room F2 | 76 | no h/s | ------ | ------ | ------ |
| OAK-H41 | Plate to party wall, rooms F1/2/9 | 69 | 13 | AD 1524 | AD 1579 | AD 1592 |
| OAK-H42 | Mid-rail 4, party wall, rooms F2/12 | nm | --- | ------ | ------ | ------ |
| OAK-H43 | East-west ceiling beam, room F9 | 72 | h/s | AD 1567 | AD 1638 | AD 1638 |
| OAK-H44 | North-south beam, party wall, rooms F1/9 | 71 | no h/s | AD 1553 | ------ | AD 1623 |

*Table 1: continued*

| Sample number | Sample location | Total rings | Sapwood rings* | First measured ring date | Last heartwood ring date | Last measured ring date |
|---|---|---|---|---|---|---|
| | Ground floor beams | | | | | |
| OAK-H45 | Eastern north-south ceiling beam, room G2 | 61 | no h/s | ------ | ------ | ------ |
| OAK-H46 | South-west ceiling beam, room G2 | 95 | 7 | AD 1500 | AD 1587 | AD 1594 |
| OAK-H47 | North-west ceiling beam, room G2 | nm | --- | ------ | ------ | ------ |
| OAK-H48 | Main north-south ceiling beam, room G3 | 83 | 12 | AD 1514 | AD 1584 | AD 1596 |
| OAK-H49 | North-east dragon beam, room G3 | 128 | no h/s | AD 1430 | ------ | AD 1557 |
| OAK-H50 | Southern east-west ceiling beam, room G3 | 54 | 14C | ------ | ------ | ------ |
| OAK-H51 | Fireplace bressummer beam, room G3 | nm | --- | ------ | ------ | ------ |
| OAK-H52 | North-south ceiling beam, room G4 | 108 | 8 | AD 1455 | AD 1554 | AD 1562 |
| OAK-H53 | Partition wall beam, rooms G3/4 | 68 | h/s | AD 1522 | AD 1589 | AD 1589 |
| OAK-H54 | East-west ceiling beam, room G6 | 54 | no h/s | ------ | ------ | ------ |
| OAK-H55 | North-west dragon beam, room G9 | 58 | h/s | AD 1504 | AD 1561 | AD 1561 |
| OAK-H56 | Main east-west ceiling beam, room G9 | 63 | h/s | AD 1518 | AD 1580 | AD 1580 |
| OAK-H57 | Main north-south ceiling beam, room G9 | 73 | no h/s | ------ | ------ | ------ |
| OAK-H58 | East-west ceiling beam, room G8 | nm | --- | ------ | ------ | ------ |
| OAK-H59 | Main north-south ceiling beam, room G8 | nm | --- | ------ | ------ | ------ |
| OAK-H60 | South-west dragon beam, room G8 | 70 | no h/s | ------ | ------ | ------ |
| | | | | | | |
| | | | | | | |
| | Cellar beams | | | | | |
| | | | | | | |
| OAK-H61 | Eastern ceiling beam | 62 | h/s | AD 1572 | AD 1633 | AD 1633 |
| OAK-H62 | Western ceiling beam | 66 | h/s | AD 1563 | AD 1628 | AD 1628 |

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

*Table 2: Results of the cross-matching of site sequence OAKHSQ01 and relevant reference chronologies when first ring date is AD 1405 and last ring date is AD 1590*

| Reference chronology | Span of chronology | *t*-value | |
|---|---|---|---|
| | | | |
| Ordsall Hall, Salford, Greater Manchester | AD 1385–1534 | 10.1 | ( Arnold *et al* 2004 ) |
| England | AD 401–1981 | 9.2 | ( Baillie and Pilcher 1982 unpubl ) |
| Wales and West Midlands | AD 1341–1636 | 9.1 | ( Siebenlist-Kerner 1978 ) |
| Tusmoore Park, Oxon | AD 1359–1545 | 8.2 | ( Howard *et al* 1992 ) |
| St Briavel's Castle, Glos | AD 1362–1636 | 7.8 | ( Howard *et al* 1999 ) |
| Kingsbury Hall, Kingsbury, Warwicks | AD 1391–1564 | 7.8 | ( Arnold and Howard 2006 ) |
| Naas House, Lydney, Glos | AD 1373–1568 | 7.6 | ( Howard *et al* 1998a ) |
| Primrose Hill, Kings Norton, Birmingham | AD 1354–1593 | 7.3 | ( Arnold *et al* 2008 ) |

*Table 3: Results of the cross-matching of site sequence OAKHSQ02 and relevant reference chronologies when first ring date is AD 1456 and last ring date is AD 1599*

| Reference chronology | Span of chronology | *t*-value | |
|---|---|---|---|
| | | | |
| Sharpcliffe Hall, Sharpcliffe, Staffs | AD 1466–1647 | 6.2 | ( Arnold and Howard 2007a unpubl ) |
| Brices Farm barn, Clavering, Essex | AD 1461–1521 | 5.7 | ( Tyers 1995 ) |
| Cressing Temple Granary, Essex | AD 1487–1622 | 5.7 | ( Andrews *et al* 1994 ) |
| Old Abbey Farm, Risley, Cheshire | AD 1460–1534 | 5.3 | ( Nayling 1998 ) |
| Hoyles Farm, Bradfield, Derbys | AD 1448–1552 | 5.1 | ( Howard *et al* 1993 ) |
| St Swithun's Church, Woodborough, Notts | AD 1529–1650 | 5.0 | ( Arnold and Howard 2008 ) |
| Lamonby Farm, Burgh by Sands, Cumbria | AD 1464–1615 | 5.0 | ( Howard *et al* 1992 ) |
| Stoneleigh Abbey, Stoneleigh, Warwicks | AD 1398–1658 | 4.8 | ( Howard *et al* 2000 ) |

*Table 4: Results of the cross-matching of site sequence OAKHSQ03 and relevant reference chronologies when first ring date is AD 1553 and last ring date is AD 1638*

| Reference chronology | Span of chronology | *t*-value | |
|---|---|---|---|
| | | | |
| Oak House Barn, West Bromwich | AD 1562–1655 | 6.7 | ( Howard *et al* 1991 ) |
| Fieldgate Farm, Acocks Green, Birmingham | AD 1496–1653 | 6.7 | ( Howard *et al* 1989 ) |
| Sherwood Forrest, Notts | AD 1426–1981 | 6.0 | ( Laxton and Litton 1988 ) |
| Hempshill Hall, Nuthall, Nottingham | AD 1566–1702 | 6.0 | ( Arnold and Howard 2006 unpubl ) |
| Aston Hall, Aston, Birmingham | AD 1457–1624 | 5.7 | ( Howard 2005 unpubl ) |
| Rushall Hall Barn, Rushall, Walsall, West Midlands | AD 1510–1672 | 5.6 | ( Howard 2004 ) |
| Cromford Bridge House, Cromford, Derbys | AD 1416–1613 | 5.5 | ( Arnold and Howard 2007b unpubl ) |
| Cheddleton Grange, Cheddleton, Staffs | AD 1551–1682 | 5.4 | ( Howard *et al* 1998b ) |

## FIGURES

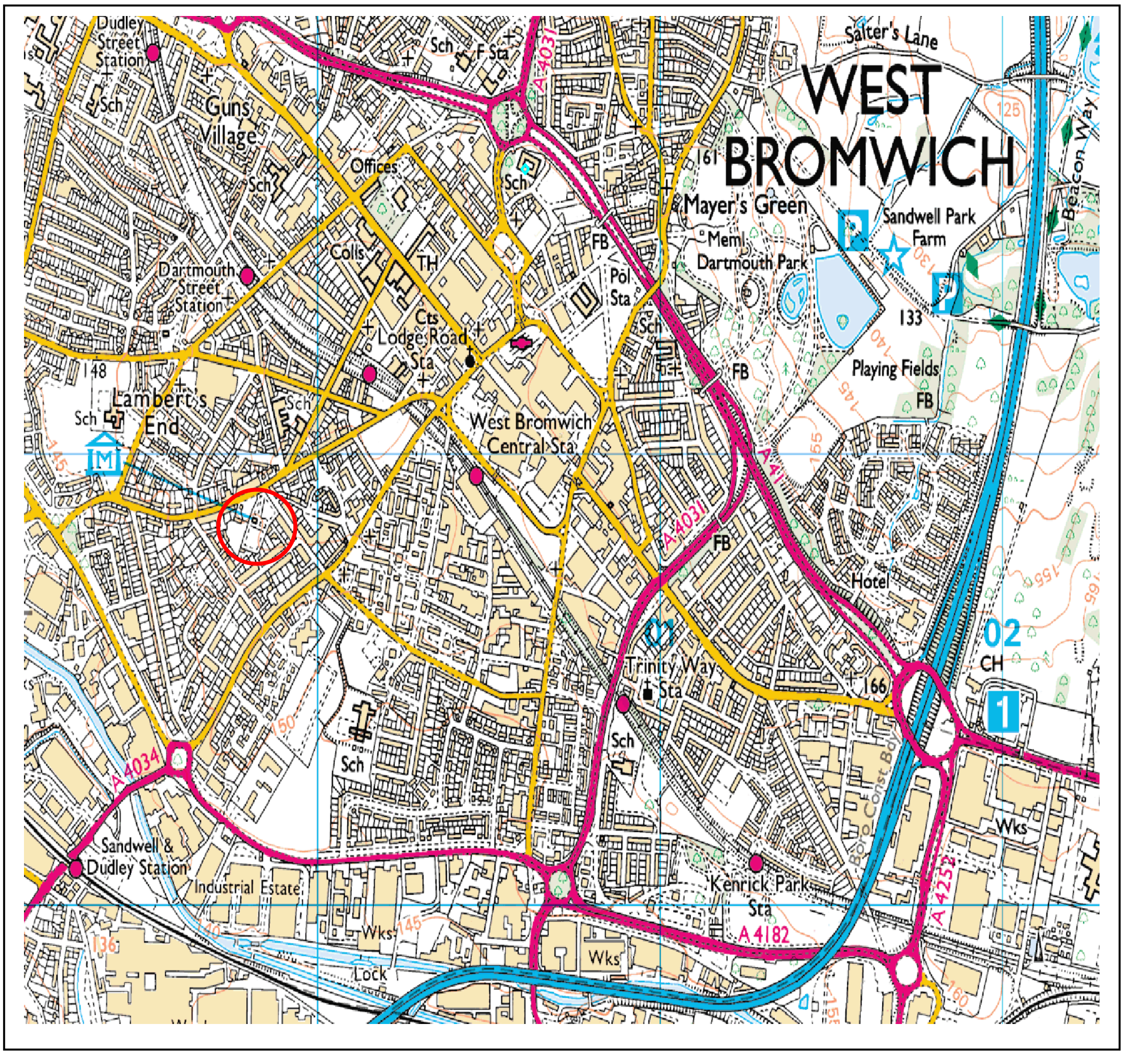



*Figure 1: location of The Oak House, West Bromwich (circled)*

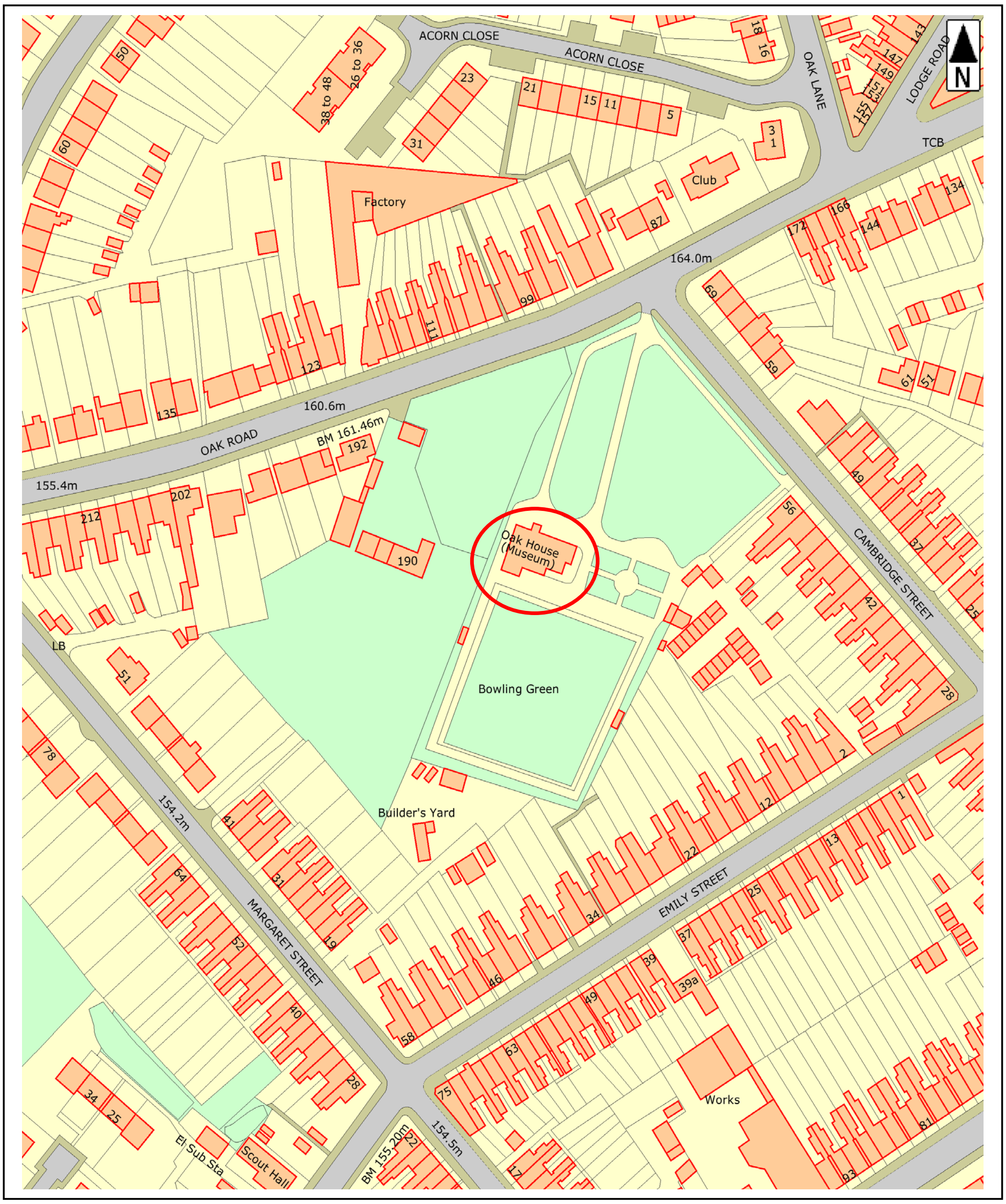



*Figure 2: location of the buildings, circled*

*Figure 3: The north façade of Oak House*

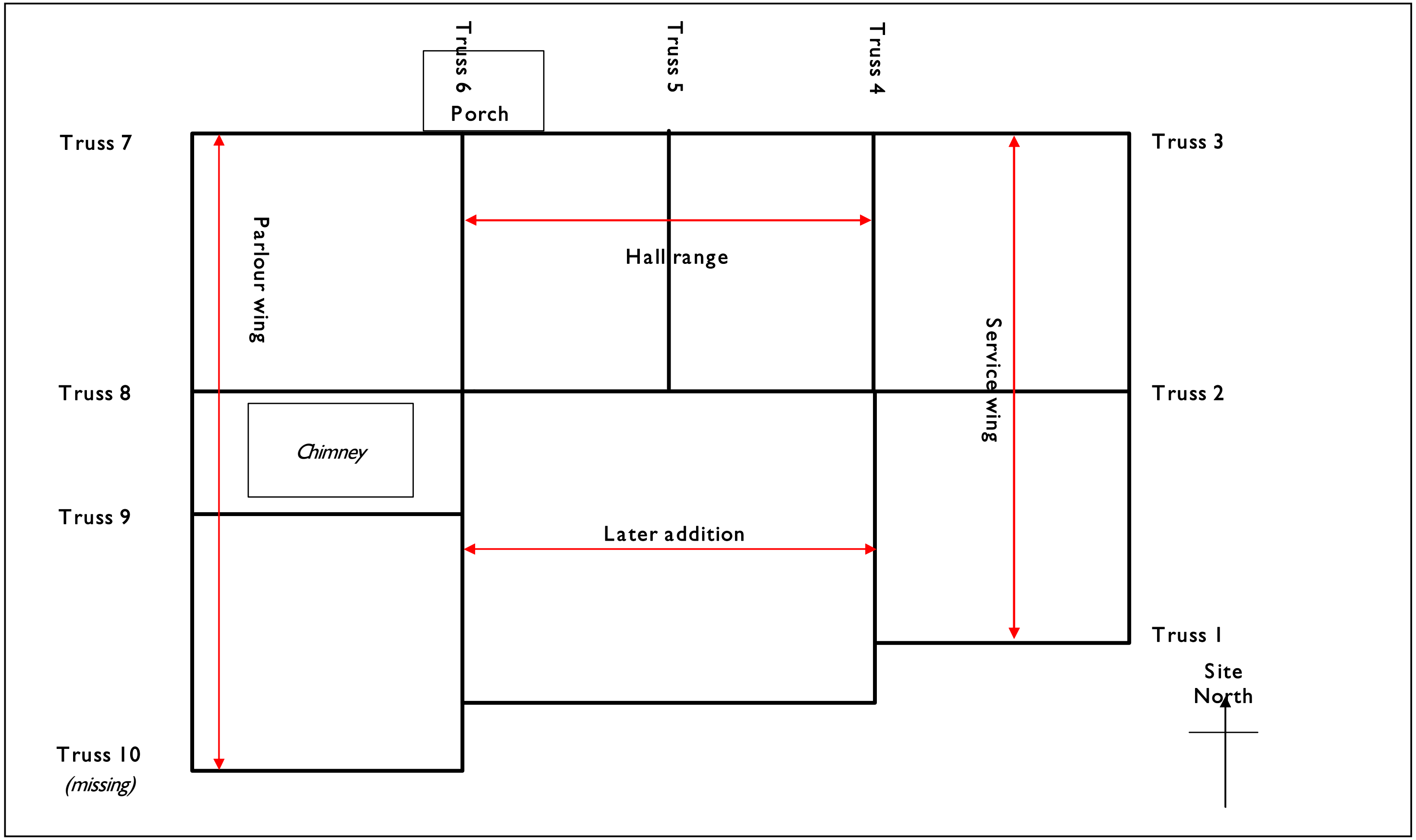
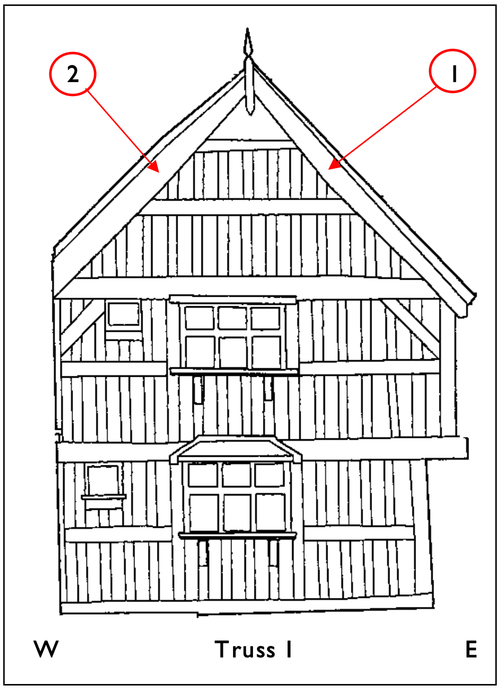



*Figure 4: Simple schematic plan of The Oak House to show layout and roof-truss position (after Birmingham Archaeology)*



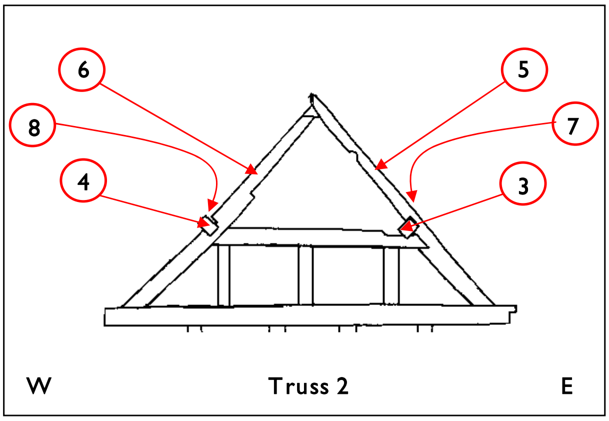




*Figure 5a/b: Trusses 1 and 2 in the east wing to show sampled timbers (viewed from the south looking north) (after Birmingham Archaeology)*

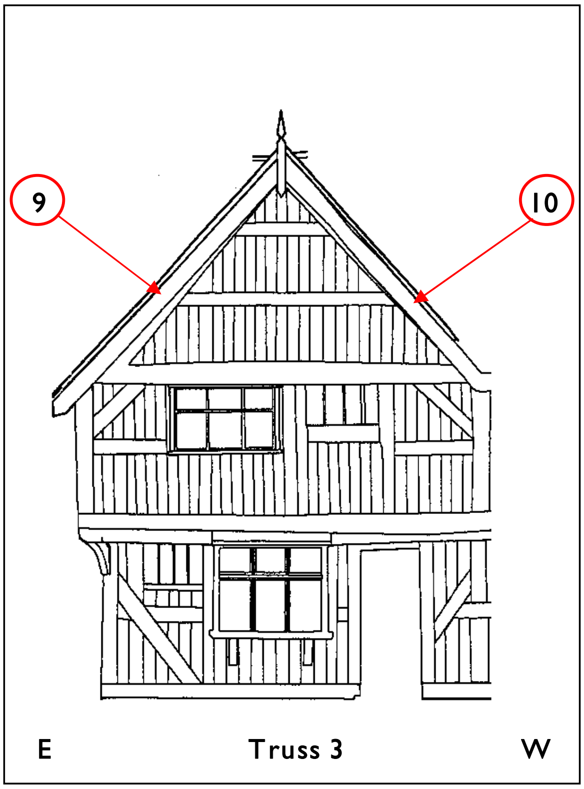
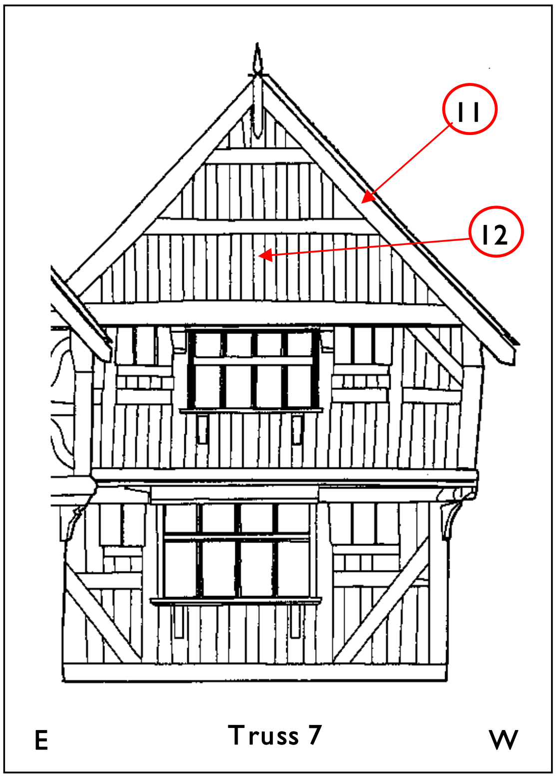



*Figure 5c: Truss 3 in the east wing to show sampled timbers (viewed from the north looking south) (after Birmingham Archaeology)*



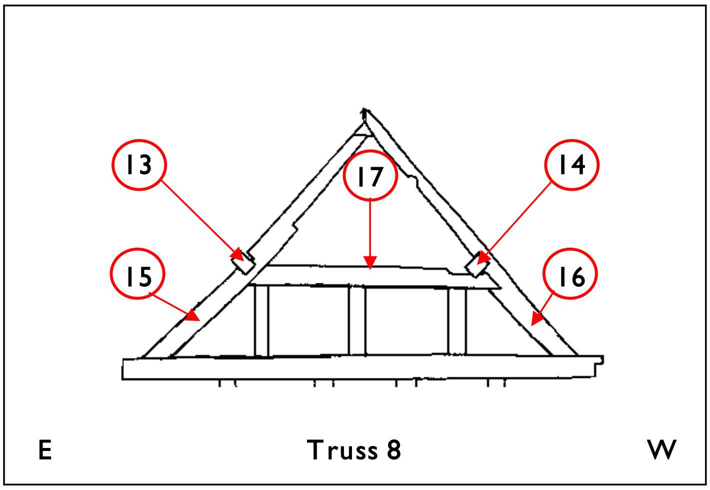




*Figure 6a/b: Trusses 7 and 8 in the west wing to show sampled timbers (viewed from the north looking south) (after Birmingham Archaeology)*

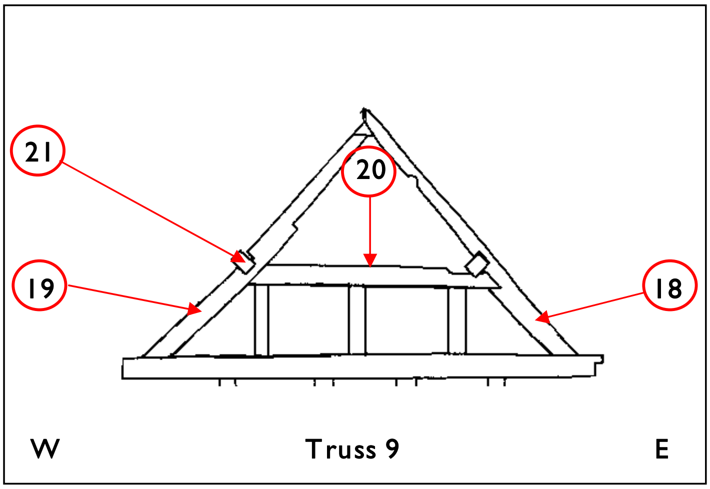
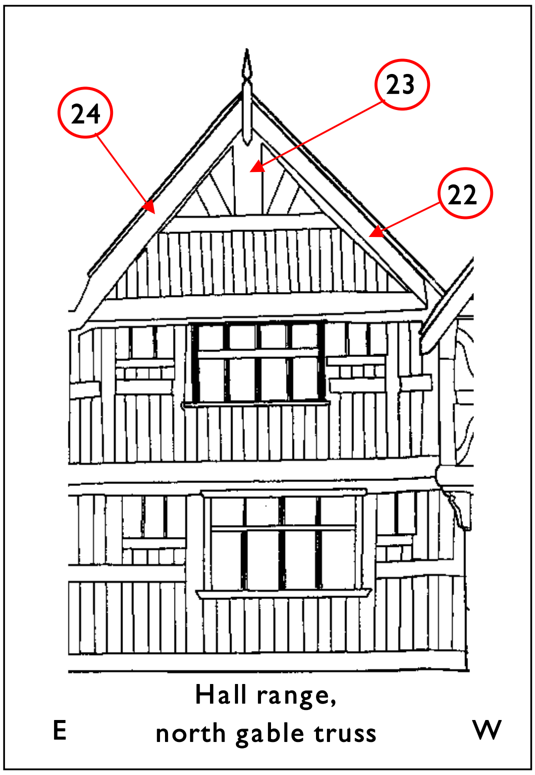



*Figure 6c: Truss 9 in the west wing to show sampled timbers (viewed from the south looking north) (after Birmingham Archaeology)*



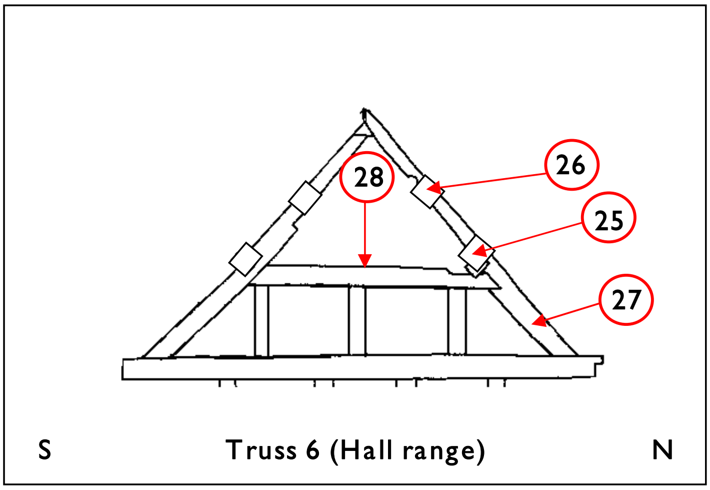




*Figure 7a/b: Hall range roof to show sampled timbers (viewed from the north looking south (top) and east looking north (bottom)) (after Birmingham Archaeology)*

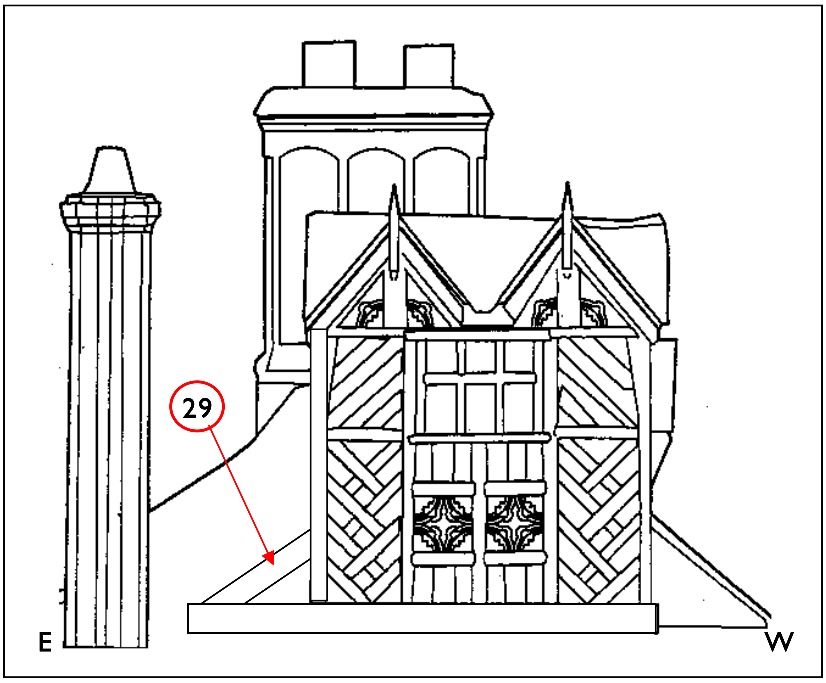



*Figure 8: View of the Belvedere to show sampled timber (viewed from the north looking south) (after Birmingham Archaeology)*

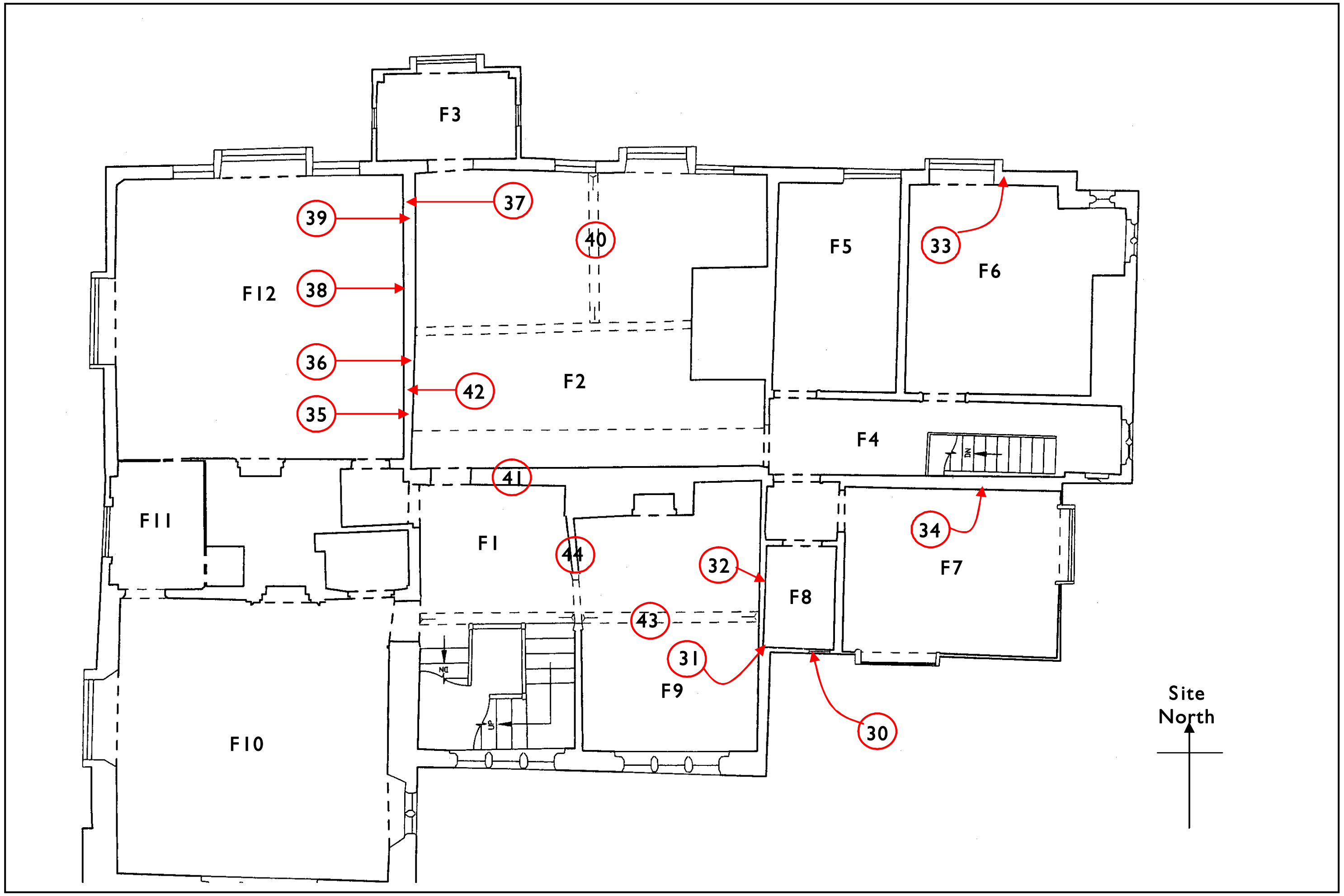



*Figure 9a: First-floor plan to show position of sampled timbers (after Birmingham Archaeology)*

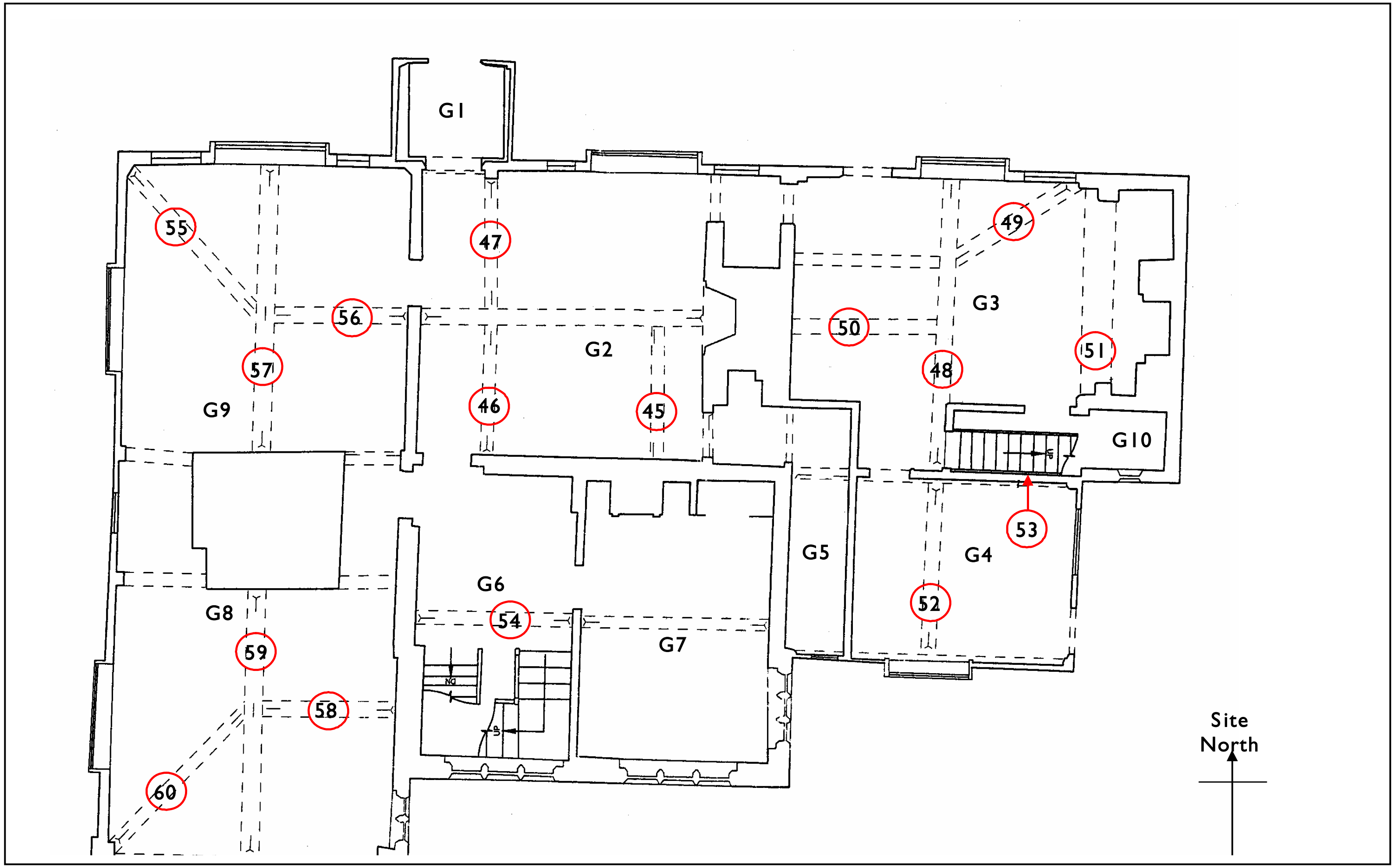



*Figure 9b: Ground-floor plan to show position of sampled timbers (after Birmingham Archaeology)*

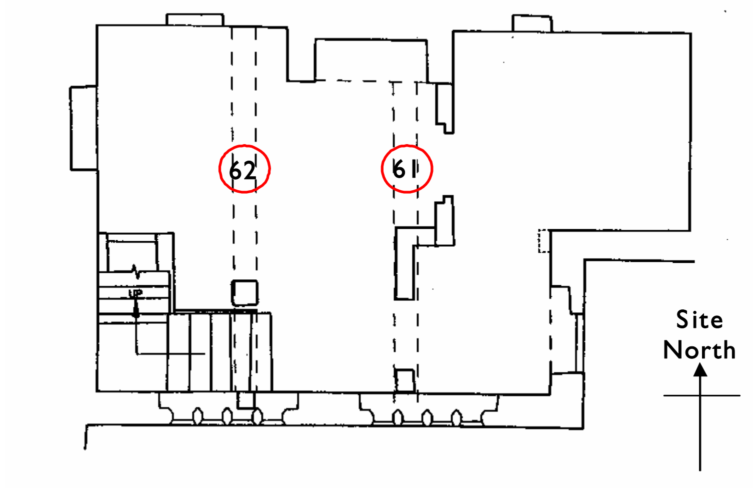



*Figure 9c: Plan of the basement to show sampled timbers (after Birmingham Archaeology)*

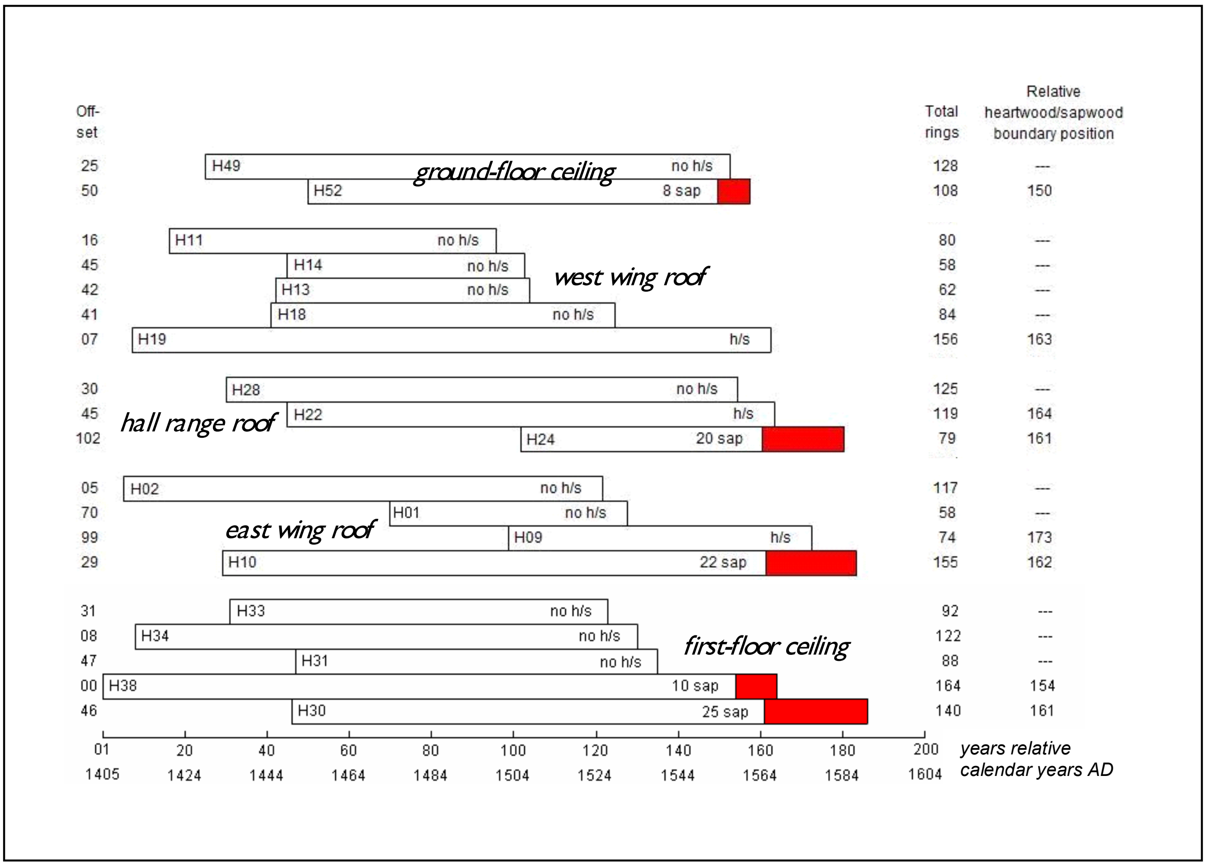
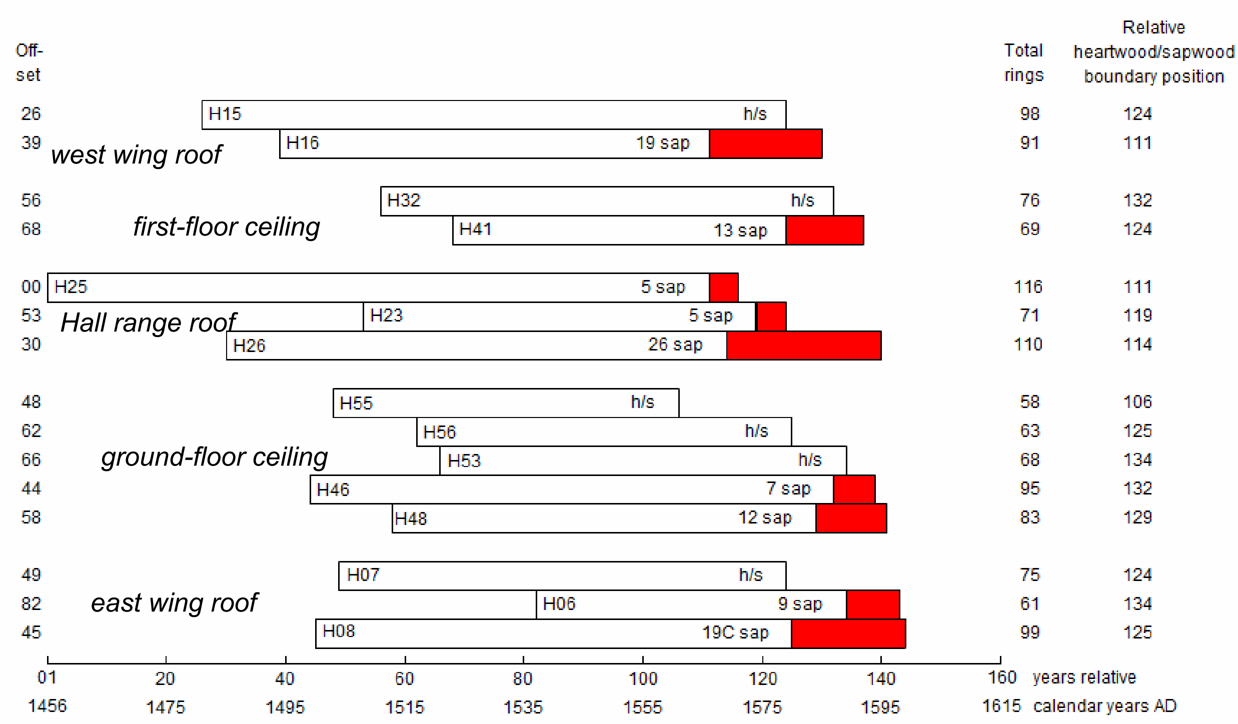
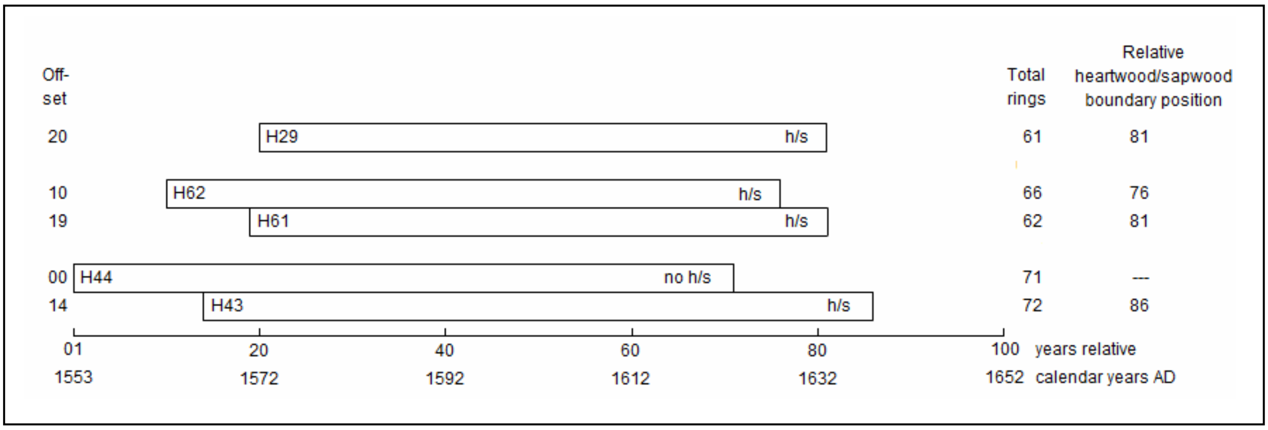


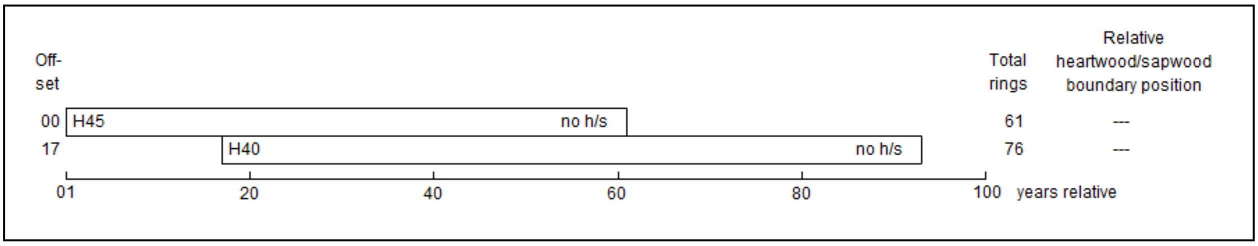

*Figure 10: Bar diagram of the samples in site chronology OAKHSQ01 sorted by sample location*




White bars = heartwood rings. Shaded area = sapwood rings
h/s = heartwood/sapwood boundary
C = Complete sapwood is retained on the sample

*Figure 11: Bar diagram of the samples in site chronology OAKHSQ02 sorted by sample location*



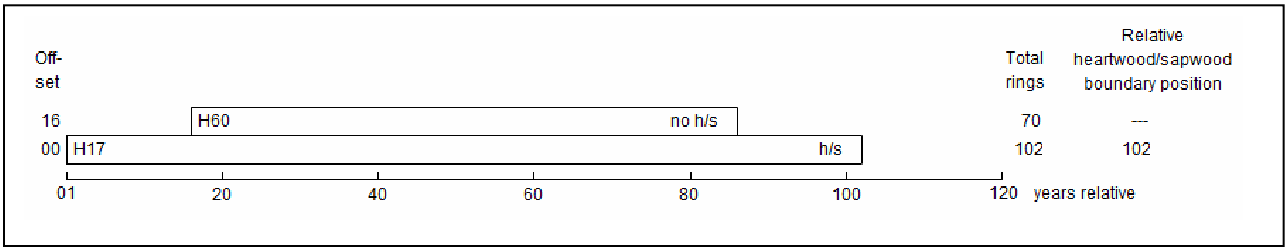
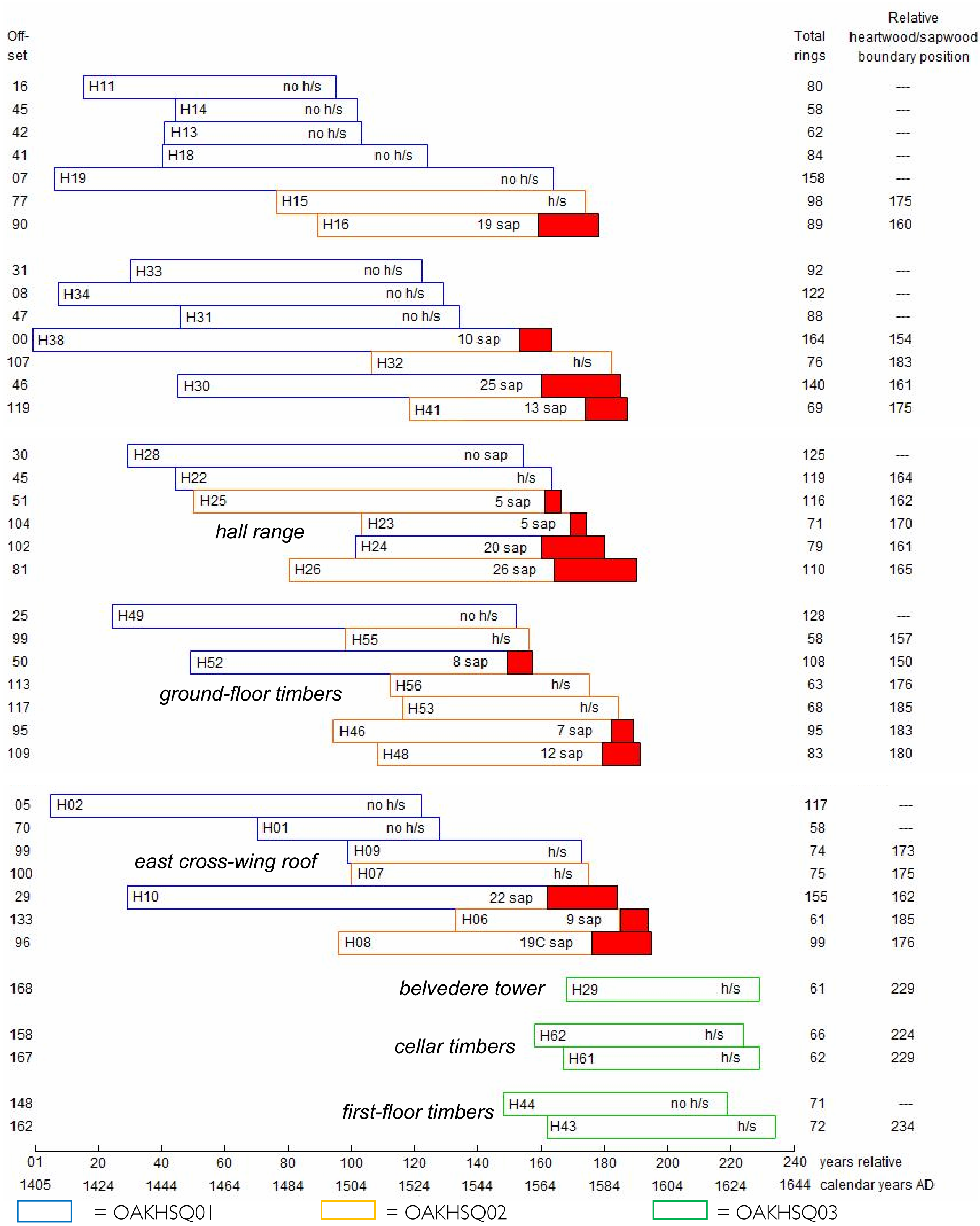




*Figure 12/13/14: Bar diagrams of the samples in site chronologies OAKHSQ03 (top), OAKHSQ04 (middle), and OAKHSQ05 (bottom)*




White bars = heartwood rings. Shaded area = sapwood rings. h/s = heartwood/sapwood boundary

C = complete sapwood is retained on the sample

*Figure 15: Bar diagram of all 34 samples in site chronologies OAKHSQ01 and SQ02 sorted by sample location and in last measured ring date order*

## DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

OAK-H01A 58
537 531 562 572 437 509 512 524 563 451 461 436 431 586 512 459 494 470 249 207
265 222 290 286 217 80 53 39 67 88 105 104 88 93 121 183 229 229 267 253
217 198 143 177 181 190 183 295 257 222 273 282 187 132 204 204 210 203
OAK-H01B 58
461 511 516 587 441 530 523 514 580 446 445 445 454 556 502 473 501 473 240 209
266 218 293 285 213 80 50 50 69 97 111 104 94 90 128 157 223 256 270 269
214 183 152 178 184 182 184 295 242 226 276 289 188 139 205 198 212 204
OAK-H02A 117
176 202 186 128 118 112 151 145 191 106 225 176 164 199 175 191 179 192 171 181
210 154 264 171 197 207 158 147 99 85 100 92 84 81 104 117 119 110 138 130
151 163 155 112 121 113 139 144 82 70 120 73 78 81 65 59 71 56 83 66
48 55 50 59 48 56 68 65 90 120 126 166 164 169 148 135 88 77 48 43
46 56 51 57 51 63 71 63 61 68 71 79 61 62 90 92 90 86 82 82
66 92 75 83 67 70 71 68 85 102 68 89 88 70 83 81 141
OAK-H02B 117
159 208 184 132 109 132 134 157 201 102 228 161 171 197 180 207 165 187 186 183
198 169 258 171 196 208 123 152 102 83 93 92 79 93 100 122 113 119 148 127
155 146 125 120 109 122 149 140 85 73 113 76 76 80 63 61 69 65 79 66
55 49 53 57 51 61 62 68 79 119 134 172 167 167 163 123 86 75 51 39
57 55 45 57 53 65 66 58 61 70 73 66 64 61 91 98 90 72 73 77
76 85 81 79 77 66 69 79 85 93 75 90 78 79 89 92 142
OAK-H03A 68
174 228 245 213 234 173 386 358 332 398 278 237 172 356 279 306 364 353 406 446
475 367 528 297 147 194 162 188 282 347 427 366 334 184 231 329 221 149 152 99
82 203 190 251 211 216 185 132 110 122 166 106 144 162 166 349 274 164 103 80
92 157 115 116 56 96 102 104
OAK-H03B 68
174 229 243 206 239 164 430 369 339 447 285 232 200 333 273 321 364 373 393 446
453 351 534 305 147 201 160 171 277 354 415 377 332 180 233 347 222 145 143 101
88 185 187 270 195 221 181 146 77 122 161 125 148 155 170 340 260 152 100 93
67 146 140 112 58 95 104 107
OAK-H03A 69
176 218 204 213 231 164 416 348 360 433 294 228 184 337 262 307 364 357 394 458
466 367 524 292 150 192 152 189 278 320 415 369 340 180 225 331 217 150 140 114
74 205 180 261 200 224 180 144 91 112 165 116 144 154 173 334 274 158 102 102
70 145 144 106 63 94 95 92 107
OAK-H03B 70
174 223 201 221 224 172 404 363 349 429 290 231 176 337 303 328 352 365 377 450
459 362 530 293 154 188 152 180 277 353 427 379 339 190 231 353 221 144 149 107
75 192 197 254 212 219 190 154 82 116 167 119 148 144 184 337 260 160 109 97
63 65 134 136 104 65 97 99 86 100
OAK-H05A 73
459 131 77 45 39 71 73 98 96 114 127 104 163 277 218 182 433 103 61 53
49 58 80 89 97 174 231 209 104 59 34 70 73 92 136 147 176 207 274 239
382 121 85 54 79 102 129 209 146 130 138 159 102 58 58 72 93 127 205 199
163 163 132 102 93 157 112 112 67 43 30 46 74
OAK-H05B 73

458 134 83 48 36 65 76 100 99 106 129 114 150 276 221 178 415 105 56 53
49 60 76 94 96 173 222 220 90 61 38 70 71 96 131 149 182 201 276 243
383 124 84 61 82 89 140 198 145 138 144 162 106 55 51 64 101 124 204 190
172 162 129 99 99 160 116 123 72 35 31 45 73
OAK-H06A 61
350 157 117 147 115 136 134 125 184 220 254 246 225 274 297 300 368 344 275 195
182 321 299 373 339 276 165 86 77 114 152 161 194 232 143 149 78 94 102 161
160 223 382 237 259 316 436 378 396 298 301 307 283 284 351 391 439 367 416 344
331

OAK-H06B 61
365 142 114 133 140 151 123 125 204 197 265 253 245 289 303 307 353 354 260 168
197 325 286 387 338 257 148 104 69 108 170 155 185 213 152 146 79 100 91 165
153 225 396 231 229 364 464 389 372 286 296 306 280 314 343 398 409 414 424 343
333
OAK-H07A 75
280 291 245 246 327 269 252 297 308 314 252 272 241 323 354 321 317 267 298 218
271 267 272 267 225 263 353 223 209 228 250 252 242 313 134 90 137 114 109 80
94 112 129 150 146 143 137 155 133 124 133 131 76 111 161 122 139 136 127 78
72 64 77 87 96 131 134 121 118 140 76 76 109 125 142
OAK-H07B 75
326 272 236 256 301 253 251 300 317 307 268 284 236 328 372 331 317 271 298 213
255 277 266 259 223 262 351 223 209 224 260 238 243 309 131 98 127 108 111 85
97 115 125 151 143 128 141 146 142 104 136 127 83 113 160 117 141 138 125 72
75 70 75 82 94 127 128 117 132 126 78 63 116 122 145
OAK-H08A 99
515 388 402 424 418 306 187 214 233 254 282 255 196 193 140 156 161 196 162 180
213 271 177 228 177 205 167 190 171 162 185 149 162 147 190 152 152 182 84 73
58 42 43 45 43 71 62 100 91 82 96 83 108 109 119 125 121 143 175 166
165 165 149 73 71 62 81 82 79 93 111 104 111 129 80 66 83 99 122 140
120 150 141 168 147 135 156 128 121 112 137 137 170 134 110 140 107 124 136
OAK-H08B 99
566 382 401 444 417 290 187 208 251 268 284 234 216 197 141 163 151 208 165 174
216 232 157 231 178 197 162 197 181 153 193 152 161 152 190 148 139 185 96 56
68 35 40 46 44 60 74 97 93 79 100 79 98 122 115 117 121 148 176 152
153 163 147 74 67 55 83 86 76 102 108 93 121 128 73 72 82 99 125 140
118 124 143 169 146 173 133 108 126 106 138 144 162 133 120 146 111 122 132
OAK-H09A 74
80 81 80 54 65 83 73 92 97 82 62 59 63 52 74 87 76 86 96 70
88 80 92 80 99 70 73 78 79 72 76 75 89 90 87 95 96 68 49 46
50 35 46 39 45 42 44 55 44 46 47 49 41 44 85 70 85 84 92 79
88 88 154 151 171 134 172 162 145 113 73 82 136 167
OAK-H09B 74
82 84 81 61 67 80 72 91 105 77 63 60 63 45 76 87 84 82 88 79
83 84 88 94 84 75 65 86 78 76 73 80 84 91 83 91 93 63 44 48
45 41 49 31 46 44 46 53 45 45 47 52 36 36 85 67 93 88 89 81
92 84 168 170 159 142 162 158 141 111 73 91 124 174
OAK-H10A 155
138 143 140 111 66 59 76 105 93 130 149 164 124 135 161 150 142 236 194 173
165 148 202 207 125 77 108 171 156 144 88 80 72 79 96 79 51 40 52 60
56 74 81 97 78 93 123 126 141 162 152 121 87 48 30 28 31 47 42 50
38 54 58 53 54 72 75 66 51 54 82 86 95 79 89 81 76 74 82 81
67 78 72 71 86 83 83 86 79 75 75 73 80 90 81 92 84 99 88 92
80 82 81 84 102 103 103 70 41 46 32 27 39 33 42 43 42 41 43 43
39 45 30 28 35 39 40 39 50 37 36 37 61 81 98 82 128 105 96 86
67 45 45 57 65 71 112 77 64 90 100 126 102 66 47
OAK-H10B 155
141 148 133 106 70 62 77 103 95 133 144 172 115 136 159 144 140 237 189 179
166 148 200 202 137 75 106 166 158 142 86 81 71 92 94 73 49 45 46 71
55 76 75 92 77 103 130 116 139 162 144 115 80 52 30 32 32 41 42 53
39 52 64 49 52 77 72 65 51 62 74 87 94 80 85 79 79 80 84 73
71 75 69 73 84 87 80 87 82 72 78 77 81 91 79 89 85 108 79 98
79 83 77 93 95 99 104 73 41 49 33 30 42 26 38 43 45 42 41 34

44 45 30 29 35 39 41 34 54 31 37 42 58 84 90 94 117 109 105 45
36 52 55 61 82 93 82 74 84 109 98 113 109 64 48
OAK-H11A 80
280 300 401 318 356 264 310 400 360 333 354 482 322 466 346 220 237 207 124 128
226 201 285 380 319 199 255 252 232 208 285 200 185 193 194 210 193 175 143 181
160 147 151 116 83 46 34 39 35 21 30 33 52 44 67 58 63 61 77 72
79 82 87 79 53 41 57 72 77 91 89 66 83 84 100 123 103 125 128 121
OAK-H11B 80
280 287 436 300 361 262 319 369 366 339 341 493 327 470 341 214 240 206 138 122
226 195 284 365 303 203 251 266 222 222 278 198 186 202 196 202 206 172 144 174
181 151 146 133 89 41 37 40 33 28 33 26 29 46 54 64 71 53 78 74
84 84 93 81 49 44 68 59 83 85 75 69 84 72 112 110 112 116 121 115
OAK-H12A 63
371 279 269 307 231 239 234 306 219 160 179 245 166 183 152 198 261 209 186 215
254 258 245 209 181 281 232 289 242 241 150 23 36 39 29 74 57 101 110 95
122 76 43 36 39 32 48 38 33 43 49 64 72 65 81 64 72 72 92 93
73 54 57
OAK-H12B 63
277 287 250 307 238 241 210 312 236 143 175 234 174 181 141 203 255 204 208 208
253 259 235 206 165 277 238 287 267 231 133 37 37 37 29 73 64 92 117 95
126 69 46 36 34 33 43 40 39 42 49 64 68 66 75 76 62 74 91 102
74 59 71
OAK-H13A 62
258 253 187 199 243 155 160 186 188 201 190 169 189 331 260 209 146 107 146 267
273 263 234 235 241 273 269 225 164 106 135 289 240 209 181 153 186 205 195 193
165 200 133 174 142 157 80 102 93 101 111 104 139 123 64 54 102 90 101 105
84 119
OAK-H13B 62
210 248 179 200 234 156 151 203 205 189 180 184 187 350 253 214 147 111 147 248
270 253 246 224 304 293 252 222 169 96 143 296 233 230 187 172 166 187 187 206
171 192 135 180 140 155 76 98 82 108 123 106 133 127 61 60 95 100 108 99
98 127
OAK-H14A 58
499 413 317 308 405 290 319 308 224 271 474 354 319 274 159 167 256 211 290 270
214 346 330 296 272 231 219 208 425 332 275 234 171 205 220 246 238 211 198 141
194 232 229 92 96 113 136 139 139 193 165 90 72 136 146 133 127 139
OAK-H14B 58
493 489 276 386 386 414 274 246 269 292 426 393 282 266 167 169 251 195 290 260
223 298 354 313 265 251 204 203 406 310 275 227 178 200 218 240 228 214 214 146
200 239 215 100 87 113 151 142 138 205 185 81 78 123 145 132 127 142
OAK-H15A 98
284 307 292 433 310 352 281 274 336 239 258 229 399 387 567 323 265 352 411 174
121 218 329 321 220 201 219 386 366 420 335 273 240 278 239 268 426 272 323 89
42 34 31 56 112 147 155 118 105 202 162 197 201 276 205 248 379 97 177 83
158 154 94 77 100 111 167 152 257 187 228 103 113 103 51 40 76 126 95 185
145 112 106 62 70 70 103 63 62 55 60 59 49 57 66 103 86 55
OAK-H15B 98
280 303 295 424 324 372 272 275 326 245 260 209 451 455 564 367 264 371 359 139
119 166 289 353 290 247 236 360 373 376 384 375 271 299 239 294 410 316 348 106
67 50 46 71 123 256 170 100 116 184 115 161 238 225 178 191 347 73 59 65
69 70 73 69 64 144 175 260 203 394 211 312 115 109 57 43 75 131 93 179
146 109 104 61 69 70 107 64 60 54 62 60 50 59 67 109 83 51

OAK-H16A 89
480 674 302 253 319 390 141 106 192 262 395 201 159 248 299 315 371 413 324 245
258 239 219 313 229 261 69 49 31 50 47 117 138 152 115 195 275 221 302 345
431 348 354 602 98 53 52 70 84 77 85 134 150 236 194 206 144 263 52 52
83 85 81 151 186 169 213 200 160 73 80 83 118 58 81 63 61 56 43 48
81 88 89 137 147 104 86 87 151
OAK-H16B 89
510 673 299 263 316 385 135 112 197 267 322 203 166 245 303 313 374 414 317 243
265 241 215 309 220 251 87 45 32 48 56 129 124 162 117 187 279 222 296 350
409 352 356 610 120 43 54 83 77 84 79 137 147 230 199 200 141 267 40 64
85 79 74 143 179 155 212 207 152 76 73 86 114 60 61 65 58 54 52 52
73 89 110 140 186 97 85 98 159
OAK-H17A 102
203 174 75 63 67 77 117 121 160 160 155 199 192 157 186 130 189 164 171 201
186 198 184 202 232 287 269 266 361 308 203 197 228 245 336 316 248 271 267 240
257 246 218 121 69 82 86 124 138 120 183 173 175 153 152 159 184 176 181 153
202 175 189 178 233 220 200 209 196 107 97 68 79 86 72 117 93 134 143 118
161 112 129 139 116 59 78 47 33 64 72 123 70 80 84 96 115 87 60 67
58 81
OAK-H17B 102
183 153 82 66 69 81 115 113 161 160 162 204 191 164 178 125 193 172 171 207
184 200 177 219 223 271 258 282 364 307 205 200 221 268 336 307 262 242 266 257
238 252 211 132 68 82 88 124 131 123 181 175 173 153 153 152 174 177 178 144
200 181 185 182 238 212 199 202 197 119 82 73 71 87 72 115 96 134 142 118
146 124 147 125 124 53 81 47 34 62 70 122 71 88 89 84 111 85 52 71
80 62
OAK-H18A 84
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36 31 18 47
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71 69 78 107 165 128 119 97 36 16 26 29 40 41 34 27 39 58 47 76
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OAK-H19B 156
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OAK-H20A 70
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OAK-H20B 70
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OAK-H22A 119
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OAK-H22B 119
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OAK-H23A 71
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110 122 96 100 104 57 77 62 70 75 126
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OAK-H24A 79
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71 83 78 87 95 94 110 57 64 40 66 43 96 108 89 88 67 110 99
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396 343 391 374 354 504 427 517 442 332 518 479 475 417 408 483 402 394 291 104
68 64 96 128 136 133 163 160 128 158 178 156 172 160 154 117 100 84 116 70
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70 85 90 79 95 88 108 70 45 52 69 55 81 108 90 78 76 111 99
OAK-H25A 116
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133 116 218 215 215 74 48 42 39 51 68 83 86 87 88 118 101 88 112 120
88 111 123 118 74 53 42 59 52 85 110 99 135 119 148 105 106 78 42 37

48 53 47 72 59 59 68 45 85 72 105 83 120 61 37 45
OAK-H25B 116
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OAK-H26A 110
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77 62 59 60 56 85 79 87 99 94
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82 97 105 110 92 135 95 99 105 152 122 180 191 279 86 47 35 60 39 82
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106 117 149 85 47 48 42 52 55 35 44 67 46 69 67 53 60 89 101 88
85 64 63 58 54 85 85 100 99 100
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239 309 391 318 298 371 386 325 401 84 64 73 55 49 78 122 115 124 145 118
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59 51 72 77 59 84 88 102 83 104
OAK-H27B 90
473 287 326 347 283 214 243 200 157 229 140 135 146 172 103 94 57 84 121 171
157 251 213 177 97 40 35 36 27 42 59 65 66 157 97 120 163 132 138 143
240 360 403 317 302 387 399 317 384 74 64 74 61 50 103 134 135 132 133 138
121 110 98 62 110 122 125 203 197 147 177 146 157 125 61 42 31 31 37 45
56 54 73 74 68 79 91 93 76 103
OAK-H28A 125
223 304 273 231 173 165 225 240 241 272 182 186 214 175 64 34 41 37 51 46
64 90 72 116 128 109 70 48 47 52 106 91 191 198 75 54 39 37 56 58
57 68 63 65 48 105 92 78 57 77 77 86 98 115 123 95 99 116 91 61
57 81 136 128 103 46 28 27 27 32 34 26 30 33 32 40 27 32 42 58
51 50 67 81 104 95 123 115 91 128 107 84 40 30 34 25 16 42 39 42
20 39 33 23 46 43 59 36 24 24 29 18 25 19 21 22 22 23 31 30
38 27 29 34 38
OAK-H28B 125
197 306 270 214 185 155 241 240 235 262 180 182 215 172 74 46 31 45 50 45
66 79 91 105 131 117 71 56 37 62 125 114 177 206 81 46 39 39 49 58
58 70 72 63 55 98 87 62 63 69 71 83 106 116 139 91 103 113 86 70
51 89 133 118 108 29 21 33 21 28 28 35 28 22 35 28 35 40 28 53
63 55 74 90 110 108 129 135 101 133 108 87 47 27 27 27 24 38 41 35
28 31 28 27 44 49 54 38 27 25 25 24 23 22 16 18 29 24 32 28
28 28 28 32 38
OAK-H29A 61
229 141 121 88 91 125 160 177 107 104 155 217 240 195 189 120 86 85 118 136
97 92 123 106 60 72 107 107 161 177 260 251 215 153 168 174 140 178 124 180

154 167 241 152 151 184 179 205 207 223 230 148 97 127 132 192 182 172 147 207
241
OAK-H29B 61
240 148 121 93 89 114 169 180 109 107 152 232 228 202 202 101 101 94 128 141
85 84 108 108 76 60 109 106 159 179 267 246 204 163 163 165 136 166 142 195
149 167 249 160 153 172 194 215 191 232 218 141 105 124 130 195 186 174 145 202
245
OAK-H30A 140
115 117 136 183 189 174 127 182 168 229 181 186 176 111 122 180 144 190 154 145
124 135 156 181 147 146 134 156 159 144 158 95 107 102 86 82 81 83 103 112
118 99 90 118 105 138 151 140 166 159 116 121 153 179 165 149 132 139 173 139
143 153 149 144 129 137 114 114 173 120 198 126 137 113 118 78 71 87 94 96
126 131 138 142 99 68 79 107 110 151 103 73 75 72 80 102 115 142 197 133
157 141 147 162 192 115 97 146 145 137 134 78 47 59 42 44 56 68 85 83
108 91 107 77 64 36 34 33 43 51 42 35 38 51 59 52 63 60 111 76
OAK-H30B 140
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126 122 133 178 149 147 135 139 170 139 145 96 112 98 82 72 83 89 98 120
128 97 91 113 108 142 149 142 169 145 133 122 141 183 163 155 124 146 168 146
140 177 142 148 126 116 110 130 165 124 201 107 147 113 122 67 88 81 93 100
133 132 134 149 86 63 80 114 108 149 101 71 75 70 77 106 112 147 179 133
145 154 138 175 183 107 83 150 142 118 144 83 51 49 45 41 55 60 85 82
129 81 98 83 76 44 27 34 35 49 49 40 38 48 52 53 54 74 87 86
OAK-H31A 88
146 88 116 150 117 105 126 129 126 118 155 117 103 125 142 180 175 139 108 145
162 132 161 165 125 91 93 85 63 81 67 57 64 56 41 62 60 81 99 109
98 94 93 73 122 135 185 260 192 97 89 123 157 160 147 119 172 168 127 134
188 140 137 115 115 119 155 129 99 178 143 114 120 135 105 73 61 93 82 128
128 144 157 83 79 83 142 166
OAK-H31B 88
127 84 117 151 122 108 154 124 131 121 156 118 100 128 134 182 181 133 120 139
163 124 180 157 119 90 95 84 67 80 63 63 59 56 45 57 71 74 101 101
93 94 87 80 128 139 182 257 199 94 90 126 155 153 150 127 167 172 130 138
171 143 149 110 115 119 152 125 109 170 156 112 111 140 104 56 72 88 88 126
142 148 153 60 72 85 117 177
OAK-H32A 76
316 301 283 381 310 322 512 542 334 445 474 368 392 406 431 391 410 364 399 470
307 280 297 385 384 267 447 331 234 112 93 131 191 349 279 326 316 307 296 299
346 310 330 339 269 185 167 338 322 327 309 104 55 48 59 59 61 109 125 138
110 109 113 70 117 137 95 123 188 148 87 158 208 203 212 217
OAK-H32B 76
282 303 299 357 305 331 522 514 353 416 489 364 384 406 441 392 399 359 385 445
314 261 291 388 393 249 432 335 238 106 100 117 190 362 268 331 319 325 292 304
326 300 326 359 285 167 183 344 315 312 303 102 46 48 54 58 68 106 126 141
107 119 109 71 113 124 96 124 190 135 96 155 212 198 210 214
OAK-H33A 92
103 96 72 71 132 106 107 111 92 75 56 45 99 96 118 220 166 143 156 141
161 106 124 112 115 125 114 131 86 104 127 160 165 175 154 133 125 113 151 178
174 190 172 219 187 205 188 217 176 155 92 128 113 136 179 144 140 158 180 131
145 163 171 256 214 234 227 229 262 303 205 231 198 203 122 221 265 240 301 228
192 192 210 191 215 308 281 183 214 272 130 81
OAK-H33B 92
109 87 75 82 124 108 111 102 94 72 48 50 105 102 110 222 162 148 158 139

169 105 115 113 122 114 122 140 83 101 123 164 167 170 160 129 123 121 142 183
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136 150 185 221 229 221 214 224 238 311 175 267 225 192 137 221 271 239 302 219
196 183 215 210 200 302 293 179 229 285 121 78
OAK-H34A 122
125 140 133 106 144 99 107 158 194 195 286 271 237 274 263 240 257 213 174 239
210 261 267 269 229 171 141 187 234 140 231 303 205 159 195 277 237 193 228 243
174 197 202 238 186 231 212 170 204 207 226 153 189 244 338 246 228 167 155 243
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103 102 85 72 73 92 102 78 77 79 42 30 54 50 46 52 61 76 159 127
129 122
OAK-H34B 122
133 139 125 112 151 99 112 151 167 198 290 260 239 267 310 247 241 193 196 246
203 243 264 265 222 209 155 160 242 147 214 313 209 161 203 255 240 189 221 234
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93 116 85 69 70 95 101 75 83 78 44 41 48 44 44 52 62 78 146 125
123 132
OAK-H35A 75
267 252 192 175 227 285 381 292 269 225 141 242 263 168 232 260 253 245 181 134
126 179 204 177 167 156 144 126 116 105 89 108 134 158 158 212 206 208 181 162
140 126 118 163 173 218 201 175 185 159 129 146 119 123 137 99 84 104 39 41
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OAK-H35B 75
285 252 186 182 250 299 385 283 268 223 143 257 294 195 239 258 257 238 186 126
123 191 217 168 171 152 146 118 116 115 94 117 118 156 177 205 203 197 158 175
150 130 112 171 181 221 192 177 183 161 124 150 115 129 139 99 80 67 52 32
29 42 31 83 73 73 82 73 105 79 202 154 131 149 136
OAK-H37A 56
335 227 157 161 167 314 335 277 240 150 117 132 146 203 205 182 169 121 122 191
111 135 210 148 143 158 166 156 195 194 188 174 192 139 183 135 172 108 128 127
119 165 119 114 127 175 142 154 137 178 240 246 144 150 143 174
OAK-H37B 56
333 256 172 172 162 316 326 294 236 180 122 132 147 204 194 199 171 131 105 185
120 136 216 163 140 155 180 161 187 201 184 172 179 158 179 129 176 109 121 137
111 160 125 125 132 165 132 154 140 182 244 251 148 148 140 174
OAK-H38A 164
352 361 351 349 406 375 388 438 395 411 340 284 231 212 181 222 179 156 255 199
217 226 265 197 196 179 161 177 140 136 134 118 128 129 122 167 152 91 122 121
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54 84 74 79 90 65 64 47 49 68 66 45 39 43 61 80 70 68 63 69
82 84 72 86
OAK-H38B 164
344 357 342 368 398 376 364 430 398 407 346 294 225 221 185 219 181 157 253 197
209 265 282 197 182 187 161 174 143 131 141 124 126 130 122 166 144 87 118 123
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69 91 96 78 77 78 80 79 60 89 79 99 93 74 106 69 68 48 74 73
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66 66 64 66 67 81 60 57 71 74 62 68 67 63 61 75 101 71 78 74
66 78 75 73 94 62 68 50 39 74 66 43 45 40 56 84 67 77 56 72
72 95 74 90
OAK-H40A 76
103 73 183 276 332 330 68 63 81 67 101 159 307 502 449 223 121 131 184 203
205 215 210 78 121 274 262 399 611 725 730 753 575 218 633 260 179 160 198 314
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277 484 554 369 442 219 174 194 355 311 270 429 243 290 464 430
OAK-H40B 76
106 79 180 279 307 341 94 54 65 84 119 142 317 496 463 206 101 141 196 188
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280 472 453 426 431 204 231 214 319 296 288 442 232 278 386 427
OAK-H41A 69
234 277 293 278 292 254 294 384 339 318 336 381 359 302 326 214 142 123 87 120
127 137 165 178 219 181 212 178 197 242 218 209 173 180 263 265 267 294 261 232
151 96 62 72 96 93 133 115 118 117 102 90 83 110 118 150 174 128 157 181
229 174 175 180 167 164 183 164 164
OAK-H41B 69
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114 145 170 164 212 188 203 193 191 239 218 187 174 177 249 263 287 291 279 232
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241 164 166 180 154 172 177 181 165
OAK-H43A 72
283 297 284 389 434 381 334 192 154 128 115 132 183 321 301 217 249 307 337 331
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162 168 233 150 150 148 146 125 98 82 101 160
OAK-H43B 72
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154 180 226 156 153 150 159 116 105 74 101 140
OAK-H44A 71
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112 98 116 87 105 125 75 84 88 74 127 105 99 97 105 92 110 97 119 118
131 113 125 69 71 92 104 143 91 114 130
OAK-H44B 71
713 617 361 177 253 344 323 482 667 430 385 448 286 172 133 151 127 239 303 183
141 58 92 94 115 118 141 163 153 102 160 157 204 147 152 120 131 116 138 119
113 100 127 65 108 123 79 84 87 77 125 104 102 92 107 96 103 96 122 115
129 119 127 60 69 88 117 145 91 118 117
OAK-H45A 61
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338 319 375 107 111 121 156 165 217 448 476 360 143 122 150 193 316 294 224 188
100 60 124 149 331 336 433 384 362 215 94 208 111 106 107 168 221 182 265 259
184
OAK-H45B 61
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335 344 382 108 103 132 147 187 204 434 527 353 129 140 159 208 320 317 181 250

65 74 108 140 235 447 385 394 360 194 112 117 115 117 133 159 181 156 242 261
186
OAK-H46A 95
497 336 539 584 521 527 387 215 270 344 391 417 633 584 495 396 342 203 263 422
382 89 45 48 58 51 82 125 145 174 155 286 212 189 249 217 429 284 309 259
128 68 25 43 46 46 97 91 140 142 143 125 136 206 154 212 201 148 157 234
245 282 344 107 35 28 27 44 29 34 70 97 97 85 47 61 67 71 120 203
202 113 73 122 194 204 219 180 155 169 179 278 232 290 330
OAK-H46B 95
480 334 540 595 525 517 390 212 270 359 383 427 633 575 497 398 338 198 275 430
379 112 35 55 62 43 80 127 133 170 135 291 210 196 255 218 422 293 304 220
138 69 26 38 48 49 93 99 134 144 136 130 121 217 150 209 214 138 160 244
243 275 344 106 38 29 33 37 36 41 68 84 94 94 47 47 73 81 126 197
203 99 79 128 208 207 233 181 141 169 179 280 238 289 336
OAK-H48A 83
115 106 58 63 67 109 120 220 265 243 270 374 439 353 448 350 341 338 367 357
293 333 334 309 360 347 141 84 48 67 51 58 103 111 144 187 166 164 193 280
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178 217 166
OAK-H48B 83
146 106 65 60 82 100 125 183 316 270 309 386 437 344 402 371 293 356 364 381
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98 78 76 96 70 75 60 53 56 78 102 109 124 110 116 147 105 149 147 154
183 205 209
OAK-H49A 128
318 302 374 245 286 290 234 210 232 122 145 204 139 180 172 133 156 121 163 142
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151 131 159 190 84 70 83 75 63 111 83 110 75 102 90 89 99 102 143 124
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82 70 86 68 96 71 57 60
OAK-H49B 128
310 303 373 218 292 302 232 220 235 127 146 201 143 178 168 143 155 123 158 144
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176 214 107 85 90 111 76 108 110 110 119 139 89 124 86 81 58 61 59 88
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OAK-H50A 54
18 53 42 68 134 168 199 153 186 90 71 49 105 188 267 469 130 148 96 49
30 39 48 82 97 124 124 78 71 39 45 60 117 248 105 50 115 215 154 222
331 246 184 210 320 269 358 325 290 164 138 114 88 101
OAK-H50B 54
18 54 42 66 138 166 201 152 179 91 77 51 101 189 267 469 125 153 97 49
35 42 53 86 93 114 123 78 65 39 44 64 121 248 101 56 105 212 156 226
321 279 189 200 307 285 355 314 299 166 134 114 88 102
OAK-H52A 108
203 340 318 271 225 210 184 202 235 154 185 242 216 222 213 201 218 210 197 99
46 40 30 34 57 39 82 70 95 61 83 84 94 83 90 82 21 41 30 60

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103 75 91 100 109 169 178 201 113 136 163 116 77 108 143 137 197 95 76 85
53 55 81 72 82 100 123 83 79 72 61 52 27 48 42 59 71 71 82 73
73 66 59 89 86 118 135 152
OAK-H52B 108
201 325 325 279 213 211 183 226 223 164 201 257 219 226 212 192 216 217 188 91
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88 72 60 74 97 123 115 136
OAK-H53A 68
476 430 414 379 495 507 455 483 433 530 484 404 512 541 568 565 556 578 148 58
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OAK-H53B 68
506 410 406 396 492 500 455 471 440 542 467 400 512 538 568 565 577 570 146 49
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502 475 544 398 309 262 335 111 76 48 37 59 61 52 50 77 81 98 77 56
52 64 104 120 130 115 126 156
OAK-H54A 54
386 320 242 251 276 182 253 270 223 240 153 186 177 160 192 236 356 332 297 302
359 400 340 321 239 325 226 233 259 227 197 213 237 171 223 130 200 213 173 191
200 161 184 262 237 249 248 141 157 224 151 146 168 173
OAK-H54B 54
376 317 277 257 275 173 262 257 236 273 149 186 179 159 201 259 357 334 303 310
399 397 359 300 250 319 217 225 249 235 205 205 201 166 224 150 183 239 159 207
187 169 175 269 238 242 254 136 157 219 158 140 155 178
OAK-H55A 58
358 385 283 313 308 438 409 482 488 380 344 365 353 335 411 346 320 106 55 31
60 78 103 112 141 97 133 145 117 176 209 244 294 307 450 197 124 200 161 171
114 104 194 334 543 434 495 376 446 292 308 299 343 291 391 174 329 396
OAK-H55B 58
356 396 298 291 318 425 410 462 495 386 359 357 366 334 412 343 320 103 50 43
59 75 106 122 134 88 137 140 118 176 209 246 296 308 448 196 138 220 169 171
112 103 192 335 550 460 455 376 453 271 324 295 353 281 397 179 323 395
OAK-H56A 63
341 361 343 118 44 40 62 51 69 112 110 135 111 198 129 151 186 232 269 283
314 283 136 60 32 64 40 45 91 162 183 131 126 125 180 238 195 270 187 150
179 233 234 235 251 110 34 51 32 48 75 73 89 106 106 91 57 63 68 82
100 165 151
OAK-H56B 63
379 366 325 129 39 50 57 57 75 108 111 128 113 192 140 150 179 240 271 282
309 275 142 58 35 55 55 35 100 149 183 132 131 119 189 226 195 270 187 152
170 244 231 229 258 112 37 49 38 45 77 71 89 107 108 93 52 66 71 71
104 169 157
OAK-H57A 73
132 152 327 357 276 395 454 383 494 453 402 299 378 259 267 328 277 291 251 183
163 163 156 221 169 127 245 208 109 149 174 189 184 175 164 167 215 185 228 241
199 241 206 199 97 66 45 41 78 94 88 123 140 170 143 155 173 129 187 204
189 180 187 206 227 215 208 225 209 196 245 153 161
OAK-H57B 73

135 127 310 372 285 388 447 399 497 449 370 325 387 266 284 313 279 278 249 182
178 158 144 224 188 116 243 212 114 148 169 192 182 178 158 161 219 184 230 244
195 226 194 201 101 67 51 43 69 96 82 116 145 161 152 160 167 129 193 201
195 178 184 200 226 201 211 212 220 182 245 174 157
OAK-H60A 70
387 507 513 539 525 512 471 522 608 776 596 497 839 697 460 693 541 556 511 559
311 473 454 330 550 564 459 443 123 52 47 58 86 82 144 155 177 201 144 210
256 298 272 242 339 308 225 226 255 323 236 346 273 173 89 29 35 27 26 32
44 48 71 79 83 65 135 115 111 140
OAK-H60B 70
346 491 510 548 517 501 454 539 619 763 603 506 830 707 468 689 550 537 519 559
310 473 438 323 545 552 470 449 124 48 45 60 80 95 140 175 183 196 147 204
256 295 270 245 329 303 225 243 255 324 229 335 261 157 78 25 30 31 30 39
40 64 64 99 64 79 128 125 114 142
OAK-H61A 62
277 349 182 132 157 117 180 241 324 241 198 296 334 270 315 299 227 196 173 191
151 151 125 163 158 123 134 126 118 124 124 181 168 154 187 213 156 154 162 192
160 160 154 155 112 104 135 156 159 159 134 132 90 88 78 89 72 71 73 56
74 99
OAK-H61B 62
291 348 173 135 160 112 180 243 326 225 196 303 342 264 311 279 230 201 171 196
152 138 122 169 152 135 131 132 110 132 128 166 158 158 190 197 161 153 171 188
166 144 174 152 105 109 129 159 160 159 127 139 81 90 84 102 80 70 58 68
74 96
OAK-H62A 66
256 305 324 263 353 347 283 386 545 383 308 254 130 201 230 272 196 285 283 227
255 319 255 270 251 169 248 172 188 202 177 227 228 103 105 129 80 72 69 58
88 105 73 77 108 75 80 100 70 85 104 96 117 73 82 111 119 158 108 135
100 59 43 53 60 84
OAK-H62B 66
244 303 322 260 345 344 291 421 549 379 312 252 122 202 232 261 215 287 275 219
255 318 255 289 249 172 248 173 199 195 186 219 230 107 95 137 76 63 72 57
90 104 77 84 101 75 79 98 78 77 99 87 111 73 75 109 123 169 97 134
107 51 41 59 64 74

# 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 A1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths for oaks, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of oak timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring.

If the bark is still on the sample, as in Figure A1, then the date of the last ring will be the date of felling of the oak from which it was cut. There is much evidence that in medieval times oaks cut down for building purposes were used almost immediately, usually within the year or so (Rackham 1976). Hence if bark is present on several main timbers in a building, none of which appear reused or are later insertions, and if they all have the same date for their last ring, then we can be quite confident that this is the date of construction or soon after. If there is no bark on the sample, then we have to make an estimate of the felling date; how this is done is explained below.

## The Practice of Tree-Ring Dating at the Nottingham Tree-Ring Dating Laboratory

1. **Inspecting the Building and Sampling the Timbers.** Together with a building historian the timbers in a building are inspected to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can sample *in situ* timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer rings than this, 50 for example, sequences of widths become difficult to match to a unique

position within a master sequence of ring widths and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure A2 has about 120 rings; about 20 of which are sapwood rings – the lighter rings on the outside. Similarly the core has just over 100 rings with a few sapwood rings.

To ensure that we are getting the date of the building as a whole, or the whole of a phase of construction if there is more than one, about 8–10 samples per phase are usually taken. Sometimes we take many more, especially if the construction is complicated. One reason for taking so many samples is that, in general, some will fail to give a date. There may be many reasons why a particular sequence of ring widths from a sample of timber fails to give a date even though others from the same building do. For example, a particular tree may have grown in an odd ecological niche, so odd indeed that the widths of its rings were determined by factors other than the local climate! In such circumstances it will be impossible to date a timber from this tree using the master sequence whose widths, we can assume, were predominantly determined by the local climate at the time.

Sampling is done by coring into the timber with a hollow corer attached to an electric drill and usually from its outer rings inwards towards where the centre of the tree, the pith, is judged to be. An illustration of a core is shown in Figure A2; it is about 150mm long and 10mm diameter. Great care has to be taken to ensure that as few as possible of the outer rings are lost in coring. This can be difficult as these outer rings are often very soft (see below on sapwood). Each sample is given a code which identifies uniquely which timber it comes from, which building it is from and where the building is located. For example, CRO-A06 is the sixth core taken from the first building (A) sampled by the Laboratory in Cropwell Bishop. Where it came from in that building will be shown in the sampling records and drawings. No structural damage is done to any timbers by coring, nor does it weaken them.

During the initial inspection of the building and its timbers the dendrochronologist may come to the conclusion that, as far as can be judged, none of the timbers have sufficient rings in them for dating purposes and may advise against sampling to save further unwarranted expense.

All sampling by the Laboratory is undertaken according to current Health and Safety Standards. The Laboratory's dendrochronologists are insured.

*Figure A1: A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976*


*Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil*

*Figure A3: Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measured twice to ensure that an error has not been made. This type of apparatus is needed to process a large number of samples on a regular basis*


*Figure A4: Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical*

**2. Measuring Ring Widths.** Each core is sanded down with a belt sander using medium-grit paper and then finished by hand with flourgrade-grit paper. The rings are then clearly visible and differentiated from each other with a result very much like that shown in Figure A2. The core is then mounted on a movable table below a microscope and the ring-widths measured individually from the innermost ring to the outermost. The widths are automatically recorded in a computer file as they are measured (see Fig A3).

**3. Cross-Matching and Dating the Samples.** Because of the factors besides the local climate which may determine the annual widths of a tree's rings, no two sequences of ring widths from different oaks growing at the same time are exactly alike (Fig A4). Indeed, the sequences may not be exactly alike even when the trees are growing near to each other. Consequently, in the Laboratory we do not attempt to match two sequences of ring widths by eye, or graphically, or by any other subjective method. Instead, it is done objectively (ie statistically) on a computer by a process called cross-matching. The output from the computer tells us the extent of correlation between two sample sequences of widths or, if we are dating, between a sample sequence of widths and the master, at each relative position of one to the other (offsets). The extent of the correlation at an offset is determined by the *t*-value (defined in almost any introductory book on statistics). That offset with the maximum *t*-value among the *t*-values at all the offsets will be the best candidate for dating one sequence relative to the other. If one of these is a master chronology, then this will date the other. Experiments carried out in the past with sequences from oaks of known date suggest that a *t*-value of at least 4.5, and preferably at least 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton and Litton 1988; Laxton *et al* 1988; Howard *et al* 1984–1995).

This is illustrated in Figure A5 with timbers from one of the roofs of Lincoln Cathedral. Here four sequences of ring widths, LIN-C04, 05, 08, and 45, have been cross-matched with each other. The ring widths themselves have been omitted in the bar diagram, as is usual, but the offsets at which they best cross-match each other are shown; eg the sequence of ring widths of C08 matches the sequence of ring widths of C45 best when it is at a position starting 20 rings after the first ring of C45, and similarly for the others. The actual *t*-values between the four at these offsets of best correlations are in the matrix. Thus at the offset of +20 rings, the *t*-value between C45 and C08 is 5.6 and is the maximum found between these two among all the positions of one sequence relative to the other.

It is standard practice in our Laboratory first to cross-match as many as possible of the ring-width sequences of the samples in a building and then to form an average from them. This average is called a site sequence of the building being dated and is illustrated in Figure A5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences of the four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. Thus in Fig A5 if the widths shown are 0.8mm for C45, 0.2mm for C08, 0.7mm for C05, and 0.3mm for C04, then the corresponding width of the site sequence is the average of these, 0.55mm. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

The straightforward method of cross-matching several sample sequences with each other one at a time is called the 'maximal *t*-value' method. The actual method of cross-matching a group of sequences of ring-widths used in the Laboratory involves grouping and averaging the ring-width sequences and is called the 'Litton-Zainodin Grouping Procedure'. It is a modification of the straightforward method and was successfully developed and tested in the Laboratory and has been published (Litton and Zainodin 1991; Laxton *et al* 1988).

4. **Estimating the Felling Date.** As mentioned above, if the bark is present on a sample, then the date of its last ring is the date of the felling of its tree (or the last full year before felling, if it was felled in the first three months of the following calendar year, before any new growth had started, but this is not too important a consideration in most cases). The actual bark may not be present on a timber in a building, though the dendrochronologist who is sampling can often see from its surface that only the bark is missing. In these cases the date of the last ring is still the date of felling.

Quite often some, though not all, of the original outer rings are missing on a timber. The outer rings on an oak, called sapwood rings, are usually lighter than the inner rings, the heartwood, and so are relatively easy to identify. For example, sapwood can be seen in the corner of the rafter and at the outer end of the core in Figure A2, both indicated by arrows. More importantly for dendrochronology, the sapwood is relatively soft and so liable to insect attack and wear and tear. The builder, therefore, may remove some of the sapwood for precisely these reasons. Nevertheless, if at least some of the sapwood rings are left on a sample, we will know that not too many rings have been lost since felling so that the date of the last ring on the sample is only a few years before the date of the original last ring on the tree, and so to the date of felling.

Various estimates have been made and used for the average number of sapwood rings in mature oak trees (English Heritage 1998). A fairly conservative range is between 15 and 50 and that this holds for 95% of mature oaks. This means, of course, that in a small number of cases there could be fewer than 15 and more than 50 sapwood rings. For example, the core CRO-A06 has only 9 sapwood rings and some have obviously been lost over time – either they were removed originally by the carpenter and/or they rotted away in the building and/or they were lost in the coring. It is not known exactly how many sapwood rings are missing, but using the above range the Laboratory would estimate between a minimum of 6 (=15-9) and a maximum of 41 (=50-9). If the last ring of CRO-A06 has been dated to 1500, say, then the estimated felling-date range for the tree from which it came originally would be between 1506 and 1541. The Laboratory uses this estimate for sapwood in areas of England where it has no prior information. It also uses it when dealing with samples with very many rings, about 120 to the last heartwood ring. But in other areas of England where the Laboratory has accumulated a number of samples with complete sapwood, that is, no sapwood lost since felling, other estimates in place of the conservative range of 15 to 50 are used. In the East Midlands (Laxton *et al* 2001) and the east to the south down to Kent (Pearson 1995) where it has sampled extensively in the past, the Laboratory uses the shorter estimate of 15 to 35 sapwood rings in 95% of mature oaks growing in these parts. Since the sample CRO-A06 comes from a house in Cropwell Bishop in the East Midlands, a better estimate of sapwood rings lost since felling is between a minimum of 6 (=15-9) and 26 (=35-9) and the felling would be estimated to have taken place between 1506 and 1526, a shorter period than before. Oak boards quite often come from the Baltic region and in these cases the 95% confidence limits for sapwood are 9 to 36 (Howard *et al* 1992, 56).

Even more precise estimates of the felling date and range can often be obtained using knowledge of a particular case and information gathered at the time of sampling. For example, at the time of sampling the dendrochronologist may have noted that the timber from which the core of Figure A2 was taken still had complete sapwood but that some of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 20mm, a reasonable estimate can be made of the number of sapwood rings lost, say 12 to 15 rings in this case. By adding on 12 to 15 years to the date of the last ring on the sample a good tight estimate for the range of the felling date can be obtained, which is often better than the 15 to 35 years later we would have estimated without this observation. In the example, the felling is now estimated to have taken place between AD 1512 and 1515, which is much more precise than without this extra information.

Even if all the sapwood rings are missing on a sample, but none of the heartwood rings are, then an estimate of the felling-date range is possible by adding on the full compliment of, say, 15 to 35 years to the date of the last heartwood ring (called the heartwood/ sapwood boundary or transition ring and denoted H/S). Fortunately it is often easy for a trained dendrochronologist to identify this boundary on a timber. If a timber does not have its heartwood/sapwood boundary, then only a *post quem* date for felling is possible.

**5. Estimating the Date of Construction.** There is a considerable body of evidence collected by dendrochronologists over the years that oak timbers used in buildings were not seasoned in medieval or early modern times (English Heritage 1998; Miles 1997, 50–5). Hence, provided that all the samples in a building have estimated felling-date ranges broadly in agreement with each other, so that they appear to have been felled as a group, then this should give an accurate estimate of the period when the structure was built, or soon after (Laxton *et al* 2001, fig 8; 34–5, where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storage before use, or if there is evidence the oak came from abroad (eg Baltic boards), then some allowance has to be made for this.

**6. Master Chronological Sequences.** Ultimately, to date a sequence of ring widths, or a site sequence, we need a master sequence of dated ring widths with which to cross-match it, a Master Chronology. To construct such a sequence we have to start with a sequence of widths whose dates are known and this means beginning with a sequence from an oak tree whose date of felling is known. In Figure A6 such a sequence is SHE-T, which came from a tree in Sherwood Forest which was blown down in a recent gale. After this other sequences which cross-match with it are added and gradually the sequence is 'pushed back in time' as far as the age of samples will allow. This process is illustrated in Figure A6. We have a master chronological sequence of widths for Nottinghamshire and East Midlands oak for each year from AD 882 to 1981. It is described in great detail in Laxton and Litton (1988), but the components it contains are shown here in the form of a bar diagram. As can be seen, it is well replicated in that for each year in this period there are several sample sequences having widths for that year. The master is the average of these. This master can now be used to date oak from this area and from the surrounding areas where the climate is very similar to that in the East Midlands. The Laboratory has also constructed a master for Kent (Laxton and Litton 1989). The method the Laboratory uses to construct a master sequence, such as the East Midlands and Kent, is completely objective and uses the Litton-Zainodin grouping procedure (Laxton *et al* 1988). Other laboratories and individuals have constructed masters for other areas and have made them available. As well as these masters, local (dated) site chronologies can be used to date other buildings from nearby. The Laboratory has hundreds of these site sequences from many parts of England and Wales covering many short periods.

**7. Ring-Width Indices.** Tree-ring dating can be done by cross-matching the ring widths themselves, as described above. However, it is advantageous to modify the widths first. Because different trees grow at different rates and because a young oak grows in a different way from an older oak, irrespective of the climate, the widths are first standardized before any matching between them is attempted. These standard widths are known as ring-width indices and were first used in dendrochronology by Baillie and Pilcher (1973). The exact form they take is explained in this paper and in the appendix of Laxton and Litton (1988) and is illustrated in the graphs in Figure A7. Here ring-widths are plotted vertically, one for each year of growth. In the upper sequence of (a), the generally large early growth after 1810 is very apparent as is the smaller later growth from about 1900 onwards when the tree is maturing. A similar phenomenon can be observed in the lower sequence of (a) starting in 1835. In both the widths are also changing rapidly from year to year. The peaks are the wide rings and the troughs are the narrow rings corresponding to good and poor growing seasons, respectively. The two corresponding sequence of Baillie-Pilcher indices are plotted in (b) where the differences in the immature and mature growths have been removed and only the rapidly changing peaks and troughs remain, that are associated with the common climatic signal. This makes cross-matching easier.

*t*-value/offset Matrix

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

Bar Diagram

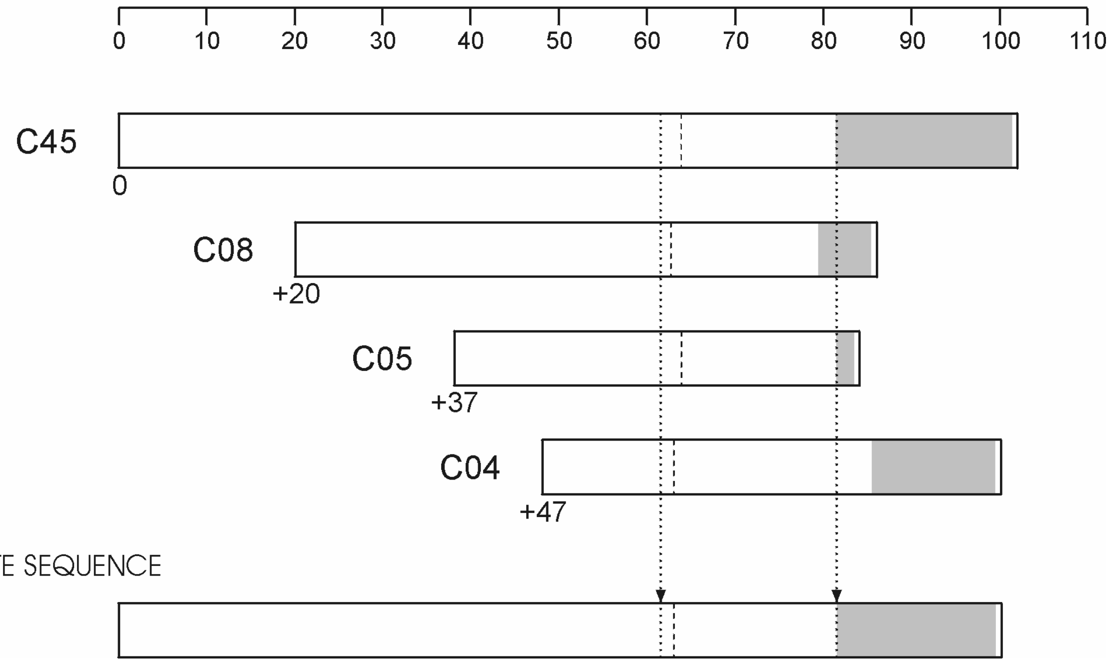



*Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them*

The bar diagram represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set at relative positions (offsets) to each other at which they have maximum correlation as measured by the *t*-values. The *t*-value/offset matrix contains the maximum *t*-values below the diagonal and the offsets above it. Thus, the maximum *t*-value between C08 and C45 occurs at the offset of +20 rings and the *t*-value is then 5.6. The site sequence is composed of the average of the corresponding widths, as illustrated with one width

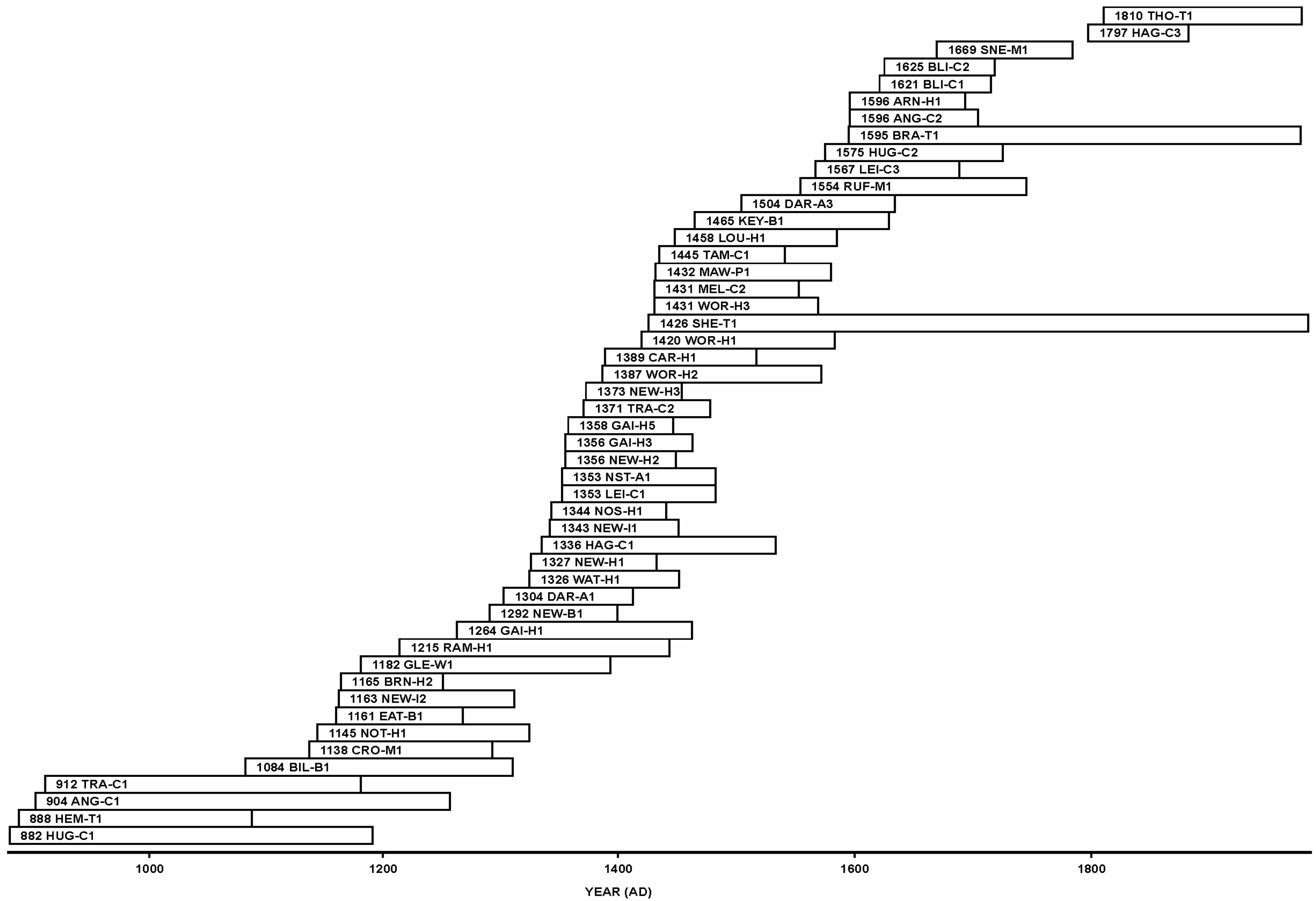
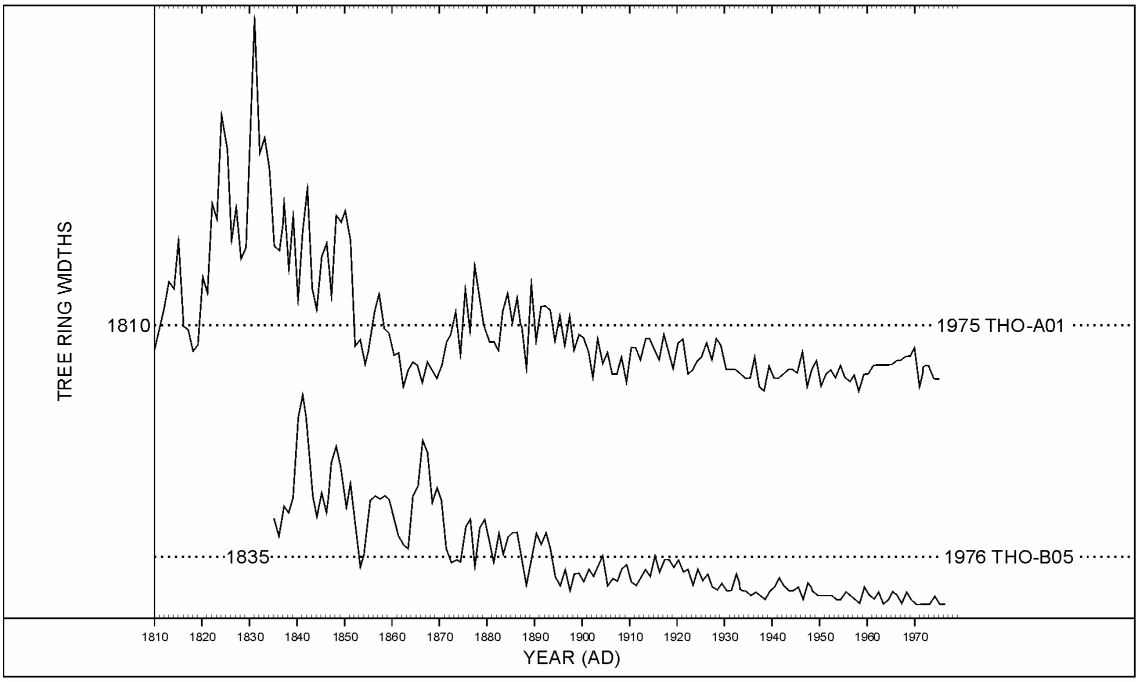



*Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87*

(a)




(b)

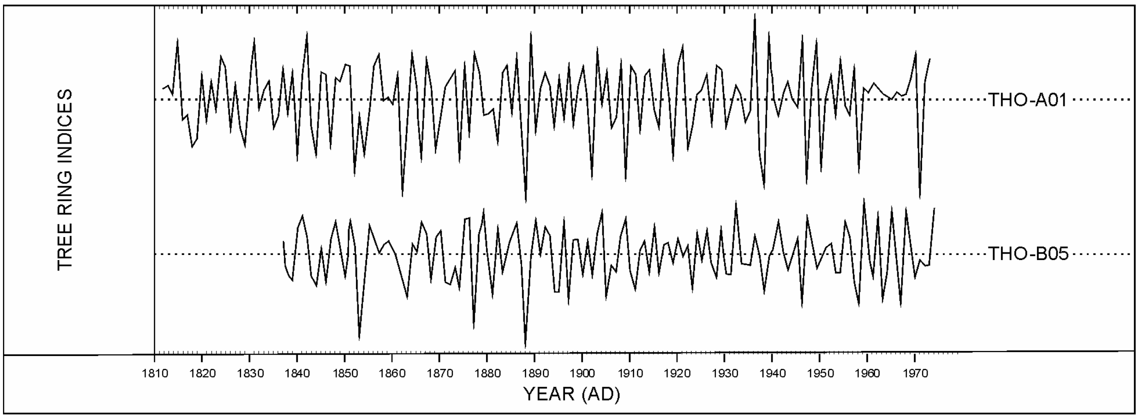



*Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known*

Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree are wider than the later ones of the older tree in both sequences

*Figure A7 (b): The Baillie-Pilcher indices of the above widths*

The growth trends have been removed completely

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