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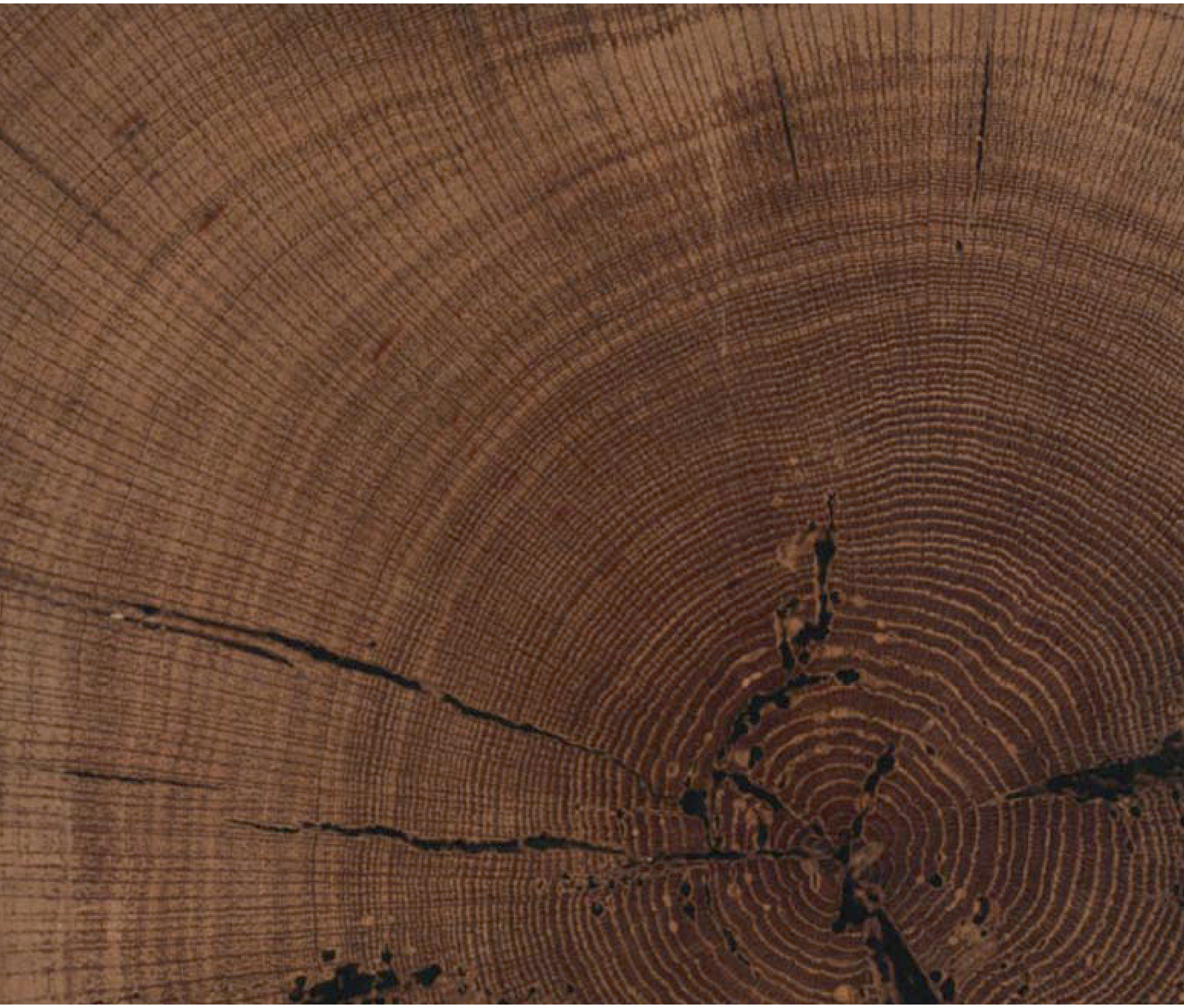
THE OLD STANDARD (NOS 1 AND 2), LITTLE KEIGWIN (NO 5), AND KEIGWIN (NO 7), KEIGWIN PLACE, MOUSEHOLE, CORNWALL TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard



ARCHAEOLOGICAL SCIENCE

ENGLISH HERITAGE

THE OLD STANDARD (NOS 1 AND 2), LITTLE KEIGWIN (NO 5), AND KEIGWIN (NO 7), KEIGWIN PLACE, MOUSEHOLE, CORNWALL

TREE-RING ANALYSIS OF TIMBERS

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SUMMARY

Analysis by dendrochronology of 49 out of 60 samples obtained from the three properties of this building complex (11 samples having been rejected) has produced three site chronologies comprising 32, 3, and 2 samples each, these site chronologies having 240 rings, 91 rings, and 75 rings respectively. Only the first of these site chronologies, which contains samples from all three properties, can be dated, its rings spanning the years AD 1374 –1613.

Whilst it is theoretically possible that some parts of the 'Keigwins', perhaps the hall, pre-date the AD 1595 Spanish raid on Mousehole, the absence of any evidence for damage to or reuse of earlier timbers, plus the presence of other timbers felled in the early-seventeenth century, including two certainly felled in AD 1612 and AD 1613, suggests that much of the material post-dates the raid.

CONTRIBUTORS

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ACKNOWLEDGEMENTS

The occupants, Brian and Greta Ashby of Keigwin, John and Liz Anderson of Little Keigwin, and Greta White of No 2 Keigwin Place, cooperated enthusiastically with this programme of tree-ring analysis. Eric Berry and Nick Cahill provided extensive descriptions, drawings, and photographs of the buildings.

ARCHIVE LOCATION

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DATE OF INVESTIGATION

2007

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INTRODUCTION

The Grade-II* listed buildings, Little Keigwin (No 5 Keigwin Place) and Keigwin (No 7 Keigwin Place), in Mousehole (SW 469 263, Figs 1, 2, and 3), referred to collectively as the 'Keigwins', form two parts of what is regarded as having once been a single sixteenth-century manor house. The 'Keigwins' are reputed to be the only buildings to have survived the Spanish raid on Mousehole of AD 1595. The Old Standard, adjacent to the 'Keigwins' at Nos 1 and 2 Keigwin Place, also Grade-II* listed, is believed to be of early-seventeenth century date (Fig 4).

The 'Keigwins' is generally considered to be the former principal house of the Keigwin family, who lived in Mousehole from about AD 1550 to about AD 1750. They seem to have operated as merchants, trading in pilchards and other goods. They were also not only property owners, at various times holding manorial rights in both Raginnis and Alverton manors (the two main holdings in Mousehole), but were Cornish scholars, Royalist leaders, and rebels too. It is reputed that at times they were also smugglers.

In AD 1726, the various manorial rights owned by the family, with perhaps some property, were sold by James Keigwin to Uriah Tonkin. However, it may be that the old house was part of what was sold with other Keigwin property in Paul parish to the Veale family of Trevaylor in AD 1752. By the late-eighteenth century, the old house had become a public house known as the Keigwin Arms, a use that survived until at least the AD 1930s.

In the early-mid twentieth century Keigwins was extensively renovated by Harris Humphries. In AD 1952 a 'fourth' sale took place, of land and buildings that had been owned by Harris Humphries, including Old Keigwin, a store on the opposite side of the road to the north-west, and a garden to the south. Also in AD 1952 Little Keigwin (the east part of Keigwins) was sold separately and the two properties have been used as separate private dwellings since then.

Stylistic or architectural dating

Close examination of the building complex has demonstrated that Keigwin and Little Keigwin are probably the result of the subdivision of a single house, which is itself the result of a complex series of building phases. It is difficult to place any of these phases far back in the Middle Ages. Analysis of the townscape in the Mousehole survey suggests the possibility that Keigwin and Little Keigwin are a late medieval/early modern encroachment into a formerly open area, whilst the separate Old Standard, Nos 1 and 2 Keigwin Place, structurally later than the 'Keigwins', is believed to date to the early seventeenth century.

Keigwin

The older architectural features of the front range of Keigwin, that is the hall and cross-wing, appear to be of a late-sixteenth or early-seventeenth century date; the moulding of main beams and joists in the hall, of fire surrounds, of the door surrounds to the front and back-passage doorways, are all of this rather ambiguous date, and help little with dating the building relative to the locally significant date of AD 1595.

The dating of the rear range of Keigwin, that is the kitchen wing, is based on its surviving original roof structure, which appears to be of two phases, both with carpentry details similar to the roof of the front (hall) range. One, smoke-blackened, truss at the west end of the kitchen roof had one tier of collars, whereas the three trusses at the east end had two tiers of collars (Figs 5a/b). The single truss may be coeval with the front, hall range, of Keigwin, with the three other trusses apparently being put in possibly slightly later.

The parlour wing of Keigwin appears to have been added to the front, hall range, and possibly added to the rear kitchen wing, and if so may be an infill build. The carpentry detail of the roof structure over the parlour chamber is different to the other roof structures at Keigwin that are similar to the roof structures over the front ranges of both Little Keigwin and the Old Standard. The pillared porch (Fig 6) in front of Keigwin is probably mid-late seventeenth century.

Little Keigwin

The front range of Little Keigwin, that is the upper chamber, appears to be of the same date/building phase as the front, hall, range of Keigwin. However, much of the present rear wing of Little Keigwin, that is the kitchen element, appears to be of a later date. The east wall here, though, clearly contains fabric from an earlier wing, including the remains of a seventeenth-century fireplace that incorporates a later oven in its rear room. The front projecting wing of Little Keigwin is probably early-eighteenth century, based on the surviving panelling in its upper chamber. A plan showing the possible phasing of the building is given in Figure 7.

The Old Standard, Nos 1 and 2, Keigwin Place

The Old Standard, now split into two separate dwellings as Nos 1 and 2 Keigwin Place, is believed, on the basis of stylistic evidence of the building detail, to be of early-seventeenth century date. There is documentary evidence, in the form of a will, to suggest that this house was here by AD 1630, and structural evidence to show that it is later than the 'Keigwins'. It is built of granite rubble with a steep slurried slate roof with gable ends. It is of two storeys, with three windows with granite mullions (although most of the mullions have been taken out), moulded jambs, lintels and dripmoulds. The building has two ground-floor doorways with moulded jambs and lintels, again with dripmoulds. There are two end chimney stacks of granite with moulded bell-topped.

THE ROOFS AND CEILING

Original oak roof structures survive over the front range (the hall of Keigwin and the upper chamber of Little Keigwin) as well as over the rear range (the kitchen wings to both Keigwin and Little Keigwin) of this building complex (Fig 8).

The front range roof comprises four narrow bays of trusses over Little Keigwin (the upper chamber roof) and four wider bays over Keigwin (the hall roof). The trusses have partially halved lap-dovetailed (or fishtail) collar joints (Fig 9) and halved apices. The collars are straight and the principal rafters and collars are slightly chamfered; some original rafters pegged to the purlins remain. Some surviving plaster at the west end of Keigwin is possible evidence that the front range of the building may have been originally open to the roof, although it might equally show use of the loft space for storage – not unlikely, given that the Keigwin family operated a major merchanting business from the house.

The easternmost truss of Keigwin has a much wider space between it and the (twentieth-century) party wall to Little Keigwin; the extra space is the same width as the main wall of the building. This indicates the possible removal of a stone wall east of the cross passage that ran up into the roof, and may even have been a gable end wall.

The roof over Little Keigwin has good survival of original purlins and also some original rafters pegged to the purlins. Carpenter's marks match at the joints and follow in sequence along the roof. Arched timbers under the trusses are original to the 'barrel' ceiling at this end (but later than the main roof structure), but the plasterwork has all been replaced. Arched timbers under the trusses in the Keigwin front range demonstrate the former existence of a plaster barrel ceiling here as well.

The roof of the Keigwin kitchen wing has two phases of construction, both with similar carpentry details to the roof to the front building range. However, the two-bay (one smoke-blackened truss) west end of this wing has one tier of collar joints whereas the east end has three original trusses, each with two tiers of collar joints, perhaps a precautionary constructional detail stimulated by failure of the west truss that now has a broken rafter to its south side. There are three chimney breasts projecting within the roof space, the one to the north-west serving the parlour and chamber above, the one to the south-west serving the fireplace(s) in the west wall of the rear range, and the one in the south-east corner relating to the attached house to the south (No 8 Wesley Square).

The roof over the parlour wing appears to be coeval with the probable late-seventeenth century date of the plaster ceiling underneath, part of which has been replaced.

A small number of joists can be seen in the ground floor ceiling of the front range of Keigwin. There are no stylistic or decorative features by which these timbers can be dated and they show neither signs of being older timbers reused, nor of being later insertions. There is no reason to suspect that they are not of the same date as the roof timbers.

Understanding the chronological relationship of the various roofs within the 'Keigwins' is a matter of considerable difficulty. They all show a marked similarity in detail, with lap-dovetailed pegged collars, trenched purlins, pegged rafters, all in oak. Only the roof over the Keigwin parlour appears to be a little later, the collars are pegged and half-jointed to the surface of the trusses. The unusual double collared roof over the Keigwin kitchen range is also constructed with the same details. In terms of dating, this presents problems.

These roofs are all of the same type, broadly late-sixteenth to mid-seventeenth century (similar examples occur elsewhere at Trerice, although there the purlins are threaded through the principal trusses, an older form, and at Cullacott in Werrington parish, where the parlour roof, on the basis of an inscription on a granite lintel over the parlour window, is dated c AD 1579). They are also similar to the roof of The Old Standard (covering both Nos 1 and 2 Keigwin Place), which is believed to be no later than AD 1630. Although very similar, there is clearly, on the basis of the structural evidence, a sequence of different phases to the 'Keigwins' roofs and the roof of The Old Standard; it may be that some or all of them predate AD 1595, or are as late as the mid-seventeenth century remodelling of the upper floors. In this context, it is significant that the projecting gabled and fleur-de-lis decorated lateral stack to Keigwin is typical of the seventeenth century rather than the sixteenth century.

Within the roof space of The Old Standard there are six slender and lightly built principal-rafter frames with collars (but no tiebeams), the principal rafters carrying double purlins, but no ridge. The common rafters are also small and slender.

SAMPLING

Sampling and analysis by tree-ring dating of timbers within the 'Keigwins' were commissioned by English Heritage, the analysis of material from six distinct areas being requested. Primary amongst these were the roof of the hall, parlour, and kitchen ranges of Keigwin, plus timbers of the ground-floor ceiling of the hall. In addition, the main roof of Little Keigwin (the upper chamber) and the roof of The Old Standard were also to be sampled (there being no other suitable timbers in the lower parts of either of these two buildings).

The purpose of this programme of tree-ring analysis was to inform statutory advice and to compliment survey and description work undertaken for the Victoria County History (Berry and Cahill forthcoming). It was hoped that tree-ring analysis would help elucidate the development of this complex and confirm whether or not it was a potentially unique survivor of the AD 1595 Spanish raid. It was also hoped that the analysis of these three potentially coeval buildings would produce a well-replicated set of data to add to the still relatively sparse, though now growing, dendrochronological network for this region. Thus, from the material available a total of 60 samples was obtained by coring. Each sample was given the code MSH-A (for Mousehole, site 'A') and numbered 01–60. A total of 13 samples, MSH-A01–13, was obtained from the upper chamber roof of Little Keigwin with a further twelve samples, MSH-A14–25, being obtained from the hall roof of Keigwin. A further five samples, MSH-A26–30, were then taken from the roof of the parlour wing of Keigwin, with ten samples, MSH-A31–40, also taken from the rear wing of Keigwin. Four samples, MSH-A41–44, were taken from the ground-floor ceiling beams of Keigwin. Finally, in addition to the samples taken from the 'Keigwins', a total of 16 samples, MSH-A45–60, was taken from the roof of The Old Standard.

It will be apparent from this that some areas, the parlour roof of Keigwin for example, are not as well represented as some of the other roofs, where at least ten samples have been obtained. This variation in numbers is not due to a lack of timbers, for there were further timbers available, but was caused by many of them being derived from fast-grown trees with wide annual growth-rings. As such they were very unlikely to provide satisfactory samples for tree-ring dating. In the case of the ground-floor ceiling, the number of beams available was much more limited, and these timbers were more variable in their suitability for tree-ring dating.

Where possible the positions of these samples are marked on plans made as part of the

Victoria County History survey and provided by Nick Cahill and Eric Berry. These are reproduced here as Figures 10a–e. Details of the samples are given in Table 1. In this Table the bays, trusses, and other timbers have been located and numbered following the schema on the drawings provided.

The Laboratory would like to take this opportunity to thank Brian and Greta Ashby of Keigwin, John and Liz Anderson of Little Keigwin, and Greta White of No 2 Keigwin Place for their great help and cooperation during sampling, and for their enthusiasm for this programme of tree-ring analysis. We would also like to thank Eric Berry and Nick Cahill for the use of their notes verbatim in the introduction and description of the roofs above, and their plans and drawings elsewhere in this report.

ANALYSIS

Each of the 60 samples obtained was prepared by sanding and polishing. It was seen at this point that a total of 11 samples had too few rings for reliable dating, ie, less than 54, and these were rejected from this programme of analysis. The annual growth-rings of the remaining 49 samples were measured, however, the data of these measurements being given at the end of this report. The data of these 49 measured samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), this allowing three groups of cross-matching samples to be formed.

The 32 samples of the first group cross-match with each other as shown in the bar diagram, Figure 11a. These 32 samples were combined at their respective off-sets to form site chronology MSHASQ01, this having an overall length of 240 rings. This site chronology was compared to a number of relevant reference chronologies for oak, this indicating a consistent cross-match with a large number of these when the date of the first ring is AD 1374 and the date of the last ring is AD 1613. Evidence for this dating is given in Table 2.

The three and two samples of the second and third group respectively cross-match with each other as shown in the bar diagrams, Figures 12 and 13. These samples were likewise combined at their respective off-sets to form site chronologies MSHASQ02 and MSHASQ03, these having overall lengths of 91 and 75 rings respectively. These two site chronologies were compared to the relevant reference chronologies for oak but there was no further satisfactory cross-matching, and these samples must remain undated.

All three site chronologies were compared with the 12 remaining measured but ungrouped samples, but there was no further satisfactory cross-matching. Each of these 12 remaining samples was then compared individually with a full range of reference chronologies for oak, but again there was no satisfactory cross-matching, and all these samples must also remain undated.

INTERPRETATION

Analysis by dendrochronology of 49 measured samples from this site has produced a single dated site chronology comprising 32 samples, its 240 rings dated as spanning the years AD 1374–1613. Samples from all elements of the 'Keigwins' as well as from 2 Keigwin Place are to be found in this site chronology, with the felling date, or felling date ranges for the timbers used being calculated from these results.

Little Keigwin – upper chamber roof (samples 1–13)

For example, the heartwood/sapwood boundary exists on the majority of samples, eight, from the upper chamber roof of Little Keigwin, at a very similar date, the average date of these eight heartwood/sapwood boundaries being AD 1578. Using a 95% confidence limit of 15–40 rings for the amount of sapwood the trees might have had would give them an estimated felling date in the range AD 1593–1618. Such a range encompasses the actual felling dates of two samples from this roof, MSH-A 02 and A07, which have complete sapwood, and were felled in AD 1613 and AD 1612 respectively.

There are, however, two outliers from the general consistency of the heartwood/sapwood boundary date of the majority of samples, in the form of MSH-A03 and A09. These two samples have heartwood/sapwood transition dates of AD 1559 and AD 1599 respectively. Although again using a 95% confidence limit of 15–40 rings for the amount of sapwood the trees might have had would give them estimated felling dates in the range AD 1574–99 and AD 1614–39, respectively, it is more likely that they were felled at about the same time as all the others in this roof, and that they simply had more than the usual number of sapwood rings in one case, and less than the usual in the second.

Keigwin – hall roof (samples 14–25)

Of the 12 samples from the hall roof of Keigwin, five have been rejected as having too few rings for reliable analysis, and of the seven measured, only three have dated. Of these three dated samples, only one, MSH-A24, retains the heartwood/sapwood boundary, this being at AD 1537 (with a last measured sapwood ring date of AD 1542). Using the same sapwood estimate as above, 15–40 rings, would give the timber represented by this sample an estimated felling date in the range AD 1552–77.

Because they do not have a heartwood/sapwood boundary, the felling date ranges of the other two samples from this roof, MSH-A15 and A22, cannot be determined. It is unlikely, however, that the timber represented by the former sample (last heartwood ring date AD 1487) was felled before AD 1502 and that represented by the latter (last heartwood ring date AD 1505) was felled before AD 1520. It is certainly possible that they were felled at the same time as the timber represented by sample MSH-A24.

Keigwin – parlour wing roof (samples 26–30)

Five samples were obtained from the parlour wing roof of Keigwin, with one sample being rejected as having too few rings. Of the four samples measured, only one, MSH-A27, has dated. This sample, with 12 sapwood rings, has a last measured ring date AD 1595, and thus a heartwood/sapwood transition date of AD 1583. Using the usual sapwood estimate would give the timber represented by this sample an estimated felling date in the range AD 1598–1623.

Keigwin – rear wing (samples 31–40)

Ten samples were obtained from the roof of the rear wing to Keigwin. Of this number three were rejected as having too few rings. Of the seven measured samples, only three, all with some sapwood or at least the heartwood/sapwood boundary, have dated. The average heartwood/sapwood boundary on these three samples is dated to AD 1587. Using the same sapwood estimate as above would give these timbers an estimated felling date in the range AD 1602–27.

Keigwin – ground-floor ceiling beams (samples 41–4)

Finally, four samples were also obtained from the ground-floor ceiling beams of Keigwins. All four samples dated, but only one sample, MSH-A41, retains a heartwood/sapwood boundary (with no sapwood), this boundary being dated to AD 1576. It is likely that the tree represented was felled in the period AD 1591–1616.

Given the absence of the heartwood/sapwood boundary on the other three samples, the felling date of the other timbers from this ceiling cannot be deduced. It is unlikely, however, to be less than 15 years after the last measured ring date of the samples, ie, not before AD 1531, not before AD 1542, and not before AD 1589.

No 2 Keigwin Place (samples 45–60)

From the roof of No 2 Keigwin Place at total of 16 samples was obtained, two of which were not measured due to the shortness of their ring sequences. Of the 14 samples which were measured, nine have been dated. Of these nine dated samples, three retain some sapwood or the heartwood/sapwood boundary. The average date of the heartwood sapwood boundary on these three dated samples is AD 1586. Using the usual sapwood estimate, 15–40 rings, would give the timbers represented an estimated felling date in the range AD 1601–26. Although some of the other samples, without the heartwood/sapwood boundary, have much earlier last measured rings dates (the earliest, on sample MSH-A59 is dated AD 1459), there is no reason to suspect that they are old timbers reused (there is no visible evidence for this), and were not felled at the same time as all the other timbers. This difference in date may be due to the way the beams have been converted from the original trees, with some being taken from the centre of the trees, and others from the outer parts.

An attempt to summarise these results is given below. Here the number of samples obtained from each area dated is given, along with the number of samples dated. The date of the average heartwood/sapwood boundary ring, on those samples where it exists (this usually being less than the number of samples dated) is also given. The felling date range is calculated using a 95% probability of 15–40 rings for the amount of sapwood the trees might have had.

	Sample numbers	Samples obtained	Samples dated	Average heart/sap	Felling date range
Little Keigwin – upper chamber	1–13	13	10	AD 1578	AD 1593–1618
Little Keigwin – upper chamber			1	AD 1559	AD 1574–99
Little Keigwin – upper chamber			1	AD 1599	AD 1614–39
Keigwin – hall	14–25	12	3	AD 1537	AD 1552–77
Keigwin – parlour wing	26–30	5	1	AD 1583	AD 1598–1623
Keigwin – rear wing	31–40	10	3	AD 1587	AD 1602–27
Keigwin – ceiling beams	41–44	4	4	AD 1576	AD 1591–1616
No 2 Keigwin Place	45–60	16	9	AD 1586	AD 1601–26
Totals		60	32		

It will be seen from the above that Keigwin is thus represented by 11 dated samples, Little Keigwin by 12 dated samples, and The Old Standard by 9 dated samples. It may also be seen that in some instances, Keigwin hall for example, individual roofs are dated on only a small proportion of the samples actually taken, in the case of the hall, 3 out of 12, with only 1 of the 3 dated samples having a heartwood/sapwood boundary. It may also be seen that, as a whole. It may also be seen from Table 1 that the majority of the rejected samples come from Keigwin, with, for example, 5 of the 12 samples from the hall roof being unsuitable.

However, taken overall, it will be seen that the majority of samples indicate heartwood/sapwood transition dates towards the last quarter and very end of the sixteenth century. This, and the existence of complete sapwood on two samples, suggests that, while some beams may be slightly earlier, most of the dated timber is of early-seventeenth century date. The general similarity in the heartwood/sapwood date of the majority of dated samples is illustrated in the bar diagram, Figure 11b, where the samples with this transition are sorted by its relative position/date. From this Figure it will be seen that the boundary on the majority of samples varies by only 23 rings from relative position 194 (AD 1567) on sample MSH-A13 to relative position 217 (AD 1590) on sample MSH-A02. A variation such as this is indicative of timbers having felling dates spread over a short period of time.

It may also be seen from the bar diagram of Figure 11b, and the summary above, however, that there could be two , and maybe even three, possible exceptions to this general trend of early-seventeenth century felling. The first possible exception may be found on MSH-A24 which, at AD 1537 (relative position 164), has the earliest heartwood/sapwood transition date of any sample. Using a 95% probability of 15–40 rings for the amount of sapwood the trees are likely to have had would give this timber an estimated felling date in the range AD 1552–77.

The second possible exception is found in sample MSH-A03. This has a heartwood/

sapwood transition date of AD 1559 (relative position 186), slightly earlier than most of the other samples. While it is strictly possible that it too was felled at a similar time as all the other timbers from this roof (if it had a slightly excessive number of sapwood rings, which is statistically possible, given the number of cores taken), it is also possible that it was felled slightly earlier than the others from this roof. Using a 95% probability of 15–40 rings for the amount of sapwood the trees are likely to have had would give this timber an estimated felling date in the range AD 1574–99.

The third possible exception may be found in sample MSH-A09, from the Old Standard, which has a later heartwood/sapwood transition date than the other samples of AD 1599 (relative position 225). It is possible that it too was felled a similar same time as the other timbers (if it had a lower than usual number of sapwood rings, which is again possible given the number of cores taken), but it is also possible that it was felled slightly later than the others from this roof. Using a 95% probability of 15–40 rings for the amount of sapwood the trees are likely to have had would give this timber an estimated felling date in the range AD 1614–39.

DISCUSSION AND CONCLUSION

Given the semi-independent nature of the buildings in this complex, it is possible, though this is not at all certain, that some differences in the construction dates of the different roofs and the ceiling might be expected. Unfortunately, given the lack of bark edge and complete sapwood on most of the timbers throughout the 'Keigwins', it has not been possible to determine precisely any clear differences in the construction date between the areas investigated.

The felling date range of a number of timbers, those without a heartwood/sapwood transition, cannot be determined, and it is thus theoretically possible that they pre-date the Spanish raid on Mousehole of AD 1595. Other timbers, those with early heartwood/sapwood transition dates may also pre-date the raid as well. It is also theoretically possible that half a dozen or so timbers were felled in the late-sixteenth century but still, literally, immediately before the raid.

However, taken overall, the existence of complete sapwood on two samples, with felling dates of AD 1612 and AD 1613 for the two timbers represented, and the relative position of the heartwood/sapwood boundary on many other samples, where it exists, suggests that much of the timber is likely to be of early-seventeenth century date. It is also noticeable that there is no structural evidence, by way of clearly redundant mortices or peg holes, for reuse, and no evidence of, say, fire damage to any of the possibly earlier timbers which, if they were felled earlier, would then have been reused in an early-seventeenth reconstruction phase at the 'Keigwins'. This early seventeenth century felling of timber includes some in the parlour wing, which, on the basis of the survey, was thought to be c AD 1700. It would thus appear that much of the dated material postdates the Spanish raid on Mousehole of AD 1595.

Such an interpretation by tree-ring dating thus supports the views of the structural survey of the building phases and their roofs undertaken by Eric Berry and Nicholas Cahill. This survey shows that the decorative and stylistic features of the buildings are consistent with an early-seventeenth century date, and that, whilst there is clearly a sequence of different phases to the roofs, they are of similar design and construction, and that there is no evidence of repair, insertion, or reuse, as would most likely be the case were the present roof pre-AD 1595 with large-scale early-seventeenth century repairs.

It may be of interest to note that although there were cross-matches between some samples with high t-values (MSH-A03 and A13, for example, matching with a value of t=10.2, and MSH-A49 and A51 matching at t=10.1, suggesting the trees represented were growing close to each other), and although eventually a group of 32 dated samples is formed, the intra-site matching is not particularly high. This could be taken as an indication that timbers from different woodland sources may have been used, or that the trees were widely scattered. These various sources, however, do all appear to be located in the West Country for, as may be seen from Table 2 which shows the reference chronologies against which site chronology MSHASQ02 matches best, the highest t-values are found with those made up of material from other west of England sites.

There appears to be no cross-matching between samples from different roofs with t-values high enough to indicate that any two beams might have been derived from the same tree. Whilst the existence of such cross-matching could be taken to indicate that different roofs were under construction at the same time, its absence does not in itself prove that they were not.

Also of interest may be the possibility that the trees used at No 2 Keigwin Place were quite long-lived or aged when they were felled. As can be seen from both Table 1 and the bar diagram, Figures 11a/b, there appears to be an early group of timbers from this roof without any sapwood, and a later group of timbers, with sapwood. These two groups do not overlap chronologically by very many years, if at all in some cases. Given that the timbers of this roof were very thin – hardly more than thick planks in some cases – it is possible that the two groups represent the inner and outer portions of the same trees. Given that the innermost rings on some of these early samples appear to be a little way short of the centre of the trees, which thus began growing in, say, *c* AD 1400, the trees themselves may have been in excess of 200 years of age when felled in the early-seventeenth century.

The samples from the roof of Little Keigwin hall are equally long-lived, but they are different to those from 2 Keigwin Place in that they are more likely to represent whole trees. Furthermore, if it assumed that all the dated timbers from Keigwin are felled in the early-seventeenth century, then it is likely that they are from long-lived trees too. All in all, the material from the 'Keigwins' and 2 Keigwin Place appear to be derived from long-lived trees, but it appears possible that the timbers of No 2 Keigwin Place and the 'Keigwins' have been converted differently.

Of the 49 samples which were measured, 12 remain ungrouped and undated. Whilst some of these remaining samples have ring numbers which are at, or close to, the lower limit of statistical reliability, several others have higher numbers. Indeed, as will be seen from Table 1, three samples have in excess of 100 rings. Whilst some of these samples do have slight disturbances to their growth rings, MSH-A46 for example, most of the others show no problems, such as distortion or compression of the rings, which would make cross-matching and dating difficult. It is possible that the undated timbers are from different woodland sources, making them, in effect 'singletons'. Such samples are often more difficult to date than longer well-replicated site chronologies, particularly in south-west England where there is less reference data available.

In this respect the material from Mousehole is thus particularly important. The 32 dated samples have combined to make a long, well replicated, chronology for the far southwest, its 240 rings spanning the late-medieval–post-medieval period. In terms of its geographical and temporal context it is likely to make an important contribution to the growing corpus of data from this region.

BIBLIOGRAPHY

Arnold, A J, Howard, R E, and Litton, C D, 2005 *Tree-ring analysis of roof timbers at the church of Saint Ciricus and Saint Julitta, St Veep, near Lostwithiel, Cornwall*, Centre for Archaeol Rep, 47/2005

Arnold, A J, and Howard, R E, 2006 *Church of St Ildierna, Lansallos, Cornwall: tree-ring analysis of timbers from the roofs and pews*, EH Res Dep Rep Ser, 49/2006

Berry, E, and Cahill, N, forthcoming *Keigwins, Mousehole* (Keigwin and Little Keigwin and their relationship to adjacent and associated buildings including the Old Standard)

Howard, R E, Laxton, R R, and Litton, C D, 1998a *Tree-ring analysis of timbers from Naas House, Lydney, Gloucestershire*, Anc Mon Lab Rep, 36/1998

Howard, R E, Laxton, R R, and Litton, C D, 1998b *Tree-ring analysis of timbers from 26 Westgate Street, Gloucester*, Anc Mon Lab Rep, 43/1998

Howard, R E, Laxton, R R, and Litton, C D, 2000 *Tree-ring analysis of timbers St Briavel's Castle, Gloucestershire*, Anc Mon Lab Rep, 42/1999

Siebenlist-Kerner, V, 1978 Chronology, 1341–1636, for hillside oaks from Western England and Wales, in *Dendrochronology in Europe* (ed J M Fletcher), BAR Int Ser, 51, 295–301

Tyers, I, 2004 *Tree-ring analysis of oak timbers from Pendennis Castle, near Falmouth, Cornwall*, Centre for Archaeol Rep, 38/2004

Tyers, C, and Tyers, I, forthcoming *Godolphin House, Godolphin Cross, Cornwall: scientific dating deport – tree-ring analysis of timbers*, EH Res Dep Rep Ser, -

Table 1: Details of samples from The Keigwins, Mousehole, nr Penzance, Cornwall

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Little Keigwin - Hall roof					
MSH-A01	North principal rafter, truss 1	100	10	AD 1495	AD 1584	AD 1594
MSH-A02	South principal rafter, truss 1	119	23C	AD 1495	AD 1590	AD 1613
MSH-A03	Collar, truss 1	123	11	AD 1448	AD 1559	AD 1570
MSH-A04	South upper purlin, truss 1 – 2	147	h/s	AD 1425	AD 1571	AD 1571
MSH-A05	South common rafter 1, truss 1 – 2	68	no h/s	AD 1392	------	AD 1459
MSH-A06	South common rafter 2, truss 1 – 2	81	no h/s	------	------	------
MSH-A07	South common rafter 3, truss 1 – 2	86	23C	AD 1527	AD 1589	AD 1612
MSH-A08	South principal rafter, truss 2	66	6	AD 1520	AD 1579	AD 1585
MSH-A09	Collar, truss 2	54	4	AD 1550	AD 1599	AD 1603
MSH-A10	North upper purlin, truss 2 – 3	141	no h/s	AD 1405	------	AD 1545
MSH-A11	North principal rafter, truss 3	69	15	AD 1520	AD 1573	AD 1588
MSH-A12	South principal rafter, truss 3	67	22	AD 1524	AD 1568	AD 1590
MSH-A13	Collar, truss 3	130	22	AD 1460	AD 1567	AD 1589
	Keigwin - Hall roof					
MSH-A14	North principal rafter, truss 1	122	no h/s	------	------	------
MSH-A15	South principal rafter, truss 1	90	no h/s	AD 1398	------	AD 1487
MSH-A16	Collar, truss 1	54	26	------	------	------
MSH-A17	North principal rafter, truss 2	nm	---	------	------	------
MSH-A18	South principal rafter, truss 2	nm	---	------	------	------
MSH-A19	Collar, truss 2	54	27	------	------	------
MSH-A20	North principal rafter, truss 3	nm	---	------	------	------
MSH-A21	South principal rafter, truss 3	55	10	------	------	------
MSH-A22	Collar, truss 3	110	no h/s	AD 1396	------	AD 1505
MSH-A23	South purlin, west gable – truss 1	nm	---	------	------	------
MSH-A24	North purlin, truss 1 – 2	96	5	AD 1447	AD 1537	AD 1542
MSH-A25	South purlin, truss 2 – 3	nm	---	------	------	------

Table 1: Continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Keigwin – parlour wing					
MSH-A26	East principal rafter, truss 4	103	5	------	------	------
MSH-A27	West principal rafter, truss 4	58	12	AD 1538	AD 1583	AD 1595
MSH-A28	East principal rafter, truss 5	54	17	------	------	------
MSH-A29	West principal rafter, truss 5	nm	---	------	------	------
MSH-A30	West lower purlin, truss 4 - 5	91	h/s	------	------	------
	Keigwin – rear kitchen wing					
MSH-A31	North principal rafter, truss 1	80	5	AD 1513	AD 1587	AD 1592
MSH-A32	South principal rafter, truss 1	nm	---	------	------	------
MSH-A33	Collar, truss 1	75	13	------	------	------
MSH-A34	North principal rafter, truss 2	nm	---	------	------	------
MSH-A35	South principal rafter, truss 2	nm	---	------	------	------
MSH-A36	Collar, truss 2	109	h/s	AD 1476	AD 1584	AD 1584
MSH-A37	North principal rafter, truss 3	55	8	------	------	------
MSH-A38	South principal rafter, truss 3	65	12	------	------	------
MSH-A39	North principal rafter, truss 4	65	4	AD 1530	AD 1590	AD 1594
MSH-A40	South principal rafter, truss 4	54	2	------	------	------
	Keigwin - ceiling beams					
MSH-A41	Ceiling beam 2 (from east wall)	77	12	AD 1512	AD 1576	AD 1588
MSH-A42	Ceiling beam 4	86	no h/s	AD 1442	------	AD 1527
MSH-A43	Ceiling beam 6	143	no h/s	AD 1432	------	AD 1574
MSH-A44	Ceiling beam 7	105+	no h/s+60	AD 1412	------	AD 1516

Table 1: Continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Old Standard / No.2					
MSH-A45	North principal rafter, truss 1	97	no h/s	AD 1403	------	AD 1499
MSH-A46	South principal rafter, truss 1	82	h/s	------	------	------
MSH-A47	Collar, truss 1	nm	---	------	------	------
MSH-A48	North principal rafter, truss 2	nm	---	------	------	------
MSH-A49	South principal rafter, truss 2	93	no h/s	AD 1408	------	AD 1500
MSH-A50	North principal rafter, truss 3	81	h/s	AD 1510	AD 1590	AD 1590
MSH-A51	South principal rafter, truss 3	92	no h/s	AD 1407	------	AD 1498
MSH-A52	North principal rafter, truss 4	58	h/s	------	------	------
MSH-A53	South principal rafter, truss 4	54	no h/s	------	------	------
MSH-A54	North principal rafter, truss 5	90	no h/s	AD 1415	------	AD 1504
MSH-A55	South principal rafter, truss 5	140	4	AD 1454	AD 1589	AD 1593
MSH-A56	Collar, truss 5	58	10	------	------	------
MSH-A57	North principal rafter, truss 6	69	h/s	AD 1512	AD 1580	AD 1580
MSH-A58	South principal rafter, truss 6	111	no h/s	AD 1420	------	AD 1530
MSH-A59	Collar, truss 6	86	no h/s	AD 1374	------	AD 1459
MSH-A60	Lower south purlin, east gable to truss 2	62	h/s	------	------	------

*h/s = the last ring on the sample is the heartwood/sapwood boundary
nm = sample not measured
C = complete sapwood retained on the sample, the last measured ring date is the felling date of the timber

Table 2: Results of the cross-matching of site chronology MSHASQ01 and relevant reference chronologies when first ring date is AD 1374 and last ring date is AD 1613

Reference chronology	Span of chronology	*t*-value	
Goldophin House, Godolphin Cross, Cornwall	AD 1376–1620	9.1	(Tyers and Tyers forthcoming)
Wales and West Midlands	AD 1341–1636	7.7	(Siebenlist-Kerner 1978)
St Briavel's Castle, Gloucestershire	AD 1362–1636	7.3	(Howard *et al* 1999)
Church of St Ildierna, Lansallos, Cornwall	AD 1355–1514	7.2	(Arnold and Howard 2006)
Pendennis Castle, nr Falmouth, Cornwall	AD 1358–1541	6.9	(Tyers 2004)
Naas House, Lydney, Gloucestershire	AD 1373–1568	6.9	(Howard *et al* 1998a)
26 Westgate Street, Gloucester	AD 1399–1622	6.4	(Howard *et al* 1998b)
Church of SS Ciricus and Julitta, St Veep, Cornwall	AD 1352–1512	5.8	(Arnold *et al* 2005)

Figure 1: Map showing the general location of The Keigwins, Mousehole

Figure 2: Map showing the precise location of the Keigwins, Mousehole

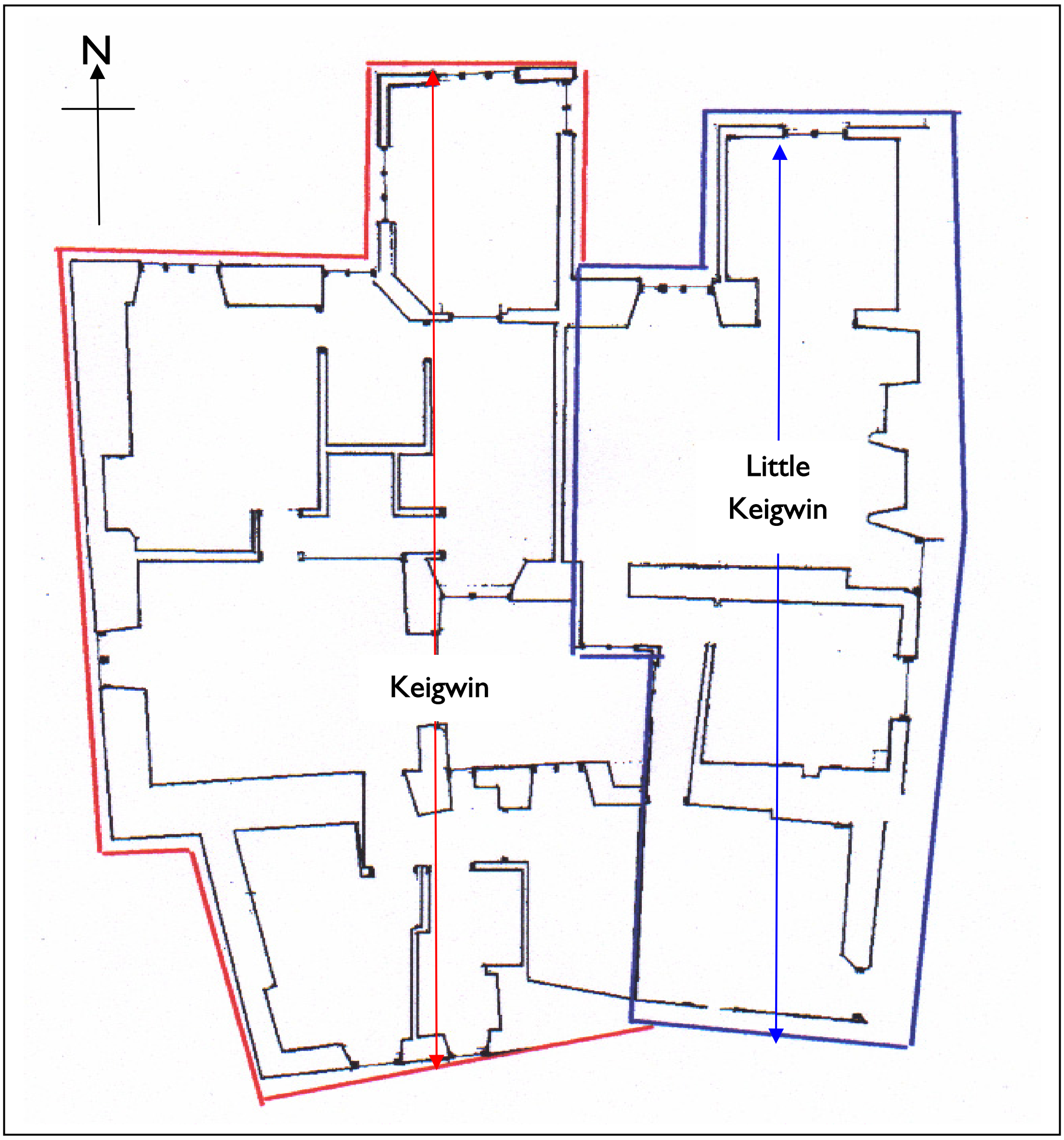


Figure 3: Simple plan of Keigwin and Little Keigwin (the 'Keigwins')

Figure 4: View of The Old Standard, Nos 1 and 2 Keigwin Place

(after Eric Berry and Nicholas Cahill)

Figure 5a (top): Keigwin, roof over the rear range, showing smoke-blackened truss

Figure 5b (bottom): Keigwin, roof over the extension to rear range, originally with two tiers of collars

(after Eric Berry and Nicholas Cahill)

Figure 6: Keigwin, the porch

(after Eric Berry and Nicholas Cahill)

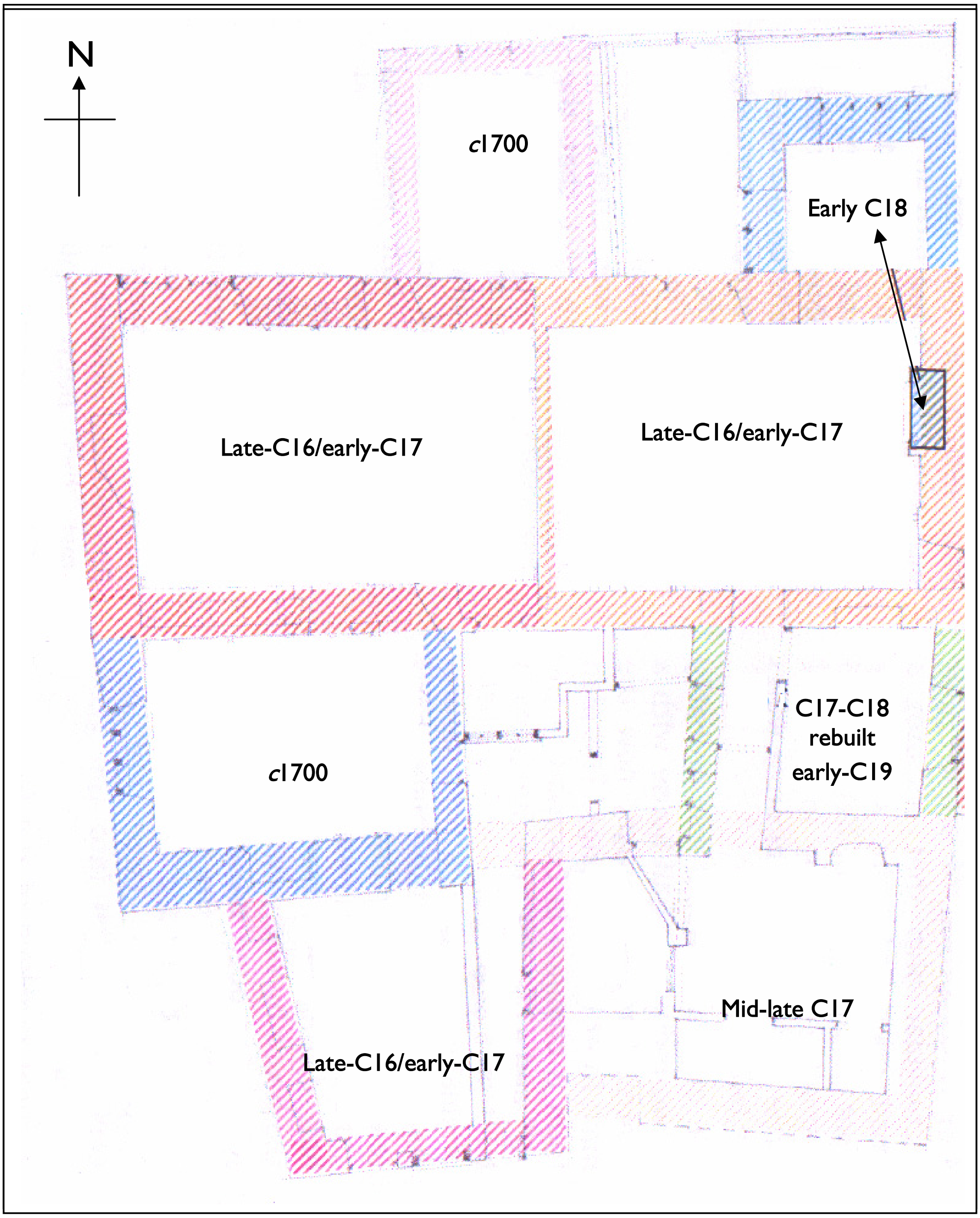


Figure 7: Plan to show probable phasing of the building
(after Eric Berry and Nicholas Cahill)

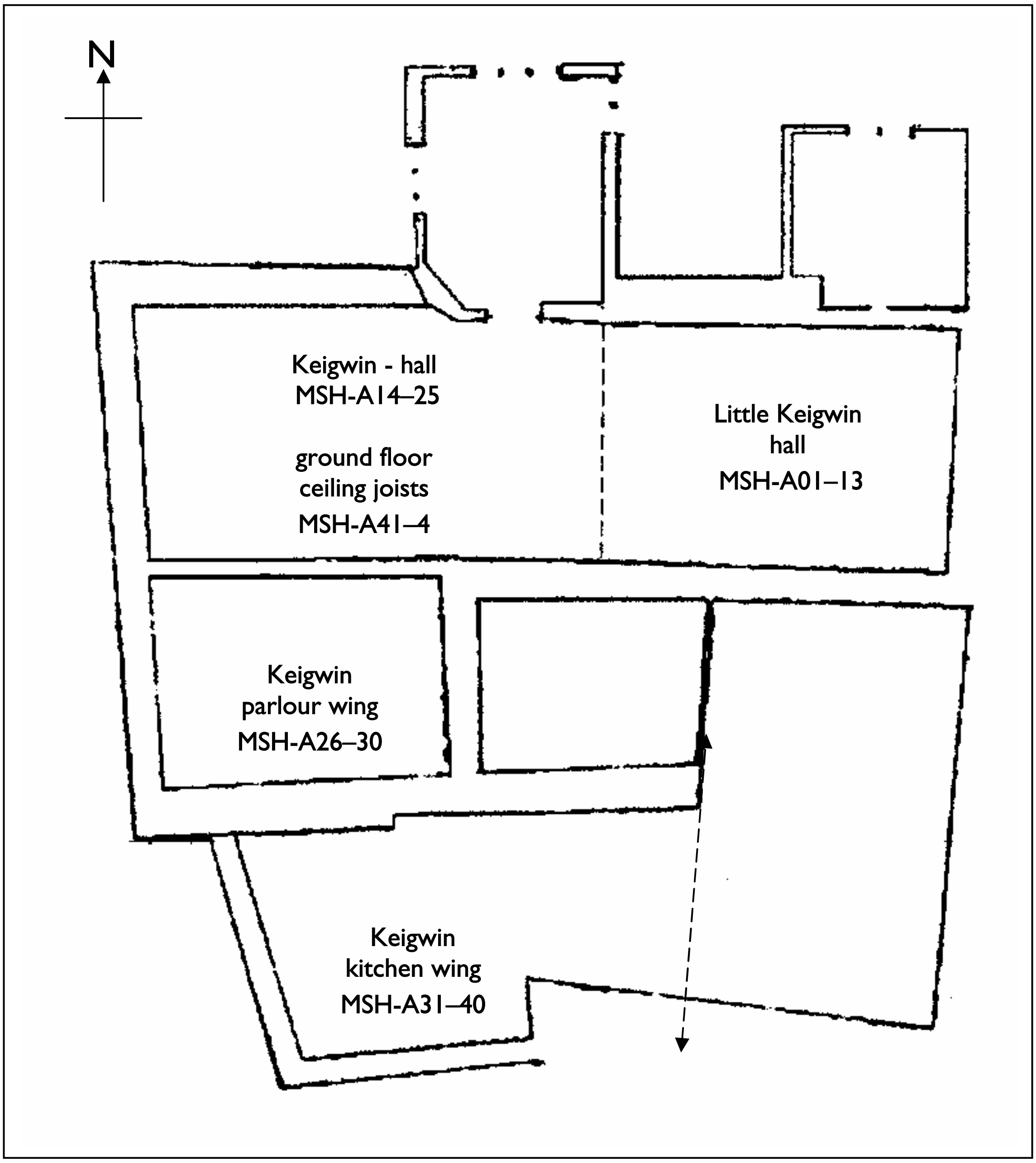


Figure 8: Plan to show different roofs areas of Keigwin and Little Keigwin, and the samples obtained therein

(based on plans by Eric Berry and Nicholas Cahill)

Figure 9: Little Keigwin (the upper chamber roof) showing the partially halved lap-dovetailed (or fishtail) collar joints
(after Eric Berry and Nicholas Cahill)

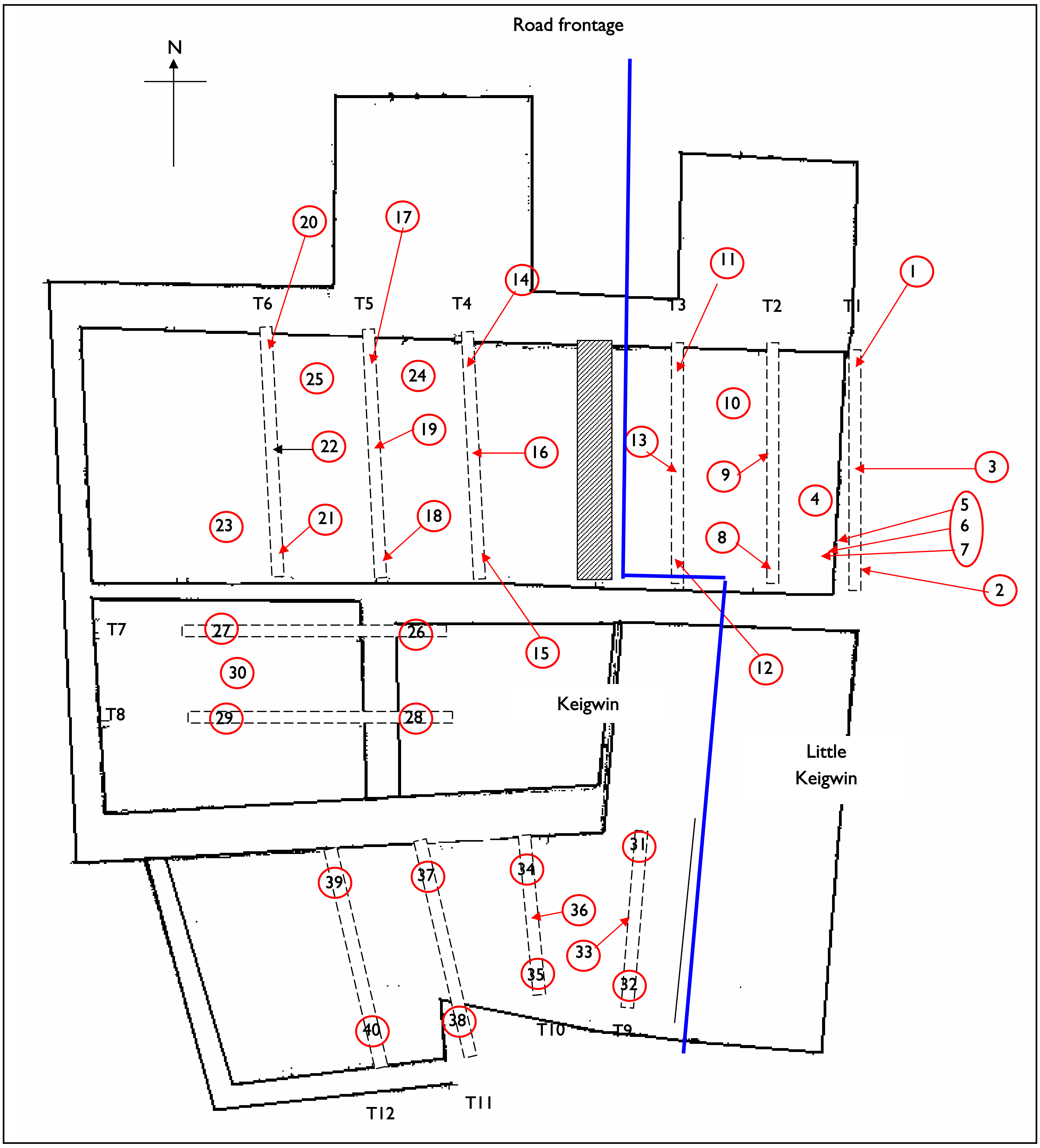


Figure 10a: Plan of the 'Keigwins' to show approximate position of sampled timbers
(after Eric Berry and Nick Cahill)

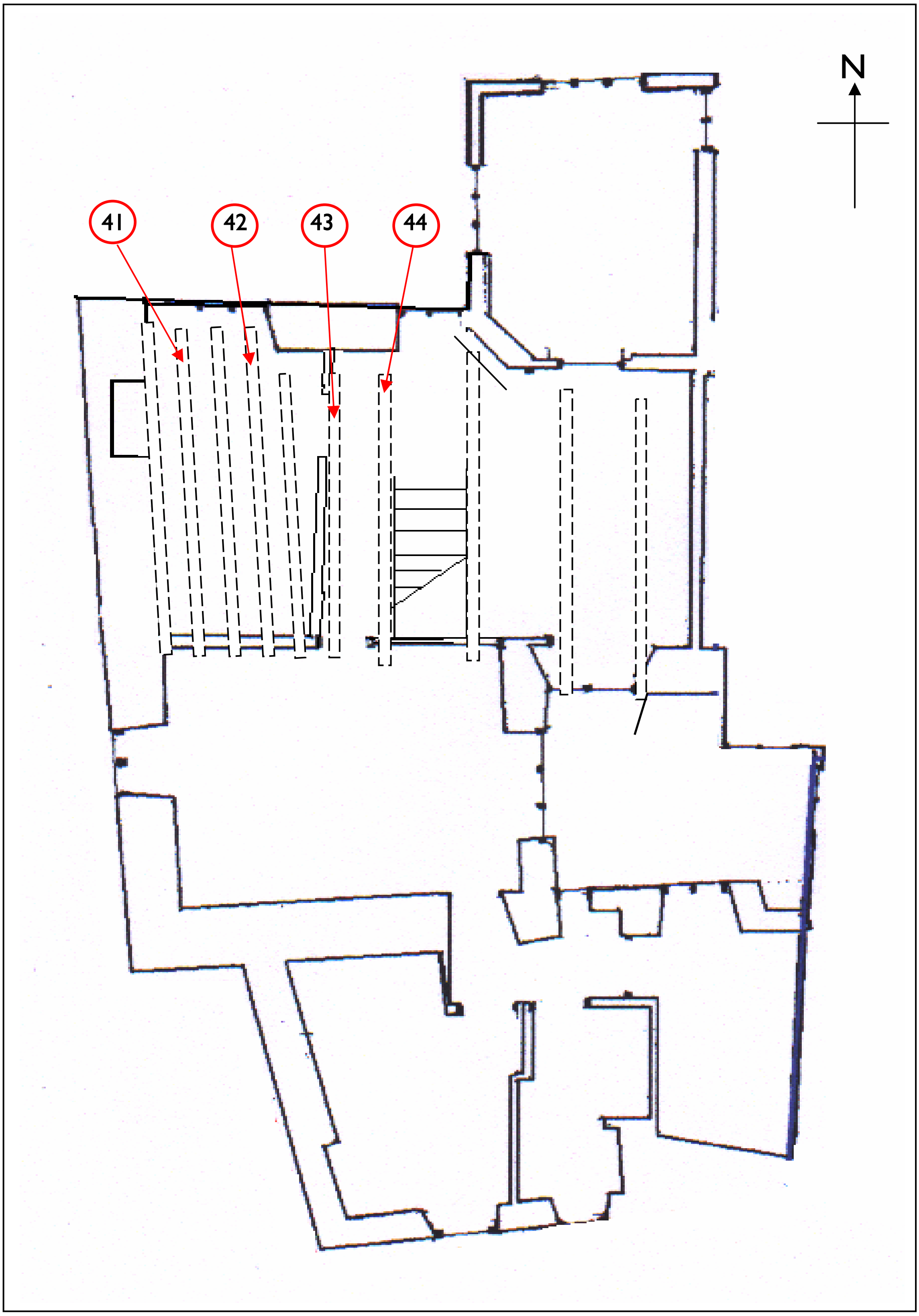


Figure 10b: Plan show samples from the ground-floor ceiling beams of Keigwin
(after Eric Berry and Nicholas Cahill)

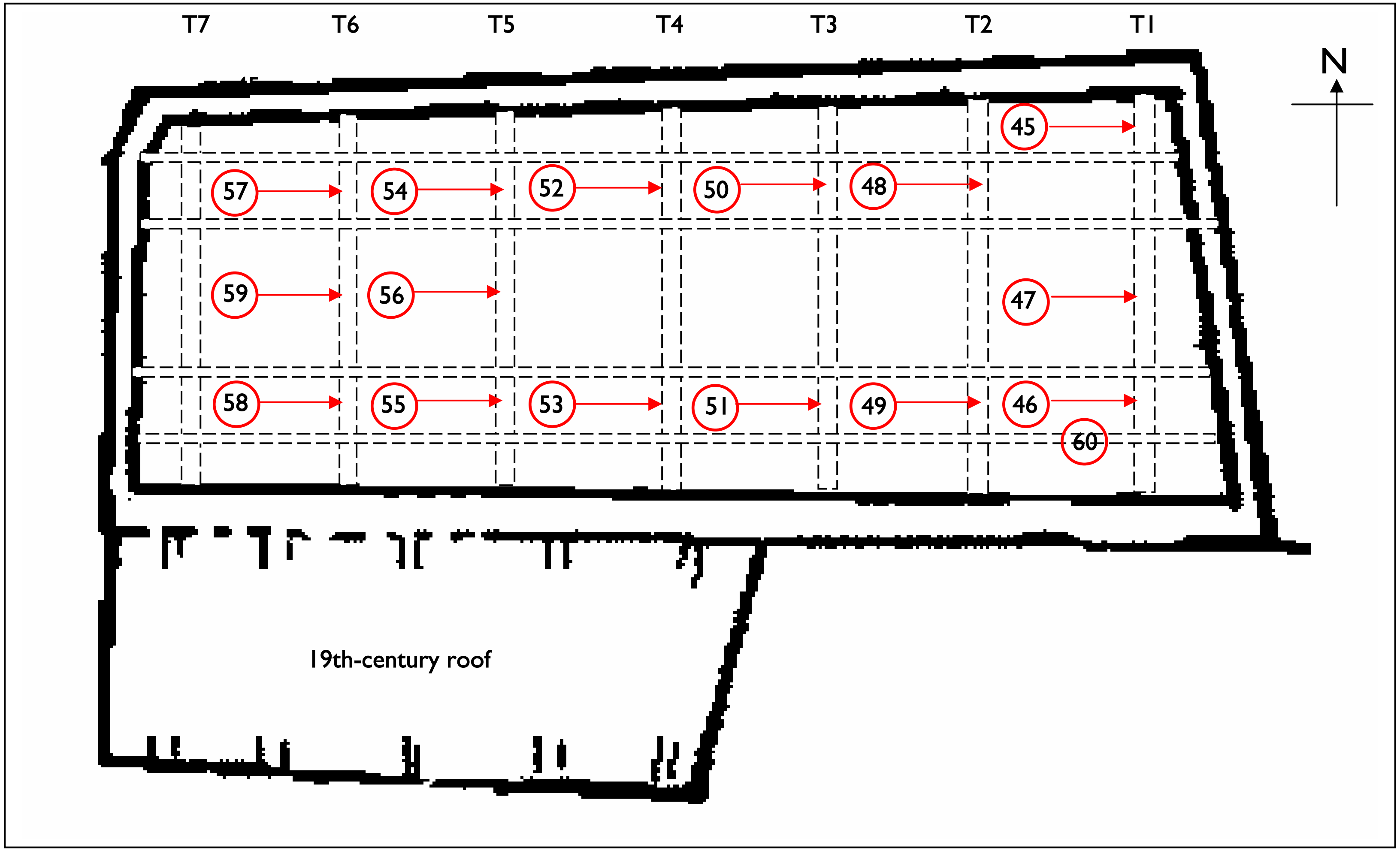


Figure 10c: Plan to show approximate position of sampled timbers from the roof of The Old Standard
(after Eric Berry and Nicholas Cahill)

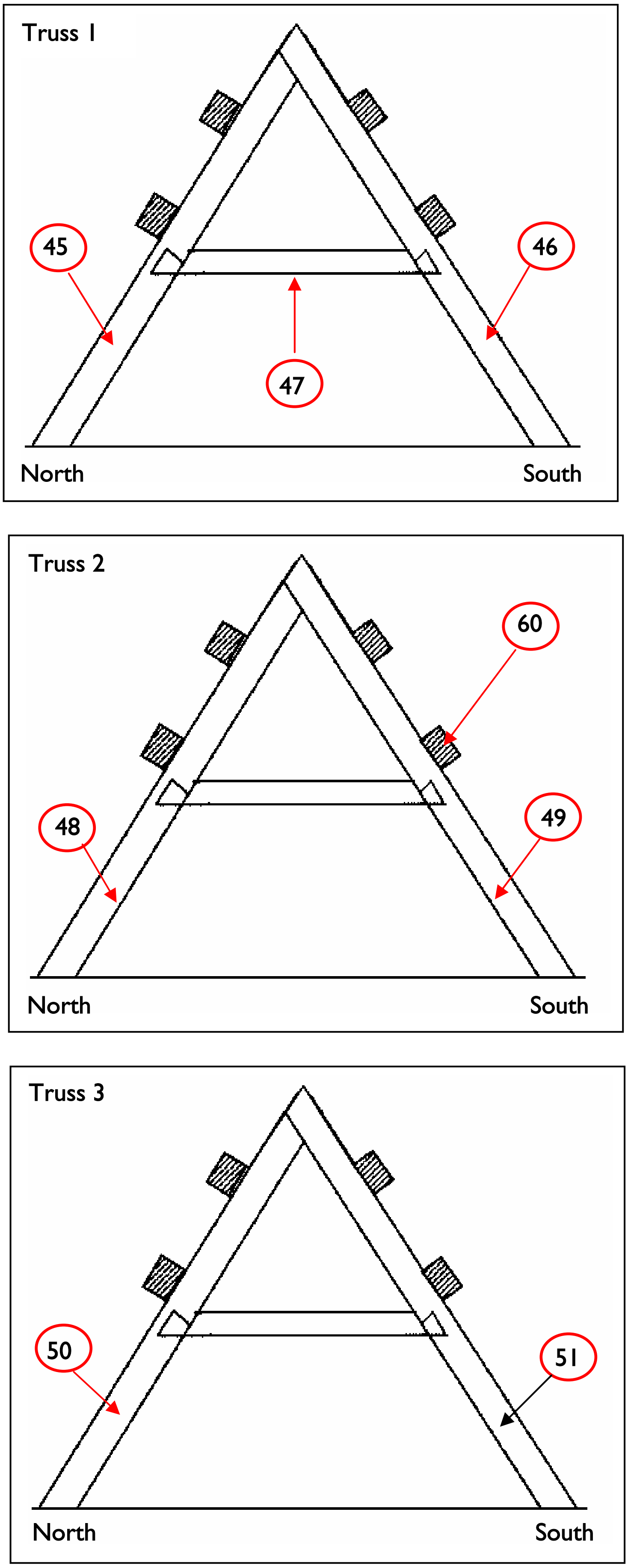


Figure 10d: Drawings to show location of samples from the roof of The Old Standard, viewed from the west looking east (after Eric Berry and Nicholas Cahill)

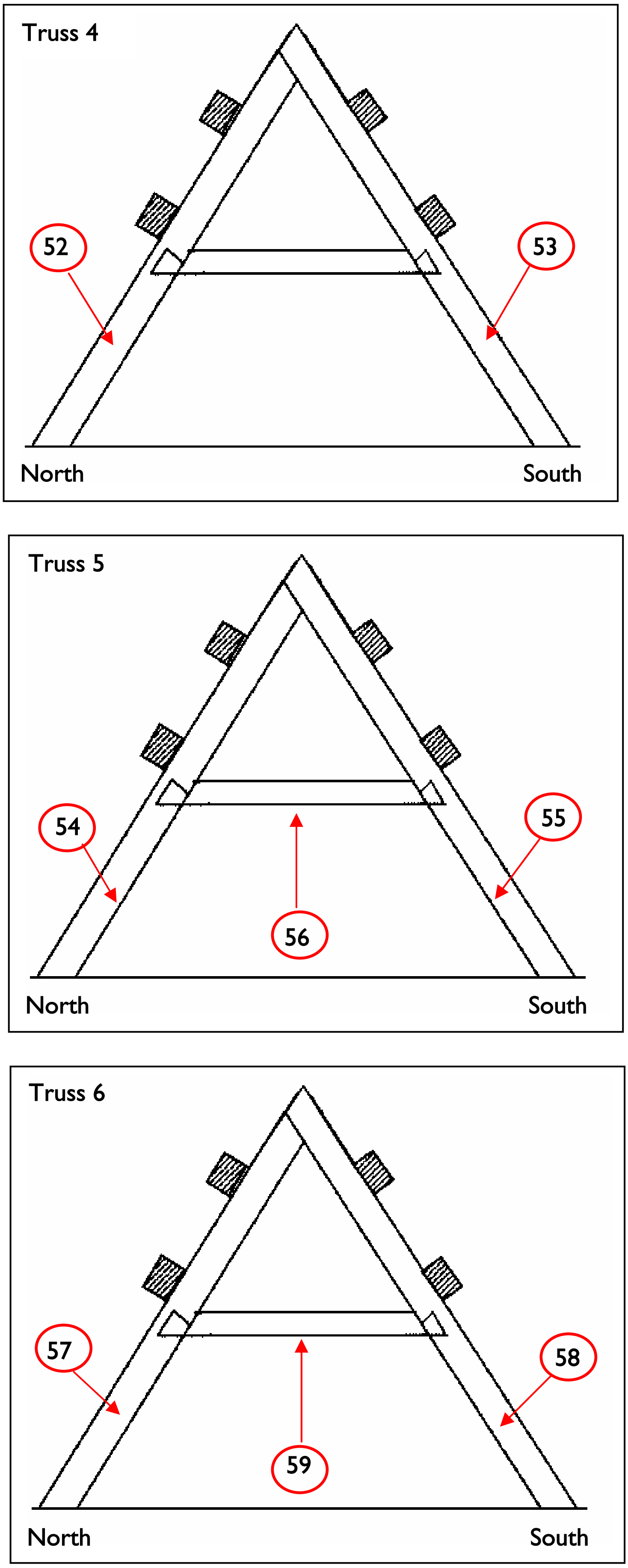
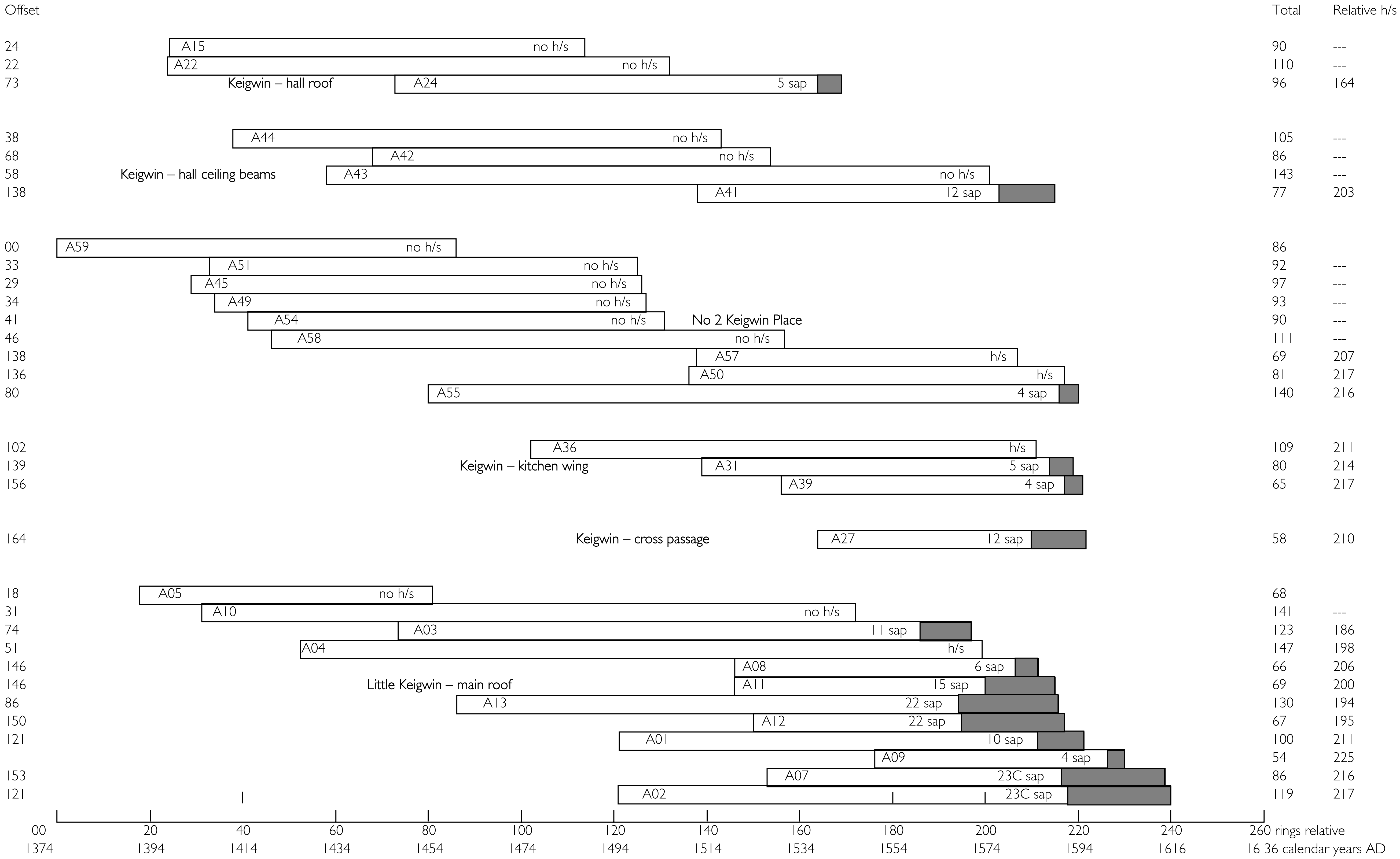


Figure 10e: Drawings to show location of samples from the roof of The Old Standard, viewed from the west looking east (after Eric Berry and Nicholas Cahill)

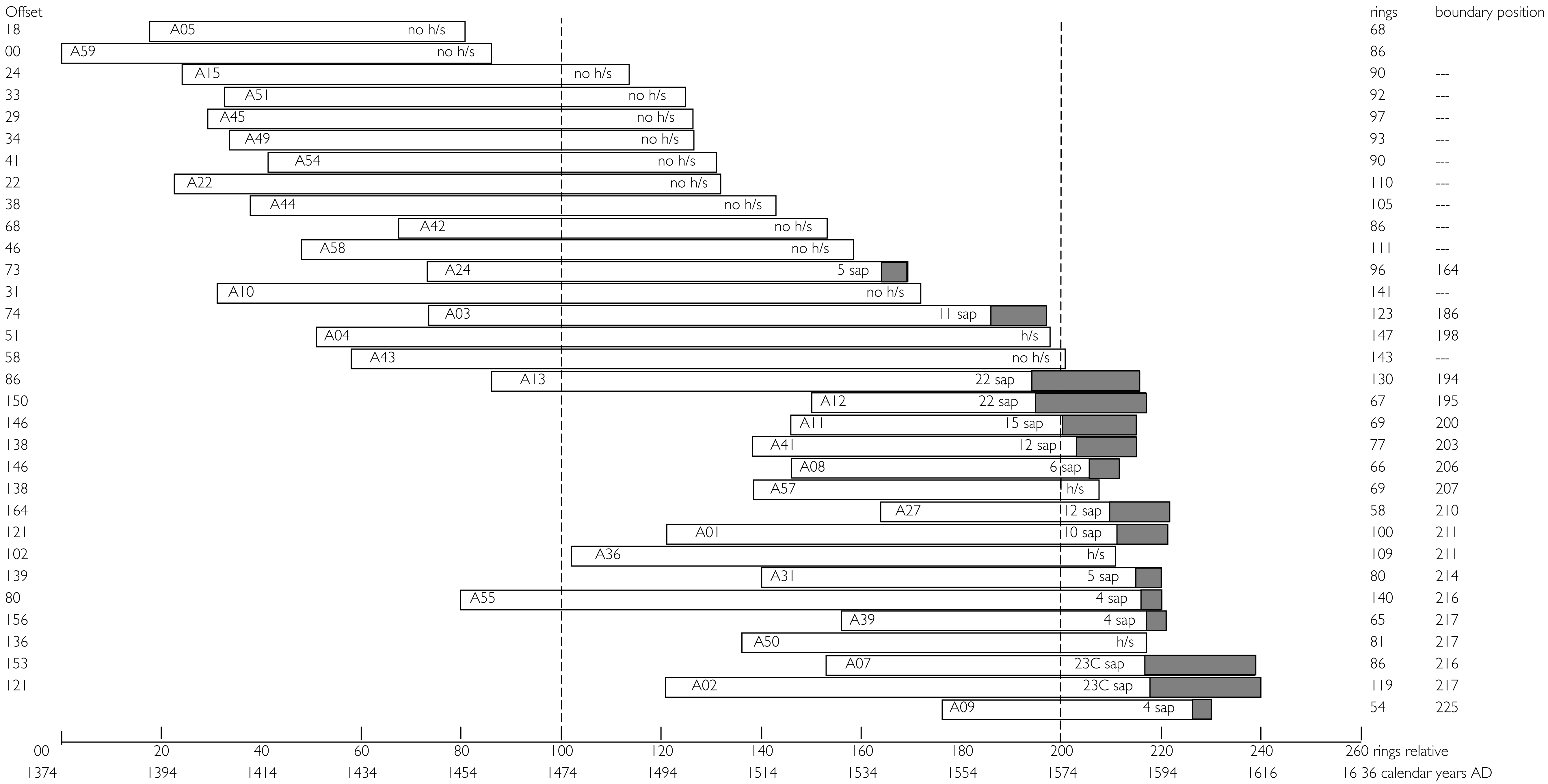


White bars = heartwood rings, shaded area = sapwood rings

h/s = the last measured ring is at the heartwood/sapwood boundary; only the sapwood rings are missing

C = complete sapwood is retained on the sample, the last measured ring date is the felling date of the timber

Figure 11a: Bar diagram of the samples in site chronology MSHASQ01



White bars = heartwood rings, shaded area = sapwood rings
h/s = the last measured ring is at the heartwood/sapwood boundary; only the sapwood rings are missing
C = complete sapwood is retained on the sample, the last measured ring date is the felling date of the timber

Figure 11b: Bar diagram of the samples in site chronology MSHASQ01sorted by last measured ring position for samples without the heartwood/sapwood transition, and by relative position/date of the transition of those with the heartwood/sapwood boundary

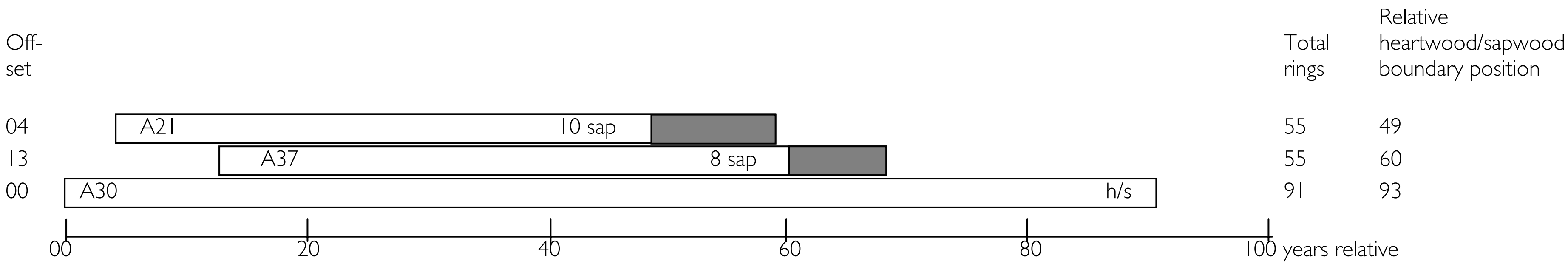
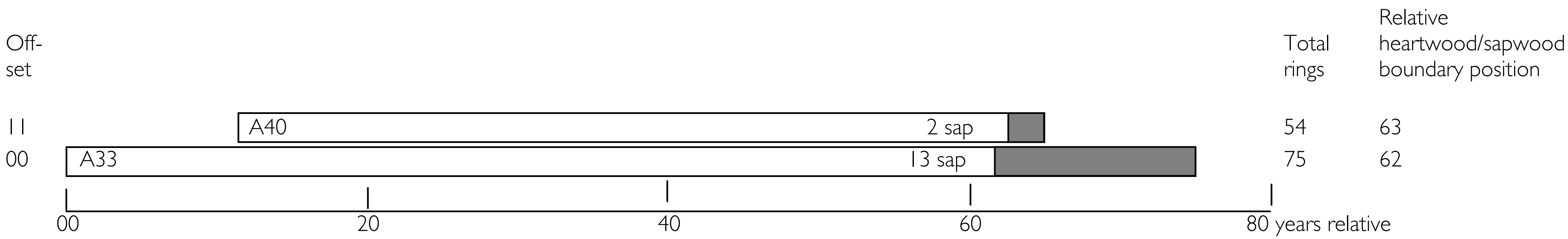


Figure 12: Bar diagram of the samples in site chronology MSHASQ02



White bars = heartwood rings, shaded area = sapwood rings
h/s = the last ring on the sample is at the heartwood/sapwood boundary; only the sapwood rings are missing

Figure 13: Bar diagram of the samples in site chronology MSHASQ03

DATA OF MEASURED SAMPLES

measurements in 0.01mm units

```
MSH-A01A 100
 118  84  77  66  78  80  77  63  61  64  63  69  56  71 132  94 119  87 102  92
  84  81  93 119 113  97  76 107  82  80  79 105  97  99 104  61  94  84  95 106
 108 100  88  89  86 151  98  91 128 125 104  74  89  76 101  93  89  47  62  84
 126  69  87  72 113  67  68 112  68  89  81  59  61  57  83 124 134 100 100  92
  94  76  85  79  84  99 107  67  68  78  83  84  88  71  93  75  66  54  50  87
MSH-A01B 100
  81  84  83  59  83  74  79  61  68  63  70  68  56  63 133  99 125  92  96  94
  84  84  90 116 118  93  83  98  83  81  81 109 100 116  97  64  95 104  85 114
  95 107  87  93  76 161 115  81 133 130  78  80  85  87 100 100  97  41  67  79
 102  75  84  80 107  68  71 118  66  89  80  51  72  55  78 113 130  93 106 108
  88  87  72  86  87  99  95  62  83  82  76  84  85  66 108  50  70  68  44  98
MSH-A02A 119
  77 138 115 108  77  60  63  77  43  67  72  78  84  79 104  68  85  91 101  92
  83  71  71 110 103 123  91 112 111 120  94  91  97  97  93  99  91  91 121 145
 113 120 215 145  87 101 109 100 159  93  90  92  87  81  93  75 109  61  82  66
  76  82 104  69  91  60  92  63  85  96 143  91  77  83  90 129 165 115 100 148
  94  82  75  85 114 115 126  83  94  96  79  75  87  79 143 133  91 123 163 146
 127 108 128 139 138 156 159  93 112 117  80 128 111 123 135  86  95  54  60
MSH-A02B 119
  93 125 113 105  68  62  67  73  49  60  78  90  91 122  88  70  88  97  99  82
  69  74  73 115 100 131 108 109  92 124  92 108  80 104  96 102 112  73 125 144
 108 121 195 152 102  95 110  97 133  96  84 103  73  82  90  82 105  60  75  70
  82  74 110  70 100  59  94  66  75  96 111  95  76  84 108 119 162 111 107 152
  85  86  72  82 105 120 131  78 102  83  79  73  88  80 157 100  95 137 139 150
 122 107 134 156 124 149 144  91 103 122 100 120 110 135 130  91  91  47  59
MSH-A03A 123
 115 155  93 157 103 129 161 126 143  74  87  52  52  78  78  94  86 108 150 146
 102 102 125 123 128 147 183 216 235 214 161 148 125 184 134 148 135 153 139 157
  82 103 111 125 131 135  99 110  85  92  66  71  52  55  40  60  66  83 110  99
  80 121 105  98 100  84 111 103 176  98  95 121 104  97 135  83 121 135 125 106
 116 103  89 155 128 115 100  93 125 115  85 104 125 103  94  74  70  78 122 122
 102  74 108 142  92  91  89 158 122 108  78 137 100 104  89  70  75  80  53  41
  46  46  72
MSH-A03B 123
 151 127  79 150 106 131 170 116 149  80  71  54  55  67  93  92  84 124 133 115
 117  96 113 135 137 144 184 208 228 219 159 146 129 182 136 139 130 159 146 161
  87 103 113 117 131 146  91 110  90  88  66  67  44  56  49  55  70  89 113  92
  87 112 109 100  97  91 102 119 176  86 116 113  93 113 154  97 131 144 126 113
 117  92  95 156 131 121  95  85 115 124  79  86 126 104  96  86  70  72 115 122
 101  86  98 137  88  92  85 145 132 100  67 143 106  83 110  56  88  89  53  45
  45  41  83
MSH-A04A 147
  71  73  46  69  66  83  72  86  74  84  93  92  81  97  71  87  50  60  33  30
  37  31  49  42  49  43  58  41  59  59  58  64  47  77  47  76  43  41  41  36
  38  29  58  76  53  62  57  49  44  44  46  43  44  41  45  40  55  50  56  59
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  98 111  92  91  81  47  70  48  40  65  60  69  84  61  82  83  71  59  84  83
 127  76  90  76  85  84  70  55  50  66  95  68  73  84  80  70  61  73  67  95
  84  62  48  58  63  78 108
MSH-A04B 147
  86  65  53  60  71  72  69  86  82  81 104  94  94  87  80  79  56  53  47  36
  34  35  50  46  45  36  52  45  52  71  47  57  51  71  43  69  43  44  32  41
  40  35  56  75  54  55  65  50  43  47  51  39  40  40  52  48  46  55  52  62
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  26  36  41  41  53  52  47  47  35  41  39  39  27  42  73  59  73  98  72  92
  88 111  86  99  75  56  72  54  51  44  71  74  72  75  68  95  69  61  91  71
 128  82  89  75  88  77  88  39  49  71  89  73  69  84  81  70  68  68  67  99
  83  53  47  71  63  82 104
MSH-A05A 68
 123 184 175 198 230 141 170 150 161 115  88 204 151 186 196 139 142 199 169 133
 109 119 102 135 118  94  96  51 139 127  47  91  86  46  64  47  66  76  82  99
 102  82  49  75  57  95  74  62  82  53  39  43  61  65  83  67  69  67  62  99
  61  67  64  46  79  75 104 102
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MSH-A05B 68
 138 181 163 202 242 154 173 144 158 111  88 204 154 196 191 135 148 191 149 122
 124 110 106 135 109 107  90  61 146 103  58  85  93  39  66  51  76  69  84  93
  97  85  57  62  68  83  87  66  70  54  40  46  60  71  84  75  66  62  61  82
  63  57  68  54  77  77  93  96
MSH-A06A 81
  43  45  32  76  57  93  60  54  73  72  69  59 105  94  98 134  73  70  53  59
  50  64  69  82  64  65  67  58  67  53  75  68  75  76  90  86  86  66  88  80
 113  91  92 151 111  92 113  94  70 103  80  93  79  72  75  78 101  80  79  69
  81  65 106  63  71  65  76  63  61  59  75 112 111 118  93 118  99 121 128  97
 111
MSH-A06B 81
  40  46  34  70  56  97  53  66  69  67  80  61  94  83  93 139  79  64  72  49
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 131  85  97 156  98 109 103  95  73  91  89  72  79  77  70  83  96  89  72  78
  77  69 100  66  69  58  74  59  61  71  58 125 102 110 102 122 100 109 133  99
 121
MSH-A07A 86
 125 102  93  82 102  87 140 147 128 123 154 134 111 115 120  97 159 120  90 113
 112  79 102  90 114  68  89  77  95  88 123  98 107  89  97  99  80 129 119  96
  94  68  92 109 151 143 116 178 119  94  72  94 104 118 115  89 100  86  92  93
 129 101 195 109 101 132  81 111  96  83 122  82 109  96 174 115  60  99 106 110
  86 101  88  65  61  63
MSH-A07B 86
 142 104  80  97  85  98 125 154 121 129 179 131 101 127 116 100 159 124  97 108
 117  73 104  86 115  70  89  86  99  87 110 104  93 100  90  94  81 125 128 109
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 130  97 213 113 100 113  89 126  87  83  96  85  96 100 125  74  80  85  85  94
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MSH-A08A 66
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  71  90 180 105 101  83  54  52  86  87  98 153 122 112 113 110 150
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MSH-A46A 82
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 146 219 207 147 186 153 139 158 138 176 193 180 202 180 157 125  94 104 105 112
 157 134  84 125 152 130 142 138 122 146 115 133 130 186 160 121  85 114 123 101
 123 147
MSH-A46B 82
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 178 220 201 123 170 203 190 131 100 161 255 219 127 115 203 222 185 186 169 161
 154 177 189 159 190 149 127 157 128 181 202 187 183 166 167 118  96 111 107 118
 139 132  98 125 143 138 135 135 118 148 126 135 135 179 156 126  84 109 129  96
 110 163
MSH-A49A 93
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MSH-A49B 93
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 133 139 127 147 146 172 114 189 183 142 109 131 124 101 102  86  77  72  66 109
 181 168 147 153 169 151 109  93  90 116 128 118  90  99 104 101 116 101 114 123
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MSH-A51A 92
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 159  94  97 131 117  80  77 118 135 147 116 142
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 111 120 143 111 127 159 115 141 129 115 132  91  88  77  62  68  42  42  52  62
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  71  87  92 134 107 156 154 158 162  87 112 110 122 168 119  55  47  62  58  67
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  75  77  96 132 103 161 166 155 166  84 114 115 128 160 130  62  52  50  64  72
 122 135  67  84  97 106 118  99  83  65  80  84 114  65  51  34  39  39  53  53
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MSH-A55A 140
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 101 142 125 100  77  68  70  80  73  61  55  66  59  98  69  67  50  35  40  42
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MSH-A55B 140
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  82 108 114 145 152  96  76  93 171 163 161 143 151 139 121 119 111 153
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 231 202 260 260 162 208 254 223 266
MSH-A57B 69
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MSH-A58A 111
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MSH-A59A 86
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 102 131 202 160 165 168 137  82  62 123 137 229 189 128 127 121  80  63 114 100
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MSH-A59B 86
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 104 117 201 148 173 159 173  96  75 134 141 229 185 127 128 123  84  65 110 107
 109 128 167 148  72  57 118 108  38  60  67  99 108  82  86 115 127 121 123 139
 151 164 189 206 107  77  56  52  28  26  54  68  85 134  91  91  86  92 104 102
 144  76  72  48  91  72
MSH-A60A 62
 163 140 188 111  93 145  99  97  92  95 130 145 193 268 183 197 263 292 263 267
 220 217 182 190 166 116 147 164 161 172 147 163 119 135 144 151 164 207 182 134
 116 126 165 116 138 190 143 110 117 125 155 191 169 145  92  85  82 125 133 138
 104 123
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MSH-A60B 62
 126 138 185 128 112 137 103 101  92 105 160 144 172 263 181 196 262 275 280 268
 215 221 190 181 155 128 144 172 157 171 157 158 124 135 140 155 158 215 168 130
 130 125 163 121 133 192 140 109 117 130 153 173 172 139  89  96  85 119 141 129
 109 137
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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,

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

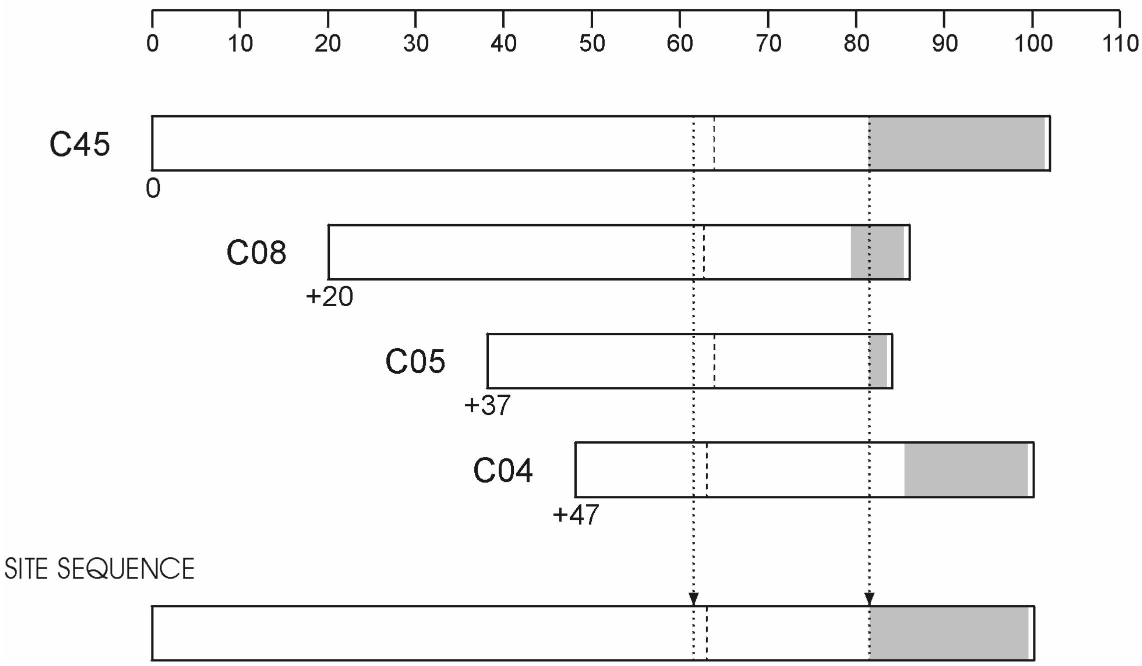


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

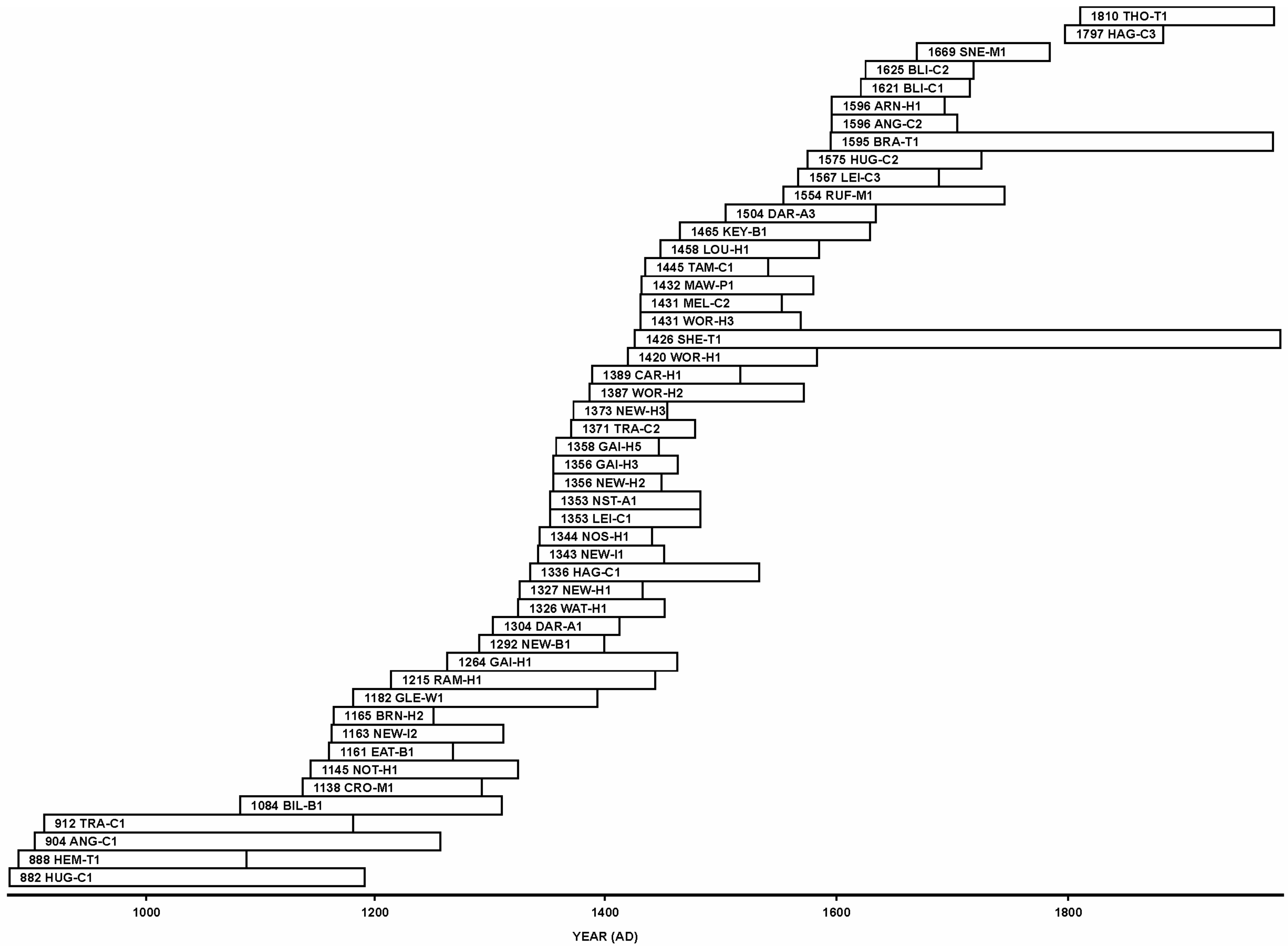
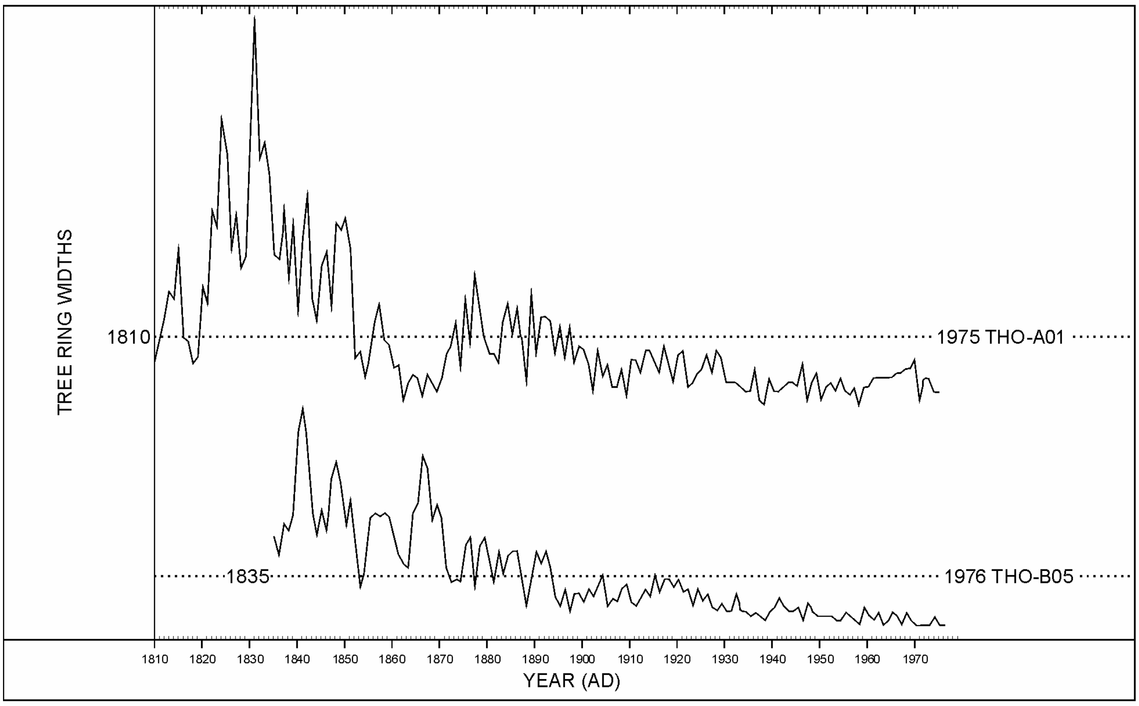


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

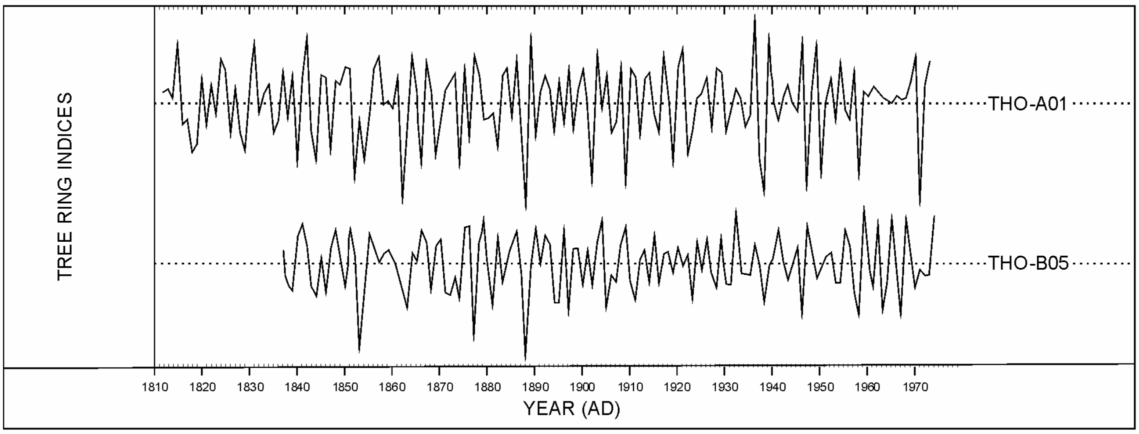


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

References

Baillie, M G L, and Pilcher, J R, 1973 A simple cross-dating program for tree-ring research, *Tree-Ring Bull*, 33, 7–14

English Heritage, 1998 *Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates*, London

Hillam, J, Morgan, R A, and Tyers, I, 1987 Sapwood estimates and the dating of short ring sequences, *Applications of tree-ring studies*, BAR Int Ser, 3, 165–85

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1984–95 Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect*, 15–26

Hughes, M K, Milson, S J, and Legett, P A, 1981 Sapwood estimates in the interpretation of tree-ring dates, *J Archaeol Sci*, 8, 381–90

Laxon, R R, Litton, C D, and Zainodin, H J, 1988 An objective method for forming a master ring-width sequence, *P A C T*, 22, 25–35

Laxton, R R, and Litton, C D, 1988 *An East Midlands Master Chronology and its use for dating vernacular buildings*, University of Nottingham, Department of Archaeology Publication, Monograph Series III

Laxton, R R, and Litton, C D, 1989 Construction of a Kent master dendrochronological sequence for oak, AD 1158 to 1540, *Medieval Archaeol*, 33, 90–8

Laxon, R R, Litton, C D, and Howard, R E, 2001 *Timber: Dendrochronology of Roof Timbers at Lincoln Cathedral*, Engl Heritage Res Trans, 7

Litton, C D, and Zainodin, H J, 1991 Statistical models of dendrochronology, *J Archaeol Sci*¸18, 29–40

Miles, D W H, 1997 The interpretation, presentation and use of tree-ring dates, *Vernacular Architect*, 28, 40–56

Pearson, S, 1995 *The Medieval Houses of Kent, an Historical Analysis*, London

Rackham, O, 1976 *Trees and Woodland in the British Landscape*, London