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**Summary**

Fifty-one samples were obtained from within this building of which forty-three were analysed in conjunction with approximately 90 other samples obtained by other Laboratories during previous programmes of dating. This combined analysis produced four site sequences.

The first sequence, which included twenty-three newly measured samples, has 168 rings and spans AD 1489 - AD 1656. Interpretation of the sapwood indicates that two phases of felling are represented, the first in AD 1612 - 18, the second in AD 1652 -56.

The second sequence consists of three new samples having 180 rings spanning AD 1069 - AD 1248. It is unlikely that these timbers were felled before AD 1263, and they probably represent reused material.

The third sequence also includes three new samples and indicates timber felled in AD 1459, AD 1536, and between AD 1591 to AD 1616.

The fourth sequence contains four new samples. Although 101 rings long, it cannot be dated.

This programme of analysis confirms the use of probable late-thirteenth or early-fourteenth century timber, a mid fifteenth-century phase of building, the use of timber felled in the mid-sixteenth century, and the extensive early seventeenth-century redevelopment. This analysis, however, also shows a hitherto undated mid seventeenth-century phase of felling.

**Keywords**

Dendrochronology
Standing Building

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## Introduction

Staircase House, sometimes referred to as "Staircase Café", comprises a confusing and rambling range of timber-framed buildings on several levels fronting, and running northwards from, the north-east side of the market place in Stockport (SJ897906; Figs 1 and 2). The apparently long history of the site, its development and alterations, the fact that the land slopes away to the rear or north of the building, and that a street frontage is to be found along its east side have made for a juxtaposition of garrets and gables. A schematic outline plan of the site is given in Figure 3, showing the site broken up into its basic elements of street frontage, timber-framed and stone-built rear wings, the jettied structure, and the northern and southern warehouse.

In its original form it is believed to have been a timber-framed merchant's townhouse with warehousing and storage, and is thus an important survival in the town. It is currently listed as a Grade II* building. Parts of the building have already been the subject of tree-ring analysis. A small number of samples were obtained in AD 1990 during minor works to the upper floors. The dating at this time of three samples from the cruck elements indicated a probable mid to late fifteenth-century felling date for the timbers used in this early phase (Esling *et al* 1990).

A further very modest number of samples was obtained in AD 1996 (Tyers 1996). It was only as a result of a subsequent fire that a more substantial programme of sampling was initiated. The results of this work show that the felling of some timbers used here may have taken place in the mid-sixteenth century, with modifications on a larger scale taking place later using timber felled in the early seventeenth century (Tyers 1999). There was also evidence at this time that timber probably originally felled in the late-thirteenth century was reused here.

Although hindered by partition walls, roofs, ceilings and other obstructions, plus safety considerations, these three episodes of tree-ring analysis have between them already produced cores from 90 different oak timbers. Unfortunately, almost certainly due to the limited nature of access to large quantities of timbers from any one phase, the number of samples from this site that have been dated is low.

Since 1999 30A & 31 The Market Place have been purchased by Stockport Metropolitan Borough Council to become the centrepiece of a Heritage Lottery funded redevelopment of the area into retail, museum, and information space. The fire action, subsequent repairs and the current (AD 2002/3) redevelopment has provided an opportunity to re-examine the structure in terms of its possible historical phasing and sequential development. This work, with its removal of many latter internal divisions and its provision of large scale scaffold platforms, has allowed greatly increased access to areas and timbers that were previously beyond reach.

## Sampling

As a result of previous tree-ring analysis it was believed that the building contained two distinct phases, the original late fifteenth-century merchants town house and its subsequent modification in the early seventeenth century, with minor elements of other phases of felling representing other alterations also being present. The current programme of sampling and analysis by tree-ring dating of timbers from this building were commissioned by English Heritage. The purpose of this was to provide a more extensive range of samples so that, in conjunction with those obtained previously, a greater proportion of the total might be dated. It was hoped that this would provide a more comprehensive chronological framework for the development of the complex and hence guide repair priorities.

Thus, fifty-one different oak timbers from a wide range of locations within the building were sampled by coring. Each sample was given the code STK-A (for Stockport, site "A"). Given that 90 samples have already been obtained from this complex these new samples were numbered consecutively 91 – 141. Since one of the purposes of this programme of analysis was to provide material for dating, timbers were selected by a number of criteria. Timbers were selected for sampling not only on the basis of their appearing to be original or directly related to a phase or structure, but also on having sufficient rings for satisfactory analysis by tree-ring dating and on the basis of having sapwood or the heartwood/sapwood boundary. Timbers were also selected if it was thought that they would provide good dendrochronological samples, that is those with plenty of rings, whether they had the heartwood/sapwood boundary or not. This was done in order to increase the chances of dating a greater proportion of the timbers and make the site chronology more robust. Timbers which appeared to be reused within a phase or structure were also sampled.

In respect of this sampling strategy however, it was very noticeable that a great many timbers were very wide ringed, thus having too few rings and being unsuitable for analysis, despite their size. This was particularly so with the wall framing on the east, northern, and western side, and with the timbers of the majority of roofs. It was only with persistent examination that additional timbers with sufficient rings could be found.

Drawings showing the layout of the building made by Greater Manchester Archaeological Unit were provided by English Heritage, with other drawings being supplied by the architects, Donald Insall. Given that these are survey or building plans they do not always show individual timbers, and the positions of the beams samples can be marked only approximately. These drawings are reproduced here as Figures 4 - 7 Details of the samples are given in Table 1 and can be used in conjunction with the drawing to locate timbers sampled. In this report all elements of timbering, trusses, frames, bays, posts, etc, have been numbered and described on a north to south, or east to west basis as appropriate.

The Laboratory would like to take this opportunity to thank a number of people for their help and cooperation during this programme of sampling. Firstly we would like to thank Robina McNeil of Greater Manchester Archaeological Unit for her help in discussing the possible phasing of the building. We would also like to tank Robin Fraser of Donald Insall Associates, Architects for arranging site access and for helpful on-site discussions. We would also like to thank John Baskerville, foreman and site agent to the builders for being so enthusiastic about the project, and providing ladders, cables, lights, and other equipment during sampling.

We would also like to thank Ian Tyers of the University of Sheffield Dendrochronology Laboratory for so readily making available the data from the 1996 and 1999 programmes of sampling and for providing copies of the report.

## Analysis

Each of the fifty-one newly acquired samples was prepared by sanding and polishing. It was seen at this stage that eight samples had less than 54 rings, too few for satisfactory analysis, and the annual growth-ring widths of these were not measured. The data of the remaining 43 samples measured are given at the end of the report. For the purposes of analysis the growth-ring widths of the 43 newly measured samples and the measured samples from the earlier analysis by the Sheffield University Laboratory were all compared with each other by the Litton/Zainodin grouping procedure (see appendix). At a minimum *t*-value of 4.5 four groups of samples, which included a mixture of new samples and those obtained previously, could be formed. Other groups, which contained only samples from the previous analysis, could also be formed, but as they have already been reported upon they are not repeated here.

The growth-ring widths of all cross-matching samples obtained in all programmes of coring were combined at the indicated relative off-set positions to form site chronologies STKASQ01 – STKASQ04. Each of the four site chronologies was then compared with a series of relevant reference chronologies for oak. This indicated dates for three site chronologies, the *t*-values for this dating being given in Tables 2 – 4. Each of the four site chronologies was then compared with the other three and with the remaining newly measured, ungrouped, samples but there was no further, satisfactory, cross-matching.

Each of the 10 remaining newly measured ungrouped samples were then compared individually with a full range of relevant reference chronologies for oak but, again, there was no further satisfactory cross-matching.

Although the four site chronologies STKASQ01 - STKASQ04 have been produced by analysis of *all* samples obtained from this site, for the purposes of this report the relative off-set positions of the *newly* acquired samples only in each group are shown in the bar diagrams, Figures 8 – 11; for the purposes of clarity the samples obtained in earlier programmes are omitted. Because of this method of all inclusive analysis but exclusion of earlier samples from the bar diagrams, it will be seen that in some instances, site chronology STKPSQ03 for example (Fig 10), some of the newly measured samples do not overlap with each other by very much, or indeed, in one instance, at all. This analysis is summarised below/overpage.

| Site chronology | Number of newly taken samples | Number of rings | Date span (where dated) |
|---|---|---|---|
| STKASQ01 | 23 | 168 | AD 1489 – AD 1656 |
| STKASQ02 | 3 | 180 | AD 1069 – AD 1248 |
| STKASQ03 | 3 | 54 (A104)<br>111 (A106/136) | AD 1406 – AD 1459<br>AD 1466 – AD 1576 |
| STKASQ04 | 4 | 101 | Undated |
| Ungrouped | 10 | --- | Undated |

## Interpretation

Analysis by dendrochronology has produced four site chronologies. The first and largest site chronology, STKASQ01, includes twenty-three newly acquired samples which together have a combined length of 168 rings. This is dated as spanning the period AD 1489 to AD 1656. It is believed that the two major phases of felling are represented by this site chronology. This is shown in Figure 8 and also in Figure 12 where the newly acquired samples are sorted by sampling group and shown in relative last ring position.

The first major phase is represented by the samples from the ceiling joists of the ground-floor room G8 (samples A97 - A100), the samples from the roof timbers of first-floor room F10 (samples A103, A107, A108, and A112) and the samples from the wall timbers of the first-floor room F10 (samples numbered between A113 - A123). Samples within each of these groups retain complete sapwood with last measured complete sapwood rings dates, and thus felling dates, of AD 1617 (STK-A97), AD 1612/1618 (STK-A112/A108), and AD 1620 (sample STJ-A116), respectively. The relative positions of the heartwood/sapwood boundaries on the other dated samples within this sub group appear to be consistent with the same, or very similar, felling dates. The second major phase of felling, represented by site chronology STKASQ01, may be seen in the roof and wall timbers of the first floor, room F11 (samples STK-A141, and samples A126/127 respectively), the timbers of the roof over the second-floor room S5 (samples A128, A130, and A134), and probably in the timber of the west wall of room G5 (sample STK-A95). Two samples in this sub-group, STK-A128 and A130, again retain complete sapwood, with last measured rings dates of AD 1652 and AD 1656 respectively. Again, the relative positions of the heartwood/sapwood boundaries on the other dated samples within this sub-group appear to be consistent with the same, or very similar, felling dates.

The second site chronology, STKASQ02 (Fig 9), includes three newly acquired samples of combined length 180 rings and dated as spanning the years AD 1069 - AD 1248. None of the samples in this group, all from reused rafters of the roof over room F11A, has the heartwood/sapwood boundary. Because of this it is not possible to say when the timbers they represent were felled but while two could have been felled earlier in the thirteenth century, it is unlikely that at least one of them STK-A138, was felled before AD 1263. This date is based on a 95% confidence limit of 15 rings for the minimum number of sapwood rings the trees might have had. Trees with such high numbers of rings are relatively uncommon particularly in the later medieval period. This, and their last ring dates, would suggest that the trees represented were felled in the early fourteenth-century at the latest.

The third site chronology, STKASQ03 (Fig 10), also contains three newly taken samples. However, these three samples appear to represent three phases of felling. The first phase is represented by sample STK-A104 from a roof timber of room F10. This sample has complete sapwood with a last measured ring date of AD 1459. It is possible, though not at all certain, that this is a reused timber from the original mid to late fifteenth-century cruck building.

The second phase of felling represented in site chronology STKASQ03 is that indicated by sample STK-A106, also a roof timber of room F10. This again has complete sapwood with a last measured ring date of AD 1536.

The third phase of felling seen in this group is represented by sample STK-A136, a stud post from the south wall of the southern warehouse. This only has the heartwood/sapwood boundary, this being dated to AD 1576. Using a 95% confidence limit for the amount of sapwood on mature oaks of 15 - 40 rings would give the timber represented by this sample an estimated felling date in the range AD 1591 - AD 1616. It is just possible that this sample represents timber felled as part of the major early seventeenth-century redevelopment of the site.

The fourth and final site chronology, STKASQ04 (Fig 11), contains four newly measured samples of combined length 101 rings. This site chronology cannot be dated. It does however represent at least two distinct periods of felling. The earliest is certainly represented by sample STK-A109, which has complete sapwood. This earlier phase of felling might also be represented by sample STK-A133. This sample does not have the heartwood/sapwood boundary but is unlikely to have been felled earlier than 15 years after its last heartwood ring date. This would put its felling at about the same time as that represented by sample STK-A109. A later phase of felling is represented by sample STK-A129 which has a heartwood sapwood/boundary at a relative position well after the last complete sapwood ring on sample STK-A109.

This interpretive information may be summarised below:

| Site chronology | Sampling area | Sample numbers | Felling date (actual or estimated) |
|---|---|---|---|
| STKASQ01 | Ground-floor room G8, ceiling joists | A97, A98, A99, A100 | |
| | First-floor room F10, roof timbers | A103, A107, A108, A112 | |
| | First-floor room F10, wall timbers | A113, A116, A118 | |
| | | A120, A121, A122, A123 | AD 1612 -20 |
| | First-floor room F12, wall timbers | A116, A119 | |
| | Ground-floor room G5, wall timbers | A95 | |
| | First-floor room F11 / F11A | A141, A126, A127 | AD 1652 - 56 |
| | Second floor, walls and roof over room S5 | A128, A130, A134 | |
| STKASQ02 | Roof over first floor room F11A | A138, A139, A140 | Probably not before AD 1263 |
| STKASQ03 | Roof of first-floor room F10 | A104 | AD 1459 |
| | Roof of first-floor room F10 | A106 | AD 1536 |
| | First floor, south warehouse | A136 | AD 1591 - AD 1616 |
| STKASQ04 | Cruck truss | A109 | Undated |
| | Second-floor room S5 | A129 | Undated |
| | Roof over second-floor room S5 | A132, A133 | Undated |

## Conclusion

Sampling and analysis by tree-ring dating in the present programme, as in the AD 1999 analysis, has again shown that the early seventeenth-century redevelopment and alteration of the site was extensive. Given that timber used in this work was felled over a period of AD 1612 - 18, the work may have taken some time and have been of an extremely large scale and of early seventeenth-century date as expected.

As in the previous analysis, this programme has also found very slight evidence of the use of timber felled in the sixteenth century, and of timber probably felled in the later thirteenth or early fourteenth century. There is also one instance of timber felled in the mid-fifteenth century. Unlike the earlier work however, this analysis has found modest evidence of a further programme of felling dating to the mid-seventeenth century which may represent a subsequent phase of redevelopment hitherto undated by dendrochronology, but possibly suspected by the structural survey.

Thus, although there is growing evidence for the use of late-thirteenth and early fourteenth century timber, this is not clearly related to a specific structure or distinct phase of building. The firmest evidence for the early history of the building remains the mid fifteenth-century cruck phase. There is then some evidence for the use of mid sixteenth-century timber, but this again, based on the tree-ring dating, is ephemeral and indistinct. It is possible however, that the timber framing of the east, north, and west walls, which were unsuitable for analysis by dendrochronology, might belong to this phase. The next two distinct stages are the early and mid seventeenth-century redevelopment phases.

Eleven of the newly acquired samples remain ungrouped and undated in this analysis. Although not especially long, the longest with 87 rings being STK-A110, they are all suitable for tree ring analysis: the shortest sample is ATK-A125 with 54 rings. Apart from a few of the samples being short-ringed, and two having possible very slight distortion, there is nothing particularly unusual about any of these samples, none of them showing stress or complacency that might make cross-matching and dating difficult.

## Bibliography


Baillie, M G L, 1977 An oak chronology for south central Scotland, *Tree-ring Bulletin*, **37**, 33 - 44

Baillie, M G L, and Pilcher, J R, 1982 unpubl A master tree-ring chronology for England, unpubl computer file *MGB-EOI*, Queens Univ, Belfast

Esling, J, Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1990 List 33 nos 2, 4, 8a/b - Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect*, **21**, 37 – 40

Fletcher, J, 1978 unpubl computer file MC10---H, deceased

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1986 List 18 no 6b - Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect*, **17**, 52

Howard, R E, Laxton, R R, Litton, C D, Morrison A, Sewell, J, and Hook, R, 1993 List 49 no 2 - Nottingham University Tree-Ring Dating Laboratory: Derbyshire, Peak Park and RCHME dendrochronological Survey 1991 - 92, *Vernacular Architect*, **24**, 43 – 4

Howard, R E, Laxton, R R, Litton, C D, Morrison A, Sewell, J, and Hook, R, 1994a List 58 no 8 - Nottingham University Tree-Ring Dating Laboratory: Derbyshire, Peak Park and RCHME dendrochronological Survey 1992 - 93, *Vernacular Architect*, **25**, 41 – 3

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1994b List 57 nos 4a, 4b, 13 - Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect*, **25**, 36 – 40

Howard, R E, Laxton, R R, Litton, C D, Morrison A, Sewell, J, and Hook, R, 1995 List 61 no 3 - Nottingham University Tree-Ring Dating Laboratory: Derbyshire, Peak Park and RCHME dendrochronological Survey 1994 - 95, *Vernacular Architect*, **26**, 53 – 4

Howard, R E, Laxton, R R, Litton, C D, Morrison A, Sewell, J, and Hook, R, 1996 List 66 no 5 - Nottingham University Tree-Ring Dating Laboratory: Derbyshire, Peak Park and RCHME dendrochronological Survey 1995 - 96, *Vernacular Architect*, **27**, 81 – 4

Howard, R E, Laxton, R R, and Litton, C D, 1998 unpubl, Dovebridge, Derbyshire, unpubl computer file *DOVBSQ01*, Nottingham University Tree-Ring Dating Laboratory

Howard, R E, Laxton, R R, and Litton, C D, 2002 *Tree-ring analysis of timbers from Blackfriars Priory, Ladybellgate Street, Gloucester*, Centre for Archaeol Rep, **43/2002**

Laxton, R R, and Litton, C D, 1988 An East Midlands master tree-ring chronology and its use for dating vernacular buildings, University of Nottingham, Dept of Classical and Archaeol Studies, Monograph Series, **III**

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, 1996 *Tree-ring analysis of oak timbers from 30a (Staircase Café) and 31 Market Place, Stockport, Greater Manchester*, Anc Mon Lab Rep, **28/96**

Tyers, I, 1999 *Tree-ring analysis of timbers from 30a and 31 Market Place, Stockport, Greater Manchester*, ARCUS Rep, **451**

Table 1: Details of samples from Staircase House, Stockport

| Sample number | Sample location | Total rings | *Sapwood rings | First measured ring date | Last heartwood ring date | Last measured ring date |
|---|---|---|---|---|---|---|
| | **Cellar / basement** | | | | | |
| STK-A91 | Southmost principal joist, room B1 | nm | --- | ---- | ---- | ---- |
| STK-A92 | Central principal joist, room B1 | nm | --- | ---- | ---- | ---- |
| STK-A93 | Northmost principal joist, room B1 | nm | --- | ---- | ---- | ---- |
| STK-A94 | Door lintel, courtyard B7 / room B2 | nm | --- | ---- | ---- | ---- |
| | **Ground floor** | | | | | |
| STK-A95 | Upper stud, west wall room G5 | 80 | h/s | AD 1558 | AD 1637 | AD 1637 |
| STK-A96 | Lower stud, west wall room G5 | 76 | h/s | ---- | ---- | ---- |
| STK-A97 | Joist 5 from east wall, room G8 | 64 | 15C | AD 1554 | AD 1602 | AD 1617 |
| STK-A98 | Joist to party wall, rooms G7/8 | 60 | no h/s | AD 1528 | ---- | AD 1587 |
| STK-A99 | Joist 3 from east wall, room G8 | 64 | 19c | AD 1552 | AD 1596 | AD 1615 |
| STK-A100 | Joist 1 from east wall, room G8 | 82 | h/s | AD 1524 | AD 1605 | AD 1605 |
| | **First floor (roof timbers)** | | | | | |
| STK-A101 | East purlin to east dormer, room F10 | 61 | 16C | ---- | ---- | ---- |
| STK-A102 | Yoke to west cruck truss, room F10 | nm | --- | ---- | ---- | ---- |
| STK-A103 | North purlin, east end room F10 | 84 | 13c | AD 1525 | AD 1595 | AD 1608 |
| STK-A104 | South common rafter, east end room F10 | 54 | 12C | AD 1406 | AD 1447 | AD 1459 |
| STK-A105 | North common rafter, east end room F10 | 58 | 14C | ---- | ---- | ---- |
| STK-A106 | Common rafter, east pitch of north dormer, room F10 | 71 | 13C | AD 1466 | AD 1523 | AD 1536 |
| STK-A107 | South common rafter, west end room F10 | 57 | 14c | AD 1552 | AD 1594 | AD 1608 |
| STK-A108 | Common rafter, east pitch of north dormer, room F10 | 67 | 14C | AD 1552 | AD 1604 | AD 1618 |

Table 1: Continued

| Sample number | Sample location | Total rings | *Sapwood rings | First measured ring date | Last heartwood ring date | Last measured ring date |
|---|---|---|---|---|---|---|
| | **First floor (roof timbers) continued** | | | | | |
| STK-A109 | Yoke to east cruck truss | 67 | 21C | ---- | ---- | ---- |
| STK-A110 | North common rafter, east end room F10 | 87 | 17 | ---- | ---- | ---- |
| STK-A111 | South lower purlin, east end room F10 | 55 | 14 | ---- | ---- | ---- |
| STK-A112 | South common rafter, east end room F10 | 54 | 15C | AD 1559 | AD 1597 | AD 1612 |
| | **First floor (wall timbers)** | | | | | |
| STK-A113 | Main corner post, north wall room F10 | 86 | h/s | AD 1518 | AD 1603 | AD 1603 |
| STK-A114 | Wall post, west wall room F12 | 54 | h/s | ---- | ---- | ---- |
| STK-A115 | Upper stud post, north wall room F10 | 79 | 13 | ---- | ---- | ---- |
| STK-A116 | Lower rail, west wall room F12 | 70 | 20C | AD 1551 | AD 1600 | AD 1620 |
| STK-A117 | Upper rail to west of doorway, rooms F10/12 | 58 | no h/s | ---- | ---- | ---- |
| STK-A118 | Upper rail to east of doorway, room F10/12 | 65 | 2 | AD 1532 | AD 1594 | AD 1596 |
| STK-A119 | Upper rail, west wall room F12 | 72 | 7 | AD 1538 | AD 1602 | AD 1609 |
| STK-A120 | Lower stud post, north wall room F10 | 95 | 12 | AD 1514 | AD 1596 | AD 1608 |
| STK-A121 | Door jamb, room F10/12 | 69 | no h/s | AD 1503 | ---- | AD 1571 |
| STK-A122 | Middle rail to east of doorway, room F10/12 | 79 | h/s | AD 1520 | AD 1598 | AD 1598 |
| STK-A123 | Stud over door, rooms F10/12 | 106 | h/s | AD 1489 | AD 1594 | AD 1594 |
| | **First floor (ceiling timbers)** | | | | | |
| STK-A124 | Ceiling joist 7 from east, room F11 | nm | --- | ---- | ---- | ---- |
| STK-A125 | Ceiling joist 6 from east, room F11 | 54 | h/s | ---- | ---- | ---- |
| STK-A126 | Ceiling joist 2 from east, room F11 | 70 | 4 | AD 1572 | AD 1637 | AD 1641 |
| STK-A127 | Ceiling joist 4 from east, room F11 | 61 | h/s | AD 1572 | AD 1632 | AD 1632 |

Table 1: Continued

| Sample number | Sample location | Total rings | *Sapwood rings | First measured ring date | Last heartwood ring date | Last measured ring date |
|---|---|---|---|---|---|---|
| | **Second floor (wall timbers)** | | | | | |
| STK-A128 | Upper stub rail to east wall, room S5 | 128 | 32C | AD 1525 | AD 1620 | AD 1652 |
| STK-A129 | Bressummer at stairs, room S5 | 59 | no h/s | ---- | ---- | ---- |
| STK-A130 | Wall post, east side room S5 | 84 | 33C | AD 1573 | AD 1653 | AD 1656 |
| STK-A131 | Lower stub rail, east wall room S5 | nm | --- | ---- | ---- | ---- |
| | **Second floor (roof timbers)** | | | | | |
| STK-A132 | South principal rafter, east gable over room S5 | 67 | h/s | ---- | ---- | ---- |
| STK-A133 | North principal rafter, east gable over room S5 | 55 | h/s | ---- | ---- | ---- |
| STK-A134 | South V-strut east gable over room S5 | 55 | 10 | AD 1596 | AD 1640 | AD 1650 |
| STK-A135 | South stud, east gable over room S5 | 54 | 20C | ---- | ---- | ---- |
| | **First floor (wall and roof timbers)** | | | | | |
| STK-A136 | Stud post to south wall of southern warehouse | 63 | h/s | AD 1514 | AD 1576 | AD 1576 |
| STK-A137 | Rail to north wall of southern warehouse | 77 | 20C | ---- | ---- | ---- |
| STK-A138 | Common rafter 3, west pitch, roof over room 11A | 180 | no h/s | AD 1069 | ---- | AD 1248 |
| STK-A139 | Common rafter 12, west pitch, roof over room 11A | 110 | no h/s | AD 1090 | ---- | AD 1199 |
| STK-A140 | Common rafter 13, west pitch, roof over room 11A | 66 | no h/s | AD 1070 | ---- | AD 1135 |
| STK-A141 | Common rafter 7, west pitch, roof over room 11A | 54 | 7 | AD 1572 | AD 1618 | AD 1625 |

*h/s = the heartwood/sapwood boundary is the last ring on the sample
C = complete sapwood retained on sample, last measured ring date is felling date of tree
c = complete sapwood retained on tree but all or part lost from sample during coring

Table 2: Results of the cross-matching of the newly measured samples in site chronology STKASQ01 and relevant reference chronologies when the date of their first ring is AD 1489 and their last ring date is AD 1658

| Reference chronology | Span of chronology | *t*-value | |
|---|---|---|---|
| England | AD 401 - 1981 | 11.0 | ( Baillie and Pilcher 1982 unpubl ) |
| East Midlands | AD 882 - 1981 | 8.5 | (Laxton and Litton 1988 ) |
| Scotland | AD 946 - 1975 | 8.2 | ( Baillie 1977 ) |
| Frith Hall, Brampton, Derbys | AD 1480 - 1602 | 7.8 | ( Howard *et al* 1993 ) |
| Dimple Farm, Matlock, Derbys | AD 1497 - 1593 | 7.8 | ( Howard *et al* 1996 ) |
| Dovebridge, Derbys | AD 1502 - 1617 | 7.6 | ( Howard *et al* 1998 unpubl ) |
| Bedehouses, Wirksworth, Derbys | AD 1479 - 1583 | 7.5 | ( Howard *et al* 1994a ) |
| Wales and West Midlands | AD 1341 - 1636 | 6.1 | ( Siebenlist-Kerner 1978 ) |
| MC10---H | AD 1386 - 1585 | 6.6 | ( Fletcher 1978 unpubl ) |

Table 3: Results of the cross-matching of the newly measured samples in site chronology STKASQ02 and relevant reference chronologies when the date of their first ring is AD 1069 and their last ring date is AD 1243

| Reference chronology | Span of chronology | *t*-value | |
|---|---|---|---|
| England | AD 401 - 1981 | 7.2 | ( Baillie and Pilcher 1982 unpubl ) |
| Brecon Cathedral | AD 996 - 1227 | 6.1 | ( Howard *et al* 1994b ) |
| St Hugh's Choir, Lincoln Cathedral | AD 882 - 1391 | 5.2 | ( Laxton and Litton 1988 ) |
| Gloucester Blackfriars | AD 1024 - 1237 | 5.1 | ( Howard *et al* 2002 ) |
| Sandwell Priory, West Midlands | AD 1042 - 1158 | 4.9 | ( Howard *et al* 1986 ) |
| Ordsall Hall, Stockport | AD 1076 - 1345 | 4.8 | ( Howard *et al* 1994b ) |
| Hansacre Hall, Staffs | AD 965 - 1279 | 4.4 | ( Esling *et al* 1990 ) |

Table 4: Results of the cross-matching of the newly measured samples in site chronology STKASQ03 and relevant reference chronologies when the date of their first ring is AD 1406 and their last ring date is AD 1576

| Reference chronology | Span of chronology | *t*-value | |
|---|---|---|---|
| England | AD 401 - 1981 | 9.5 | ( Baillie and Pilcher 1982 unpubl ) |
| East Midlands | AD 882 - 1981 | 8.4 | ( Laxton and Litton 1988 ) |
| Scotland | AD 946 - 1975 | 6.1 | ( Baillie 1977 ) |
| New Mills, Derbys | AD 1417 - 1566 | 9.1 | ( Esling *et al* 1990 ) |
| Ordsall Hall, Stockport | AD 1385 - 1512 | 8.1 | ( Howard *et al* 1994b ) |
| Offerton Hall, Derbys | AD 1401 - 1592 | 7.6 | ( Howard *et al* 1995 ) |
| Frith Hall, Brampton, Derbys | AD 1480 - 1602 | 7.3 | ( Howard *et al* 1993 ) |
| Wales and West Midlands | AD 1341 - 1636 | 7.0 | ( Siebenlist-Kerner 1978 ) |

**Figure 1: Map to show general location of Staircase House**

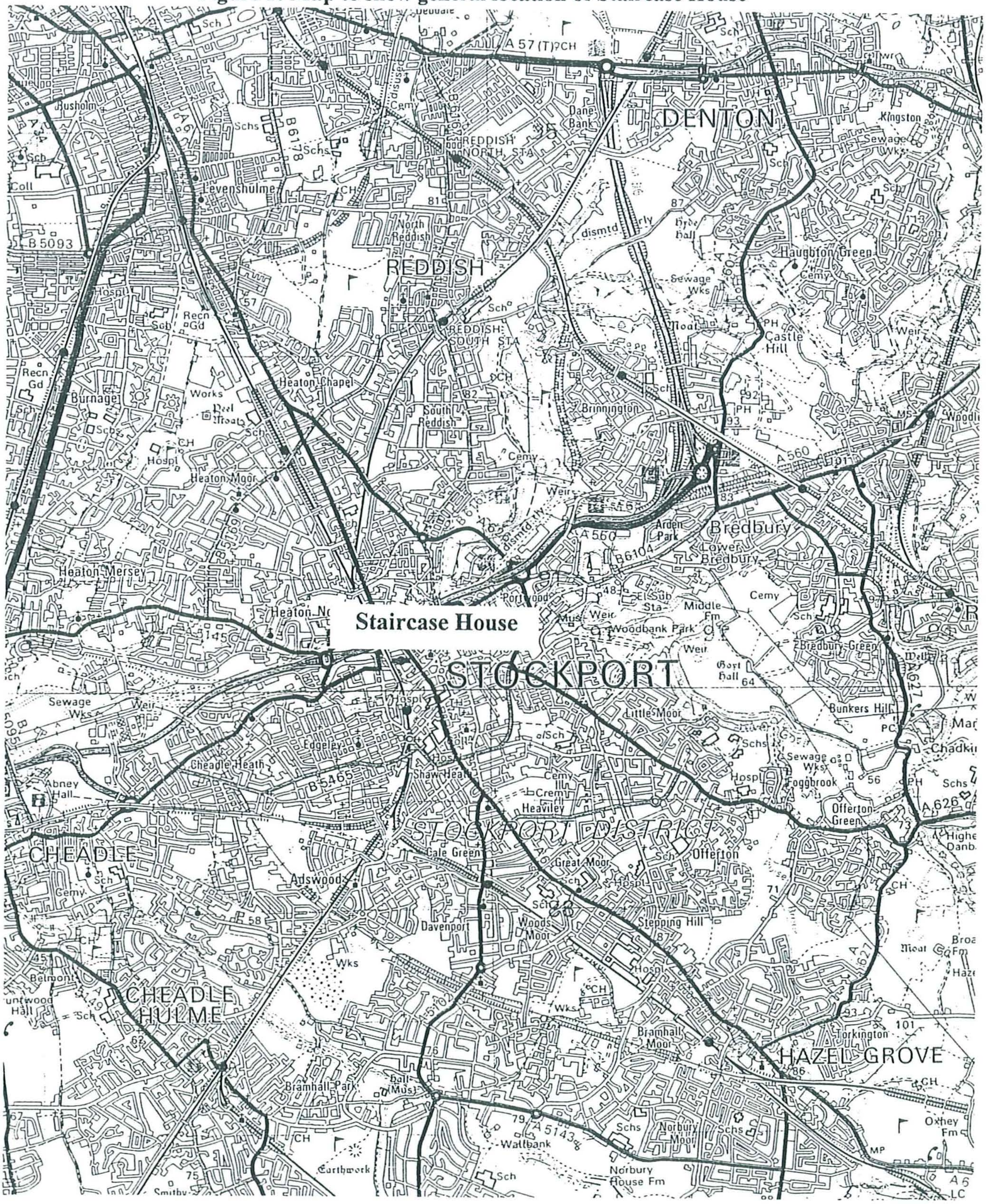


**Figure 2: Map to show specific location of Staircase House**

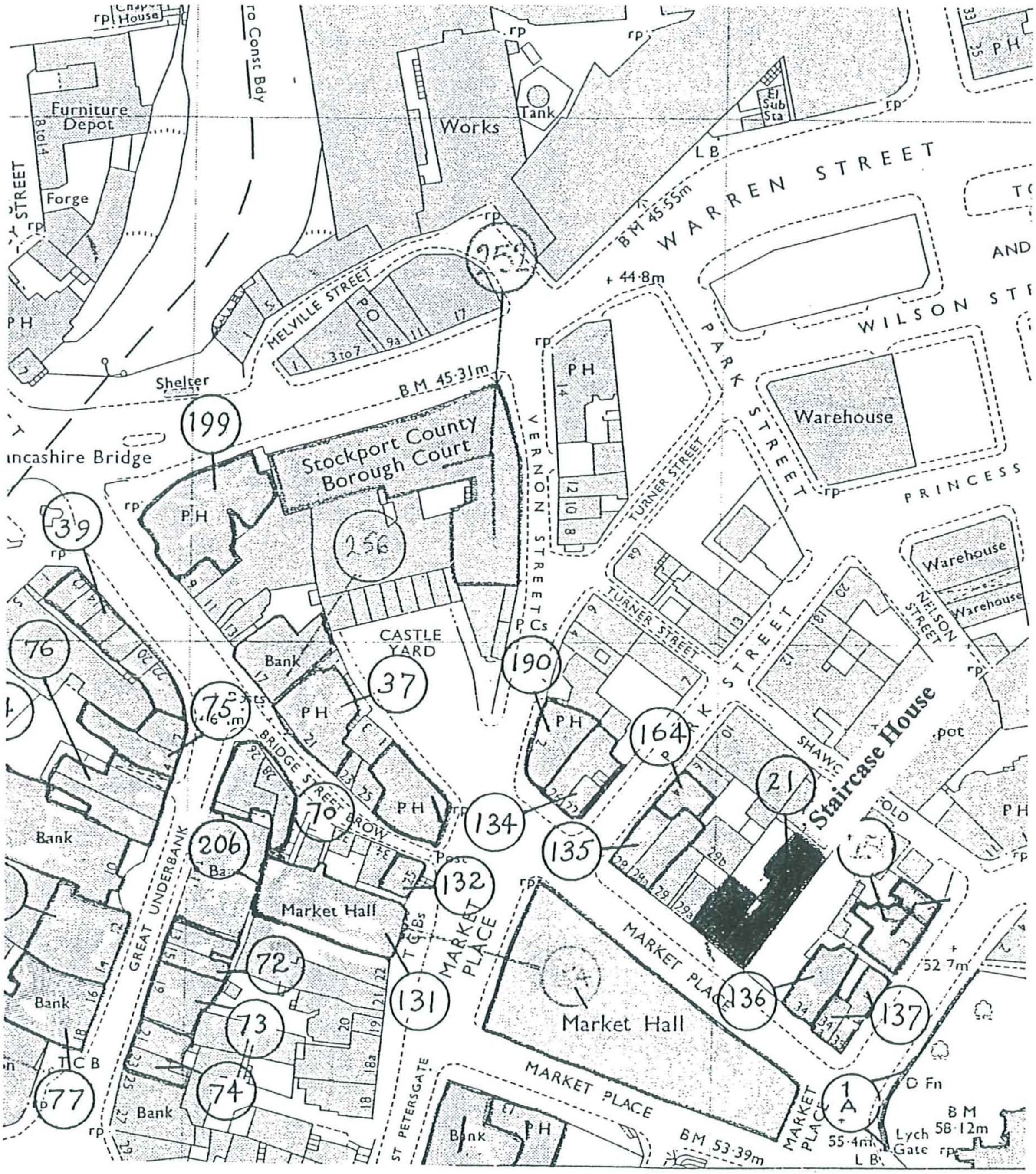


Figure 3: Schematic plan of Staircase House at ground-floor level

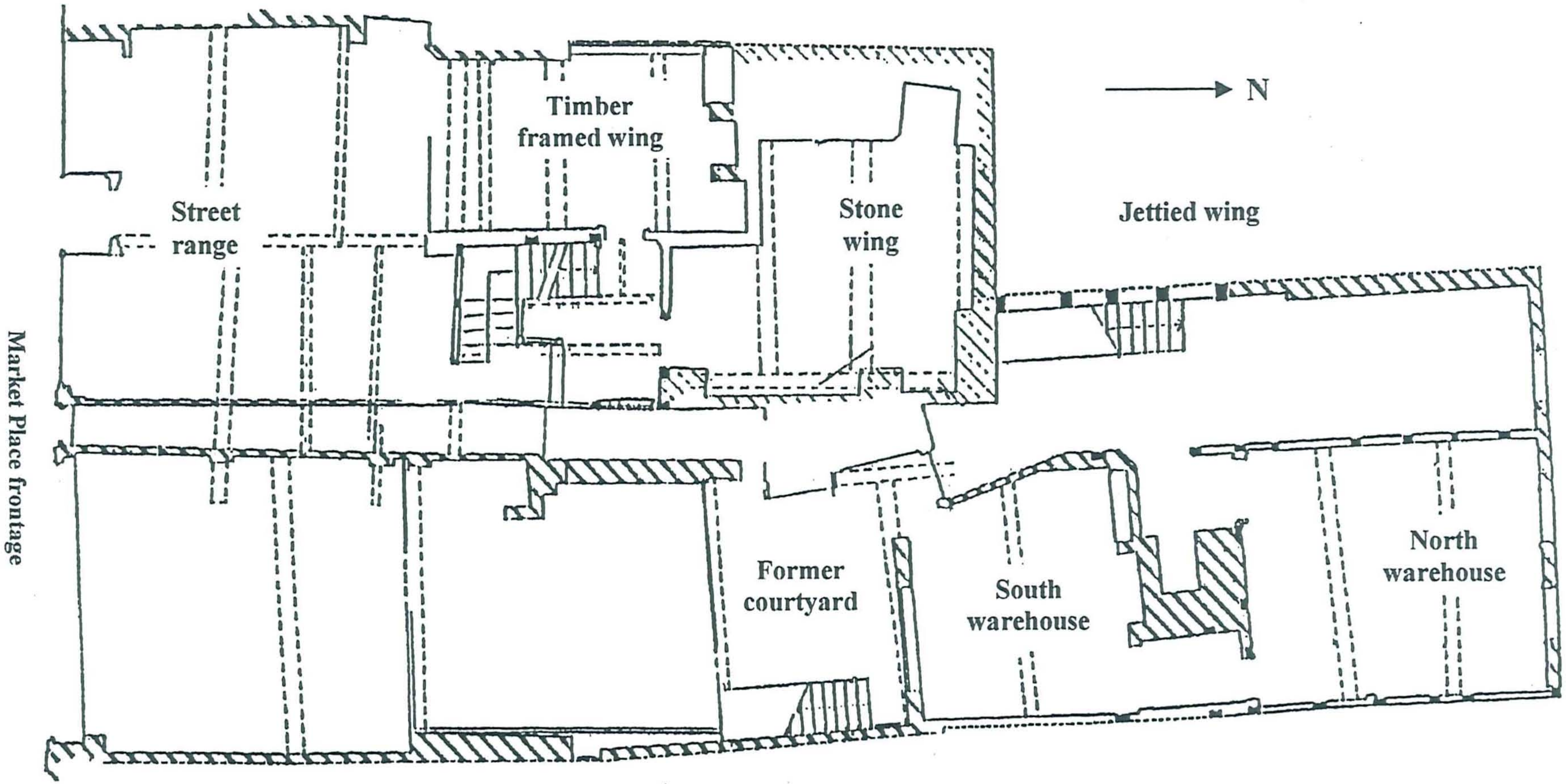


**Figure 4: Drawing to show approximate location of sampled timbers from the cellar / basement**

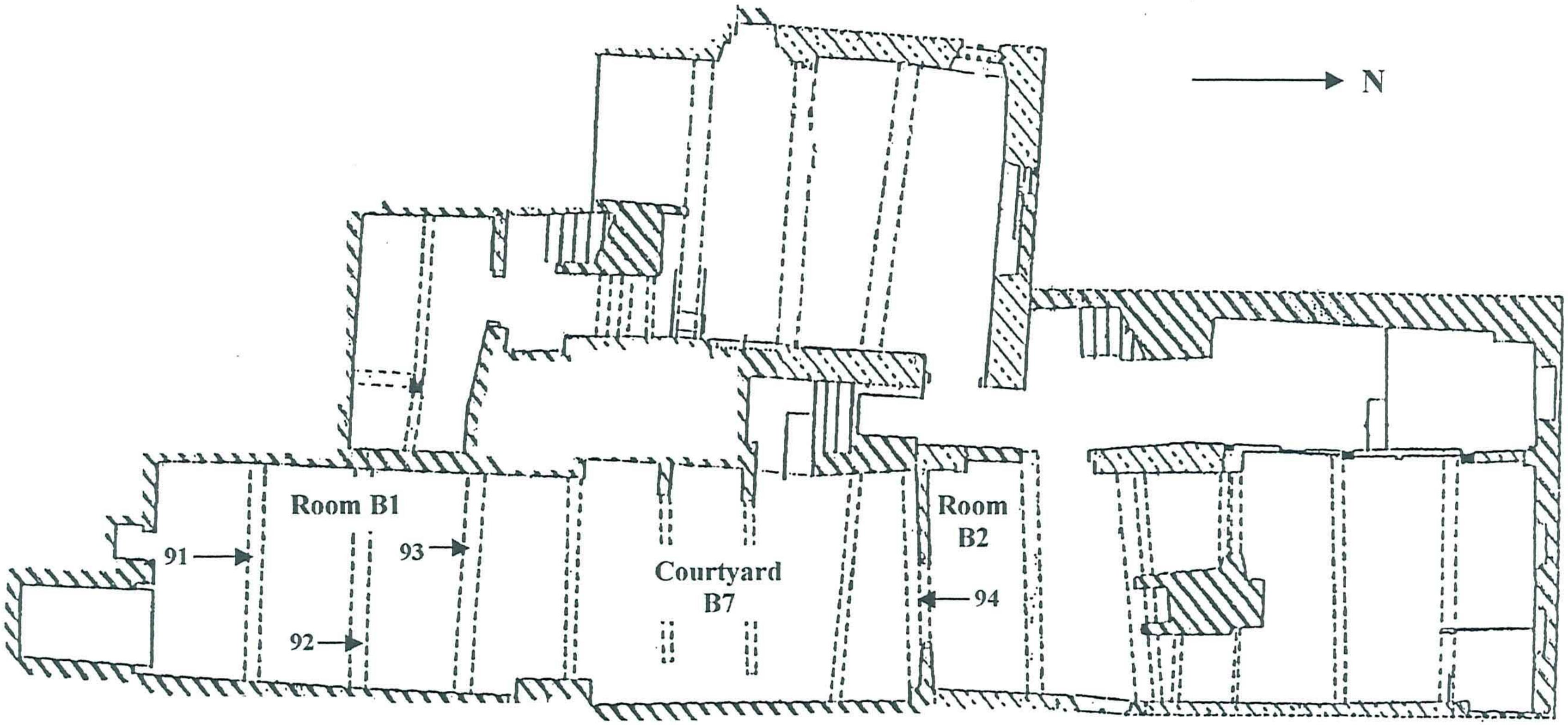


**Figure 5: Drawing to show approximate location of sampled timbers from the ground floor**

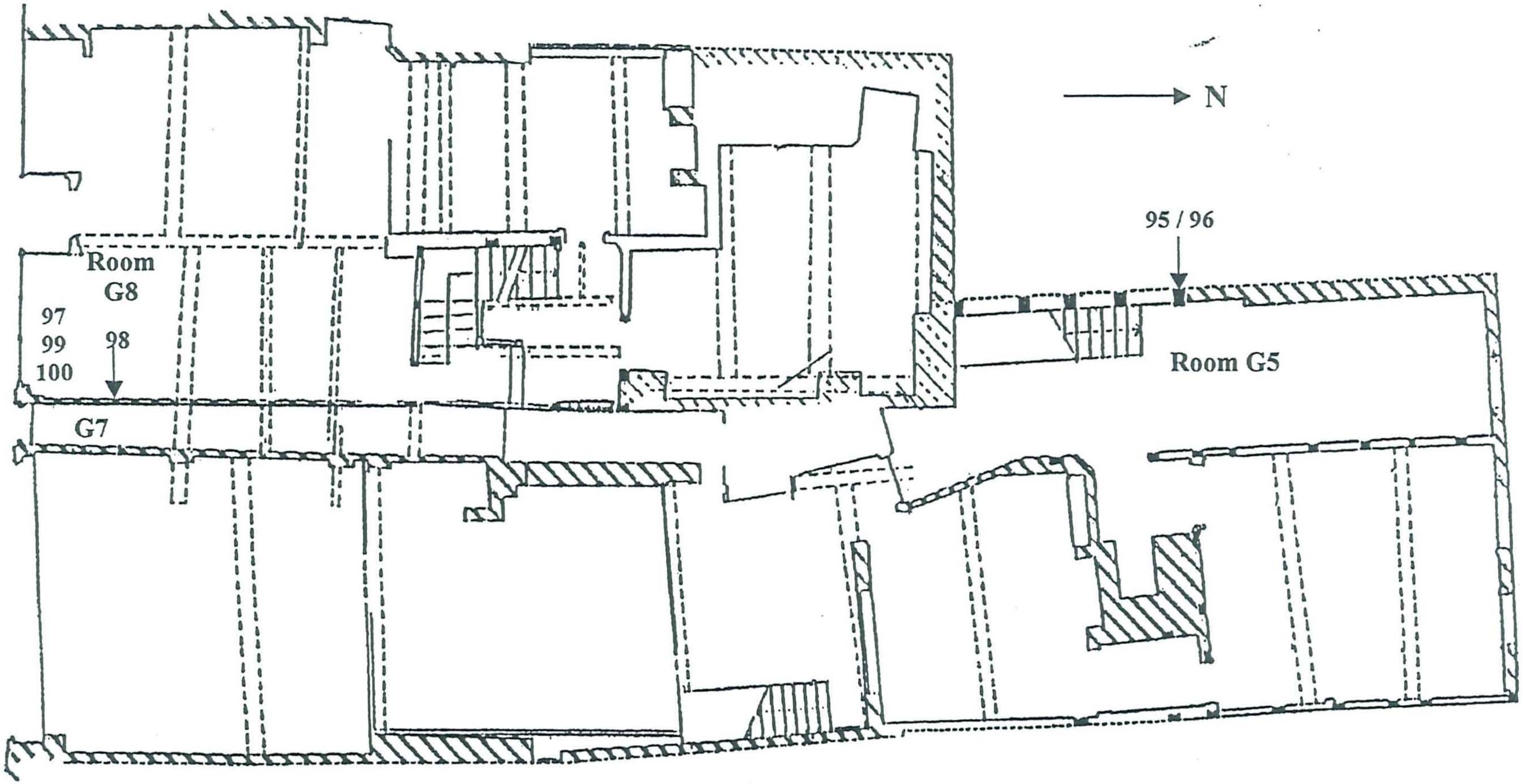


Figure 6: Drawing to show approximate location of sampled timbers from the first floor

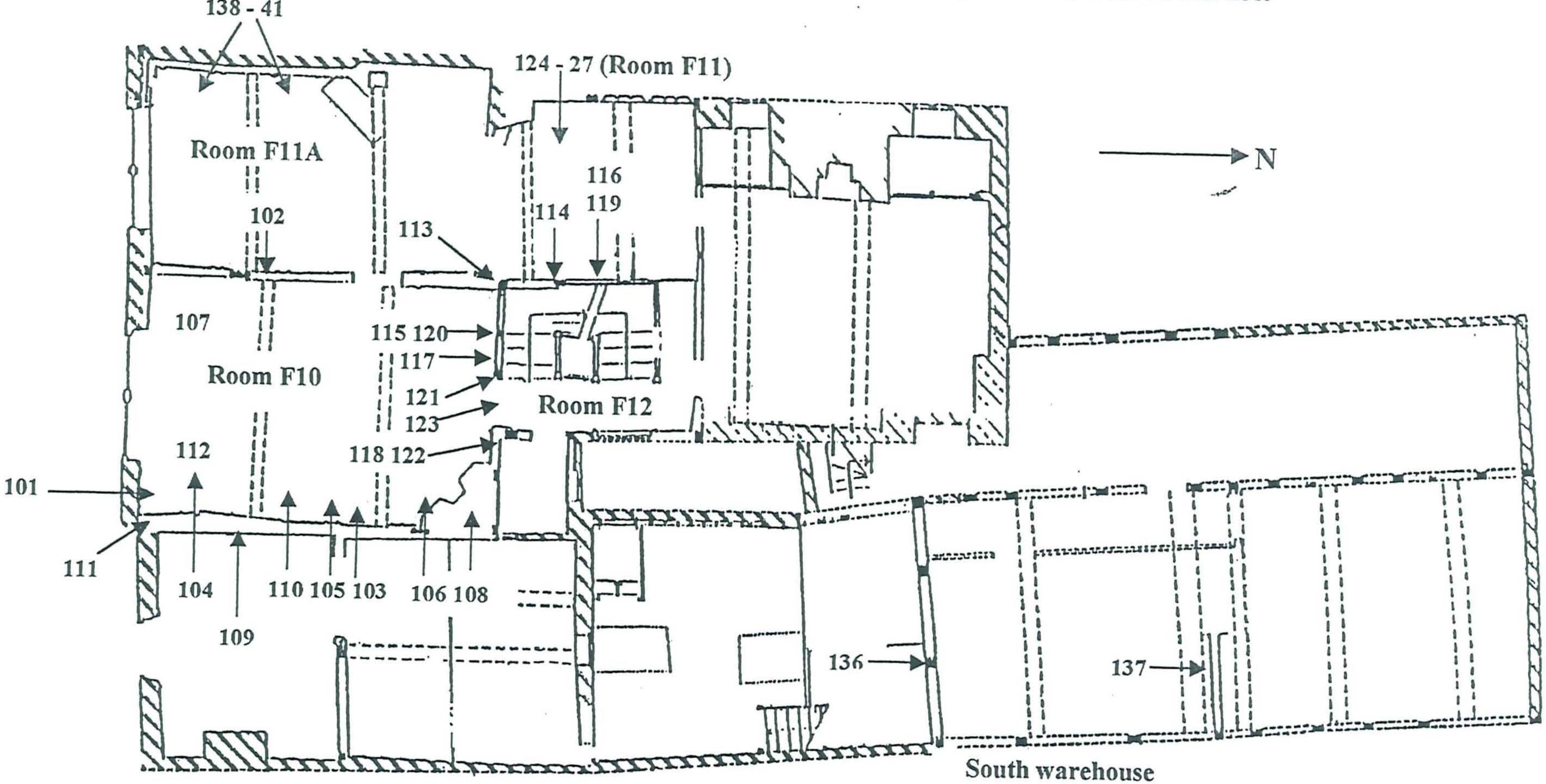


**Figure 7: Drawing to show approximate location of sampled timbers from the second floor and roof**

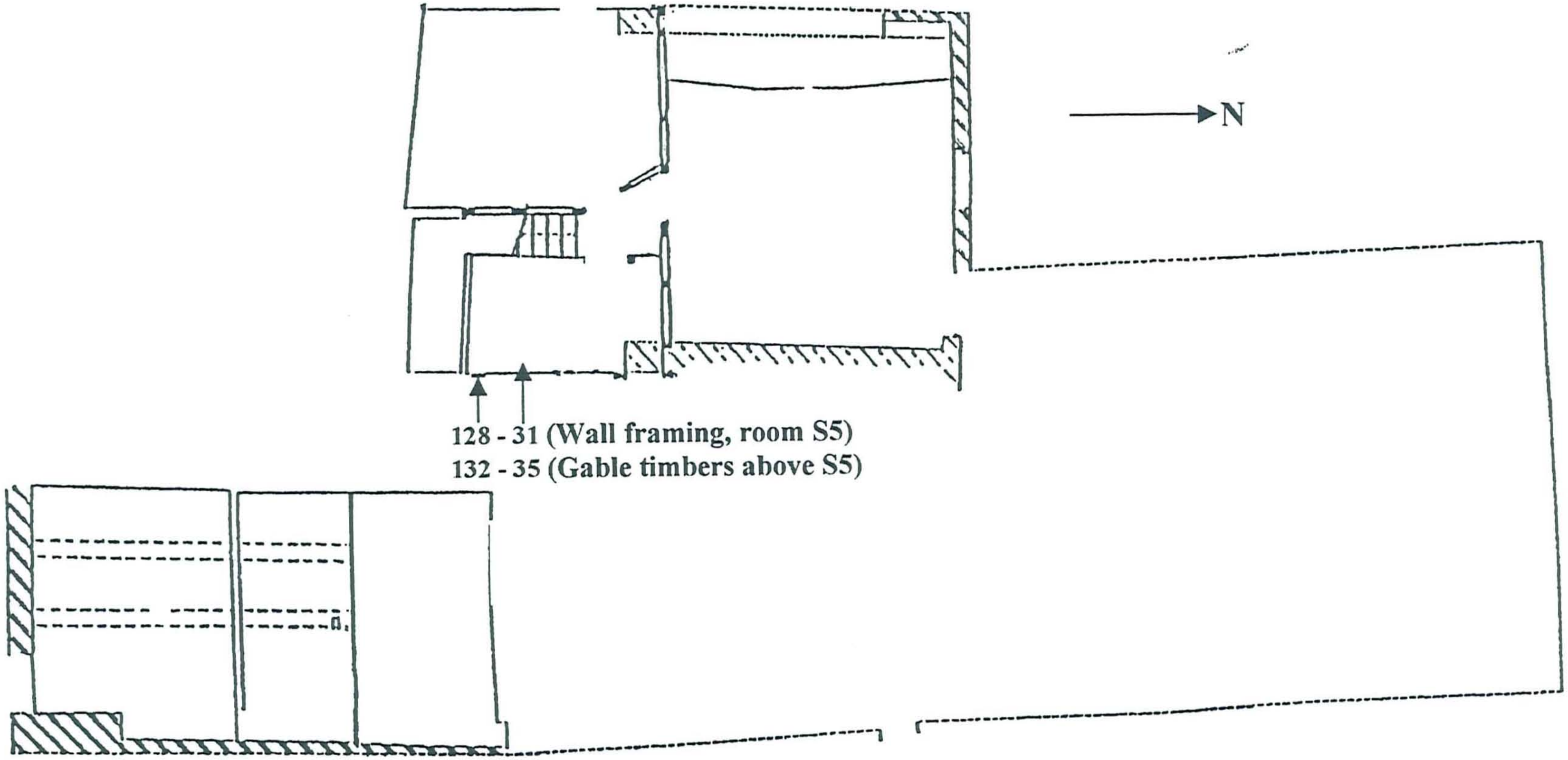
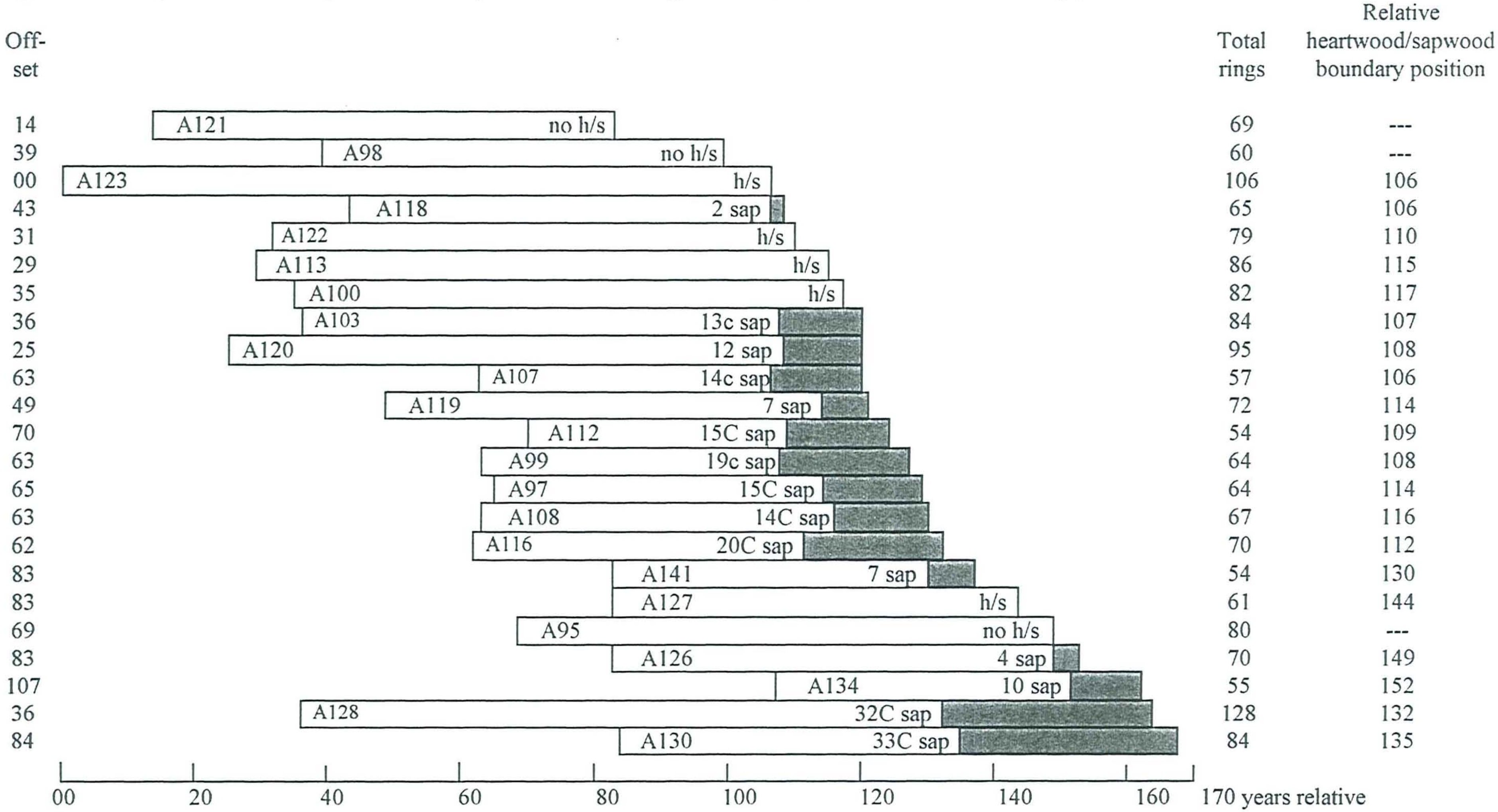


Figure 8: Bar diagrams of the newly measured samples in site chronology STKASQ01, shown in order of last ring position




white bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample
C = complete sapwood retained on sample
c = complete sapwood on sample, all or part lost during sampling

Figure 9: Bar diagrams of the newly measured samples in site chronology STKASQ02

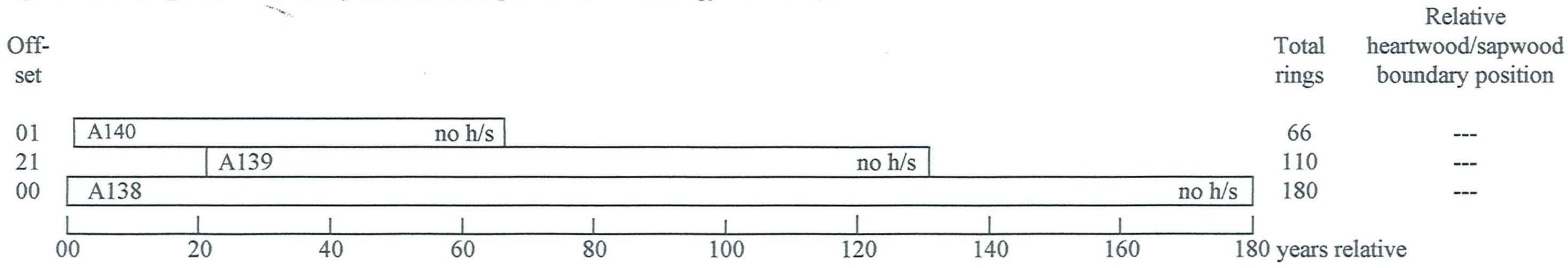



Figure 10: Bar diagrams of the newly measured samples in site chronology STKASQ03

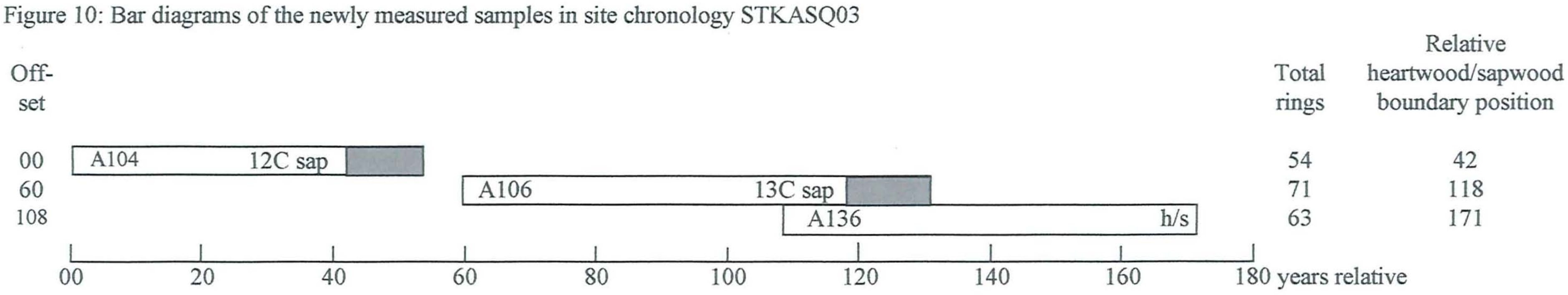
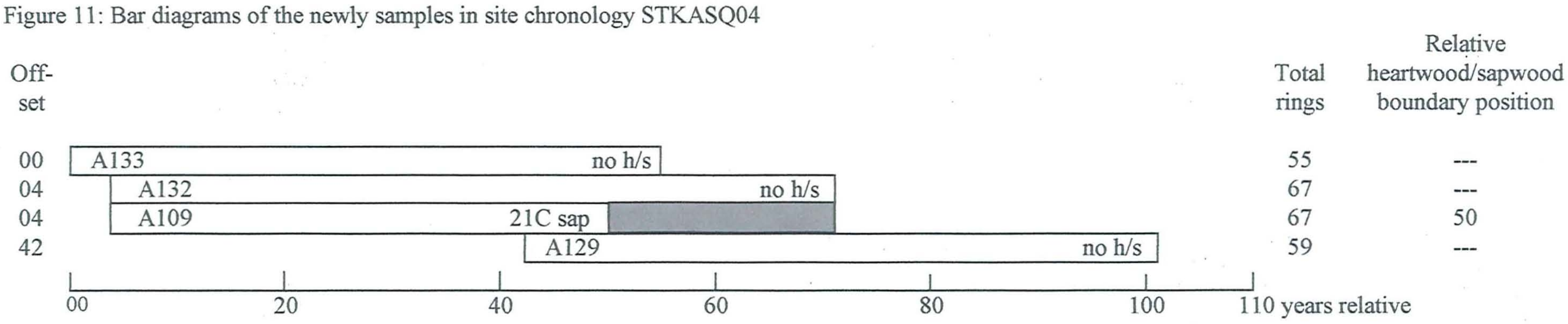
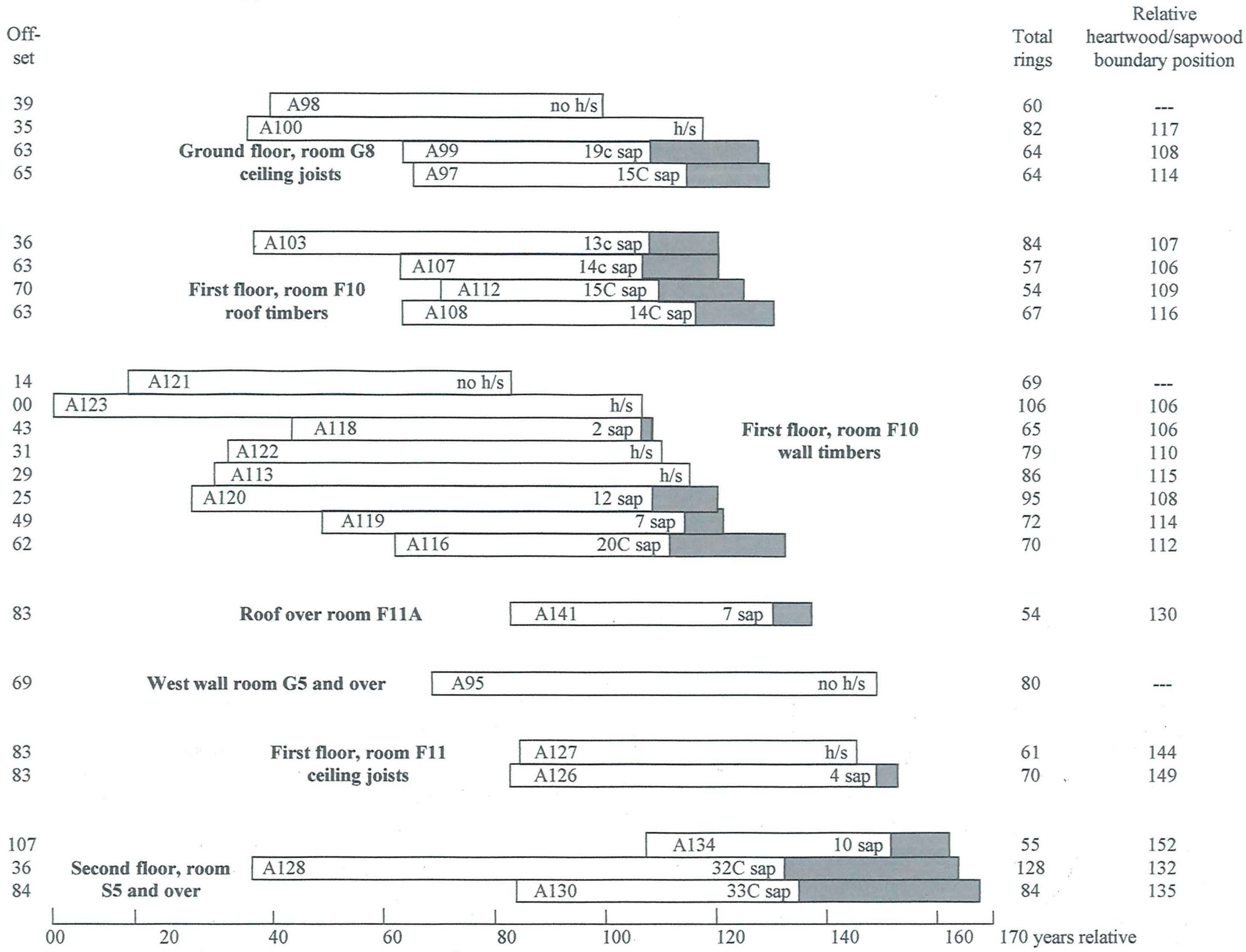



Figure 11: Bar diagrams of the newly samples in site chronology STKASQ04




white bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample
C = complete sapwood retained on sample
c = complete sapwood on sample, all or part lost during sampling

Figure 12: Bar diagrams of the newly measured samples contained in site chronology STKASQ01, sorted by sampling area in order of relative last ring position




white bars = heartwood rings, shaded area = sapwood
h/s = heartwood/sapwood boundary is last ring on
C = complete sapwood retained on sample
c = complete sapwood on sample, all or part lost during sampling

Data of measured samples – measurements in 0.01mm units

STK-A95A 80
289 528 372 498 392 307 231 128 144 60 73 48 184 189 175 176 204 216 265 186
188 280 231 124 113 140 138 205 173 100 77 177 126 88 109 276 289 281 222 73
87 105 134 124 64 107 171 83 73 45 48 36 46 37 63 46 56 43 38 60
132 94 203 143 150 163 142 97 108 102 107 141 125 71 104 106 101 137 68 47
STK-A95B 80
284 523 351 501 392 303 217 121 150 59 72 52 178 184 175 166 195 244 253 185
191 269 219 128 117 136 144 193 179 102 67 190 141 87 106 262 290 293 232 84
88 103 133 121 69 109 167 85 80 47 30 42 49 38 64 48 50 49 45 46
137 99 190 148 148 167 144 102 103 95 127 133 124 67 111 106 101 137 70 51
STK-A96A 76
126 120 127 142 189 196 293 253 100 93 98 88 97 127 179 188 237 209 327 284
205 176 155 254 250 254 109 62 93 80 87 131 121 152 153 95 123 180 135 141
245 204 249 195 173 178 143 196 182 142 156 231 149 161 182 197 200 202 214 214
168 184 162 198 181 445 326 332 251 198 133 134 128 222 325 305
STK-A96B 76
125 120 142 144 181 213 231 268 112 89 101 85 98 139 162 188 242 215 329 278
212 173 151 269 245 261 102 70 75 85 86 133 122 147 152 103 127 168 141 137
240 204 278 162 186 170 148 178 191 130 156 224 124 162 176 195 202 212 205 219
177 185 152 222 161 456 341 324 230 200 140 133 122 227 318 262
STK-A97A 64
119 93 92 87 94 173 154 168 113 176 169 126 119 124 231 178 197 173 177 203
265 204 178 184 133 183 247 189 157 165 166 149 196 146 72 97 65 69 106 266
205 282 263 234 196 203 204 224 157 209 210 223 218 271 208 182 192 192 145 172
197 292 233 292
STK-A97B 64
109 93 95 81 96 180 143 165 121 176 169 121 121 125 229 192 183 176 168 214
248 205 173 179 149 175 241 197 163 165 166 154 192 141 77 105 75 74 110 252
214 290 252 232 196 198 212 220 165 201 210 224 224 267 209 186 185 186 163 164
193 295 215 303
STK-A98A 60
172 169 167 151 169 131 130 141 119 139 159 179 197 181 114 153 150 148 126 150
130 170 216 166 168 184 129 104 86 93 90 129 98 128 124 120 154 124 96 105
117 140 148 136 140 159 165 151 187 150 143 145 202 175 151 146 184 162 204 215
STK-A98B 60
181 176 162 179 167 153 121 149 120 141 160 195 208 178 110 158 134 144 143 150
135 171 226 179 181 167 106 115 78 92 96 125 99 134 129 111 159 117 92 110
115 129 157 142 128 164 162 162 179 140 146 145 199 178 148 160 170 154 195 212
STK-A99A 64
354 245 247 174 134 90 189 170 164 140 113 154 177 142 130 145 179 195 236 244
228 259 301 247 179 203 196 232 276 242 198 198 197 176 226 174 116 119 95 86
80 134 145 163 165 123 160 126 99 121 85 120 139 155 171 180 137 148 126 120
135 191 234 224

STK-A99B 64
341 263 241 179 117 95 200 179 159 141 127 160 153 138 132 139 170 186 235 236
213 282 337 259 193 197 188 234 284 247 197 206 203 162 225 176 115 124 89 91
88 132 139 157 174 116 172 142 99 112 93 125 140 152 189 179 139 155 127 118
142 190 234 228
STKA100A 82
208 145 218 201 186 188 167 214 201 184 170 229 171 187 188 218 229 188 158 158
136 231 202 294 255 316 329 321 230 207 125 131 113 93 129 169 156 213 126 132
147 132 168 131 176 179 187 133 130 184 223 188 207 161 141 164 242 137 145 158
162 145 170 111 101 94 84 73 126 251 189 231 246 177 161 193 126 186 173 179
196 204
STKA100B 82
178 151 214 194 196 189 169 210 201 175 174 232 172 180 186 222 233 186 142 170
140 230 202 289 257 307 357 311 226 204 132 132 115 90 136 183 150 226 128 151
144 155 151 128 167 165 196 136 132 187 219 189 208 162 143 158 239 133 147 148
165 151 166 136 102 93 86 76 124 252 161 222 245 162 128 143 133 182 179 176
192 244
STKA101A 61
456 630 590 838 636 564 592 224 194 219 167 128 144 252 215 168 197 147 188 141
164 156 182 303 226 94 176 168 81 81 66 82 100 114 149 180 98 104 78 103
105 110 125 101 160 122 198 151 88 76 153 175 197 194 217 198 148 176 195 256
254
STKA101B 61
430 633 603 858 669 585 598 233 204 220 171 139 158 259 215 165 198 154 183 151
150 156 214 294 219 109 164 194 90 76 64 86 96 120 152 182 100 108 74 98
113 109 132 88 164 118 204 160 90 84 155 161 197 207 207 187 133 163 195 237
277
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157 146 146 197 175 135 134 152 151 142 185 86 143 141 123 180 98 126 167 132
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166 115 151 208 163 127 134 155 151 134 184 80 142 123 133 181 99 129 154 141
149 122 131 186 172 164 157 118 117 63 89 55 55 76 109 123 112 84 94 94
97 82 83 94 87 142 115 137 143 134 145 115 119 101 123 128 112 84 96 121
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75 73 57 73
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406 222 231 416 327 279 259 248 200 249 174 266 263 209 284 280 217 296 229 236
234 307 319 285 209 216 275 201 292 181 164 169 166 125 114 112 112 127 178 92
114 155 293 339 237 146 136 114 110 94 148 152 186 223
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447 232 231 410 408 242 262 238 194 229 175 286 260 208 261 284 225 299 249 238
231 310 305 292 228 209 265 190 280 166 156 149 195 116 115 106 108 135 172 83
124 167 282 329 245 146 129 121 105 99 156 143 189 200
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373 242 334 278 247 274 270 273 194 210 251 246 180 194 131 132 149 156 120 141
117 135 138 204 136 154 194 219 228 140 149 151 153 195 189 198 222 193

STKA105B 58
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368 238 340 286 221 283 289 253 204 207 248 248 175 209 118 147 150 161 122 148
118 140 137 220 139 166 192 192 200 155 148 148 144 200 181 228 214 217
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241 336 309 149 138 151 188 245 214 318 304 137 77 81 88 120 73 92 107 106
115 163 72 63 50 45 42 46 44 98 142 66 135 131 93 116 148 138 131 183
160 164 150 195 176 181 253 148 141 125 122 112 116 111 136 163 141 160 244 210
153 109 71 62 62 105 77 102 81 145 192
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163 171 140 198 176 183 253 149 143 121 126 115 114 112 140 155 141 173 263 174
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192 221 140 179 99 157 179
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79 91 58 84 113 102 119
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68 70 54 53 56 51 51 57 52 59 52 62 61 72 64 64 72 78 86 42
31 32 35 30 40 38 66 44 40 43 36 44 48 43 49 37 58 70 87 65
93 82 110 85 110 100 126 104 115 132 101 123 157 130 120 106 201 160 173 150
106 128 105 113 134 213 193
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467 690 764 614 647 533 710 759 602 700 620 325 245 306 350 613 325 246 286 367
458 381 462 370 551 451 389 458 387 531 299 626 306 133 118 180 224 234 204 242
297 634 294 138 127 194 246 283 241 261 255 136 99 71 89
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500 693 727 619 663 455 658 751 598 597 619 327 231 311 366 627 322 241 291 364
435 377 458 389 531 456 377 468 390 516 331 619 313 131 121 181 226 287 229 275
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169 137 147 195 165 194 199 153 185 172 136 152 125 121
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143 202 106 109 142 98 174 159 124 80 88 57 56 96 165 168 179 210 166 149
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289
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203 302 353 384 253 201 200 284 291 268 58 47 44 52 39 51 38 65 71 119
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256
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66 74 85 120 93 74 92 71 99 118 103 136 106 118 121 151 86 98 106 137
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38 44 60 97 157 144 141 138 96 146 183 125 131 178 80 96 143 128 85 85
121 156 118 130 134 84 128 128
STKA128B 128
98 143 146 188 143 135 154 254 195 138 135 64 97 137 126 178 79 82 100 87
79 65 74 110 92 88 127 108 104 75 88 106 85 105 111 84 84 72 87 106
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323 340 343 402 352 282 243 297 212 202 241 223 235 198 188 199 185 225 250 246
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61 92 116 88 119 175 134 90 208 88 58 90 77 106 85 85 66 84 84 83
70 85 66 75

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75 80 63 95
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217 272 244 175 182 150 193 179 261 221 295 230 192 254 286 235 273 137 89 82
40 84 106 104 106 296 113 212 151 163 177 131 153 188 175 195 125 117 108 126
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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 Buildings*' (Laxton and Litton 1988b) and, for example, in *Tree-Ring Dating and Archaeology* (Baillie 1982) or *A Slice Through Time* (Baillie 1995). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The *width* of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring..

If the bark is still on the sample, as in Figure 1, then the date of the last ring will be the date of felling of the oak from which it was cut. There is much evidence that in medieval times oaks cut down for building purposes were used almost immediately, usually within the year or so (Rackham 1976). Hence if bark is present on several main timbers in a building, none of which appear reused or are later insertions, and if they all have the same date for their last ring, then we can be quite confident that this is the date of construction. If there is no bark on the sample, then we have to make an estimate of the felling date; how this is done is explained below.

**The Practice of Tree-Ring Dating at the University of Nottingham Tree-Ring dating Laboratory**

1. ***Inspecting the Building and Sampling the Timbers.*** Together with a building historian we inspect the timbers in a building to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can sample *in situ* timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer rings than this, 50 for example, sequences of widths become difficult to match to a unique position within a master sequence of ring widths and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure 2 has about 120 rings; about 20 of which are sapwood rings. Similarly the core has just over 100 rings.

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

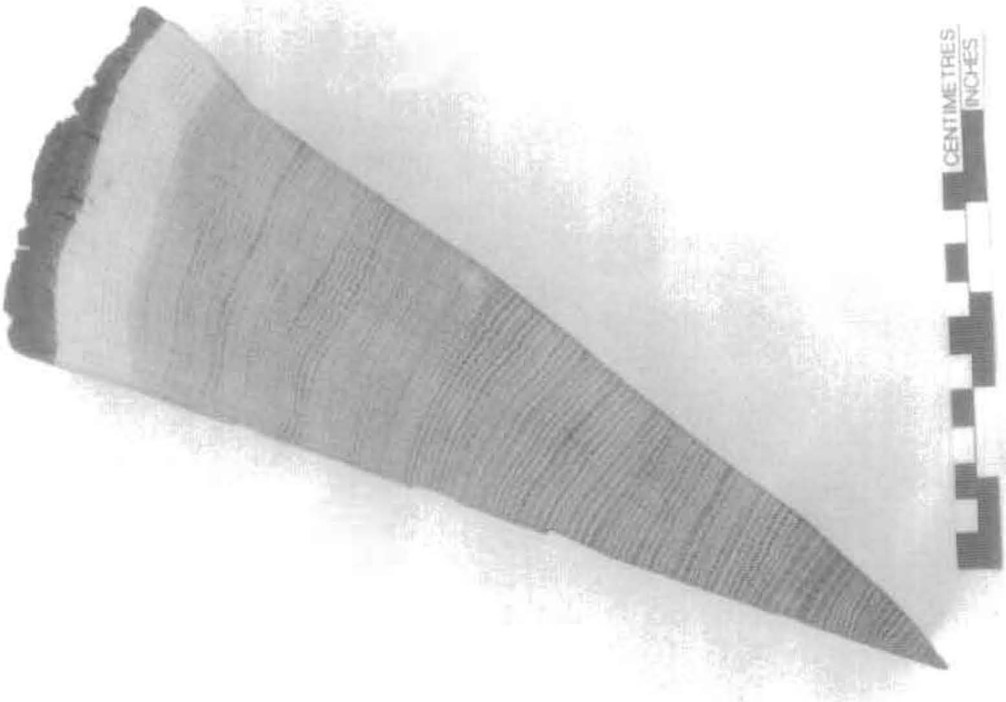


Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

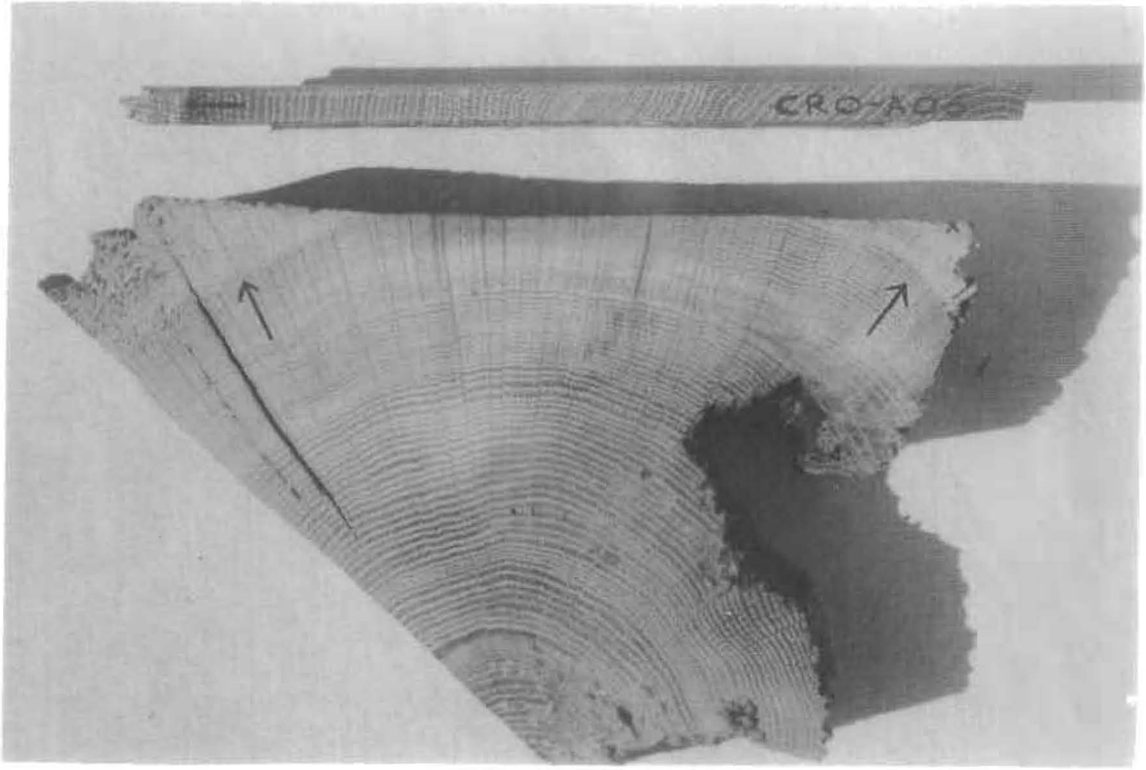

Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

Fig 3. Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measured twice to ensure that an error has not been made. This type of apparatus is needed to process a large number of samples on a regular basis.

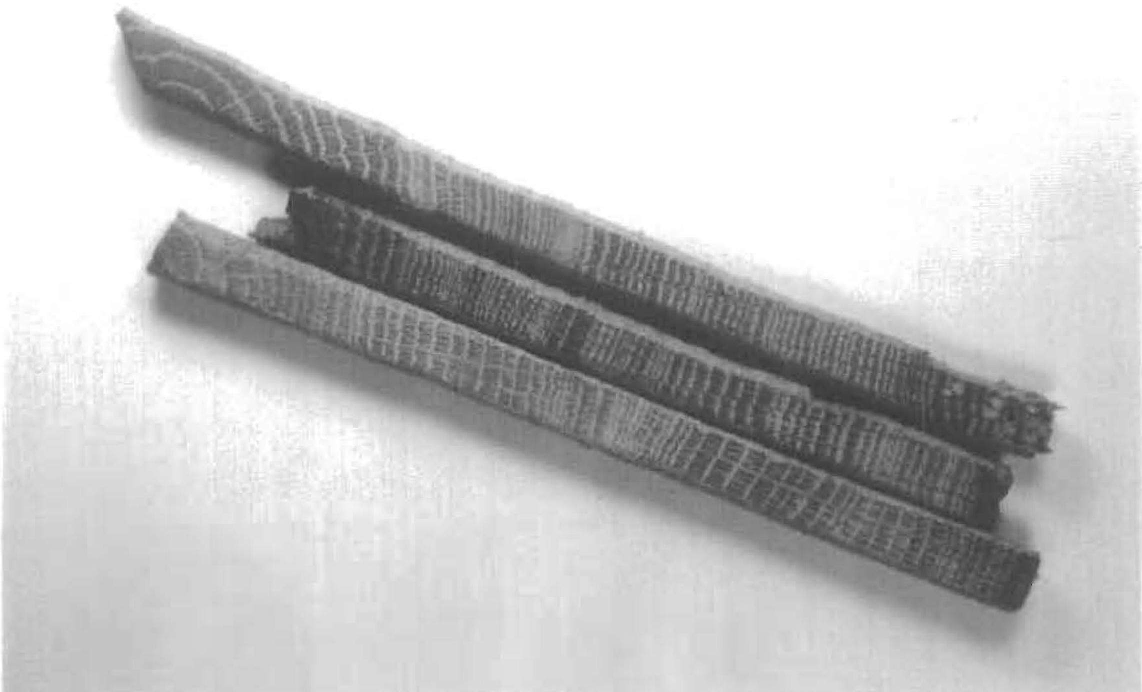

Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

Sampling is done by coring into the timber with a hollow corer attached to an electric drill and usually from its outer rings inwards towards where the centre of the tree, the pith, is judged to be. An illustration of a core is shown in Figure 2; it is about 15cm long and 1cm diameter. Great care has to be taken to ensure that as few as possible of the outer rings are lost This can be difficult as these outer rings are often very soft (see below on sapwood) Each sample is given a code which identifies uniquely which timber it comes from, which building it is from and where the building is located. For example, CRO-A06 is the sixth core taken from the first building (A) sampled by the Laboratory in Cropwell Bishop. Where it came from in that building will be shown in the sampling records and drawings. No structural damage is done to any timbers by coring, nor does it weaken them.

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

All sampling by the Laboratory is undertaken according to current Health and Safety Standards.
The Laboratory is insured with the CBA.

2. ***Measuring Ring Widths.*** Each core is sanded down with a belt sander using medium-grit paper and then finished by hand with flourgrade-grit paper. The rings are then clearly visible and differentiated from each other with a result very much like that shown in Figure 2. The core is then mounted on a movable table below a microscope and the ring-widths measured individually from the innermost ring to the outermost. The widths are automatically recorded in a computer file as they are measured (see Fig 3).

3. ***Cross-matching and Dating the Samples.*** Because of the factors besides the local climate which may determine the annual widths of a tree's rings, no two sequences of ring widths from different oaks growing at the same time are exactly alike (Fig 4). Indeed, the sequences may not be exactly alike even when the trees are growing near to each other. Consequently, in the Laboratory we do not attempt to match two sequences of ring widths by eye, or graphically, or by any other subjective method. Instead, it is done objectively (ie statistically) on a computer by a process called cross-matching. The output from the computer tells us the extent of correlation between two sample sequences of widths or, if we are dating, between a sample sequence of widths and the master, at each relative position of one to the other (offsets). The extent of the correlation at an offset is determined by the *t-value* (defined in almost any introductory book on statistics). That offset with the maximum t-value among the t-values at all the offsets will be the best candidate for dating one sequence relative to the other. If one of these is a master chronology, then this will date the other. Experiments carried out in the past with sequences from oaks of known date suggest that a t-value of at least 4.5, and preferably 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton *et al* 1988a,b; Howard *et al* 1984 - 1995).

   This is illustrated in Fig 5 with timbers from one of the roofs of Lincoln Cathedral. Here four sequences of ring widths, LIN- C04, 05, 08, and 45, have been cross-matched with each other. The ring widths themselves have been omitted in the *bar-diagram*, as is usual, but the offsets at which they best cross-match each other are shown; eg. C08 matches C45 best when it is at a position starting 20 rings after the first ring of 45. and similarly for the others. The actual t-values between the four at these offsets of best correlations are in the matrix. Thus at the offset of +20 rings, the t-value between C45 and C08 is 5.6 and is the maximum between these two whatever the position of one sequence relative to the other.

   It is standard practice in our Laboratory first to cross-match as many as possible of the sequences of the samples in a building and then to form an average from them. This average is called a site sequence of the building being dated and is illustrated in Fig 5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences from four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

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

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

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

   Quite often some, though not all, of the original outer rings are missing on a timber. The outer rings on an oak, called sapwood rings, are usually lighter than the inner rings, the heartwood, and so are relatively easy to identify. For example, they can be seen in two upper corners of the rafter and at the outer end of the core in Figure 2. More importantly for dendrochronology, the sapwood is relatively soft and so liable to insect attack and wear and tear. The builder, therefore, may remove some of the sapwood for precisely for these reasons. Nevertheless, if at least some of the sapwood rings are left on a sample, we will know that not too many rings have been lost since felling. Thus in these circumstances the date of the present last ring is at least close to the date of the original last ring on the tree, and so to the date of felling.

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

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

   More precise estimates of the felling date and range can often be obtained using knowledge of a particular case and information gathered at the time of sampling. For example, at the time of sampling the dendrochronologist may have noted that the timber from which the core of Figure 2 was taken still had complete sapwood. Sapwood rings were only lost in coring, because of their softness. By measuring in the timber the depth of sapwood lost, say 2 cm., a reasonable estimate can be made of the number of sapwood rings missing from the core, say 12 to 15 rings in this case. By adding on 12 to 15 years to the date of the last ring on the sample a good tight estimate for the range of the felling date can be obtained, which is often better than the 15 to 40 years later we would have estimated without this observation.

**T-value/Offset Matrix**

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

**Bar Diagram**

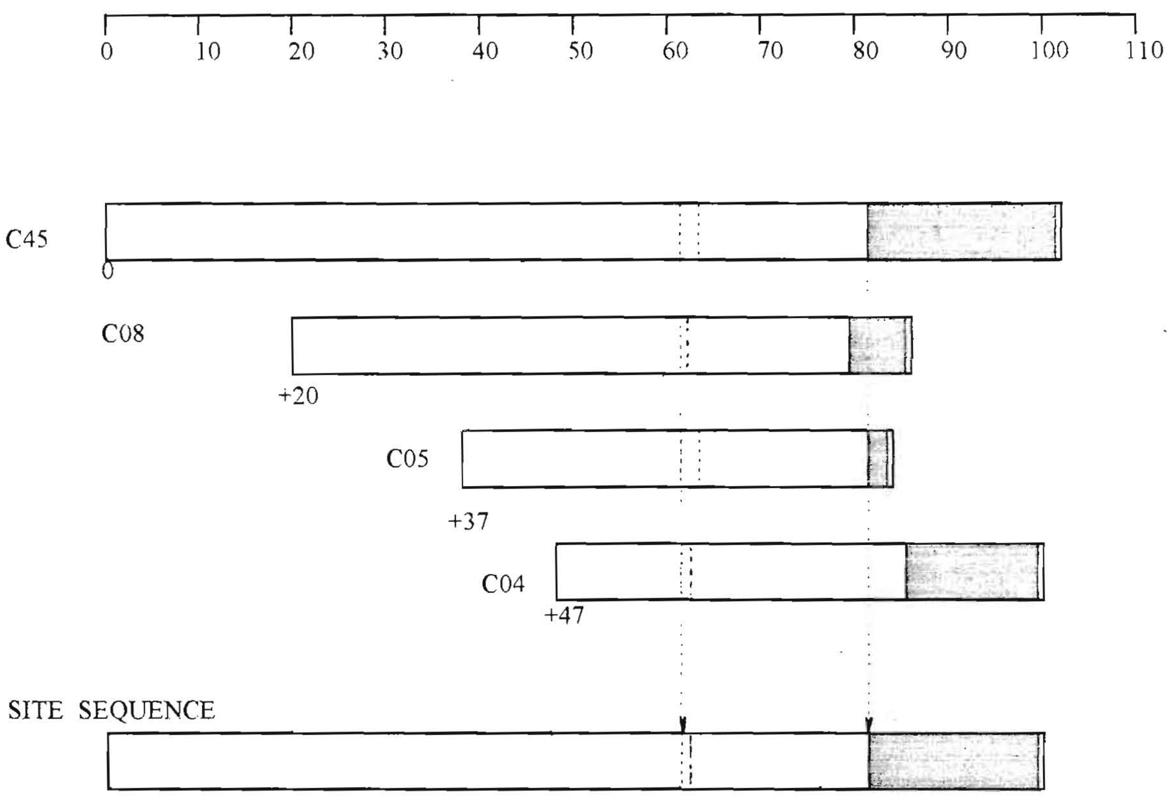


Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.
The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set at relative positions *(offsets)* to each other at which they have maximum correlation as measured by the *t-values*.
The *t-value offset* matrix contains the maximum t-values below the diagonal and the offsets above it.
Thus, the maximum t-value between C08 and C45 occurs at the offset of +20 rings and the t-value is then 5.6.
The *site sequence* is composed of the average of the corresponding widths, as illustrated with one width.

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

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

5. ***Estimating the Date of Construction.*** There is a considerable body of evidence in the data collected by the Laboratory that the oak timbers used in vernacular buildings, at least, were used 'green' (see also Rackham (1976 )). Hence provided the samples are taken *in situ*, and several dated with the same estimated common felling date, then this felling date will give an estimated date for the construction of the building, or for the phase of construction. If for some reason or other we are rather restricted in what samples we can take, then an estimated common felling date may not be such a precise estimate of the date of construction. More sampling may be needed for this.

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

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

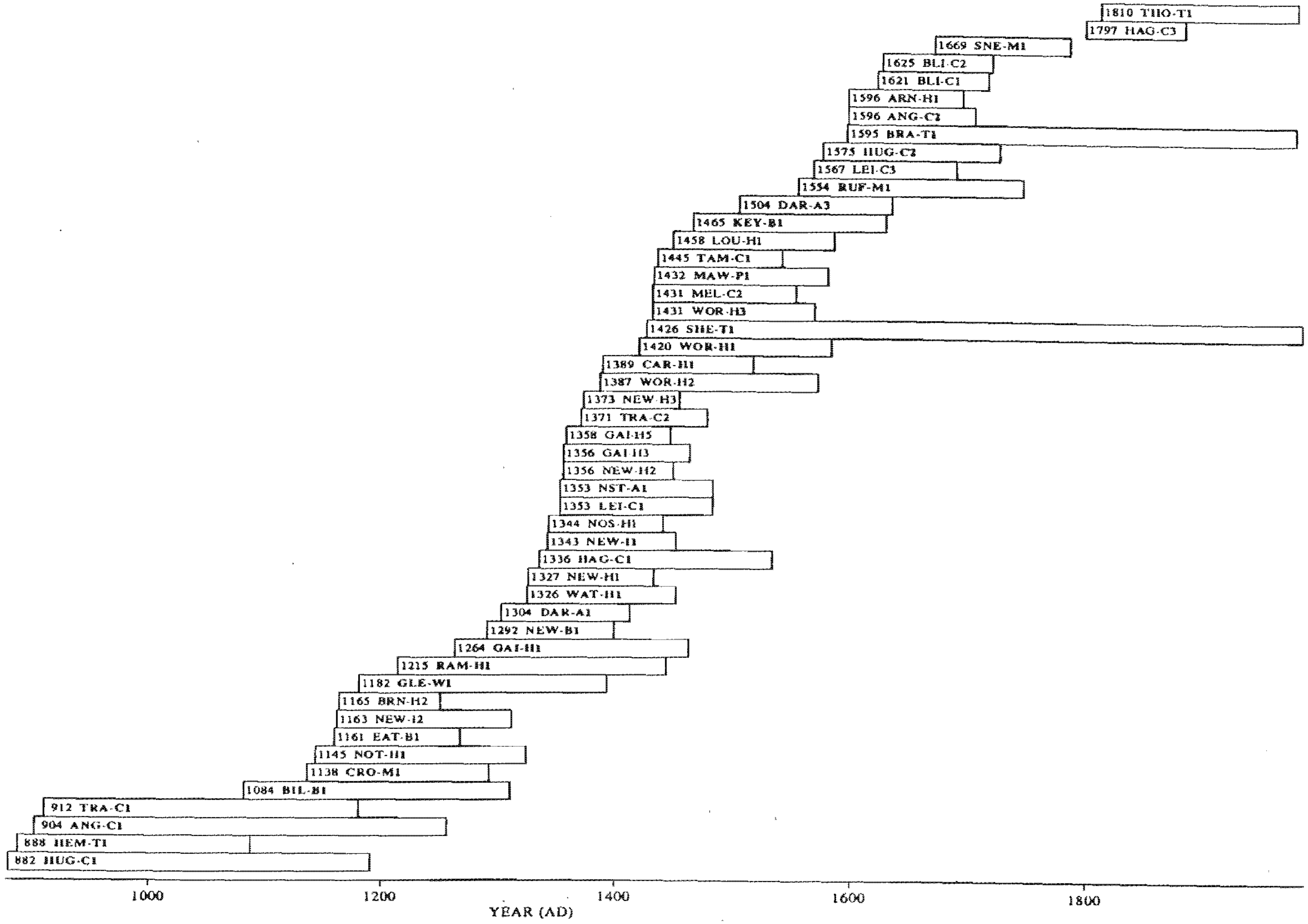


Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

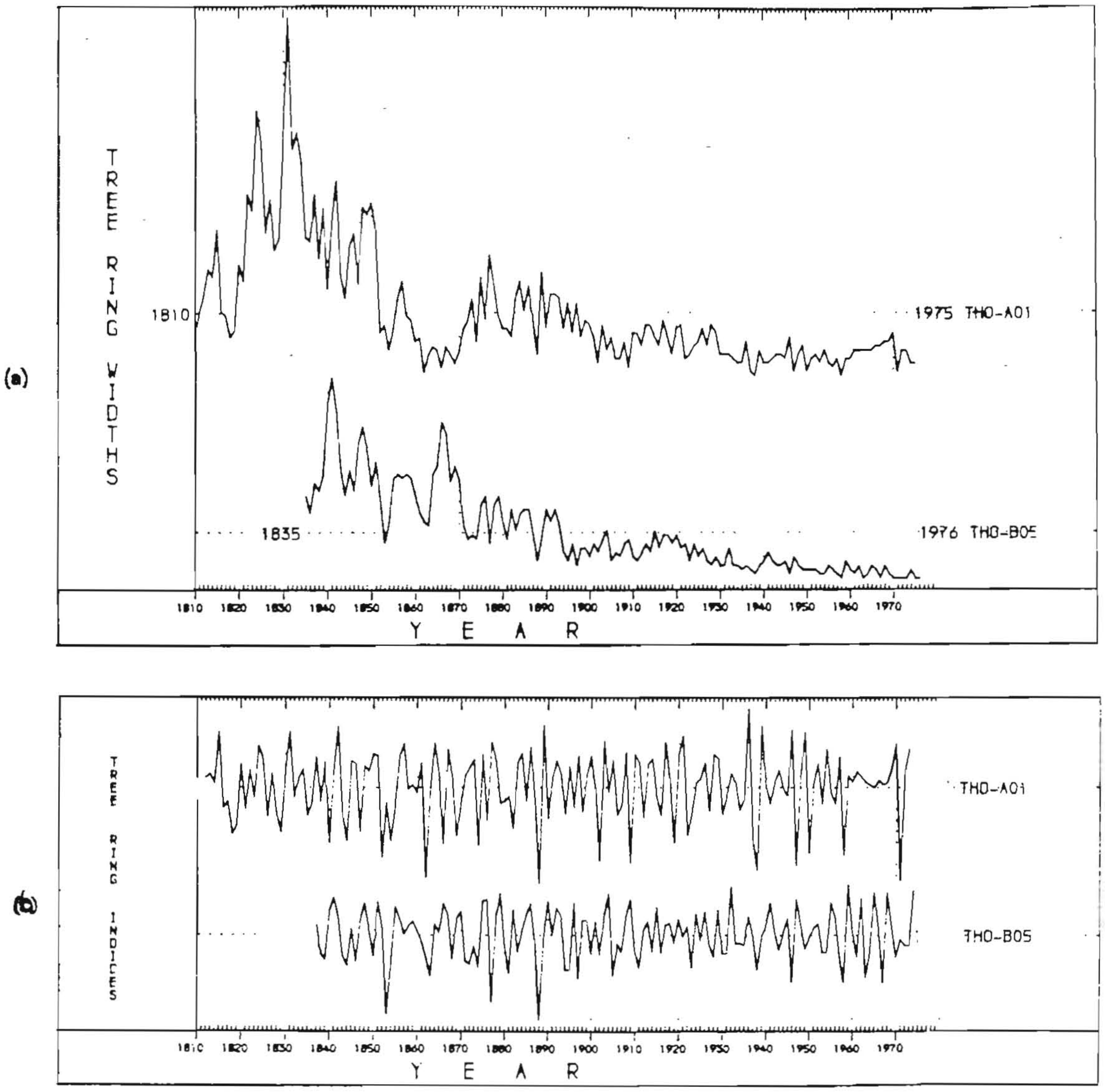


Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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

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

REFERENCES


Baillie, M G L, 1982 *Tree-Ring Dating and Archaeology*, London.

Baillie, M G L, 1995 *A Slice Through Time*, London

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

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 Architecture*, **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

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

Laxton, R R, and Litton, C D, 1988b *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, A.D. 1158 to 1540, *Medieval Archaeol*, **33**, 90-8

Litton, C D, and Zainodin, H J, 1991 Statistical models of Dendrochronology, *J Archaeol Sci*, **18**, 429-40

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

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