Centre for Archaeology Report 12/2003

Tree-Ring Analysis of Timbers from Staircase House, (30A & 31 Market Place), Stockport, Greater Manchester

R E Howard, Dr R R Laxton and Dr C D Litton

ISSN 1473-9224

The Centre for Archaeology Reports Series incorporates the former Ancient Monuments Laboratory Report Series. Copies of Ancient Monuments Laboratory Reports will continue to be available from the Centre for Archaeology (see back of cover for details).

Centre for Archaeology Report 12/2003

Tree-Ring Analysis of Timbers from Staircase House, (30A & 31 Market Place), Stockport, Greater Manchester

R E Howard, Dr R R Laxton and Dr C D Litton

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

Author's address
University of Nottingham, University Park, Nottingham, NG7 2RD

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) 111 (A106/136)	AD 1406 – AD 1459 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

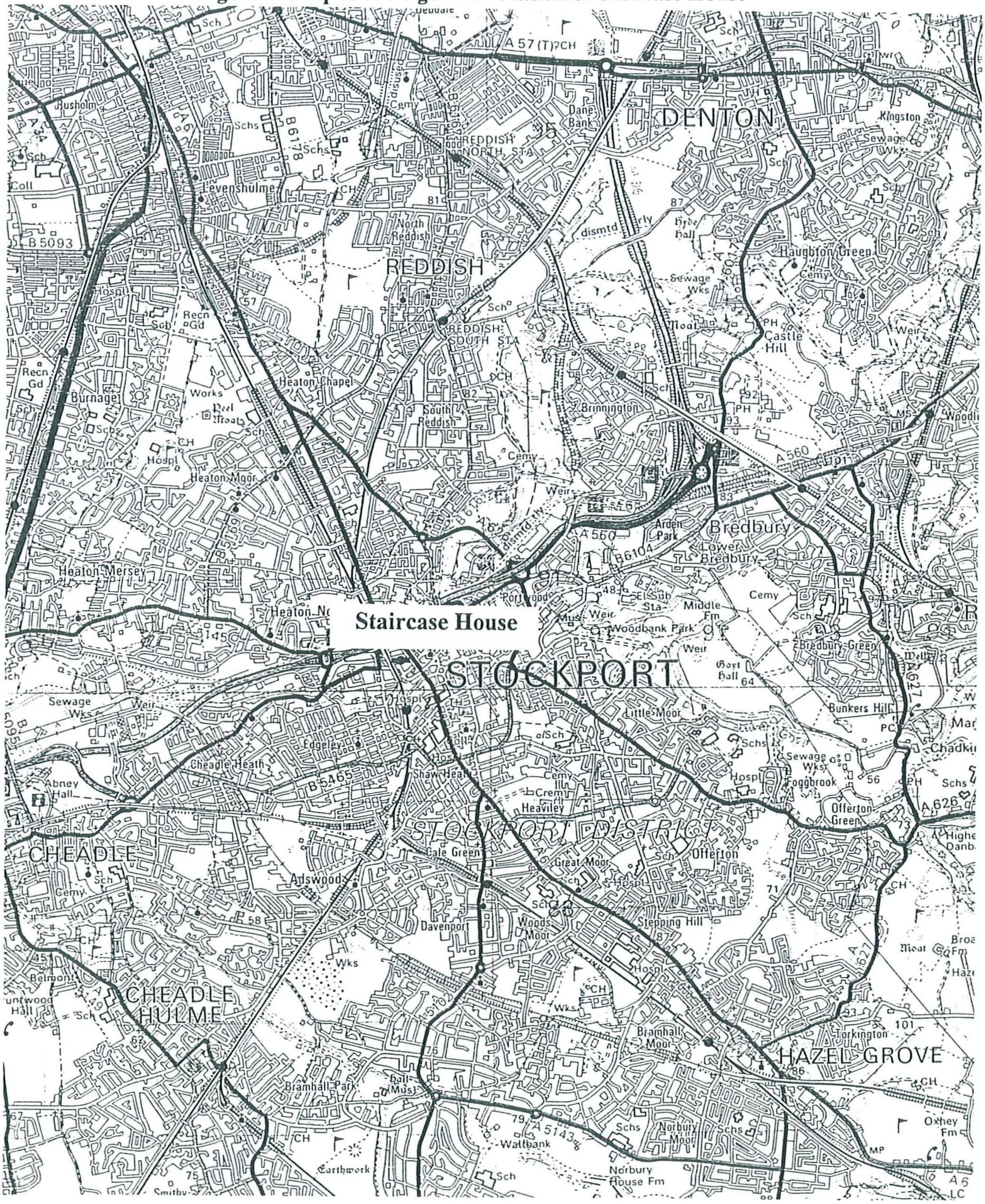


Figure 2: Map to show specific location of Staircase House

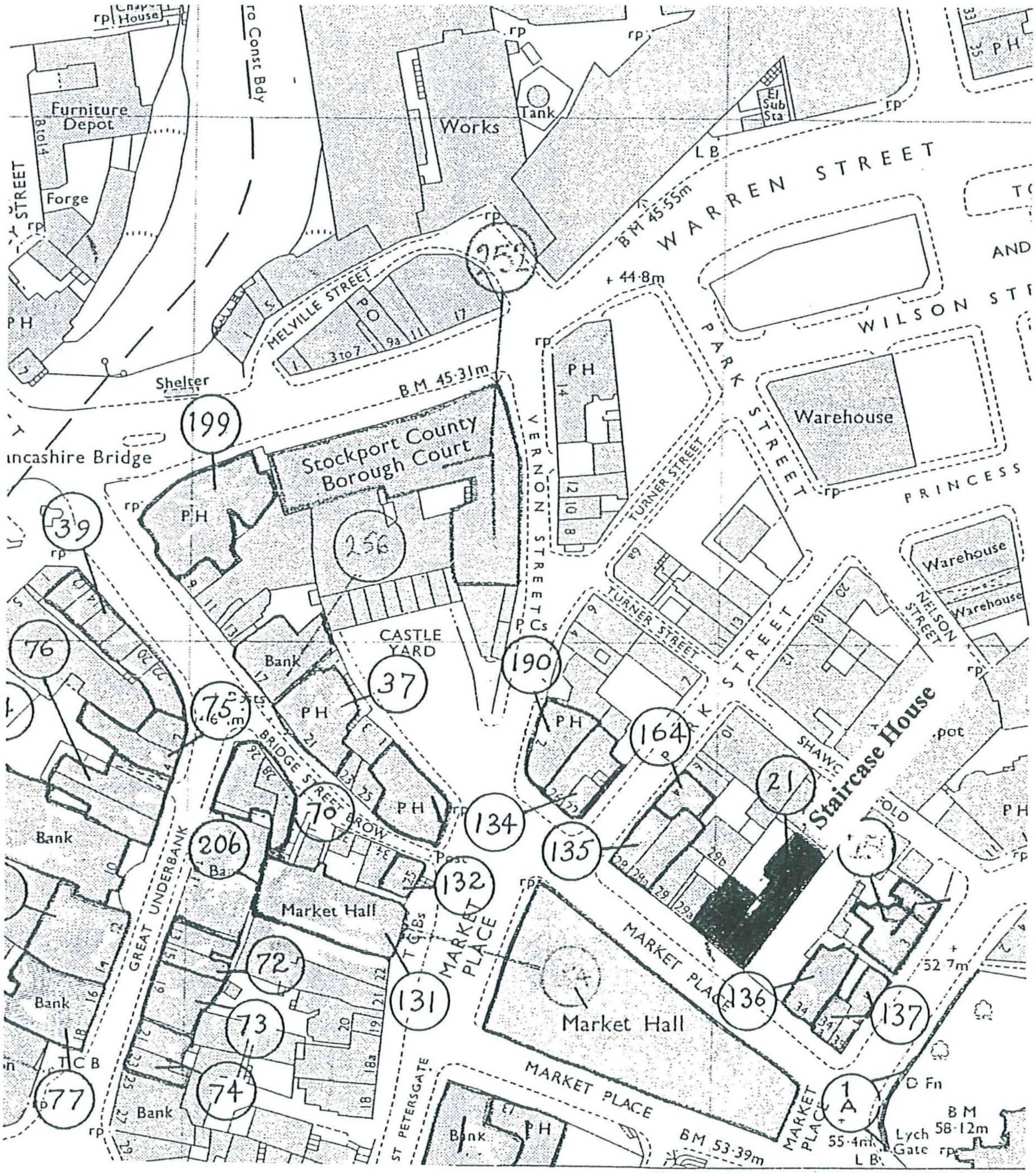


Figure 3: Schematic plan of Staircase House at ground-floor level

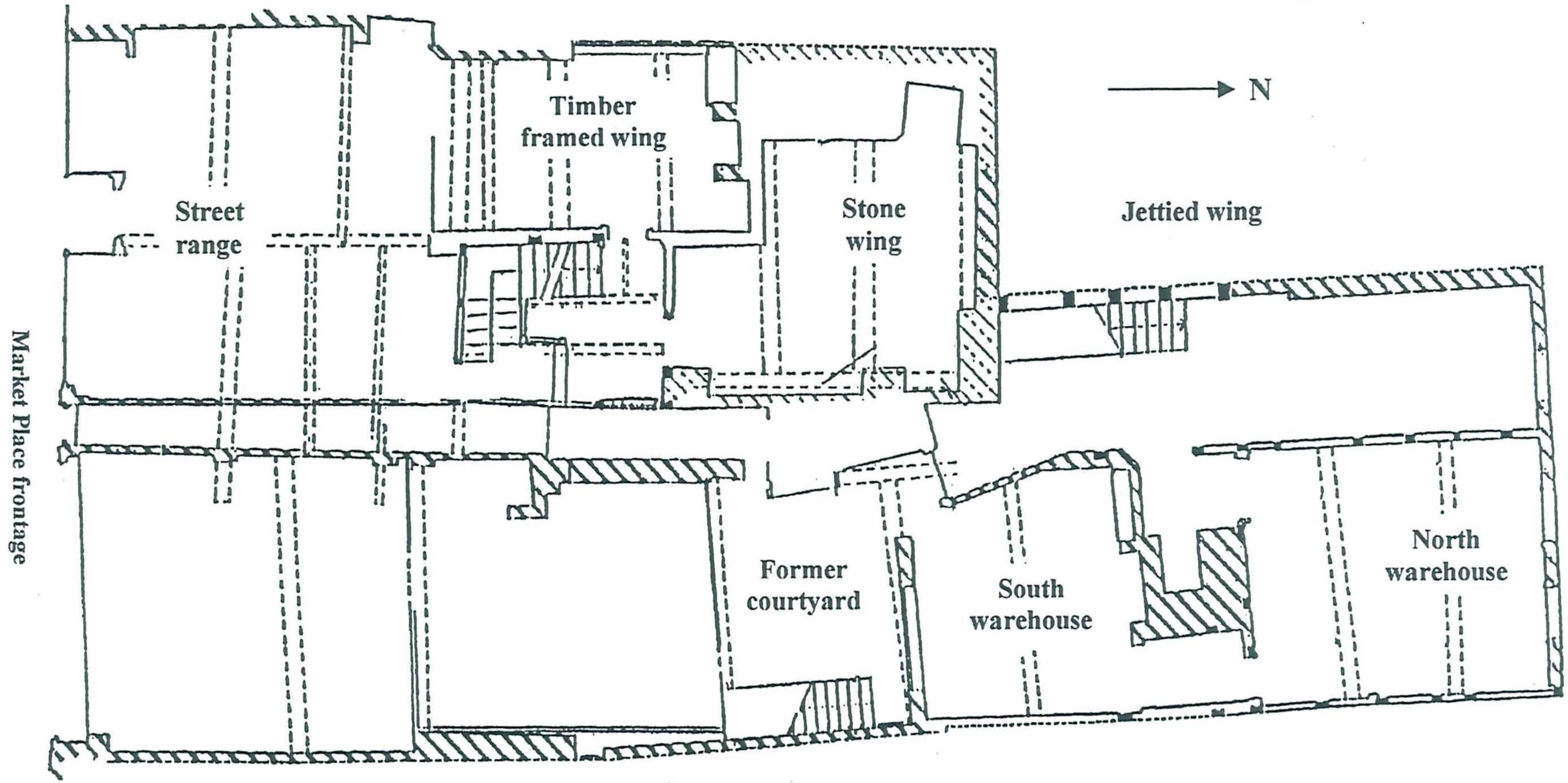


Figure 4: Drawing to show approximate location of sampled timbers from the cellar / basement

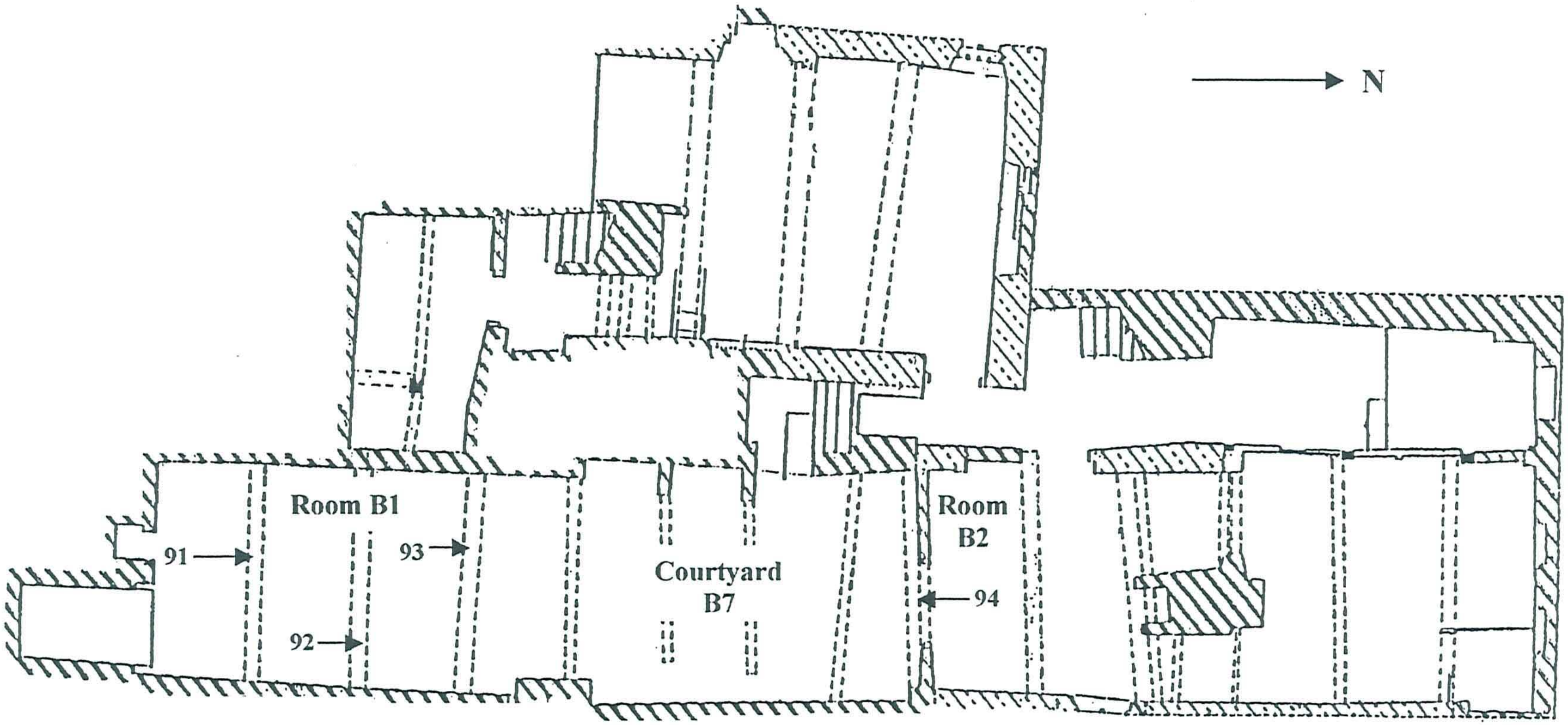


Figure 5: Drawing to show approximate location of sampled timbers from the ground floor

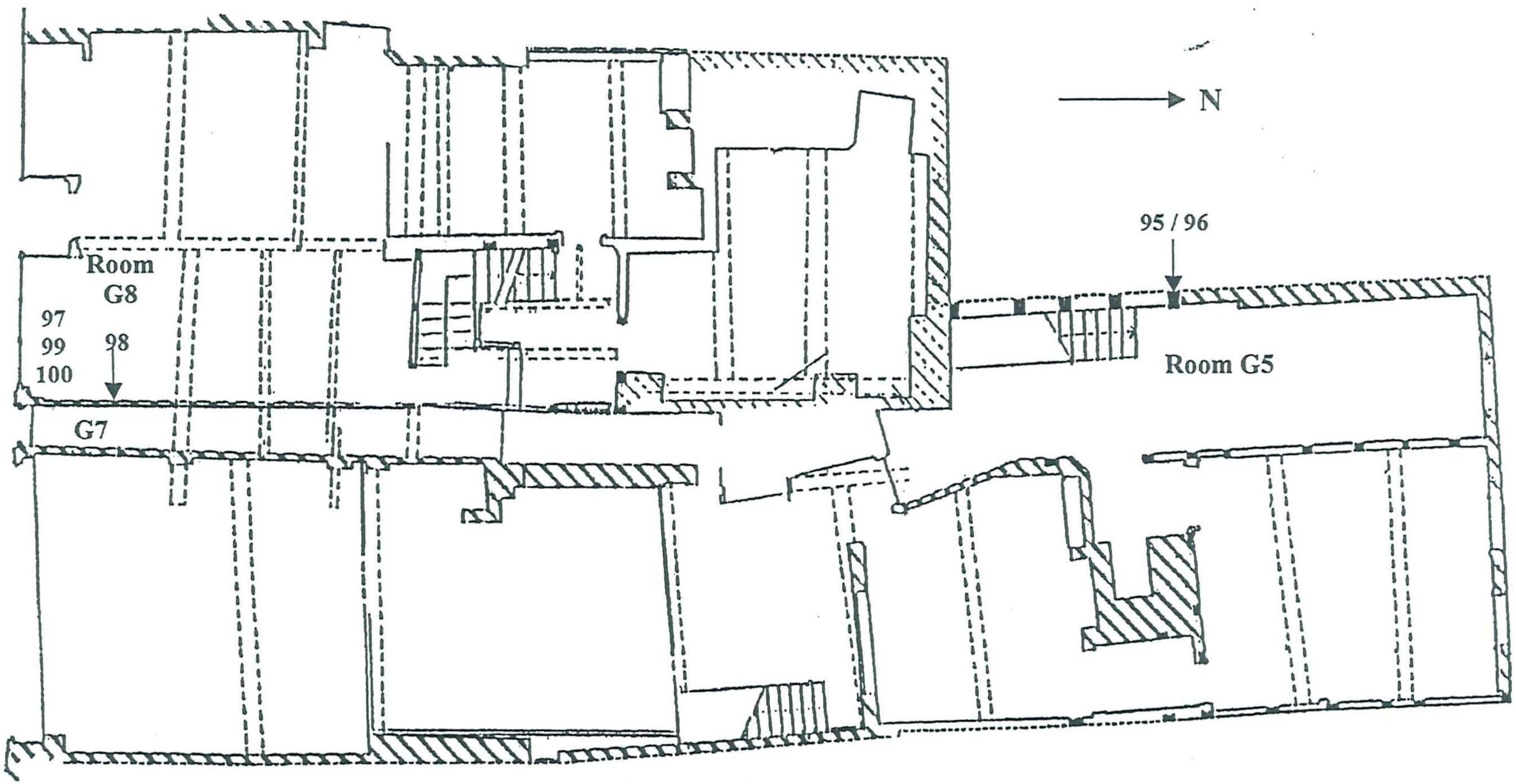


Figure 6: Drawing to show approximate location of sampled timbers from the first floor

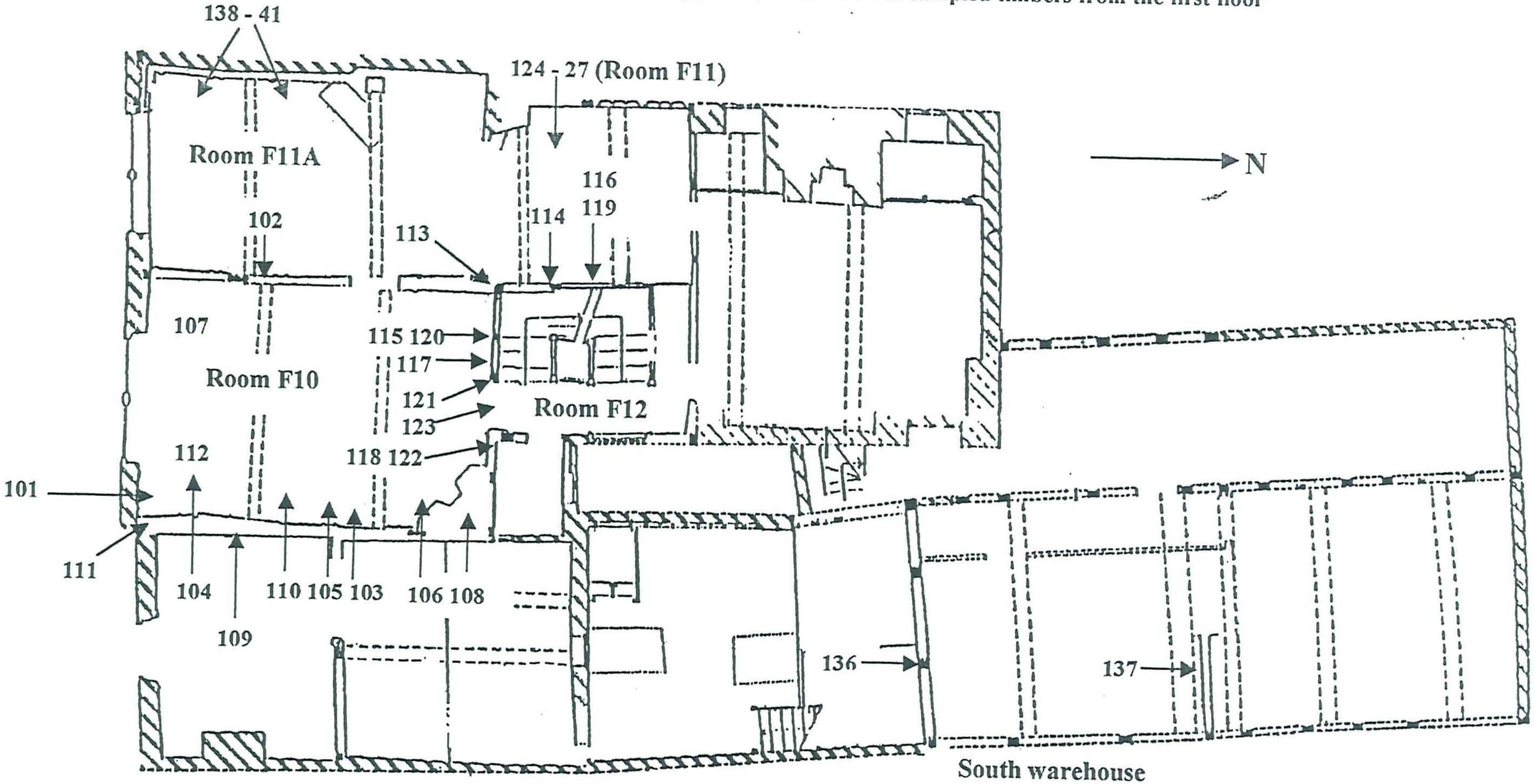


Figure 7: Drawing to show approximate location of sampled timbers from the second floor and roof

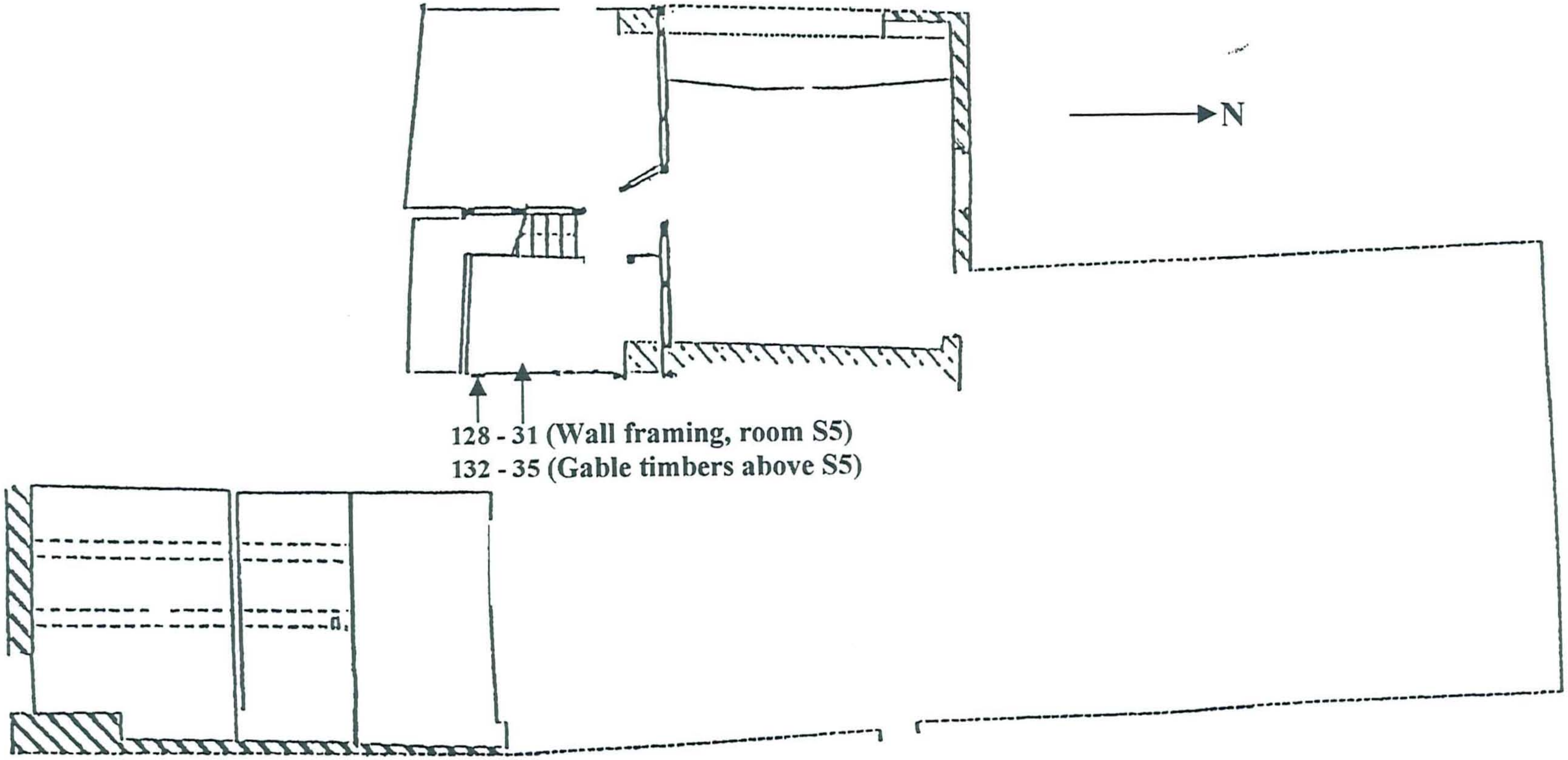
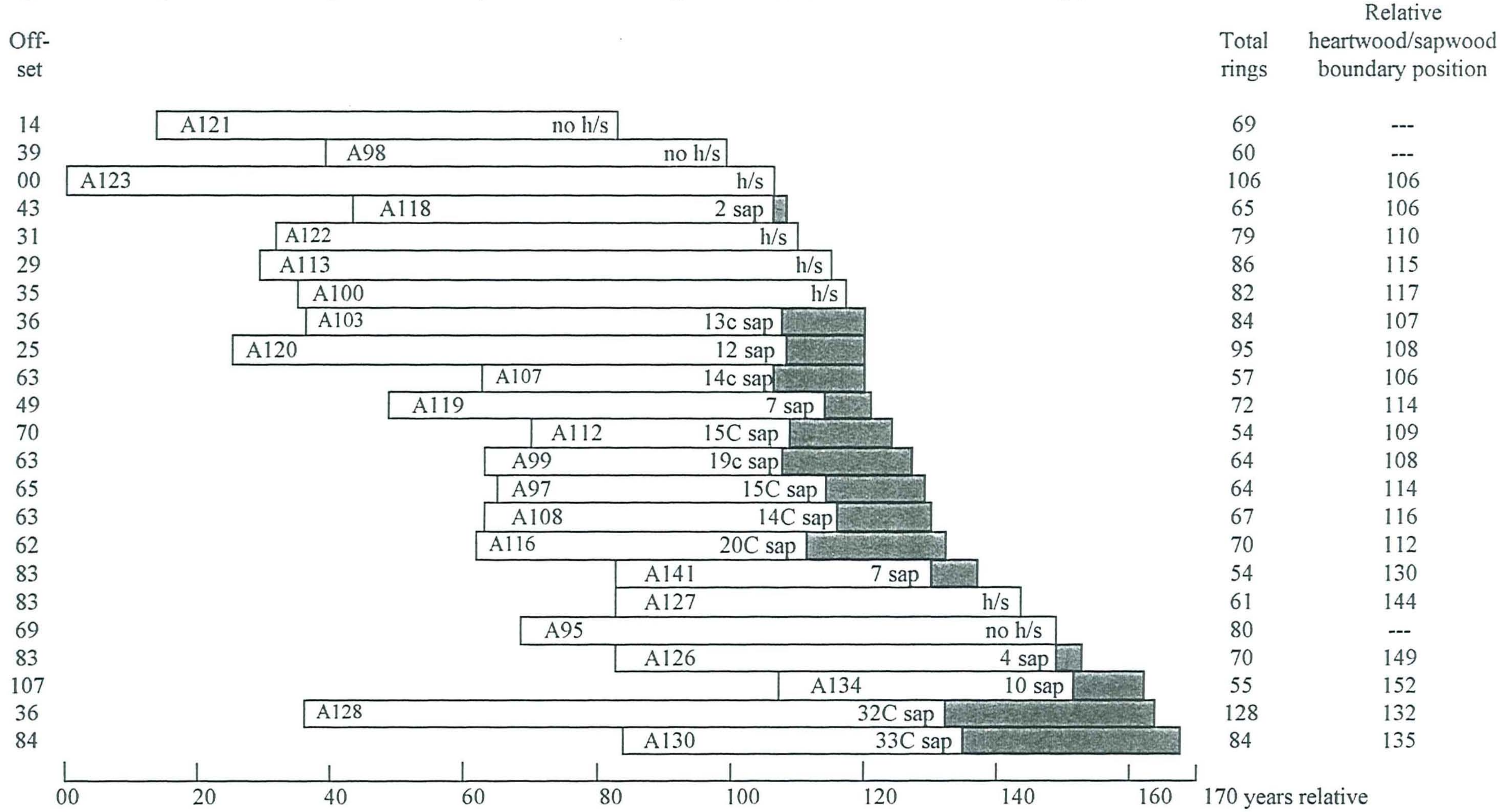


Figure 8: Bar diagrams of the newly measured samples in site chronology STKASQ01, shown in order of last ring position



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

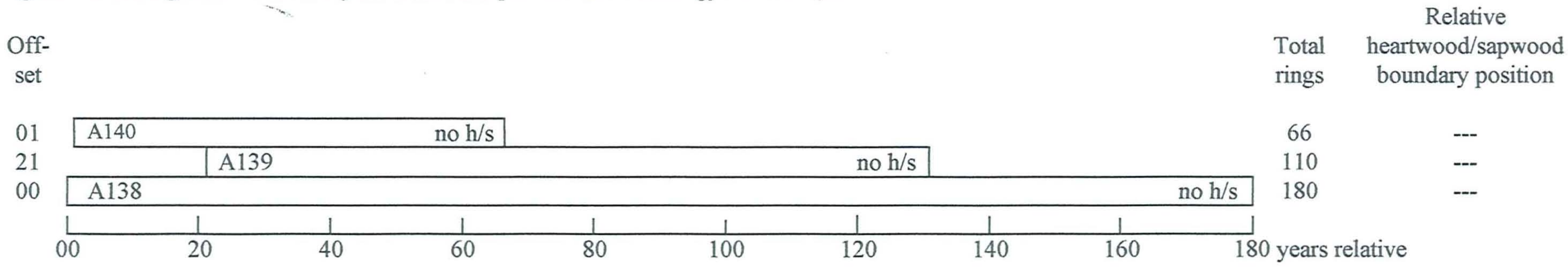


Figure 10: Bar diagrams of the newly measured samples in site chronology STKASQ03

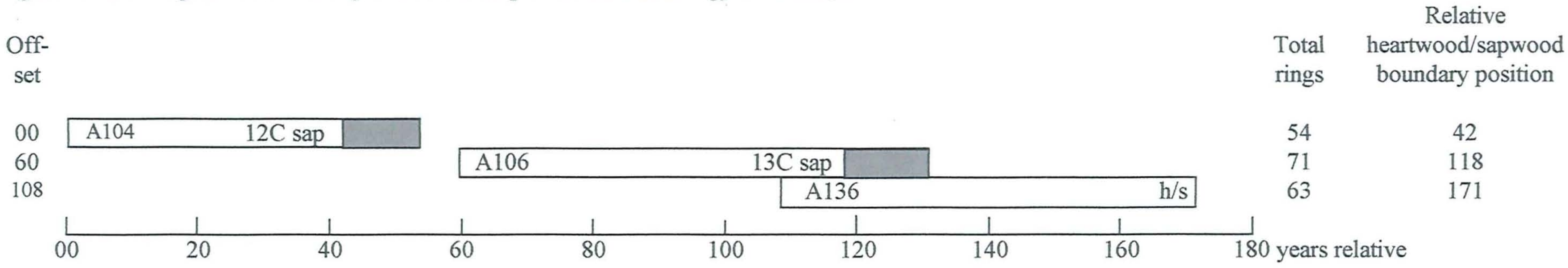
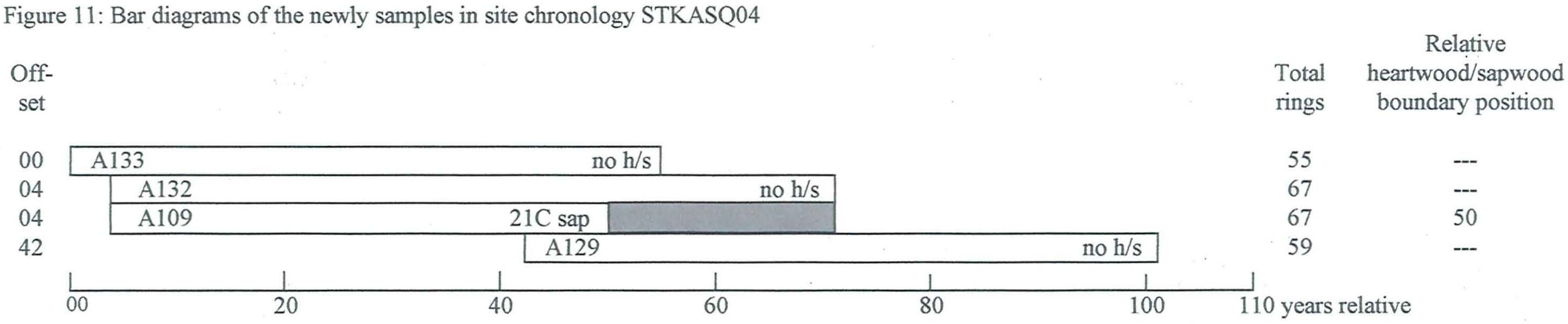
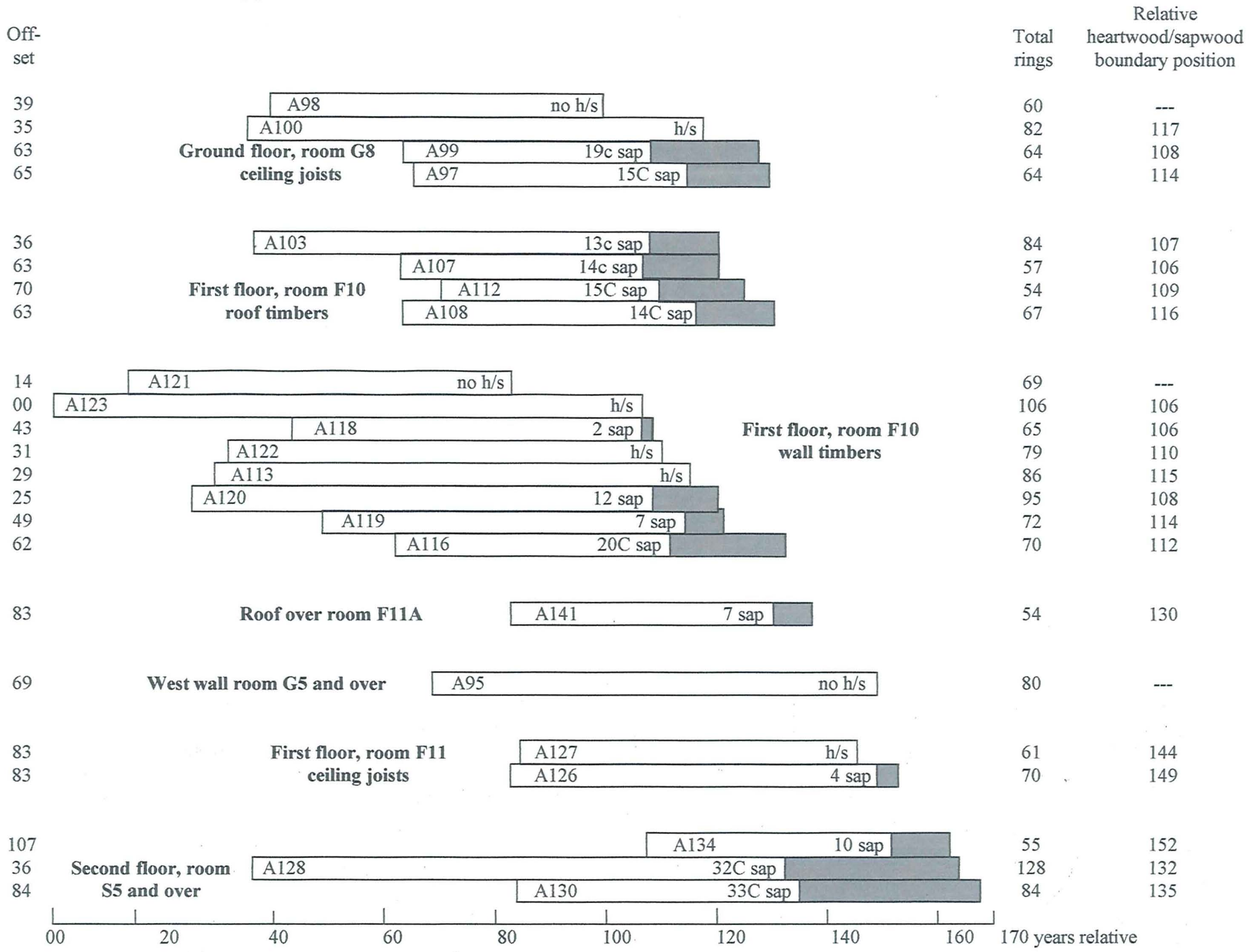


Figure 11: Bar diagrams of the newly samples in site chronology STKASQ04



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
STKA103A 84
157 146 146 197 175 135 134 152 151 142 185 86 143 141 123 180 98 126 167 132
157 122 118 186 168 168 154 113 112 60 91 52 62 69 107 128 112 93 85 101
85 90 76 91 98 144 109 147 143 133 142 112 124 103 122 127 110 83 92 139
151 134 68 42 40 33 37 34 77 89 103 87 72 82 56 63 70 58 73 93
51 66 69 56
STKA103B 84
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
151 133 63 44 43 29 44 48 77 88 117 77 80 81 50 70 73 56 68 93
75 73 57 73
STKA104A 54
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
STKA104B 54
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
STKA105A 58
198 214 254 265 205 237 156 176 222 396 277 239 242 273 275 209 242 237 180 361
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
192 209 249 250 199 250 158 179 222 400 279 238 241 265 285 214 261 238 187 356
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
STKA106A 71
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
STKA106B 71
246 338 296 156 132 149 181 250 216 323 299 141 76 88 94 112 75 92 105 113
120 150 75 64 53 48 44 48 40 107 126 72 136 132 94 120 147 132 139 177
163 171 140 198 176 183 253 149 143 121 126 115 114 112 140 155 141 173 263 174
150 114 67 69 64 97 76 109 78 153 192
STKA107A 57
226 239 177 176 142 129 164 251 237 239 213 205 237 210 205 144 214 207 202 193
190 204 202 195 164 135 136 136 199 185 166 176 163 173 211 173 107 117 96 88
115 234 246 211 195 178 182 119 125 143 162 179 214 191 187 195 218
STKA107B 57
234 244 191 176 149 114 169 247 244 241 210 200 240 199 208 142 213 198 209 196
195 195 201 204 158 142 139 133 205 180 155 181 157 166 233 145 115 96 110 87
146 232 246 191 188 172 187 132 114 145 154 162 248 157 212 202 228
STKA108A 67
265 274 189 166 136 122 183 273 251 261 227 206 241 215 227 138 201 201 195 184
193 182 229 198 171 145 147 136 200 181 149 167 160 159 198 168 100 115 101 86
152 227 236 211 194 184 184 124 106 143 141 168 173 206 183 195 155 150 133 168
192 221 140 179 99 157 179
STKA108B 67
244 267 190 165 135 120 178 286 261 247 222 215 234 210 224 132 207 197 206 202
193 177 233 199 162 140 146 132 207 177 145 167 151 166 199 166 99 118 100 86
145 236 241 209 199 180 181 130 104 138 133 156 203 188 185 189 154 138 170 153
182 208 157 149 132 166 172
STKA109A 67
256 150 196 174 260 211 177 113 214 244 203 192 255 128 140 216 193 193 174 148
176 257 155 132 169 190 133 200 184 193 186 110 135 131 186 189 229 171 85 76
130 216 250 200 218 172 162 239 125 110 108 102 83 107 117 104 119 97 98 82
79 91 58 84 113 102 119
STKA109B 67
259 142 195 171 257 222 182 125 214 231 208 188 240 132 139 215 192 195 167 158
166 224 161 135 142 192 144 199 197 199 189 112 125 135 183 191 214 188 82 71
148 207 239 204 218 169 177 223 104 119 115 114 107 114 113 122 106 117 77 75
83 109 55 80 134 79 110
STKA110A 87
33 41 51 72 51 46 52 55 62 53 58 33 30 54 43 50 62 69 96 74
68 71 58 48 60 51 46 52 58 47 59 70 60 68 67 66 67 78 83 48
31 30 33 30 42 32 71 42 44 32 56 40 38 55 50 36 60 63 102 71
91 88 111 87 110 99 123 111 108 136 98 136 168 116 114 123 182 189 184 134
106 128 104 124 140 219 193

STKA110B 87
36 49 50 69 53 50 47 53 60 54 59 29 34 51 44 48 65 70 89 81
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
STKA111A 55
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
STKA111B 55
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
312 636 302 145 110 184 234 290 242 254 253 138 96 80 96
STKA112A 54
135 103 165 105 119 158 134 118 140 186 242 208 128 121 179 161 186 161 184 136
151 200 109 109 143 105 152 144 125 91 83 53 60 93 149 171 181 212 174 159
169 137 147 195 165 194 199 153 185 172 136 152 125 121
STKA112B 54
174 110 157 116 116 160 136 113 150 181 243 216 133 120 182 163 173 172 200 136
143 202 106 109 142 98 174 159 124 80 88 57 56 96 165 168 179 210 166 149
132 152 155 175 171 192 198 155 195 164 142 150 115 130
STKA113A 86
201 286 230 208 177 227 208 174 228 207 219 158 110 174 192 173 148 273 174 175
199 142 223 134 141 147 108 144 120 135 124 168 150 189 155 203 144 147 98 71
150 181 185 172 107 127 131 116 83 94 131 248 241 177 146 132 147 129 147 115
120 152 158 117 103 97 87 99 124 88 45 61 46 72 105 144 216 209 241 192
210 183 124 170 187 184
STKA113B 86
221 268 197 255 177 226 203 173 219 199 223 165 113 161 193 171 162 258 194 186
207 154 221 156 120 137 123 153 110 133 119 198 156 199 159 179 140 143 96 79
152 198 179 165 120 112 147 108 92 96 126 250 239 174 136 142 147 136 147 148
132 108 149 117 103 93 83 98 126 76 54 54 49 55 91 107 216 135 239 200
203 165 122 172 188 156
STKA114A 54
237 294 163 121 174 207 179 229 211 192 216 217 180 200 179 135 209 190 239 211
209 236 239 252 151 188 178 185 174 150 161 123 144 168 251 167 184 212 167 203
204 284 239 294 167 122 174 200 189 221 211 191 210 231
STKA114B 54
267 265 187 138 161 180 214 235 219 171 197 232 175 184 190 135 207 197 197 210
218 238 232 268 157 267 163 183 186 130 163 111 156 180 223 188 171 186 172 223
236 228 260 275 187 137 162 183 210 230 211 177 195 231
STKA115A 79
206 259 240 273 179 227 224 244 250 166 135 192 177 259 215 256 233 243 217 240
180 204 212 138 113 127 161 264 315 231 153 131 173 144 87 101 83 118 206 140
220 118 140 125 179 184 126 179 171 162 128 130 112 124 210 92 91 114 61 82
80 165 185 192 189 298 193 138 127 157 131 82 128 89 29 36 24 72 86

STKA115B 79
225 267 250 277 188 220 238 165 273 170 143 184 185 261 210 245 235 237 218 244
164 206 214 145 118 132 153 273 320 202 174 135 162 148 95 86 105 126 200 136
216 109 152 124 171 180 117 183 180 136 129 126 121 124 204 107 84 112 70 82
79 164 186 190 196 303 201 146 140 134 130 69 128 85 37 32 25 73 52
STKA116A 70
207 146 125 122 107 72 62 56 63 82 118 98 117 102 71 44 60 96 96 154
113 119 107 64 75 59 55 56 72 99 74 63 118 92 116 97 78 49 56 66
41 66 92 94 105 66 66 65 53 57 49 31 54 87 86 100 85 67 94 73
68 75 98 95 79 66 95 97 109 106
STKA116B 70
184 143 153 120 102 70 50 69 79 92 96 87 105 88 65 57 71 83 71 145
111 114 110 76 65 53 60 62 77 93 77 63 109 88 109 108 71 54 58 58
50 66 90 99 100 67 68 59 53 68 41 40 46 79 88 91 87 77 86 78
71 71 97 88 73 63 81 131 89 126
STKA117A 58
138 205 179 140 167 184 179 191 170 190 208 195 152 141 162 133 130 118 117 121
118 122 105 122 107 94 109 99 92 94 91 107 114 100 106 97 95 117 98 96
115 144 180 167 150 198 157 204 169 181 161 177 255 238 235 238 215 279
STKA117B 58
138 214 171 137 164 189 178 212 160 180 210 227 176 136 171 141 132 119 121 127
133 118 109 115 98 103 108 95 88 104 97 92 122 100 111 79 102 117 100 100
135 148 168 165 157 193 162 170 176 175 166 164 270 229 233 244 190 254
STKA118A 65
212 192 166 231 194 224 204 223 259 177 146 190 185 217 211 219 273 307 367 313
190 173 105 95 63 74 94 133 147 131 115 104 163 172 129 107 140 205 203 169
174 147 132 140 135 138 105 172 150 152 148 125 148 181 157 148 83 125 96 39
91 110 126 139 151
STKA118B 65
267 171 147 250 194 221 207 220 255 178 153 182 192 213 226 215 282 304 368 312
169 180 105 82 71 76 86 124 142 141 112 113 159 155 138 100 146 209 197 161
185 148 150 123 131 136 102 175 154 149 148 132 141 178 163 141 80 130 92 87
101 103 109 133 143
STKA119A 72
109 84 125 90 152 132 185 212 122 145 196 241 208 369 226 204 182 118 102 96
77 125 153 126 234 161 130 82 70 62 93 121 151 106 141 116 101 60 59 66
75 117 119 106 72 121 110 115 132 88 54 66 71 54 74 102 105 122 79 77
72 69 71 55 42 67 108 128 94 119 94 115
STKA119B 72
114 88 113 94 153 148 175 249 118 158 210 259 208 293 211 198 159 130 99 82
90 114 152 149 204 123 92 73 54 57 82 85 148 118 143 120 100 64 56 65
87 107 115 102 85 108 106 112 129 99 64 78 73 55 70 110 118 129 78 73
62 78 72 54 45 65 105 131 99 99 98 118
STKA120A 95
153 164 129 96 134 218 150 215 179 140 123 114 127 168 174 115 104 172 151 131
134 180 147 152 156 109 198 132 110 200 151 172 139 163 189 163 224 172 152 191
161 94 100 91 132 176 163 185 126 94 105 95 74 75 95 125 91 73 63 69
73 70 68 79 56 82 79 61 50 56 59 62 77 61 50 46 50 51 55 107
114 129 149 131 118 115 118 135 104 107 169 110 88 113 171

STKA120B 95
131 140 140 88 130 220 152 211 186 141 121 111 125 175 176 123 105 155 118 126
139 186 147 160 175 115 190 129 108 189 153 172 133 165 183 174 221 175 148 193
131 96 95 104 137 164 169 180 108 88 118 98 74 71 82 106 99 81 64 66
71 66 75 72 63 79 76 59 53 62 57 65 80 52 56 54 42 55 58 109
130 104 148 112 118 113 125 132 100 106 173 117 104 127 161
STKA121A 69
106 179 308 211 230 158 264 171 192 186 188 164 168 119 100 113 227 160 240 184
132 112 112 123 159 182 110 94 143 144 123 135 168 138 140 150 118 216 103 92
190 164 166 122 164 174 166 189 163 164 166 125 76 66 70 119 158 143 173 108
112 132 105 82 85 104 112 121 153
STKA121B 69
111 184 318 213 243 163 243 175 202 183 220 156 182 126 115 131 212 147 229 182
155 126 114 123 164 176 101 103 157 130 120 135 167 140 146 155 124 163 120 89
211 158 170 129 146 175 160 201 163 187 170 126 73 68 75 120 143 140 177 110
108 130 102 86 79 105 111 121 126
STKA122A 79
225 337 203 204 262 169 279 221 244 194 191 232 258 222 239 202 137 113 155 164
241 109 130 173 156 201 149 177 175 280 306 274 202 197 92 115 73 52 105 192
172 193 143 133 199 141 133 116 141 133 125 102 83 165 145 236 203 150 107 144
213 105 125 123 124 145 153 121 62 54 47 50 56 200 224 264 293 241 295
STKA122B 79
262 332 233 206 248 170 287 218 250 191 202 225 244 212 218 200 131 115 157 157
257 124 114 174 157 183 133 186 183 280 285 271 208 183 101 127 69 67 95 186
162 187 129 145 211 148 133 111 152 127 106 105 66 160 148 227 210 146 109 148
200 112 116 105 115 136 153 122 44 67 46 56 54 193 223 264 287 250 247
STKA123A 106
228 318 274 139 121 178 210 309 209 175 427 265 130 124 124 109 190 151 178 181
237 198 165 220 162 155 179 128 94 137 227 144 203 154 152 115 129 123 159 180
88 98 136 113 142 135 189 123 164 174 122 194 143 117 185 198 168 124 156 179
181 199 162 135 162 137 85 59 73 97 137 128 151 102 107 133 82 83 72 108
109 124 90 83 79 101 96 110 94 99 102 96 74 63 77 69 80 87 80 63
51 49 53 46 74 84
STKA123B 106
182 329 279 145 117 173 215 304 218 169 364 246 120 136 123 128 184 159 183 155
242 168 168 217 159 170 178 136 105 123 221 134 199 152 156 122 117 126 165 186
96 95 144 119 134 138 181 142 168 151 118 196 136 118 185 199 169 129 157 182
177 199 166 128 157 133 86 65 68 103 140 130 146 106 98 135 100 88 70 99
118 123 97 72 92 80 104 107 108 94 108 87 72 62 72 62 78 93 80 64
55 43 41 52 83 151
STKA125A 54
77 62 107 146 163 184 130 124 144 213 155 149 175 122 166 145 105 98 62 66
80 96 83 93 127 108 117 137 142 179 175 161 144 123 132 114 120 131 138 110
120 136 160 126 90 49 84 63 60 80 71 118 151 183
STKA125B 54
75 71 91 129 173 193 117 122 150 202 164 155 166 117 161 147 125 84 57 61
89 95 83 87 125 117 126 118 148 181 182 162 134 126 130 110 123 119 134 110
118 145 163 110 92 50 97 73 53 66 81 113 151 159

STKA126A 70
136 138 137 162 122 118 102 170 123 128 56 48 41 46 35 36 34 57 46 83
76 112 84 113 142 109 121 146 140 79 65 74 161 122 176 196 153 98 142 108
139 120 103 108 112 147 170 154 228 149 175 119 131 117 154 148 148 190 137 180
229 124 108 166 133 203 196 142 191 151
STKA126B 70
119 134 141 175 109 119 97 162 127 135 47 44 51 46 37 34 32 53 49 82
90 101 84 113 131 114 101 151 140 86 78 71 161 120 181 205 143 115 137 105
149 109 99 107 117 139 176 143 231 158 212 132 130 105 167 143 150 188 141 160
220 129 110 167 125 207 217 142 142 151
STKA127A 61
186 282 345 380 247 218 186 286 273 254 63 44 41 46 48 45 42 66 69 109
129 200 188 215 169 107 133 158 147 62 60 69 128 137 129 107 87 70 79 69
87 111 95 104 123 109 118 149 168 171 153 138 125 87 119 132 164 236 178 184
289
STKA127B 61
203 302 353 384 253 201 200 284 291 268 58 47 44 52 39 51 38 65 71 119
127 194 194 221 170 122 136 157 138 81 54 65 124 151 141 99 93 69 88 69
81 112 90 98 103 130 133 149 164 169 160 131 116 101 110 131 182 226 181 179
256
STKA128A 128
92 147 161 174 146 140 158 246 221 119 121 74 97 127 118 170 80 84 101 92
83 65 76 106 93 93 124 105 99 80 91 102 94 99 107 93 83 62 91 110
66 74 85 120 93 74 92 71 99 118 103 136 106 118 121 151 86 98 106 137
119 111 123 102 126 91 105 78 109 103 139 106 92 106 122 85 67 49 49 71
50 71 69 55 51 54 37 52 41 39 39 33 40 40 32 44 45 34 35 42
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
69 76 87 119 92 76 92 71 95 115 111 131 113 108 128 126 91 95 94 131
114 108 116 92 134 92 115 74 98 114 136 85 104 97 126 84 67 49 46 76
52 65 68 51 53 52 38 47 42 37 36 35 34 48 29 43 43 38 39 37
43 39 63 99 157 138 135 145 100 144 177 130 126 184 86 90 146 119 93 92
96 183 105 125 117 124 115 146
STKA129A 59
285 327 345 375 338 279 246 298 224 199 225 232 238 176 182 214 182 195 232 236
296 254 290 287 323 289 353 309 206 258 235 274 233 161 180 236 236 194 181 158
197 222 196 162 163 176 166 197 115 132 144 228 169 205 217 181 278 184 200
STKA129B 59
323 340 343 402 352 282 243 297 212 202 241 223 235 198 188 199 185 225 250 246
318 239 297 283 321 297 348 307 207 284 216 278 222 178 175 230 227 197 188 154
222 251 186 162 150 186 163 193 126 131 146 218 169 219 220 176 274 210 179
STKA130A 84
524 481 249 206 258 179 324 374 284 321 175 309 234 294 191 122 139 58 67 113
116 105 206 158 112 149 127 96 76 62 105 108 101 145 125 89 83 110 80 56
87 88 118 65 106 128 94 167 111 130 116 91 79 120 101 107 126 91 70 116
61 92 116 88 119 175 134 90 208 88 58 90 77 106 85 85 66 84 84 83
70 85 66 75

STKA130B 84
445 318 216 242 257 186 322 362 272 298 189 311 227 283 185 125 139 68 57 101
123 104 195 156 127 162 132 90 74 66 96 109 111 139 123 89 78 109 73 66
83 92 112 59 114 130 90 171 112 144 118 88 79 123 95 109 123 88 70 111
62 91 111 99 117 173 129 105 195 92 60 87 81 109 82 82 66 88 80 85
75 80 63 95
STKA132A 67
167 94 108 84 87 112 125 86 119 182 212 168 146 185 172 269 194 223 276 334
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
119 151 153 148 160 150 186
STKA132B 67
121 70 133 87 91 111 114 80 119 179 216 183 124 199 168 274 206 219 248 338
238 285 239 156 190 156 186 179 262 220 284 213 193 223 276 206 273 163 79 75
52 84 99 107 141 283 127 194 156 157 165 142 154 192 180 192 117 137 102 138
118 168 153 135 158 143 154
STKA133A 55
194 144 155 201 187 179 202 174 251 267 183 256 244 371 363 398 352 296 230 310
243 283 308 541 279 403 337 264 334 255 344 304 359 332 363 256 241 448 462 352
347 217 63 41 46 53 73 73 57 138 114 139 155 164 190
STKA133B 55
237 140 143 199 210 188 191 191 277 224 207 245 258 344 362 395 367 298 249 306
240 270 293 493 276 401 338 281 325 263 330 292 391 311 360 288 269 435 527 375
336 217 68 45 38 56 72 70 64 137 112 140 159 151 203
STKA134A 55
170 117 133 158 147 117 96 109 142 147 198 200 180 190 291 282 234 321 215 261
251 264 278 244 245 235 284 209 201 147 199 209 237 262 220 236 182 172 152 169
165 207 284 160 226 298 241 224 196 170 209 174 162 165 203
STKA134B 55
170 122 135 158 138 120 82 116 146 143 195 200 178 196 316 294 232 317 214 255
232 275 282 235 252 203 263 219 198 156 183 230 230 279 211 227 193 152 144 190
160 201 282 149 197 293 267 231 185 182 202 154 168 174 271
STKA135A 54
382 399 280 289 396 261 303 328 335 398 391 356 374 340 344 241 215 238 199 249
276 295 279 380 226 199 297 289 348 467 441 37 49 68 56 46 70 89 134 118
125 119 104 116 123 138 174 226 247 263 114 112 141 156
STKA135B 54
383 409 269 285 392 267 266 337 341 397 372 345 375 362 373 242 213 246 186 238
278 286 295 345 216 194 282 287 357 463 406 39 57 66 53 47 70 89 136 116
131 118 103 119 124 134 183 203 233 268 112 114 137 154
STKA136A 63
134 177 190 225 144 165 117 129 84 87 122 65 56 54 57 57 83 122 127 136
170 153 211 174 206 208 269 232 220 186 125 105 129 145 154 183 268 201 190 133
130 209 159 139 162 197 276 274 215 265 238 118 143 136 118 162 160 154 171 167
132 163 224
STKA136B 63
174 175 188 224 164 154 117 130 98 80 107 57 57 49 58 56 82 115 141 133
142 186 197 178 210 200 238 263 210 189 146 98 121 164 149 191 258 209 187 142
107 200 161 144 160 208 267 293 209 253 247 119 131 139 120 154 160 165 145 149
141 160 201

STKA137A 77
164 232 174 158 122 153 146 138 96 95 116 211 264 255 182 127 150 162 162 171
157 217 254 243 293 234 221 232 207 217 169 205 288 227 205 177 198 246 244 235
149 170 136 117 186 179 236 249 266 298 214 257 187 280 211 272 343 242 352 290
195 71 57 56 48 61 58 70 83 97 74 102 94 140 96 96 94
STKA137B 77
176 239 161 154 120 151 145 142 98 97 146 203 259 254 170 141 157 160 160 169
177 230 230 222 306 226 227 186 239 192 185 205 276 219 198 205 144 240 252 219
160 160 137 119 180 180 245 269 251 293 213 264 181 280 192 264 333 250 345 291
221 74 69 56 57 43 50 76 85 91 80 106 87 131 105 98 109
STKA138A 180
133 89 87 83 96 89 100 148 120 124 128 114 99 99 106 101 167 151 113 142
151 77 69 87 108 103 93 104 107 90 93 101 71 70 123 104 93 87 95 86
128 108 98 66 95 81 122 151 89 99 71 57 61 64 79 94 59 58 61 57
54 55 71 61 41 44 52 48 44 46 67 80 52 63 54 51 55 61 60 72
73 72 67 70 81 57 60 74 70 63 62 60 52 50 57 51 44 42 47 46
38 42 42 39 36 36 32 33 42 43 45 46 46 44 32 36 35 34 37 30
36 46 31 34 44 36 46 41 41 44 33 35 41 32 34 26 29 26 34 36
31 35 31 34 32 26 30 38 27 25 26 24 35 28 27 25 39 32 26 48
33 31 22 38 40 46 36 50 44 33 52 42 39 45 52 34 56 37 55 55
STKA138B 180
122 103 85 85 90 89 113 157 121 127 118 121 95 98 105 109 171 142 114 141
157 76 77 80 119 91 100 98 107 88 103 96 69 71 122 100 87 88 89 105
121 100 110 68 87 90 111 163 97 108 68 58 62 60 83 95 55 57 68 57
57 80 69 57 44 43 49 44 43 51 73 77 49 62 54 47 54 62 58 76
72 71 70 66 92 62 63 70 75 59 59 55 54 50 62 50 47 41 46 52
37 37 45 37 37 37 36 36 41 50 41 41 43 43 41 32 28 39 42 38
31 44 35 31 42 36 45 35 44 44 39 31 35 33 31 30 32 33 27 26
27 35 27 34 36 20 26 33 34 31 34 24 35 33 21 28 32 36 32 39
32 40 28 43 35 39 39 45 44 35 46 47 40 42 54 42 50 42 58 59
STKA139A 110
72 79 88 118 90 110 136 106 102 95 109 76 109 126 114 86 114 97 129 149
132 109 76 80 84 125 197 135 124 79 78 78 112 107 110 92 67 61 56 59
53 56 39 48 50 61 77 44 37 50 55 53 55 52 40 36 39 39 44 49
42 46 39 47 44 57 54 65 66 55 51 49 50 56 45 44 41 42 47 51
44 49 44 48 45 40 47 39 45 65 73 62 57 40 52 57 52 53 40 51
46 59 60 67 50 60 55 52 40 37
STKA139B 110
86 85 86 117 88 111 132 110 99 95 111 83 111 127 115 86 112 90 134 155
121 101 83 80 88 124 189 141 128 81 72 84 101 112 108 92 68 55 63 58
52 45 49 45 44 75 65 40 32 58 57 51 46 44 35 45 37 33 50 40
40 51 37 51 50 53 52 71 56 66 49 55 49 52 57 42 40 50 49 50
45 52 43 49 44 37 52 40 46 71 72 62 60 48 46 60 45 50 33 51
57 59 54 69 58 58 49 43 47 45
STKA140A 66
169 166 144 149 212 251 295 241 241 211 245 165 175 235 177 224 225 224 123 225
101 133 145 156 197 217 181 168 293 259 156 113 170 209 123 153 249 196 280 154
136 146 170 149 206 211 182 204 149 79 119 161 219 312 223 202 184 200 199 159
110 116 132 159 207 282

STKA140B 66
143 177 152 141 209 251 332 242 258 210 224 167 180 234 194 227 209 218 161 219
123 134 137 175 205 218 181 168 264 241 166 116 154 209 139 149 248 198 273 162
137 142 164 163 200 216 195 200 116 104 110 157 203 308 239 191 169 220 201 137
119 108 123 162 204 258
STKA141A 54
203 302 352 381 257 201 200 285 290 267 137 152 173 222 204 199 145 171 117 107
138 217 274 256 197 209 226 162 146 124 106 147 199 190 144 165 120 128 172 208
269 298 188 214 220 245 378 273 318 243 264 248 221 258
STKA141B 54
186 282 344 381 249 210 189 286 273 253 115 134 182 211 220 197 144 179 103 129
141 207 257 262 184 210 244 164 148 120 106 155 187 190 170 138 127 142 139 232
271 298 203 196 224 249 389 259 314 249 269 235 241 278

APPENDIX

Tree-Ring Dating

The Principles of Tree-Ring Dating

Tree-ring dating, or *dendrochronology* as it is known, is discussed in some detail in the Laboratory's Monograph, '*An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Buildings*' (Laxton and Litton 1988b) and, for example, in *Tree-Ring Dating and Archaeology* (Baillie 1982) or *A Slice Through Time* (Baillie 1995). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The *width* of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring..

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

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

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

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

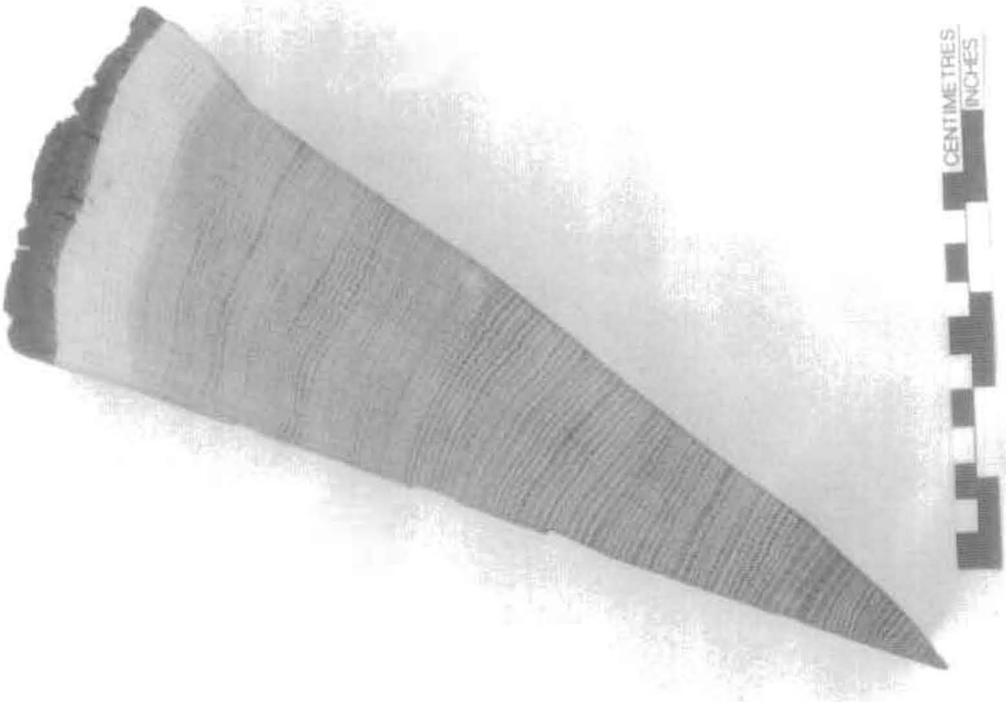


Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

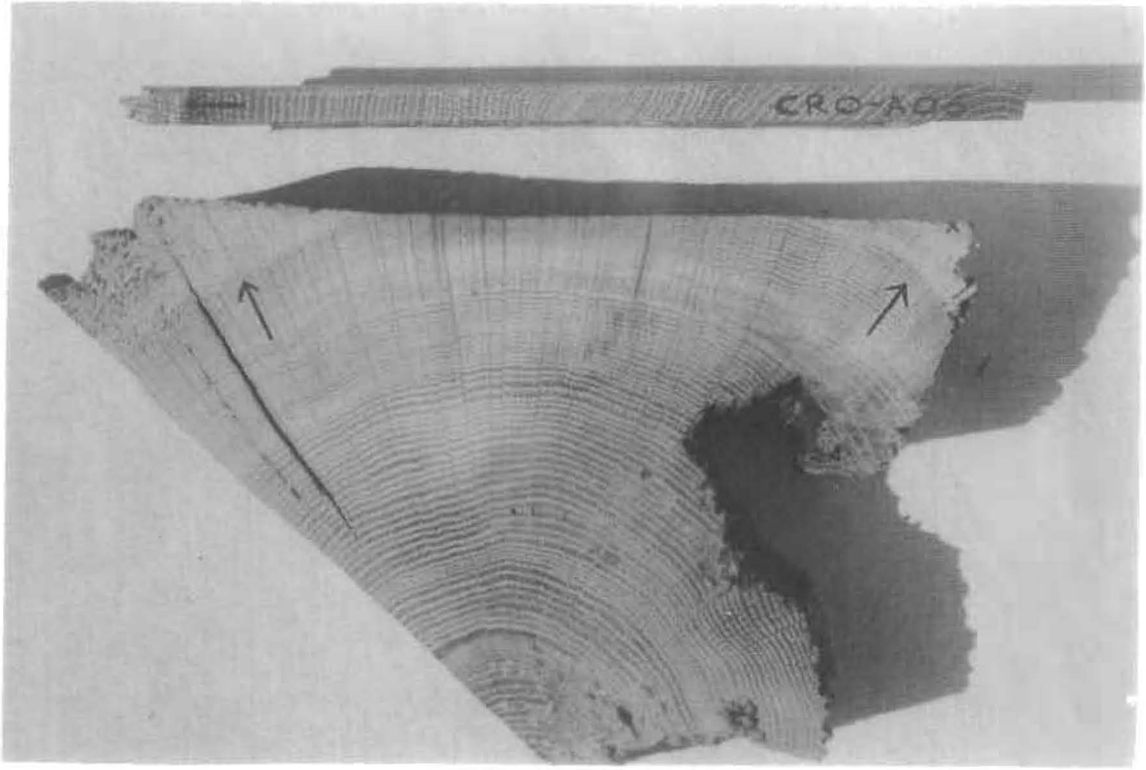


Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

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

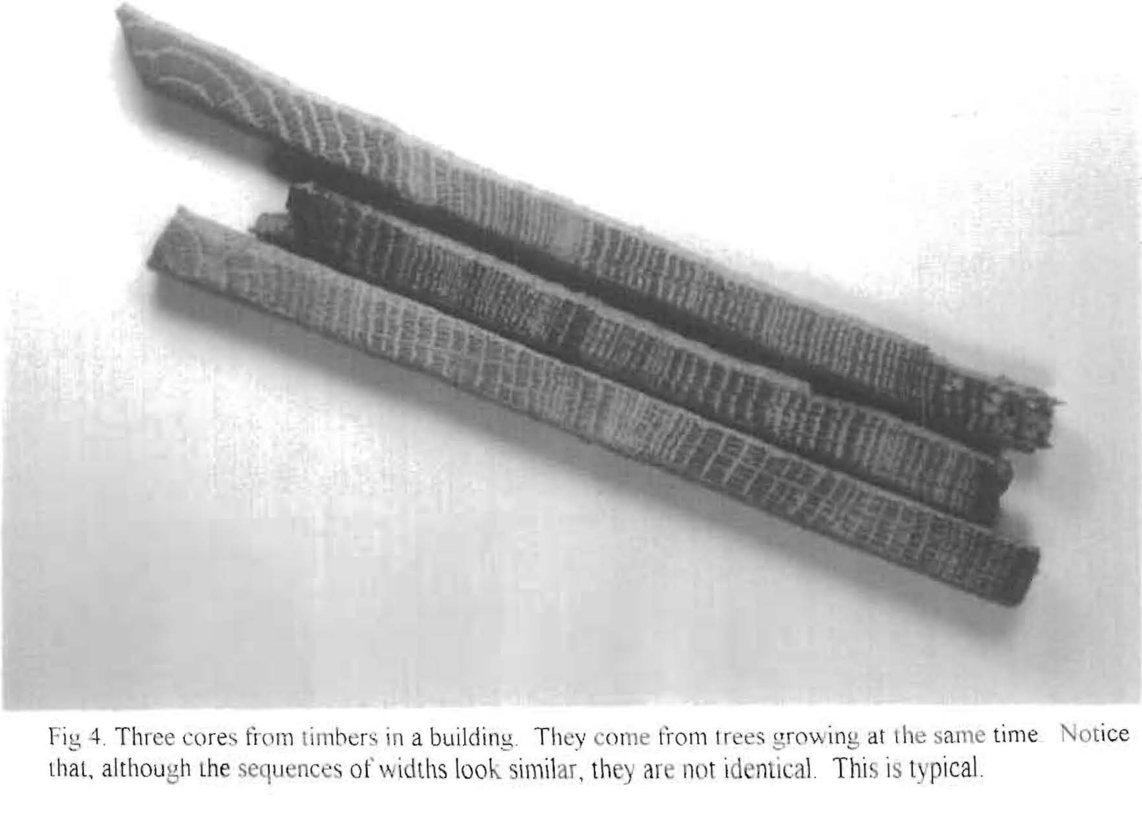


Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

T-value/Offset Matrix

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

Bar Diagram

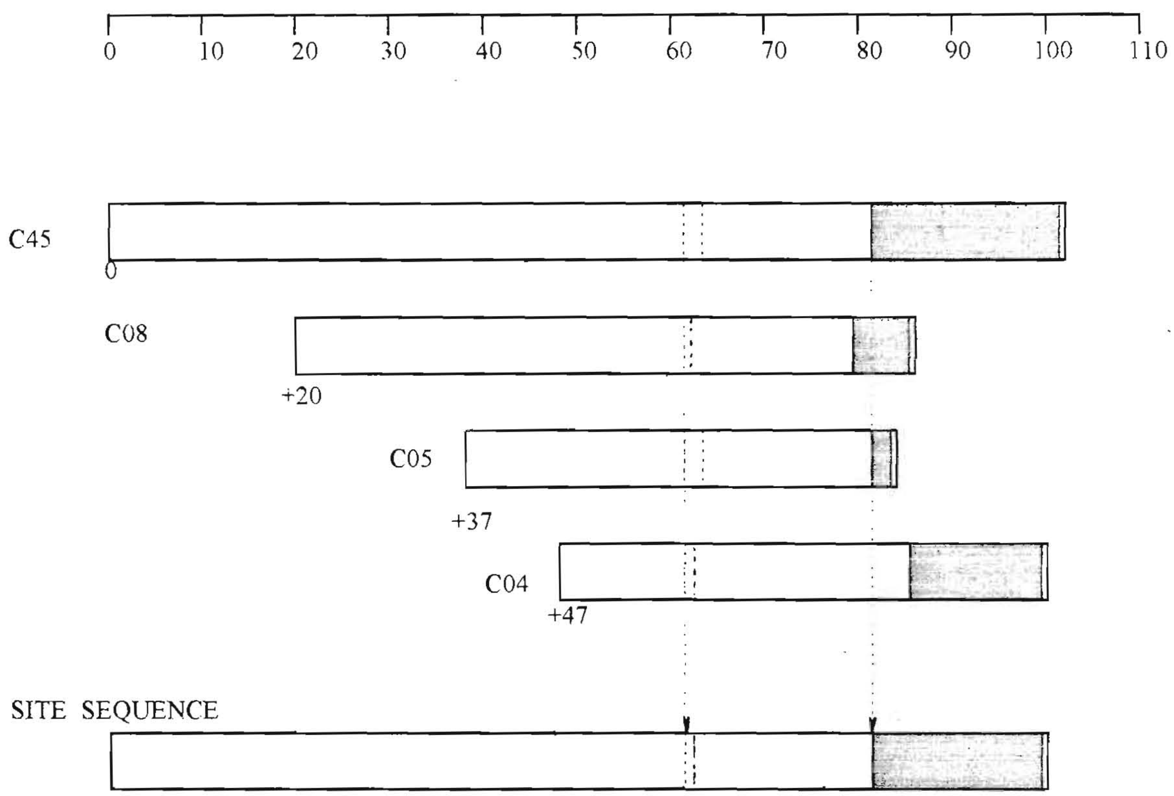


Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.
The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set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

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

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

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

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

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

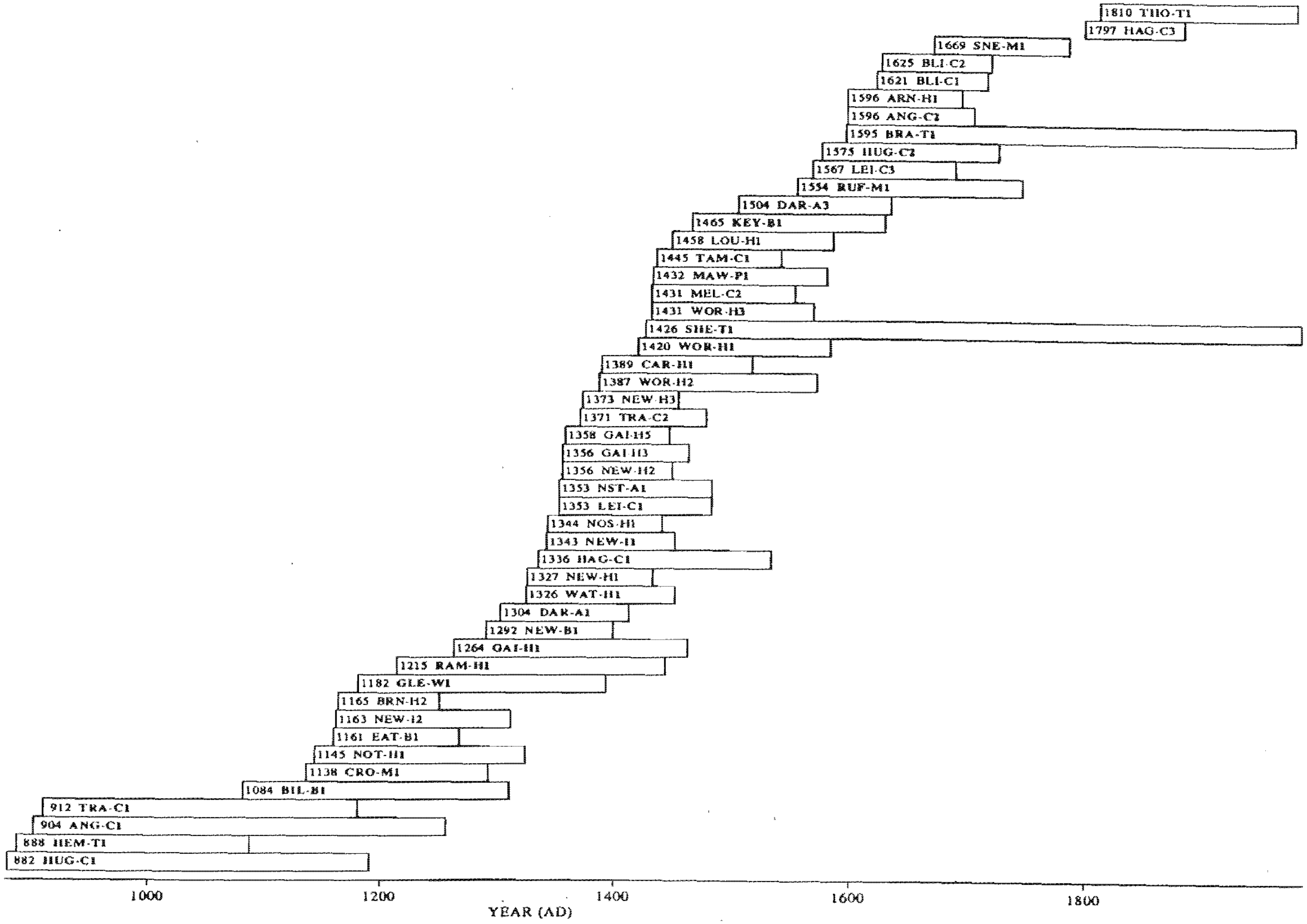


Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

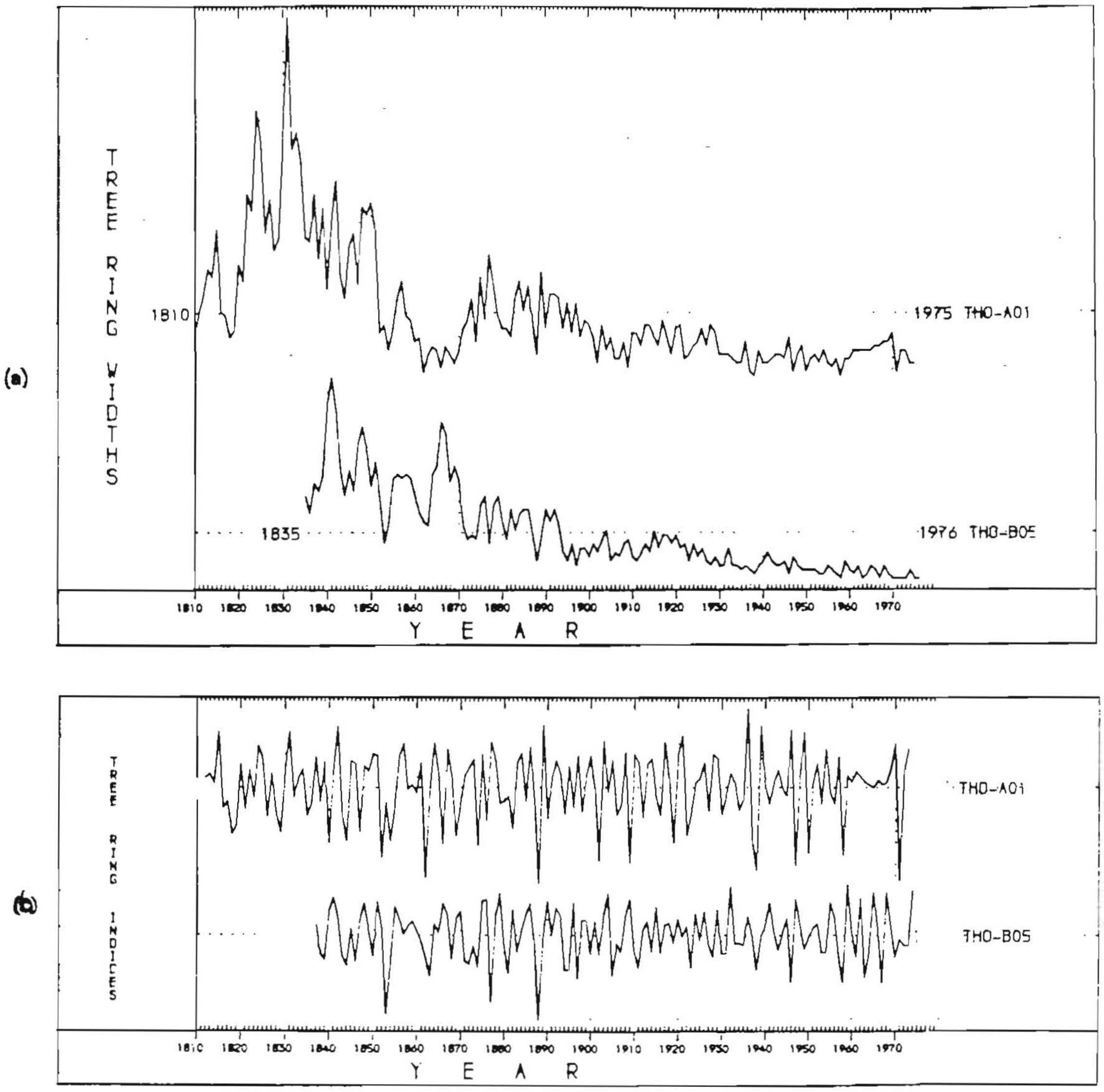


Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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

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

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