2719

Ancient Monuments Laboratory
Report 42/98

TREE-RING ANALYSIS OF TIMBERS FROM THE MAJOR AND MINOR BARNS AT ABBEY FARM, FAVERSHAM, KENT

R E Howard
R R Laxton
C D Litton

Ancient Monuments Laboratory Report 42/98

TREE-RING ANALYSIS OF TIMBERS FROM THE MAJOR AND MINOR BARNS AT ABBEY FARM, FAVERSHAM, KENT

R E Howard
R R Laxton
C D Litton

Summary

Dendrochronological analysis was undertaken of samples from thirty-four oak timbers at the two barns, the major and minor barns, at Abbey Farm, Faversham, Kent. This resulted in the production of a single dated site chronology of 128 rings, spanning the period AD 1344 to AD 1471. Interpretation of the sapwood on the samples in this site chronology indicates that the dated timbers from the minor barn were felled c AD 1426, whilst those from the major barn were felled c AD 1475. Two further timbers from the major barn were also individually dated as being felled earlier than the others, thought there was no sign of reuse.

Authors' addresses :-

R E Howard
UNIVERSITY OF NOTTINGHAM
University Park
Nottingham
NG7 2RD

Dr R R Laxton
UNIVERSITY OF NOTTINGHAM
University Park
Nottingham
NG7 2RD

Dr C D Litton
UNIVERSITY OF NOTTINGHAM
University Park
Nottingham
NG7 2RD

TREE-RING ANALYSIS OF TIMBERS FROM THE MAJOR AND MINOR BARNS AT ABBEY FARM, FAVERSHAM, KENT

Introduction

The Laboratory is grateful to Mr J. R. Harrison for the following description of the site.

'There has been little detailed investigation into the dating of the early timber-framed aisled barns of "Old Kent", ie what is described by Rigold as "the arable parts of primary settlement". Rigold's paper (Rigold 1966) remains the standard reference. Here he notes that Old Kent, East Kent, has "more truly great barns than the east Weald, Surrey and most, if not all, of Sussex put together.

This paper is the first step since Rigold's survey, where "relative rather than absolute dating" was offered towards conclusive dating of any of the buildings examined there. When eventually combined with a full building-analyst's report on the two buildings it will provide a yard-stick with which to consider the rest. The exercise was commenced, but not concluded, by Wade's students from the School of Architecture, Canterbury College of Art and Design (Blackwell *et al* 1988). It is complemented by a threatened buildings' emergency photographic record by the RCHME, taken in March 1998.

Abbey Farm, Faversham (TR 020617, see Figs 1 and 2), the site of the barns, was part of Faversham Abbey. This was built in AD 1148, and was first Cluniac and then Benedictine. The farmyard to which the barns relate abuts the site of the Abbey, of which nothing significant now remains above ground.

The farmstead, which is quite extensive (see Fig 3), is effectively derelict (April 1998). The barns stand at right-angles to each other, their corners close together, enclosing two sides of the yard. Both are fully timber-framed and are aisled. The minor barn has 5 full bays and one terminal (end) bay. The major barn is of 6 full bays with terminal bays at each end. Originally both barns will have been hip-roofed at each end, as the major barn still is. The minor barn was truncated, resulting in it having one hip and one gable, at some time after the late eighteenth century (information J Wade). Each barn has one wagon entry, both were built off flint and rubblestone bases, were probably tiled, and were externally boarded in the side walls. Cladding boards were originally wide, butt-jointed, horizontal, and flush-rebated into the sides of the main wall posts, these showing externally. Some boards of this pattern remain in places. Internally the principle of construction is that of full "passing shores" to the post heads with crown-posts/collar-purlin roofs above, and with passing shored axial posts in the centre of each end. These arrangements are common to many of the barns reviewed by Rigold.

Aside from its lost eastern section the minor barn, which is of one build, is, comparatively speaking, very complete. The structure of the major barn shows two main builds, the earlier, northern, build ending with the truss framing the south side of the wagon entry. This feature was confirmed by Mssrs Gravett and Lambert during a site visit in 1997. There is a very large nineteenth-century granary inserted at first-floor level within the barn's northern section. Views of the barn are given in Figures 4 and 5.

Some details of the structure of the northern section of the major barn are similar to those of the minor barn. In its southern section, by contrast, the detail is different, being less visually substantial and with wider bay spacings. External wall framing in the southern section is nineteenth-century in places. The roof structure here has been altered partially in recent times, in particular the original collar purlin system has been removed from the last bay.

Rigold placed the building period of what he calls "Class 1" barns (barns with passing shores and crown-post roofs) from "well before" AD 1300 to obsolescence after *c* AD 1500. He places the minor barn in the "Mature type" category which he seems to suggest might extend from AD 1350 to 1450. Those with "later characteristics" he provisionally assigned to the later fifteenth and early sixteenth centuries. He put the major barn into this second group. He did not note that it comprises two builds.

The D.O.E List description gives the date of the minor barn as *c* AD 1350 and the major barn as *c* AD 1500'.

Sampling and dating by tree-ring analysis was commissioned by English Heritage. The purpose of this was to inform a future repair programme and stimulate action on this building at risk.

Sample analysis and dating

Stage 1

A total of thirty-four oak timbers was sampled by coring at the Major and Minor barns. The twenty-two samples obtained from the Major barn were given the code FAV-A (for Faversham, site "A"), and numbered 01 - 22. The positions of the cores were recorded at the time of sampling on the plans provided, which are reproduced here as Figure 6. The trusses of the Major barn have been numbered from north to south.

The twelve samples obtained from the Minor barn were given the code FAV-B (for Faversham, site "B"), and numbered 01 - 12. The positions of these cores were also recorded at the time of sampling and are shown on Figure 7. The trusses of the Minor barn have been numbered from east to west. The details of all the samples are given in Table 1.

Some timbers required two cores to be taken from them, either because of breaks in the sample or the necessity of taking two cores to obtain both inner and outermost rings. Thus the measurements of some samples contain different numbers of rings from A to B. This can be seen for example with samples FAV-A13 A/B or FAV-A20 A/B, where A is one core from a timber and B is another core from the same timber.

Of the thirty-four samples taken five were found to have less than forty rings and were thus quite unsuitable for tree-ring dating. These very short samples were not measured.

The growth-ring width of the remaining twenty-nine samples were all measured and compared with each other by the Litton/Zainodin grouping procedure (see Appendix). At a value of $t=4.5$ two groups of samples formed. The nine samples of the first group, six from the Major barn and three from the Minor barn, cross-match each other at the off-sets shown in Figure 8.

The ring-widths from these nine samples were combined at these relative offsets to form FAVASQ01, a site chronology of 126 rings. This was successfully cross-matched with a series of relevant reference chronologies for oak, giving a first ring date of AD 1346 and a last measured ring date of AD 1471. Evidence for this dating is given by the t-values of Table 2.

Stage 2

Site chronology FAVASQ01 was then compared with the remaining twenty ungrouped samples. This indicated cross-matches with a further three samples, FAV-A09, B01, and B09, as shown in Figure 9, the t-value/offset matrix. Although one of these samples, FAV-C09, has only 47 rings, it is included. This is because of its high t-value match with FAVASQ01. Also, at this off-set, the relative position of its heartwood/sapwood boundary is consistent with that on the other samples in FAVASQ01. The positions of these three samples are shown at their indicated relative offsets in Figure 10. These twelve samples, the nine from site chronology FAVASQ01 and the additional three, were combined at these relative off-set positions to form FAVASQ05, a site chronology of 128 rings.

Site chronology FAVASQ05 was successfully cross-matched with a series of relevant reference chronologies for oak, giving a first ring date of AD 1344 and a last measured ring date of AD 1471. Evidence for this dating is given by the t-values of Table 3.

Stage 3

Site chronology FAVASQ05 was then compared with the remaining seventeen ungrouped samples with the result that a further sample, FAV-A03, from the Major Barn, cross-matched with it. This cross-match occurs with a maximum value of t=3.6, when the first ring of the sample is at plus 46 years relative to the first ring of site chronology FAVASQ05, as shown in the t-value/off-set matrix of Figure 11. The position of the sample is shown in the bar diagram of Figure 12. The relative position of the heartwood/sapwood transition and the number of sapwood rings appear to be consistent with this sample being from a timber having the same felling date as the other timbers from the Major barn contained in this site chronology.

The thirteen samples were combined at these relative off-set positions to form FAVASQ07, a site chronology of 128 rings. Site chronology FAVASQ07 was successfully cross-matched with a series of relevant reference chronologies for oak, giving a first ring date of AD 1344 and a last measured ring date of AD 1471. Evidence for this dating is given by the t-values of Table 4.

Site chronology FAVASQ07 was then compared with the remaining sixteen ungrouped samples but there was no further satisfactory cross-matching.

Stage 4

The two samples of the second group to form by the Litton/Zainodin grouping at a value of t=4.5, FAV-A13 and A14, cross-match with each other at the off-sets shown in Figure 13. The ring-widths from these two samples were combined at these relative offsets to form FAVASQ06, a site chronology of 81 rings. Site chronology FAVASQ06 was compared with a series of relevant reference chronologies for oak, but there was no satisfactory cross-matching.

Stage 5

The two site chronologies thus formed, FAVASQ06 and FAVASQ07, were then compared with each other. This indicated a cross-match between them with a maximum value of t=4.2. This is found when the first ring of FAVASQ06 is at plus 32 rings relative to the first ring of site chronology FAVASQ07, as indicated in the t-value/off-set matrix of Figure 14. As shown in the bar diagram of Figure 15, the relative positions of the heartwood/sapwood boundaries on the two samples in site chronology FAVASQ06 are consistent with the timbers they represent being of the same felling phase as the others from the Major barn represented in this bar diagram.

The fifteen samples were combined at these relative off-set positions to form FAVASQ08, a site chronology of 128 rings. Site chronology FAVASQ08 was successfully cross-matched with a series of relevant reference chronologies for oak, giving a first ring date of AD 1344 and a last measured ring date of AD 1471. Evidence for this dating is given by the t-values of Table 5.

Stage 6

Site chronology FAVASQ08 was then compared with the remaining fourteen ungrouped samples but there was no further satisfactory cross-matching.

Each of the remaining ungrouped samples with more than fifty-four rings, that is sufficient rings for satisfactory analysis, was compared separately with the full range of relevant reference chronologies. This indicated satisfactory cross-matching and dating for a further two samples only. The first sample, FAV-A20, has a first ring date of AD 1306 and a last ring date of AD 1400. The second sample, FAV-A21, has a first ring date of AD 1304 and a last ring date of AD 1387. Evidence for these dates is given in Tables 6 and 7. There is no satisfactory cross-matching between these two samples at their suggested relative off-sets, ie when the first ring of FAV-A20 is at plus 2 years relative to the first ring of FAV-A21.

Interpretation

The bar diagram of the final site chronology, FAVASQ08, shows very clearly that there are two phases of construction represented by the dated samples. The earlier phase is represented by five samples from the Minor Barn, FAV-B01, B06, B07, B09, and B12. Three of these five dated samples come from timbers with complete sapwood, although small portions of the sapwood were lost in coring. A note was made of the amount of lost sapwood at the time of coring, and an assessment made of the approximate number of sapwood rings the loss might represent. On returning to the Laboratory a check was made as to the number of sapwood rings found in a similar portion of the sapwood remaining on the sample concerned. Then an estimate based on these two sources of information was made. On the sample from this group with the latest dated sapwood ring, AD 1423 on sample FAV-B07, the lost sapwood represents only two or three rings. This would strongly indicate that this timber was felled no later than AD 1426. The portions lost from the other timbers in this group with complete sapwood are entirely consistent with them having a felling date no later than AD 1426.

The later phase of felling indicated in site chronology FAVASQ08 is represented by ten samples from the Major barn, FAV-A01, A03, A04, A07, A09, A10, A11, A12, A13, and A14. Three of these ten dated samples also come from timbers with complete sapwood, although again small portions of the sapwood were lost in coring. On the sample from this group with the latest dated sapwood ring, AD 1471 on sample FAV-B01, the lost sapwood represents only four or five rings. This would strongly indicate that this timber was felled no later than AD 1475. The portions lost from the other timbers in this group with complete sapwood are entirely consistent with them also having a felling date no later than AD 1475.

Samples from two other timbers, FAV-A20 and A21, dated separately, give different felling dates. Sample FAV-A20 has a last heartwood/sapwood boundary date of AD 1381. The usual 95% confidence limit for sapwood on mature oaks from Kent is in the range 15 to 35 rings. Allowing for the fact that it has 19 sapwood rings, this would give the timber represented by this sample an estimated felling date in the range AD 1401 to AD 1416.

Sample FAV-A21 has a last heartwood/sapwood boundary date of AD 1387 and has no sapwood. Using the same confidence limits as above for sapwood would give the timber represented by this sample an estimated felling date in the range AD 1402 to AD 1422.

Conclusion

It is apparent that the two barns use timbers with different felling dates. It would appear that the Minor barn uses timber felled no later than AD 1426. Given the limited amount of sampling in respect of the quantity of timber available, it is just possible that there are timbers of different felling dates present. However, the construction of the barn strongly suggests that it is all of one phase.

The Major barn is more problematic. The dated samples indicate a large portion of it, certainly those timbers in trusses 5, 6, and 7, that is, the southern end of the building, was built using timber felled in AD 1475. There is little significant cross-matching between the samples from the two barns. This would suggest that the timbers used came from different sources.

As stated in the introduction, Rigold placed the major barn in the late fifteenth to early sixteenth centuries, the minor barn between AD 1350 to 1450. The tree-ring dates show that his stylistic dating was reasonably accurate.

Only two of the eight samples from the timbers of trusses 1, 2, and 3 date, and these samples, FAV-A20 and A21, were the two which dated separately from the main group of seventeen samples. Their felling dates are in the range AD 1401 to AD 1416 and AD 1402 to AD 1422 respectively.

If these two are representative of truss 1, then this indicates a construction some time in the period AD 1402 to AD 1416, since there was no evidence of reuse of these timbers by way of redundant mortises etc. That is, approximately 60 years or so before trusses 5, 6, and 7. Interestingly, an estimated felling date in the range AD 1402 to AD 1416 for the timbers of truss 1 of the Major barn is much closer to the felling date of AD 1426 for the timbers of the Minor barn than for the southern end of the Major barn.

Thus, of the thirty-four cores taken, five had too few rings for analysis and were not measured. Of the remaining twenty-nine samples seventeen have been dated. Twelve remain undated. Of these some do have rather few rings, ie less than 60. It is possible that several of these undated samples remain so because of the slight complacency of the growth-rings, that is they show only slight variation from year to year and are thus more difficult to cross-match.

Table 1: Details of tree-ring samples from the major and minor barns at Abbey Farm, Faversham, Kent

Sample no.	Sample location	Total rings	Sapwood rings*	First measured ring date	Last heartwood ring date	Last measured ring date
	The Major barn					
FAV-A01	West passing shore, truss 7	69	19c	AD 1403	1452	1471
FAV-A02	West aisle plate, truss 7	88	21C	------	------	------
FAV-A03	West aisle tie, truss 7	78	14	AD 1390	1453	1467
FAV-A04	West passing shore, truss 6	78	h/s	AD 1375	1452	1452
FAV-A05	West wall post, truss 6	69	h/s	------	------	------
FAV-A06	West passing shore, truss 5	54	04	------	------	------
FAV-A07	South brace to aisle plate from west wall post, truss 6	60	02	AD 1396	1453	1455
FAV-A08	Arch brace to tie from west main post, truss 6	56	h/s	------	------	------
FAV-A09	South brace to aisle plate from west wall post, truss 5	47	h/s	AD 1406	1452	1452
FAV-A10	North arch brace to main plate from west post, truss 7	58	h/s	AD 1402	1459	1459
FAV-A11	West main post, truss 7	100	09c	AD 1363	1453	1462
FAV-A12	East main post, truss 7	84	22c	AD 1387	1448	1470
FAV-A13	East main post, truss 6	81	h/s	AD 1376	1456	1456
FAV-A14	West main post, truss 5	57	h/s	AD 1396	1452	1452
FAV-A15	Arch brace to main tie from west main post, truss 2	70	09	------	------	------
FAV-A16	West main post, truss 2	77	13	------	------	------
FAV-A17	East common rafter no 5, bay 2	54	02	------	------	------
FAV-A18	East common rafter no 7, bay 2	42	01	------	------	------
FAV-A19	West main post, truss 3	96	17	------	------	------
FAV-A20	Central main post, truss 1	95	19	AD 1306	1381	1400
FAV-A21	Post plate, central post, truss 1	84	h/s	AD 1304	1387	1387
FAV-A22	East passing shore, truss 1	NM	----	------	------	------

Table 1: continued

Sample no.	Sample location	Total rings	Sapwood rings*	First measured ring date	Last heartwood ring date	Last measured ring date
	The Minor barn					
FAV-B01	South passing shore, truss 3	57	05	AD 1357	1408	1413
FAV-B02	South main post, truss 3	NM	----	------	------	------
FAV-B03	South passing shore, truss 2	NM	----	------	------	------
FAV-B04	South main post, truss 1	67	h/s	------	------	------
FAV-B05	Stud post to north half, west end wall	70	24c	------	------	------
FAV-B06	Common rafter no 5, west roof pitch	75	23c	AD 1346	1397	1420
FAV-B07	Common rafter no 6, west roof pitch	54	18c	AD 1370	1405	1423
FAV-B08	Wall tie, centre post, truss 6	NM	----	------	------	------
FAV-B09	Common rafter no 3, bay 4, north roof pitch	76	15	AD 1344	1404	1419
FAV-B10	Common rafter no 4, bay 4, north roof pitch	NM	----	------	------	------
FAV-B11	Common rafter no 2, bay 4, north roof pitch	61	h/s	------	------	------
FAV-B12	Common rafter no 9, bay 3, north roof pitch	75	26c	AD 1346	1394	1420

*h/s = the heartwood/sapwood boundary is the last ring on sample
NM = sample not measured
c = complete sapwood on timber, all or part lost during coring

Figure 1: Map to show general location of Abbey Farm, Faversham

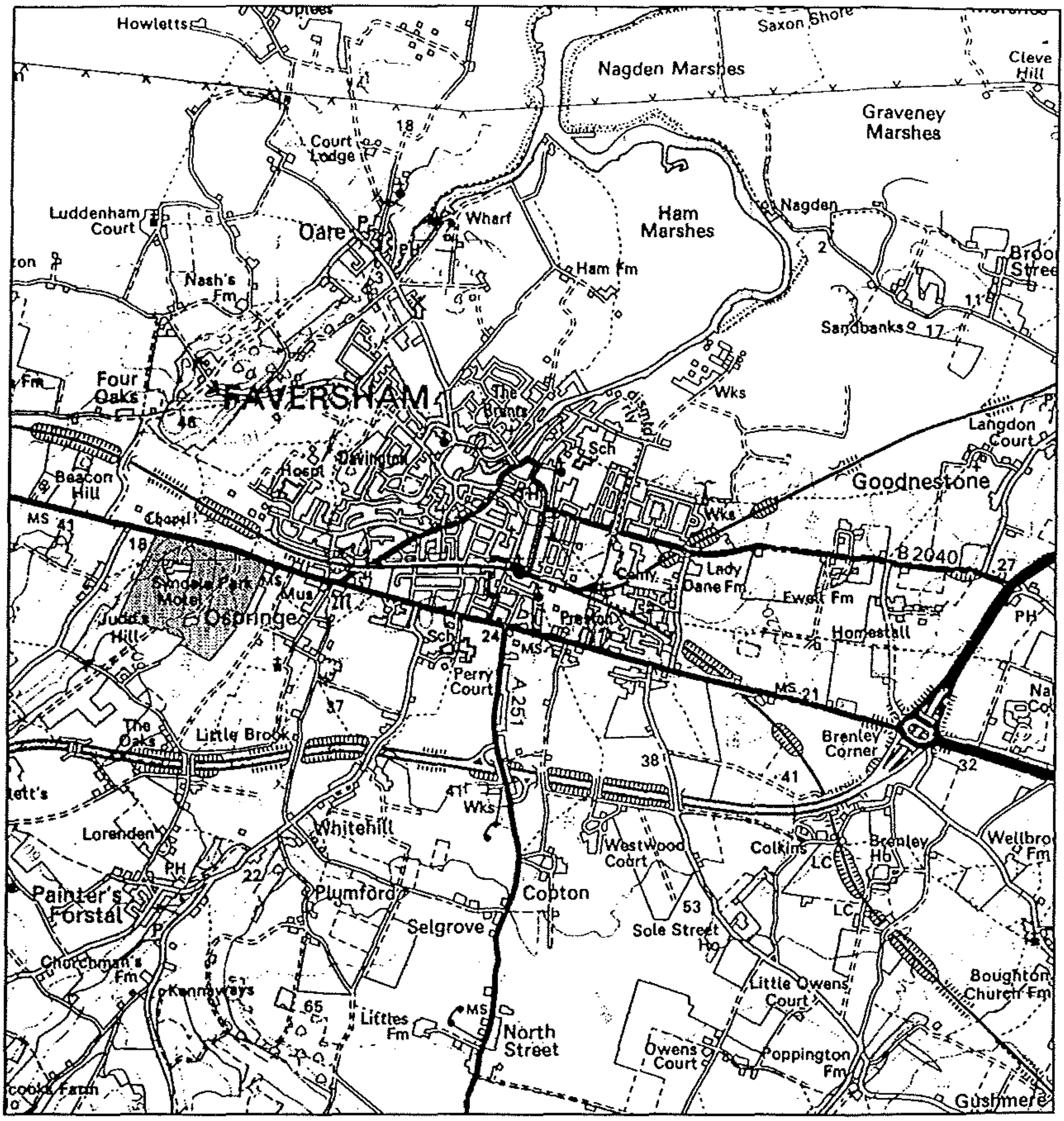
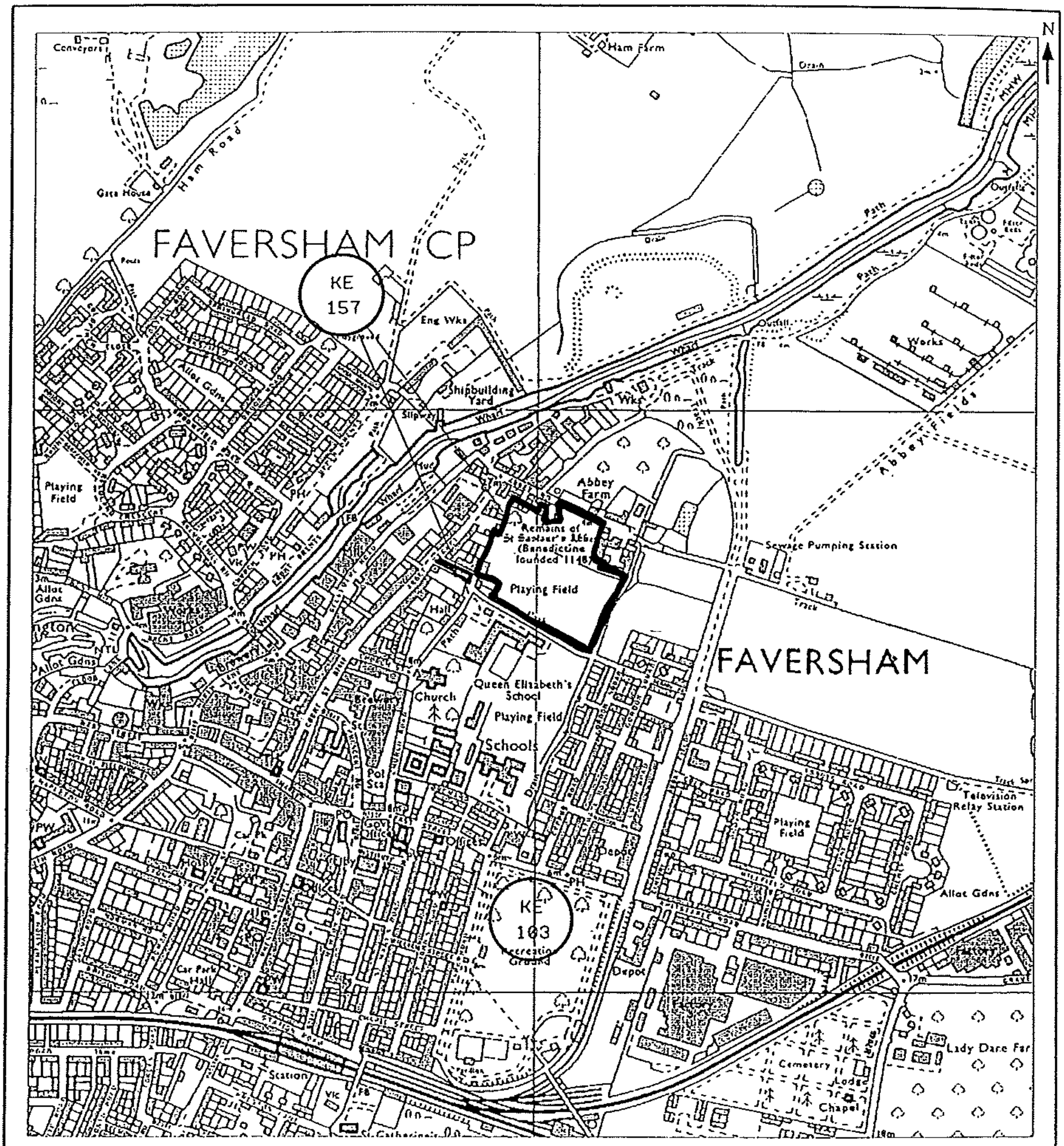


Figure 2: Map to detailed location of Abbey Farm, Faversham



For identification purposes only

Figure 3: Drawing to show arrangement of buildings at Abbey Farm

Study by Julia Bennett and Anthony Blackwell, drawings of the barn by Julia Bennett, John Billington, John Campbell

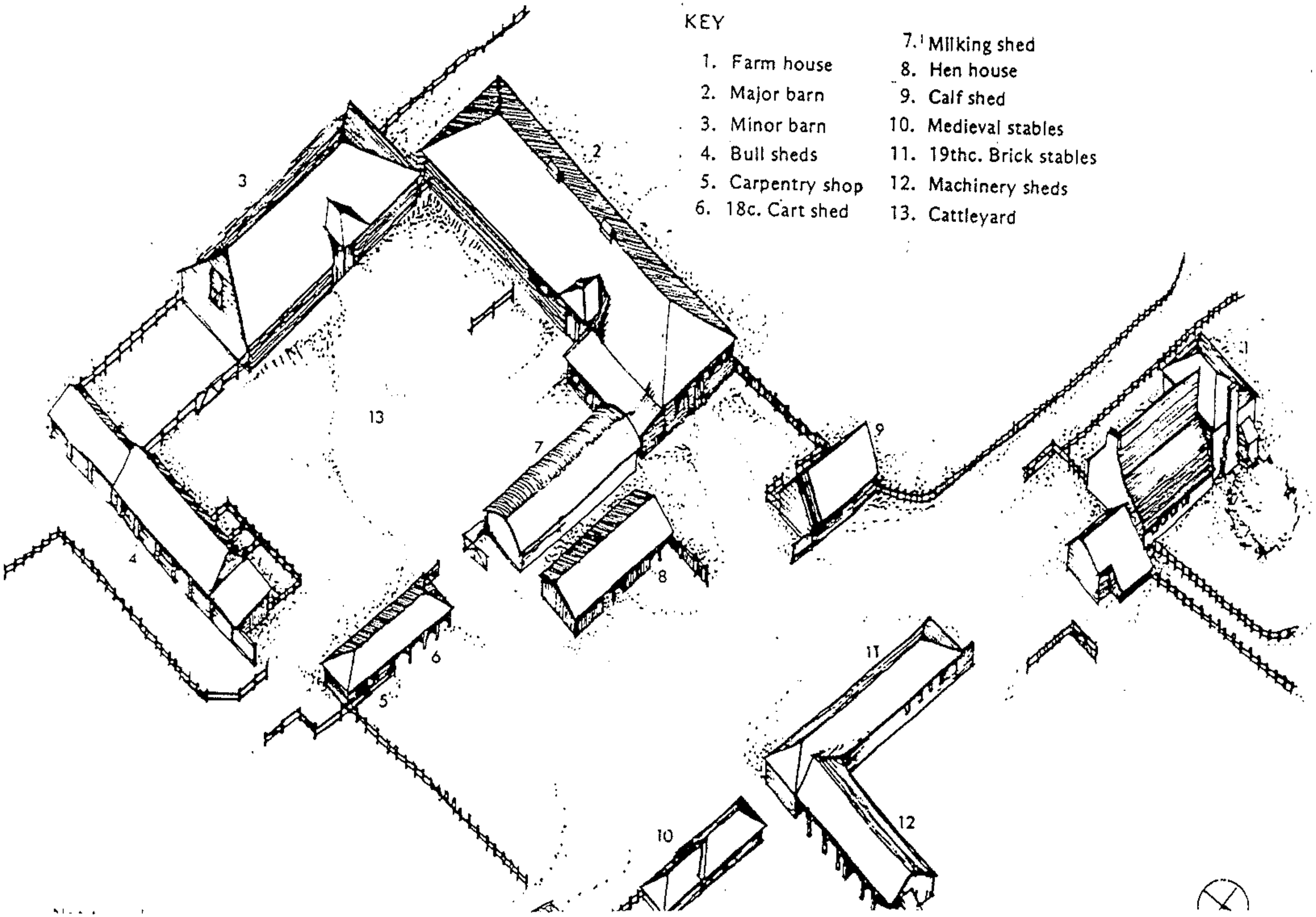


Figure 4: Drawing to show internal view of Major barn, looking north

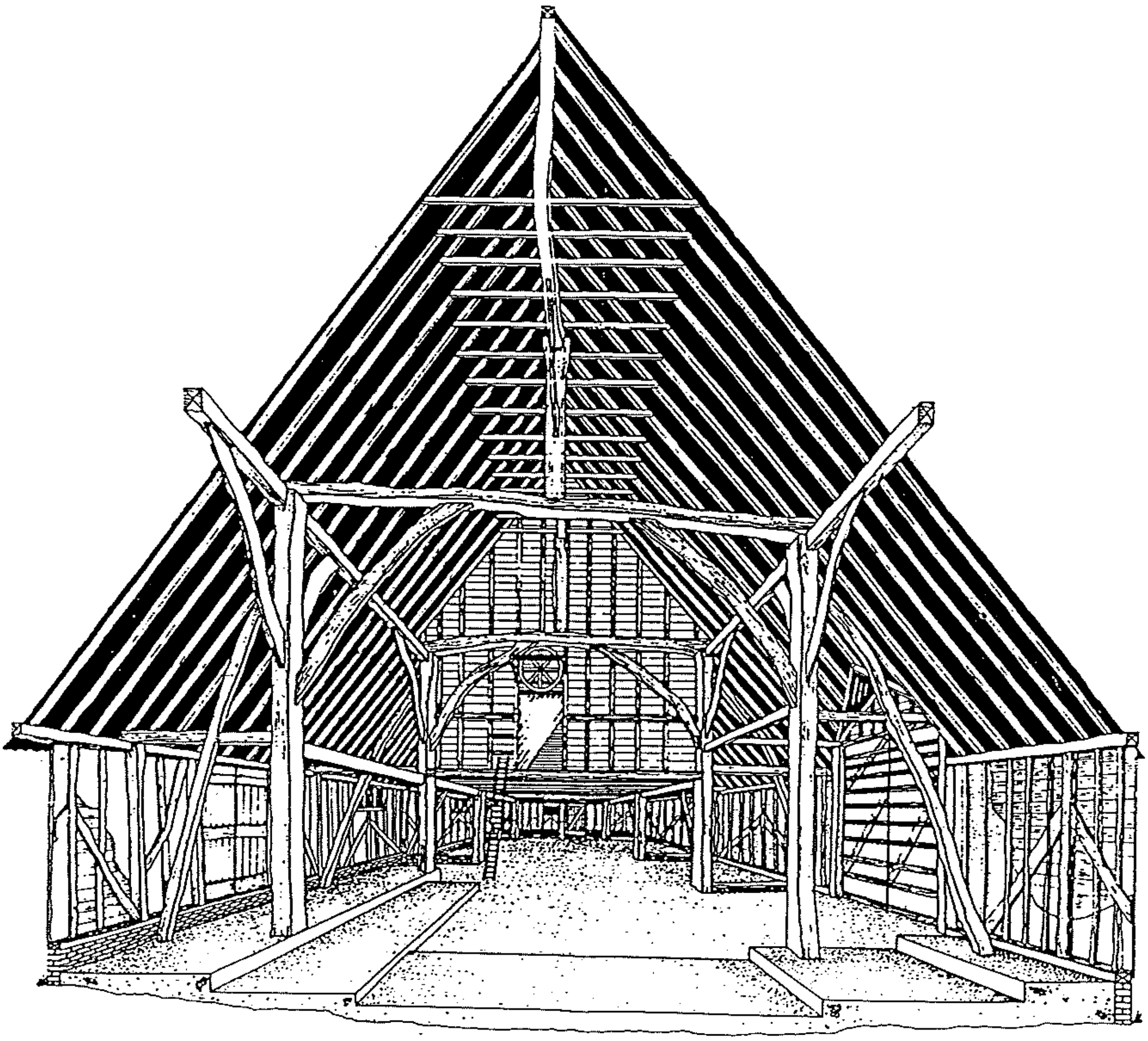


Figure 5: Drawing to show internal view of Major barn, looking south

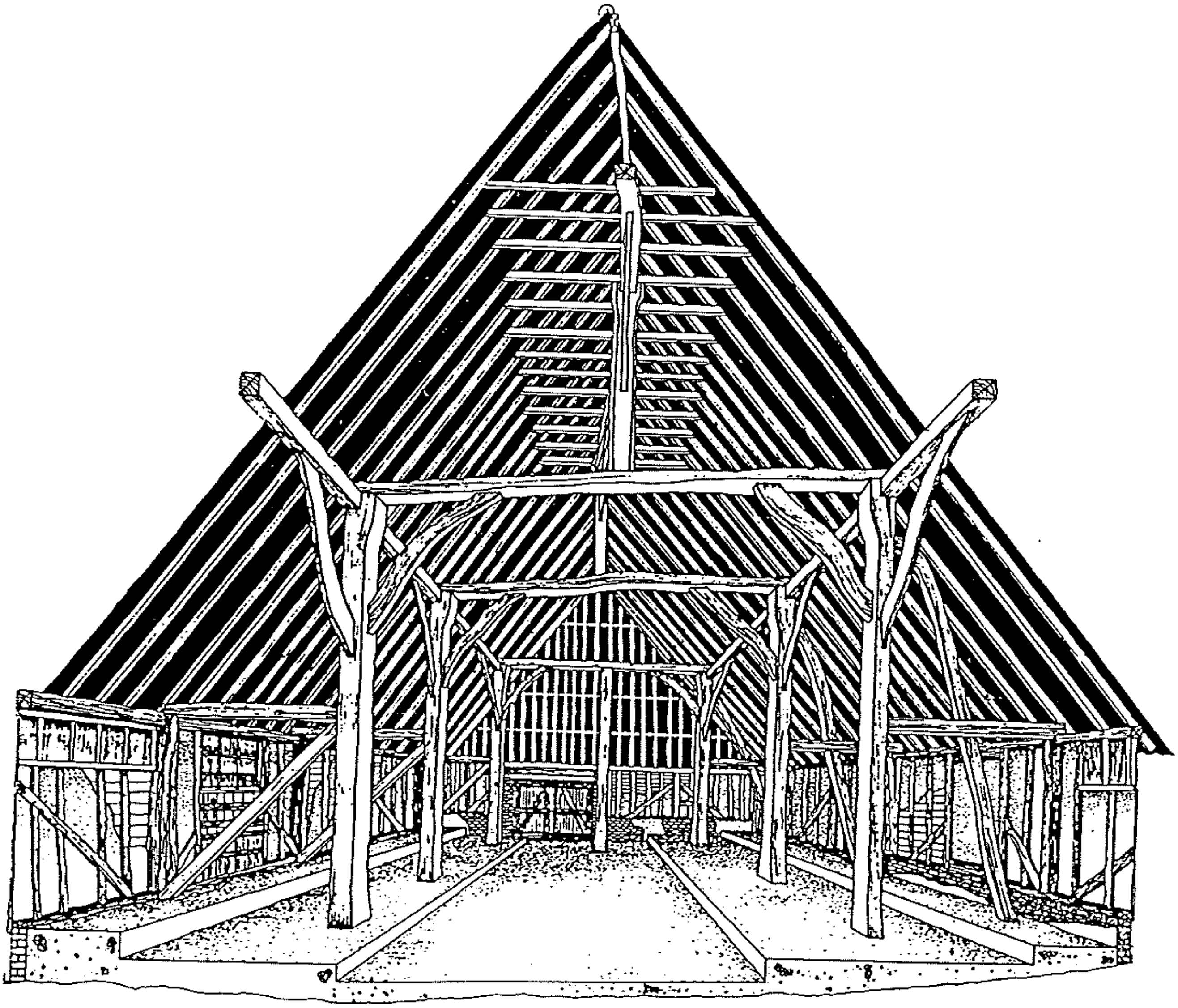


Figure 6: Plan of Major barn to show sample locations

Samples A01 - 22

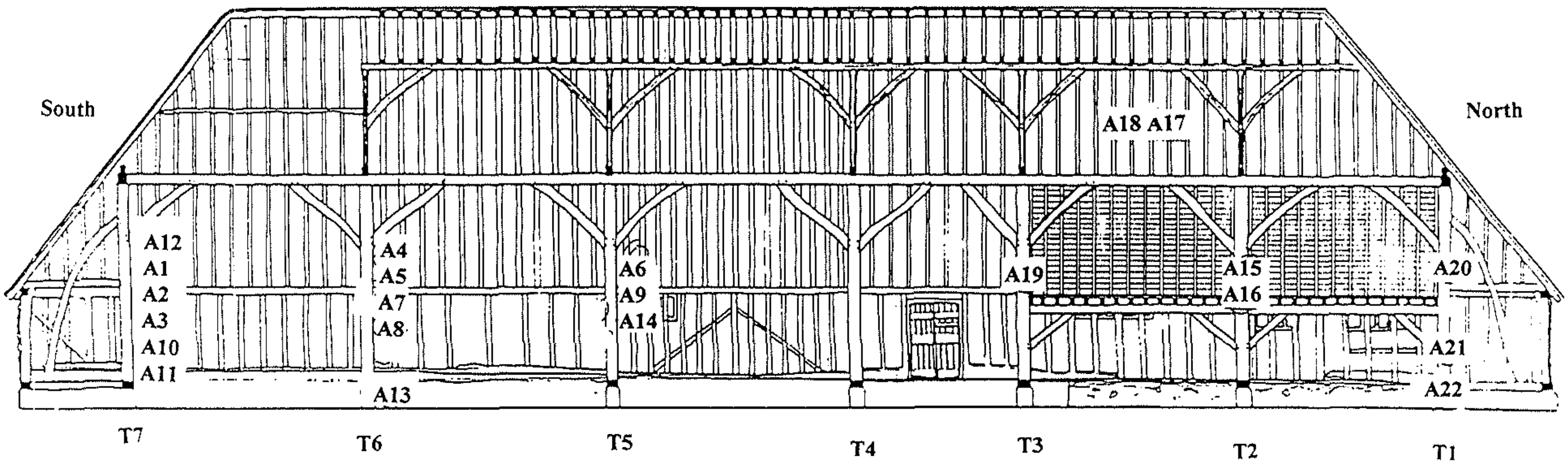


Figure 7: Plan of Minor barn to show sample locations

Sample B01 - 12

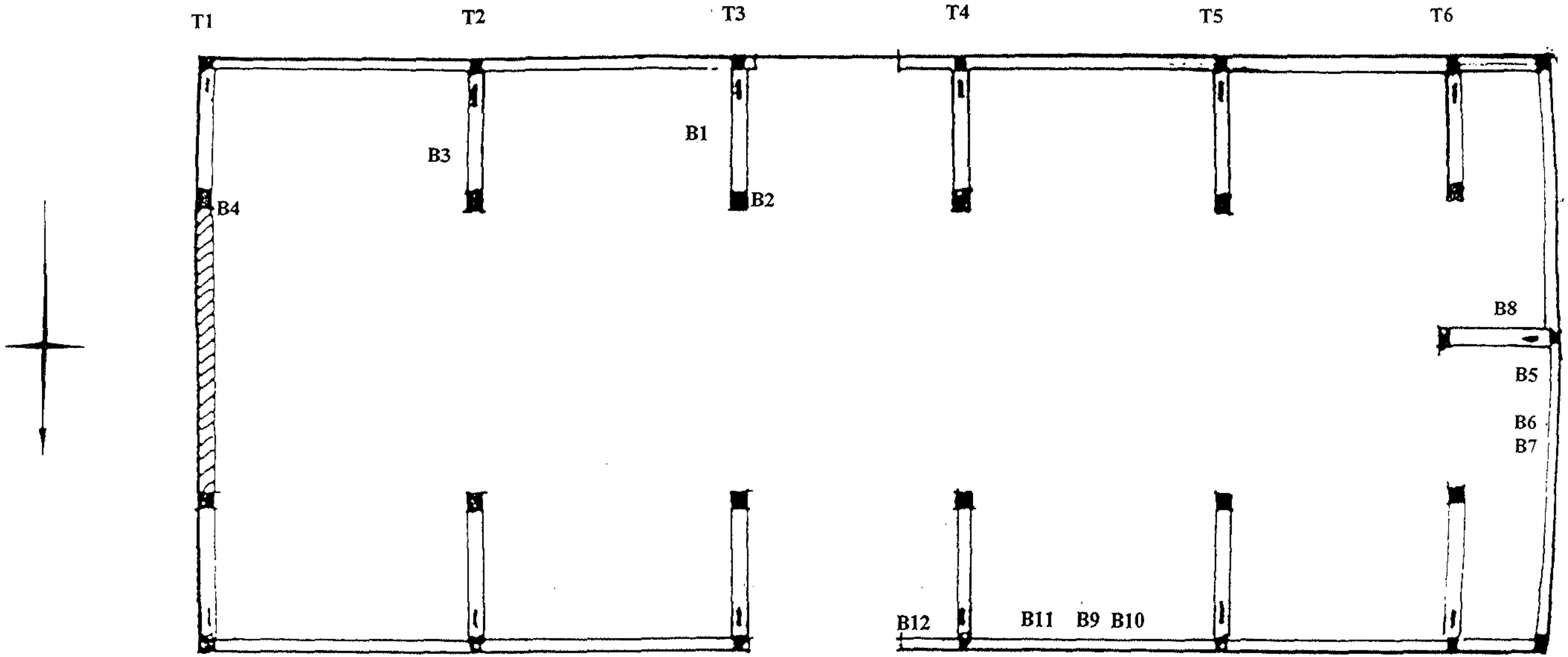
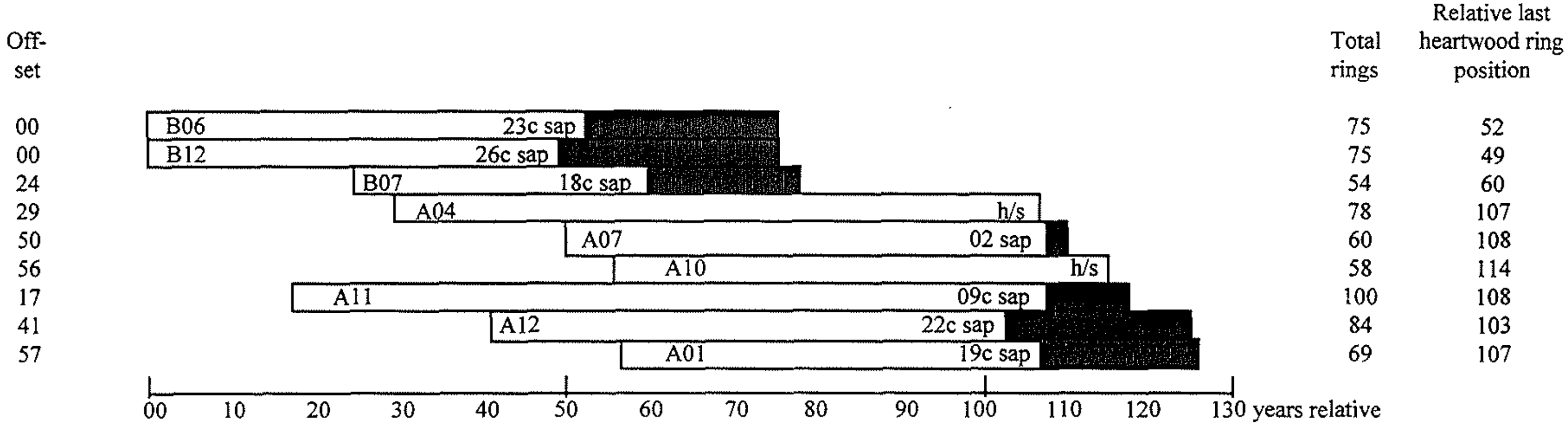


Figure 8: Bar diagram of samples in site chronology FAVASQ01



White bar = heartwood rings, shaded area = sapwood rings
h/s = only heartwood/sapwood boundary on sample
c = complete sapwood on timber, all or part lost in coring

Table 2: Results of the cross-matching of site chronology FAVASQ01 and relevant reference chronologies when first ring date is AD 1346 and last ring date is AD 1471

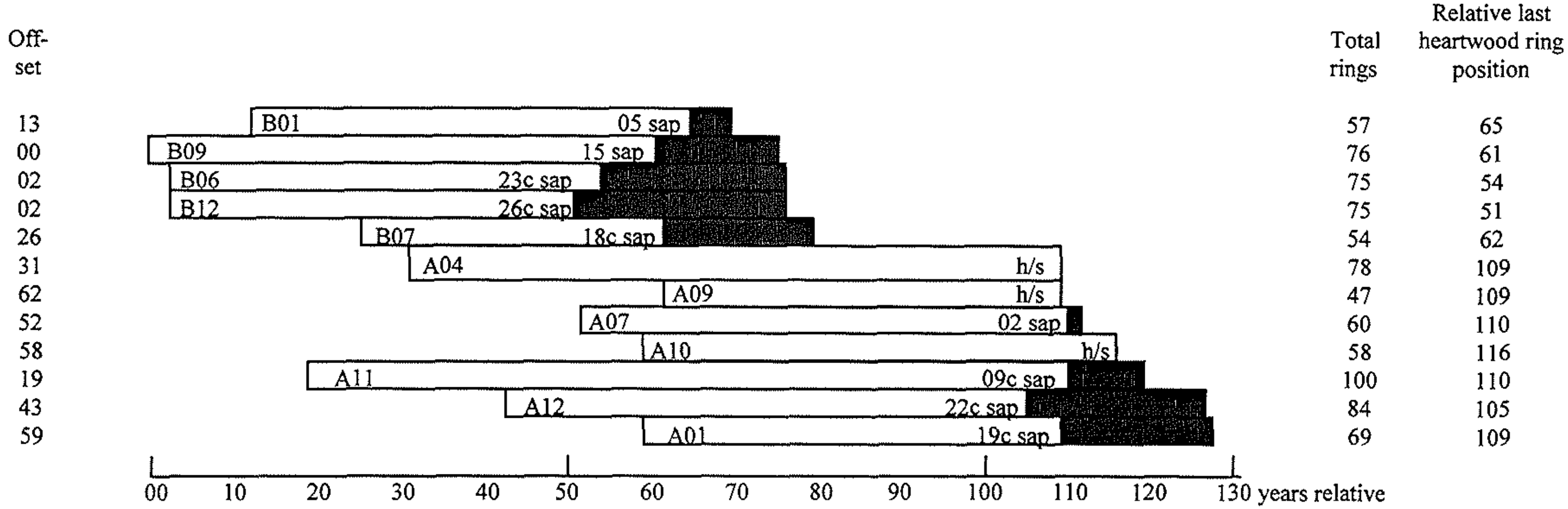
Reference Chronology	Span of chronology	t-value	
East Midlands	AD 882 - 1981	5.2	(Laxton and Litton 1988)
British Isles	AD 401 - 1981	3.6	(Baillie and Pilcher 1982 unpubl)
Southern England	AD 1083 - 1589	4.7	(Bridge 1988)
KENT-88	AD 1158 - 1540	5.5	(Laxton and Litton 1989)
MC10---H	AD 1386 - 1585	4.0	(Fletcher 1980)
High Street, Stourbridge	AD 1389 - 1462	5.7	(Esling *et al* 1989)
Mercers Hall, Gloucester	AD 1289 - 1541	5.6	(Howard *et al* 1997b)

Figure 9: T-value/off-set matrix

	SQ01	A09	B01	B09
SQ01		60	11	-02
A09	6.0			
B01	4.5			
B09	4.2			

Off-sets above diagonal, t-values below diagonal

Figure 10: Bar diagram of samples in site chronology FAVASQ05



White bar = heartwood rings, shaded area = sapwood rings
h/s = only heartwood/sapwood boundary on sample
c = complete sapwood on timber, all or part lost in coring

Table 3: Results of the cross-matching of site chronology FAVASQ05 and relevant reference chronologies when first ring date is AD 1344 and last ring date is AD 1471

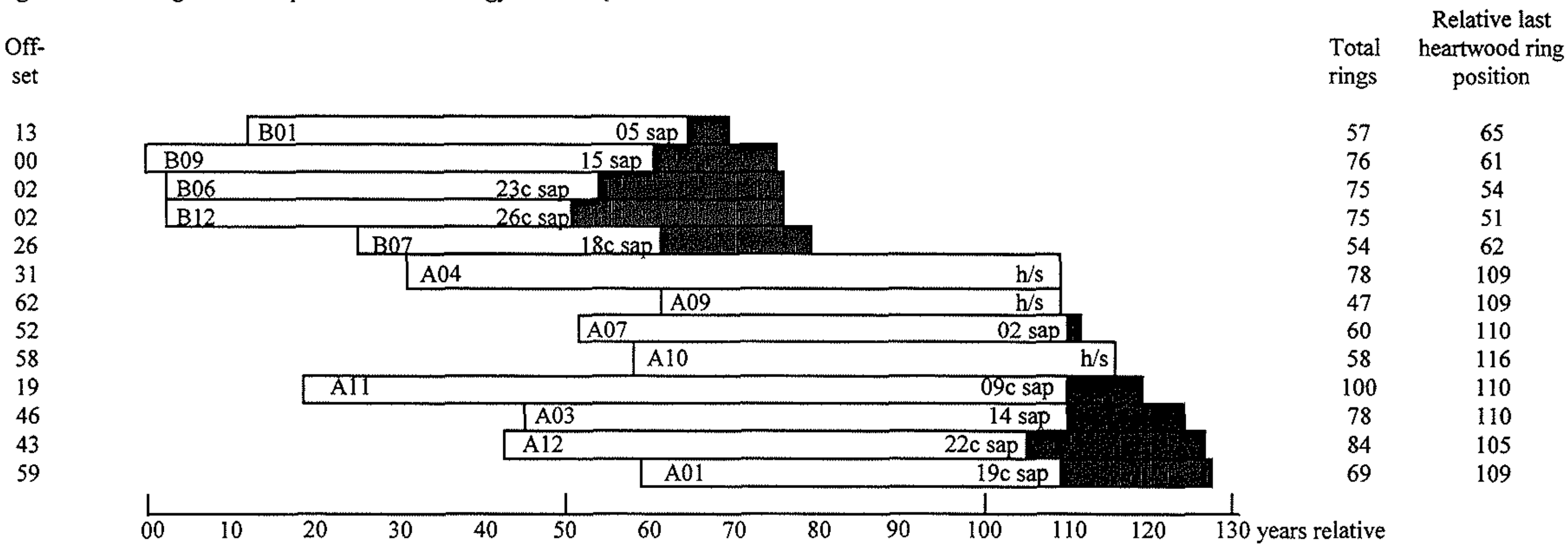
Reference Chronology	Span of chronology	t-value	
East Midlands	AD 882 - 1981	5.0	(Laxton and Litton 1988)
British Isles	AD 401 - 1981	3.4	(Baillie and Pilcher 1982 unpubl)
Southern England	AD 1083 - 1589	5.1	(Bridge 1988)
KENT-88	AD 1158 - 1540	5.1	(Laxton and Litton 1989)
MC10---H	AD 1386 - 1585	5.8	(Fletcher 1980)
High Street, Stourbridge	AD 1389 - 1462	6.0	(Esling *et al* 1989)
Mercers Hall, Gloucester	AD 1289 - 1541	5.2	(Howard *et al* 1997b)

Figure 11: T-value/off-set matrix

	SQ05	A03
SQ05		46
A03	3.6	

Off-set above diagonal, t-value below diagonal

Figure 12: Bar diagram of samples in site chronology FAVASQ07

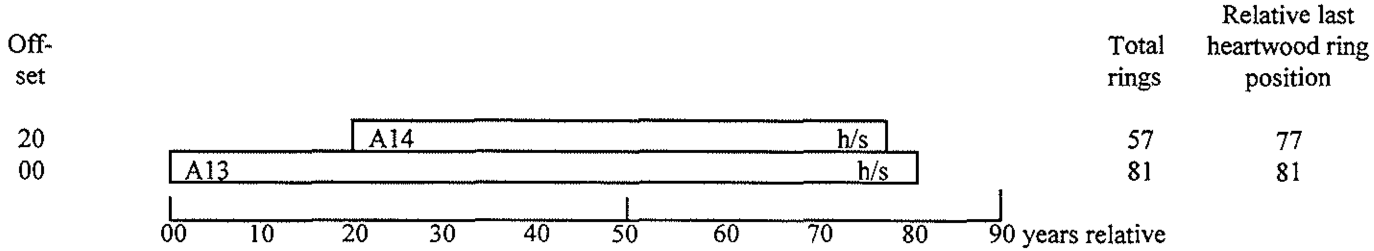


White bar = heartwood rings, shaded area = sapwood rings
h/s = only heartwood/sapwood boundary on sample
c = complete sapwood on timber, all or part lost in coring

Table 4: Results of the cross-matching of site chronology FAVASQ07 and relevant reference chronologies when first ring date is AD 1344 and last ring date is AD 1471

Reference Chronology	Span of chronology	t-value	
East Midlands	AD 882 - 1981	5.2	(Laxton and Litton 1988)
British Isles	AD 401 - 1981	3.5	(Baillie and Pilcher 1982 unpubl)
Southern England	AD 1083 - 1589	5.2	(Bridge 1988)
KENT-88	AD 1158 - 1540	5.4	(Laxton and Litton 1989)
MC10---H	AD 1386 - 1585	4.3	(Fletcher 1980)
High Street, Stourbridge	AD 1389 - 1462	5.5	(Esling *et al* 1989)
Mercers Hall, Gloucester	AD 1289 - 1541	5.9	(Howard *et al* 1997b)
Restoration House, Kent	AD 1378 - 1505	4.0	(Howard *et al* 1997a)

Figure 13: Bar diagram of samples in site chronology FAVASQ06



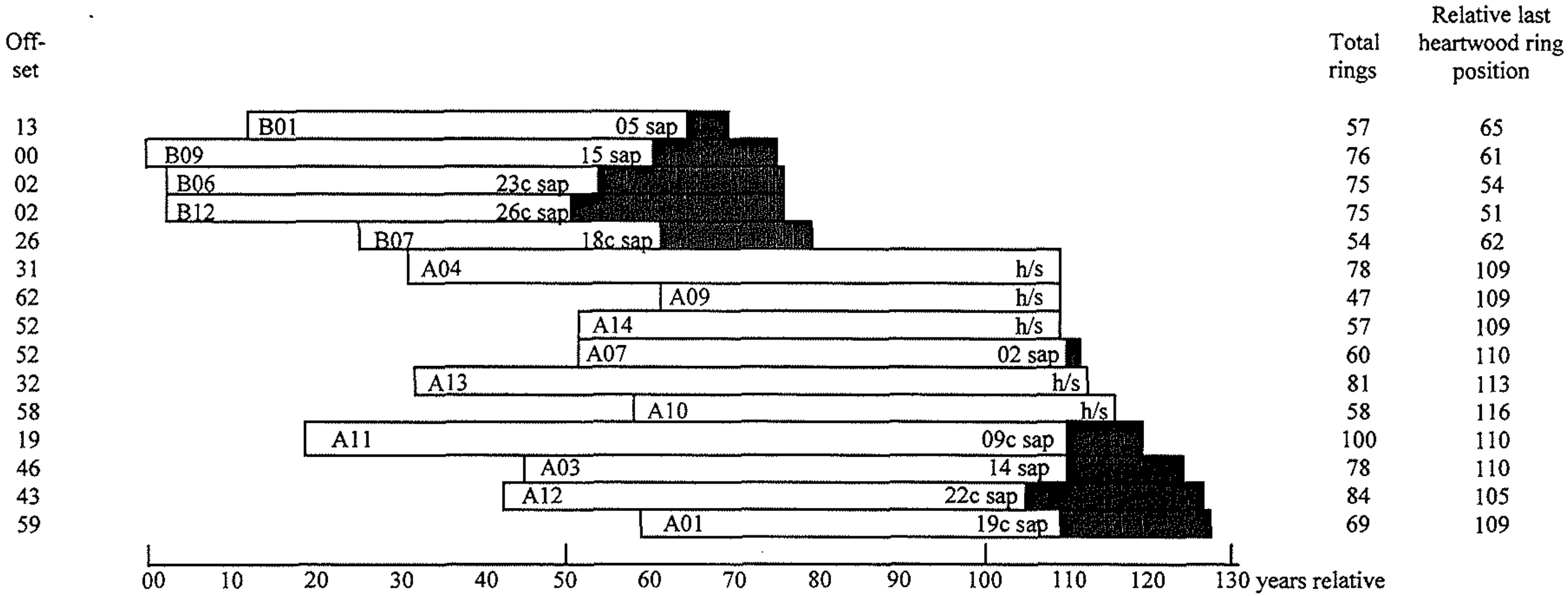
White bar = heartwood rings,
h/s = only heartwood/sapwood boundary on sample

Figure 14: T-value/off-set matrix

	SQ06	SQ07
SQ06		32
SQ07	4.2	

Off-set above diagonal, t-value below diagonal

Figure 15: Bar diagram of samples in site chronology FAVASQ08



White bar = heartwood rings, shaded area = sapwood rings
h/s = only heartwood/sapwood boundary on sample
c = complete sapwood on timber, all or part lost in coring

Table 5: Results of the cross-matching of site chronology FAVASQ08 and relevant reference chronologies when first ring date is AD 1344 and last ring date is AD 1471

Reference Chronology	Span of chronology	t-value	
East Midlands	AD 882 - 1981	5.1	(Laxton and Litton 1988)
British Isles	AD 401 - 1981	3.9	(Baillie and Pilcher 1982 unpubl)
Southern England	AD 1083 - 1589	5.3	(Bridge 1988)
KENT-88	AD 1158 - 1540	5.7	(Laxton and Litton 1989)
MC10---H	AD 1386 - 1585	4.6	(Fletcher 1980)
High Street, Stourbridge	AD 1389 - 1462	5.3	(Esling *et al* 1989)
Mercers Hall, Gloucester	AD 1289 - 1541	4.2	(Howard *et al* 1997)
Restoration House, Kent	AD 1378 - 1505	5.3	(Howard *et al* 1997)

Table 6: Results of the cross-matching of sample FAV-A20 and relevant reference chronologies when first ring date is AD 1306 and last ring date is AD 1400

Reference Chronology	Span of chronology	t-value	
East Midlands	AD 882 - 1981	2.4	(Laxton and Litton 1988)
British Isles	AD 401 - 1981	1.3	(Baillie and Pilcher 1982 unpubl)
Southern England	AD 1083 - 1589	3.4	(Bridge 1988)
KENT-88	AD 1158 - 1540	4.7	(Laxton and Litton 1989)
High Street, Stourbridge	AD 1389 - 1462	4.4	(Esling *et al* 1989)
Old Palace, Brenchley, Kent	AD 1300 - 1480	4.7	(Howard *et al* 1991)
Ightham Mote, Ivy Hatch, Kent	AD 1325 - 1555	4.3	(Howard *et al* 1995)
Clakkers Hall, Plaxtol, Kent	AD 1304 - 1442	4.2	(Howard *et al* 1988)
Ightham Mote, Ivy Hatch, Kent	AD 1276 - 1402	3.9	(Howard *et al* 1996)
Noah's Ark, East Sutton, Kent	AD 1337 - 1446	3.7	(Howard *et al* 1988)

Table 7: Results of the cross-matching of sample FAV-A21 and relevant reference chronologies when first ring date is AD 1304 and last ring date is AD 1387

Reference Chronology	Span of chronology	t-value	
East Midlands	AD 882 - 1981	2.2	(Laxton and Litton 1988)
British Isles	AD 401 - 1981	1.6	(Baillie and Pilcher 1982 unpubl)
Southern England	AD 1083 - 1589	1.0	(Bridge 1988)
KENT-88	AD 1158 - 1540	6.0	(Laxton and Litton 1989)
Bell Harry Tower, Canterbury Cathedral, Kent	AD 1311 - 1402	5.8	(Howard *et al* 1988)
Harts Farmhouse, Shottenden, Kent	AD 1305 - 1436	5.1	(Howard *et al* 1990)
Old Moat Farmhouse, Chart Sutton, Kent	AD 1255 - 1356	4.9	(Howard *et al* 1991)
Rectory Park, Horsmonden, Kent	AD 1313 - 1442	3.8	(Howard *et al* 1988)

Bibliography

Baillie, M G L, and Pilcher, J R, 1982 A Master Tree-Ring chronology for England, unpubl computer file *MGB-E01*, Queens Univ, Belfast

Blackwell, A, Bennett, J, Billington, J, and Campbell, J, 1988 Abbey Barn Faversham, in *Traditional Buildings of Kent, no 6,* 18-27

Bridge, M, 1988 The Dendrochronological Dating of Buildings in Southern England, *Medieval Archaeol,* **32**, 166-174

Esling, J, Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1989 List 29 no 12 - Nottingham University Tree-Ring Dating Laboratory Results, *Vernacular Architect*, **20**, 39-41

Fletcher, J, 1980 A list of tree-ring dates for Building Timber in Southern England and Wales, *Vernacular Architect*, **11**, 32-38

Howard, R E, Laxton, R R, Litton, C D, Cooper, N, and Pearson, S, 1988 List 28 nos 1, 4, 6, 12 - Nottingham University Tree-Ring Dating Laboratory results: Kent, *Vernacular Architect*, **19**, 48-49

Howard, R E, Laxton, R R, Litton, C D, and Pearson, S, 1990 List 34 no 7 - Nottingham University Tree-Ring Dating Results: Kent, *Vernacular Architect*, **21**, 40-42

Howard, R E, Laxton, R R, Litton, C D, and Pearson, S, 1991 List 40 nos 2, 4 - Nottingham University Tree-Ring Dating Results: Kent, *Vernacular Architect*, **22**, 43-44

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1995 List 60 no 5a - Nottingham University Tree-Ring Dating Laboratory Results: general list, *Vernacular Architect*, **26**, 47-53

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1996 List 65 no 4c - Nottingham University Tree-Ring Dating Laboratory Results: general list, *Vernacular Architect*, **27**, 78-81

Howard, R E, Laxton, R R, and Litton, C D, 1997a List 76 no 6 - Nottingham University Tree-Ring Dating Laboratory results: general list, *Vernacular Architect*, **28**, 124-129

Howard, R E, Laxton, R R, and Litton, C D, 1997b List 77 no 1b - Nottingham University Tree-Ring Dating Laboratory results: Dendrochronological Dating for English Heritage, *Vernacular Architect*, **28**, 130-132

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**

Laxton, R R, and Litton, C D, 1989 Construction of a Kent master chronological sequence for Oak, 1158-1540, *Medieval Archaeol,* **33**, 90 - 8

Rigold, S, 1966 Some major Kentish barns, *Archaeol Cantiana,* **81**, 1-30

Data of measured samples - measurements in 0.01mm units

FAV-A01A 69
412 451 399 350 275 296 284 277 307 234 240 204 201 161 152 174 140 188 216 194
247 211 186 140 135 140 124 157 117 158 101 100 108 83 72 56 49 42 45 47
48 59 60 57 72 64 80 54 74 61 58 54 70 81 83 78 69 81 82 66
56 60 76 53 63 71 72 92 95
FAV-A01B 69
438 449 438 359 296 296 285 279 353 219 247 196 211 158 154 176 144 187 214 188
242 209 192 146 128 140 133 155 127 152 103 102 105 84 80 64 39 46 41 49
52 59 53 60 65 69 71 63 68 61 63 61 56 83 82 83 65 87 76 72
53 57 76 58 56 75 68 79 94
FAV-A02A 88
522 454 579 386 250 106 74 75 192 244 441 428 384 286 225 283 367 376 296 264
327 350 454 314 258 233 242 252 231 189 163 154 190 191 106 139 208 194 199 229
199 198 209 177 189 144 155 194 198 183 211 143 190 126 158 228 232 201 217 246
152 170 187 172 247 197 243 171 255 292 274 201 205 257 326 281 230 350 223 207
189 248 221 166 190 222 204 421
FAV-A02B 88
499 433 602 393 238 104 71 85 189 240 449 432 390 297 218 268 397 373 291 262
336 341 461 313 255 263 258 250 225 193 149 163 179 196 108 149 209 202 193 241
198 204 215 178 188 158 151 199 216 183 194 147 185 127 165 229 236 197 205 239
170 184 184 187 242 181 246 175 250 293 270 188 223 244 339 270 238 341 230 207
199 252 221 160 194 207 227 425
FAV-A03A 78
177 228 198 202 256 117 102 195 300 178 134 191 187 270 341 299 213 236 283 231
322 268 256 269 330 322 238 193 231 202 260 214 174 285 230 265 206 158 170 163
190 169 178 106 97 115 83 70 49 58 76 66 69 85 79 81 77 64 105 111
97 87 65 50 63 79 88 74 77 81 63 74 76 92 63 51 75 84
FAV-A03B 78
145 240 196 221 260 111 105 198 289 177 135 188 187 274 339 296 221 239 275 221
323 259 254 272 335 321 265 181 233 208 263 211 172 282 237 261 211 163 158 155
188 165 180 93 107 98 79 77 59 74 72 75 69 82 84 82 71 69 104 105
95 97 63 49 65 73 89 72 77 76 63 84 72 81 65 74 86 79
FAV-A04A 78
177 162 175 222 232 194 181 160 160 188 613 746 457 379 316 240 282 234 215 153
135 130 139 192 190 183 180 142 125 114 104 92 65 85 79 63 92 76 79 65
75 67 66 90 68 87 92 91 128 134 120 116 107 148 113 148 88 110 93 89
109 103 100 122 93 91 93 92 57 92 118 93 100 122 130 117 145 122
FAV-A04B 78
184 161 178 222 243 190 170 133 170 214 610 752 449 395 302 244 274 230 220 153
147 137 148 168 186 178 174 155 116 116 103 91 65 82 81 67 84 78 84 78
66 65 66 96 66 80 93 101 120 128 124 111 106 152 108 158 94 105 93 90
102 89 96 116 87 87 90 90 62 97 102 105 104 122 118 116 160 134
FAV-A05A 69
197 321 315 389 372 281 267 164 146 201 123 146 137 160 156 149 139 128 77 144
122 155 200 343 309 346 295 266 278 319 321 297 199 228 172 174 214 178 142 153
144 126 89 106 103 99 115 93 149 154 127 84 72 105 121 96 124 128 105 81
121 56 72 89 62 82 50 81 69
FAV-A05B 69
204 335 312 406 356 281 268 165 149 199 118 158 138 149 153 152 136 120 86 151
111 152 196 340 315 346 292 270 283 323 322 308 199 232 164 182 209 181 135 155
148 130 90 110 96 103 117 95 138 151 126 89 70 105 122 96 126 129 105 86
119 50 79 85 65 68 58 80 64
FAV-A06A 54
117 74 102 98 153 136 242 217 224 168 92 90 91 143 133 150 165 182 174 137
174 168 152 128 149 215 194 245 356 310 458 492 442 460 431 410 416 350 403 419
422 365 264 231 409 375 379 345 335 287 438 368 206 398

FAV-A06B 54
121 83 94 99 148 138 241 206 238 153 107 105 117 144 140 139 155 189 181 142
176 161 149 125 153 217 194 258 370 311 457 489 468 461 424 411 429 344 383 428
439 381 268 214 398 388 368 314 362 243 424 380 213 406
FAV-A07A 60
323 247 282 236 212 237 223 254 273 232 215 129 154 132 175 151 118 84 83 84
55 60 72 55 66 116 96 150 152 193 152 191 194 144 182 171 162 98 122 162
240 234 198 129 166 116 111 112 134 136 78 95 103 125 97 141 140 112 120 125
FAV-A07B 60
329 247 304 228 221 275 222 268 279 223 202 137 153 133 184 158 114 88 101 82
70 56 73 49 69 118 101 150 161 156 149 200 196 131 176 178 158 102 123 160
226 177 196 127 168 129 123 103 139 133 73 97 111 118 99 149 137 117 111 114
FAV-A08A 56
189 241 120 82 123 173 188 180 195 178 133 153 201 211 233 305 330 353 413 368
263 152 116 104 93 101 98 93 97 116 105 89 101 119 141 132 168 126 130 147
161 159 216 225 264 221 171 139 177 208 242 243 259 189 227 222
FAV-A08B 56
185 212 103 79 125 198 192 173 195 158 161 152 234 222 272 326 377 346 401 379
274 148 124 103 100 108 92 90 95 116 100 94 93 113 139 134 169 128 138 148
148 152 203 225 250 216 167 144 178 219 239 239 260 200 224 223
FAV-A09A 47
184 221 250 186 240 296 249 240 211 213 179 161 213 169 256 231 168 190 222 266
246 233 206 173 234 203 214 106 90 165 199 185 216 140 161 171 135 153 173 163
118 139 140 162 122 175 147
FAV-A09B 47
130 227 254 186 257 301 247 239 215 215 160 165 211 167 245 235 174 192 218 253
244 234 220 156 236 188 189 109 99 154 206 192 215 150 149 151 143 149 176 164
115 146 134 163 128 171 152
FAV-A10A 58
194 195 228 259 256 152 200 175 163 223 177 151 190 177 114 108 142 103 145 177
154 183 133 127 100 125 151 114 144 125 146 103 101 120 105 94 85 120 128 114
104 100 105 110 112 93 84 87 87 103 79 78 101 104 129 116 113 138
FAV-A10B 58
194 184 233 278 248 179 206 191 159 244 176 156 174 173 121 107 138 100 148 175
157 181 129 135 100 123 151 109 140 123 160 101 113 114 107 88 89 109 136 115
113 90 102 111 108 99 90 84 95 97 79 76 112 126 116 115 114 122
FAV-A11A 100
202 217 156 135 151 111 182 104 127 135 97 135 134 97 106 89 80 97 118 152
133 132 136 289 214 233 212 197 199 196 183 210 220 196 196 305 275 252 305 204
219 307 260 288 184 293 174 234 220 202 165 170 185 163 131 164 124 167 167 169
226 176 163 136 182 190 115 200 128 157 103 117 124 141 155 99 100 135 114 102
118 111 127 107 97 96 102 103 153 101 119 120 126 153 151 154 139 188 133 162
FAV-A11B 100
204 211 154 131 148 120 180 98 137 145 84 96 121 89 101 89 84 93 115 154
130 133 132 293 222 235 220 199 207 189 169 213 212 195 195 305 263 253 302 208
222 299 265 280 189 286 184 231 218 206 165 169 190 153 141 154 131 165 172 157
214 184 154 152 153 178 139 194 144 151 104 128 119 131 154 107 101 126 108 102
111 122 132 107 93 90 108 107 159 112 115 116 109 161 143 153 141 157 106 177
FAV-A12A 84
249 208 271 216 303 199 213 198 181 273 329 506 362 395 415 340 390 541 541 558
417 582 429 489 490 433 382 440 352 301 359 368 299 357 283 227 276 277 250 225
192 227 183 221 139 212 116 83 130 99 161 161 141 140 124 149 106 126 152 141
135 161 193 175 222 175 135 174 205 221 181 164 143 135 123 106 122 125 193 175
149 251 173 153
FAV-A12B 84
253 216 276 212 296 206 205 199 174 278 368 488 361 391 415 341 397 543 547 542
431 560 422 494 492 427 376 447 358 312 348 376 282 352 295 223 282 284 242 227
189 227 177 218 156 206 108 90 128 103 140 146 151 147 127 144 104 134 146 140
130 161 191 174 197 168 139 188 207 204 180 181 121 127 132 112 145 100 180 176
136 253 165 163

FAV-A13A 81
122 234 197 200 174 249 284 231 211 159 223 183 169 112 145 108 134 96 104 80
146 439 326 270 253 203 179 311 462 467 463 345 373 401 362 370 346 453 397 355
304 208 336 217 263 216 218 311 298 253 210 153 239 232 224 217 264 197 186 266
196 164 197 169 214 169 136 148 158 230 179 217 185 183 137 190 134 112 154 165
214
FAV-A13B 73
275 253 299 163 211 190 142 146 111 100 102 79 108 262 228 228 195 84 192 263
328 314 306 305 370 352 311 370 354 365 332 322 264 198 359 206 299 255 276 396
326 318 285 168 237 234 222 206 275 200 182 239 189 181 180 162 191 152 192 140
186 203 178 177 178 218 115 186 140 123 128 163 210
FAV-A14A 57
327 224 293 414 357 275 213 342 494 435 438 336 416 428 385 316 345 309 307 350
291 202 213 245 333 217 219 281 240 302 246 165 196 208 193 171 202 164 136 228
190 134 108 109 137 116 125 119 119 156 155 136 120 144 85 130 167
FAV-A14B 57
293 243 296 410 374 275 217 317 505 431 441 325 419 424 365 338 344 311 323 328
295 193 220 246 335 208 208 299 242 301 239 173 185 206 192 177 211 172 140 230
176 124 112 115 127 114 153 113 110 153 129 164 142 137 83 140 175
FAV-A15A 70
212 262 136 225 200 237 244 261 191 313 255 358 278 345 410 373 449 446 361 340
280 206 250 273 186 82 63 89 88 110 130 160 121 154 288 332 329 272 281 285
267 267 216 254 415 334 346 268 298 234 283 229 349 248 379 306 367 358 348 223
185 177 250 259 226 192 247 246 297 245
FAV-A15B 70
200 209 138 215 210 233 249 260 202 322 262 350 295 366 415 385 436 471 371 343
275 196 259 275 180 81 77 86 84 111 126 152 114 178 313 330 322 263 285 287
278 261 212 244 420 330 352 273 289 233 284 237 344 248 382 318 353 361 335 238
188 184 241 262 246 156 273 255 314 218
FAV-A16A 77
399 420 506 556 363 424 428 388 311 356 482 333 324 289 257 254 290 317 270 314
364 290 261 184 198 262 288 284 288 250 219 176 178 190 180 201 172 157 161 174
123 192 172 230 226 181 238 352 262 239 152 212 245 177 245 227 180 350 410 322
353 300 177 276 304 358 262 173 275 261 264 234 193 221 241 254 208
FAV-A16B 77
412 420 522 552 368 391 451 376 332 350 479 363 347 288 280 251 287 297 309 311
341 279 272 176 205 288 288 276 242 228 215 174 163 192 186 208 177 162 166 186
130 195 178 222 225 174 243 360 266 233 159 200 213 212 250 206 202 364 401 318
357 288 174 299 322 297 284 191 270 260 265 232 193 219 224 240 234
FAV-A17A 54
137 118 120 84 96 87 133 128 122 97 94 90 148 111 90 124 149 122 124 148
137 106 138 150 161 131 223 365 329 264 331 326 322 190 234 184 147 155 140 295
192 206 197 141 155 107 142 150 154 125 166 196 191 166
FAV-A17B 54
97 131 97 99 98 82 136 128 121 103 101 78 160 113 93 116 143 118 129 149
128 108 142 151 165 135 221 367 332 261 331 328 320 202 233 184 140 159 129 290
191 222 189 148 144 116 137 146 130 150 155 250 176 154
FAV-A18A 42
166 110 130 177 188 165 190 194 139 136 213 177 132 107 92 114 86 79 95 138
139 113 116 148 117 113 106 184 206 355 462 380 454 427 311 302 297 296 284 479
362 420
FAV-A18B 42
177 111 138 172 193 158 195 194 154 130 207 177 129 109 96 111 90 73 94 143
134 111 121 141 120 111 113 181 202 357 456 387 456 415 311 311 298 297 281 493
370 382
FAV-A19A 96
70 182 181 192 310 296 209 211 169 116 165 144 142 142 151 120 124 116 83 203
426 211 265 248 146 135 181 201 168 178 116 152 183 114 152 169 118 130 142 166
142 220 190 213 127 148 150 149 148 241 294 449 420 431 429 243 275 159 249 332
207 162 148 238 272 227 263 175 189 215 198 166 225 186 225 207 388 334 331 228
272 257 486 85 48 50 71 103 76 69 135 108 199 167 184 169

FAV-A19B 96
95 194 176 199 291 307 210 226 152 129 171 143 136 128 146 129 127 111 84 200
392 211 264 240 147 130 194 196 155 178 124 165 171 124 155 175 142 131 151 158
138 220 182 222 130 145 162 137 131 233 279 450 418 429 423 233 277 172 256 334
211 164 150 259 262 221 253 184 204 222 184 168 212 190 227 209 356 341 356 259
269 254 484 101 57 50 74 83 71 79 128 105 207 172 193 171
FAV-A20A 77
343 451 471 451 557 429 383 268 328 302 300 305 191 317 326 237 206 276 187 129
139 250 226 234 181 123 158 200 165 195 151 116 173 225 140 120 199 115 165 168
176 161 122 113 183 168 117 174 190 101 134 146 133 141 161 93 155 186 117 115
114 127 116 178 101 166 120 135 90 107 94 94 102 110 127 103 123
FAV-A20B 74
204 195 215 243 218 234 208 155 195 300 199 185 148 108 139 171 118 139 218 154
223 185 245 200 138 116 168 163 114 188 188 117 137 136 134 148 152 119 127 146
122 119 118 140 112 168 134 146 110 152 79 133 99 116 118 143 131 107 95 103
87 91 101 84 145 106 91 114 95 79 96 68 82 71
FAV-A20C 62
281 182 136 190 98 189 171 169 165 142 125 159 140 117 188 173 112 156 141 126
144 160 102 131 156 111 131 118 137 106 187 118 132 100 153 79 135 108 118 116
154 138 111 113 120 85 97 100 90 133 130 87 133 112 94 94 75 87 80 92
91 113
FAV-A21A 84
392 277 235 443 454 260 290 304 398 289 363 304 337 238 238 406 328 258 293 289
365 179 458 322 377 475 321 211 213 229 375 369 376 361 269 316 322 363 439 270
197 453 301 363 407 376 239 349 148 256 424 299 265 368 260 470 302 239 236 278
429 344 333 374 470 425 276 204 209 263 213 158 268 202 201 177 220 292 667 554
389 645 697 575
FAV-A21B 81
494 453 255 289 300 394 310 386 299 326 248 238 392 345 252 301 287 357 188 449
321 392 490 328 222 209 228 362 372 385 362 263 310 333 358 447 272 227 452 293
353 382 387 258 345 173 240 401 308 264 372 256 477 286 271 231 276 419 365 337
383 463 401 300 217 197 267 235 152 264 201 205 168 236 280 676 545 354 629 700
572

Data of measured samples - measurements in 0.01mm units

FAV-B01A 57
380 272 584 337 181 284 493 320 344 384 354 325 535 461 491 440 302 322 284 352
321 390 302 261 299 253 218 202 220 282 230 270 265 325 279 233 248 244 241 227
253 366 272 266 349 230 205 246 247 190 172 261 296 193 256 218 254
FAV-B01B 57
374 274 589 330 192 313 474 320 342 386 371 330 533 508 491 422 295 324 278 368
311 399 300 269 281 262 211 210 214 297 243 277 269 317 286 225 231 295 216 217
236 360 269 261 328 245 200 252 244 190 172 261 282 196 266 218 264
FAV-B04A 67
624 338 473 301 370 374 165 260 242 121 72 168 123 156 203 200 250 184 280 171
259 195 234 227 149 92 121 103 125 107 127 187 201 183 209 205 198 162 159 129
136 141 106 101 198 226 172 162 155 192 177 137 133 168 173 167 146 190 164 176
188 131 128 100 76 114 152
FAV-B04B 67
619 355 447 314 363 387 144 270 250 130 83 157 118 162 193 189 222 212 294 179
273 206 209 224 136 92 112 97 128 105 123 162 195 179 192 213 209 145 155 151
122 148 104 99 205 230 168 154 159 190 205 138 140 169 168 164 158 192 165 182
189 136 124 103 79 103 170
FAV-B05A 70
169 277 306 212 170 131 90 95 89 145 177 263 194 181 195 204 194 215 163 185
136 109 108 102 110 99 97 106 100 125 602 318 205 322 225 177 164 177 111 68
95 67 43 62 46 76 77 102 109 65 52 73 62 70 64 77 68 64 80 61
52 58 53 58 60 87 98 141 242 142
FAV-B05B 70
197 225 302 204 178 136 90 83 101 132 179 209 192 179 193 195 198 209 157 189
131 118 103 93 115 104 104 107 98 126 597 304 203 320 231 189 168 158 116 82
89 62 42 50 57 75 80 103 122 61 51 70 83 78 60 82 68 61 80 66
50 57 54 54 62 90 95 150 227 181
FAV-B06A 75
77 160 168 173 162 111 90 174 155 131 127 115 106 134 105 90 88 82 104 55
82 86 61 95 97 126 207 189 181 152 132 149 158 133 135 144 126 113 126 104
151 135 138 137 143 102 100 87 66 66 71 82 126 101 99 142 113 108 140 139
150 116 213 197 179 191 159 147 141 145 122 143 208 110 177
FAV-B06B 75
71 173 172 164 167 121 104 165 165 121 125 106 124 142 104 91 91 86 97 58
84 79 62 95 100 117 213 191 186 152 127 150 152 138 130 145 118 117 114 115
150 131 130 129 137 104 106 85 72 70 63 77 126 107 97 141 113 90 142 117
136 145 201 173 196 195 159 149 148 147 123 154 196 111 226
FAV-B07A 54
286 191 292 226 185 103 106 139 234 310 233 265 292 268 193 280 702 583 541 558
595 460 324 246 174 139 94 106 204 188 248 390 279 248 331 290 321 216 291 224
240 249 180 160 205 204 156 178 225 147 237 225 194 237
FAV-B07B 54
324 148 256 235 204 104 91 133 227 303 239 256 296 270 197 288 702 574 544 575
594 450 310 252 177 146 88 96 208 207 230 399 271 250 342 303 312 213 276 200
242 247 180 166 198 213 143 180 236 146 239 218 200 239
FAV-B09A 76
224 243 122 95 73 43 78 68 71 77 72 64 52 44 35 46 41 41 37 55
46 66 72 107 94 156 123 126 124 112 116 106 93 147 178 171 124 131 117 130
133 116 180 142 207 291 353 255 225 196 192 164 190 190 227 176 179 193 132 139
162 176 157 140 186 160 177 172 140 139 141 127 121 99 138 121
FAV-B09B 76
232 235 120 94 70 43 74 61 74 79 78 76 49 47 42 47 36 46 36 51
54 61 61 100 85 135 127 121 123 116 116 105 93 142 180 170 118 129 124 128
134 114 181 146 200 285 354 254 226 193 194 170 194 186 233 168 192 183 140 135
164 170 158 131 189 166 167 178 140 144 137 128 117 118 148 110
FAV-B11A 61

335 248 208 244 182 96 71 59 85 83 114 142 127 126 96 118 103 83 74 44
46 31 55 57 53 39 76 93 132 116 94 116 98 84 112 110 129 123 120 106
112 106 160 305 327 492 309 352 222 198 168 144 167 114 117 127 142 155 188 167
202
FAV-B11B 61
352 232 210 256 188 79 60 48 87 82 122 144 116 111 80 102 101 74 87 49
42 39 54 58 49 44 73 84 133 113 99 117 97 79 87 108 130 123 124 112
110 117 151 297 345 505 290 329 218 202 167 136 171 112 106 133 134 161 186 163
212
FAV-B12A 75
137 130 153 149 129 99 85 96 126 89 98 82 74 89 67 61 61 63 68 62
62 123 134 179 141 104 105 95 72 67 78 140 128 149 139 135 137 119 83 87
123 95 127 129 158 80 95 70 81 70 69 71 84 76 70 82 69 92 85 100
104 95 100 103 100 92 86 85 88 80 65 88 102 102 118
FAV-B12B 75
132 105 144 139 130 118 81 103 125 88 84 80 78 81 67 61 55 79 70 63
62 120 134 174 141 100 106 98 88 68 84 135 127 143 134 139 143 113 86 85
125 96 122 130 166 102 88 77 82 77 67 65 81 80 70 78 72 84 94 105
103 96 99 100 104 101 97 87 70 79 72 95 85 97 117

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.

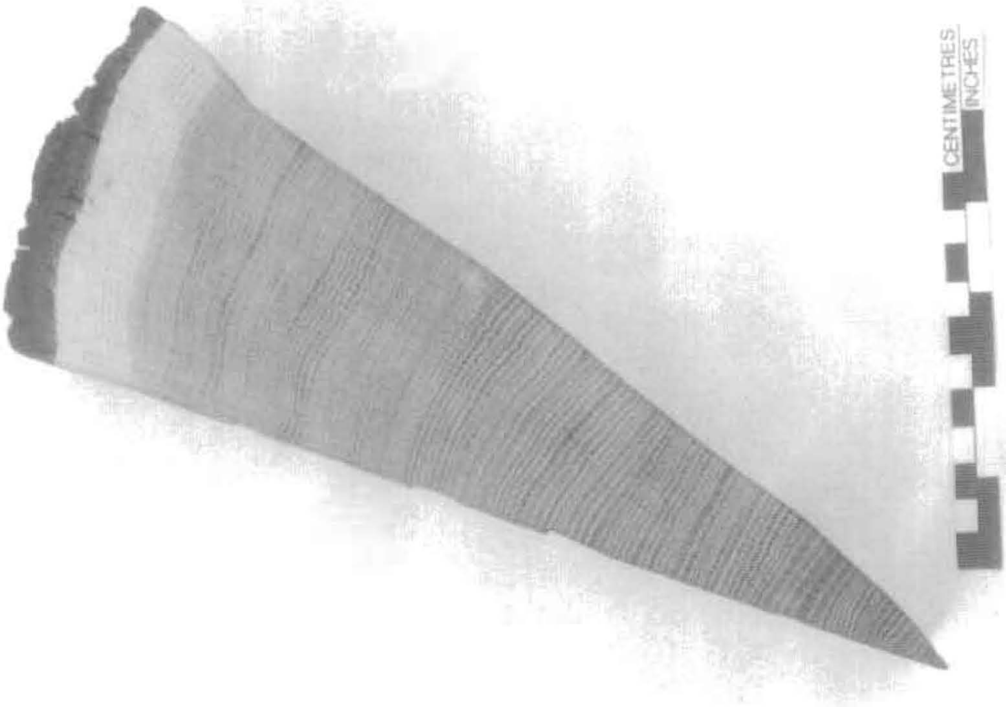


Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

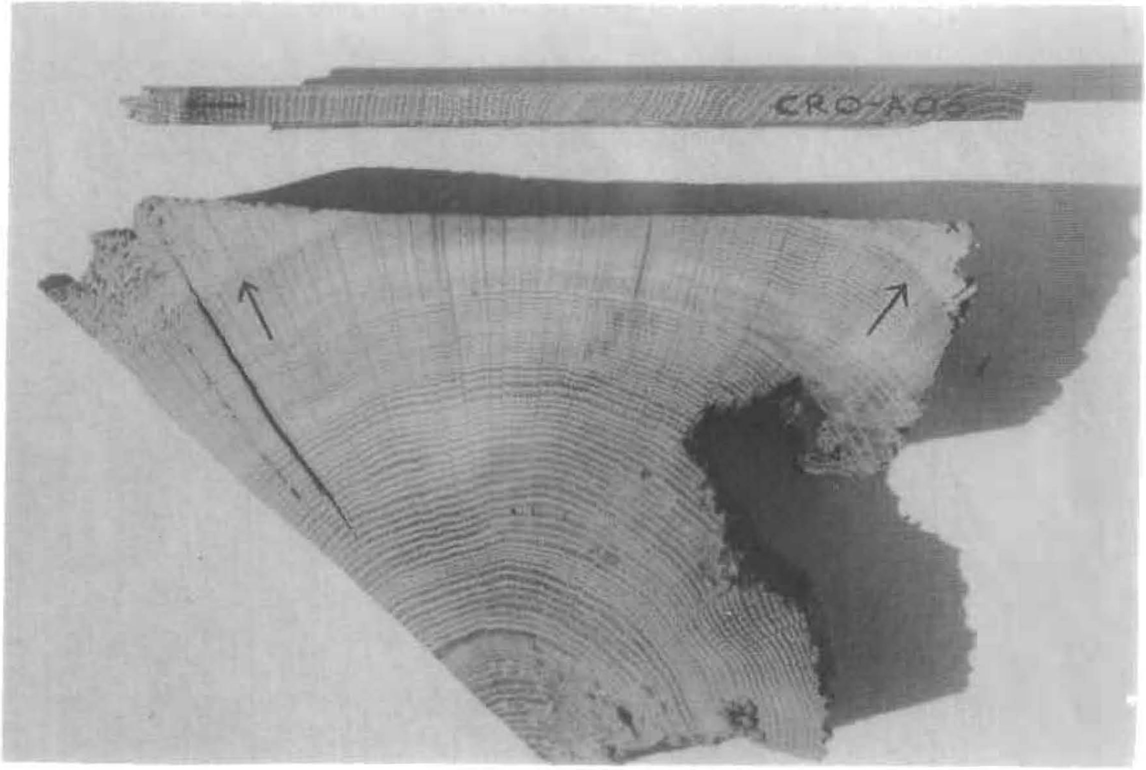


Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood: again the arrow is pointing to the H/S. The core is about the size of a pencil.

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.

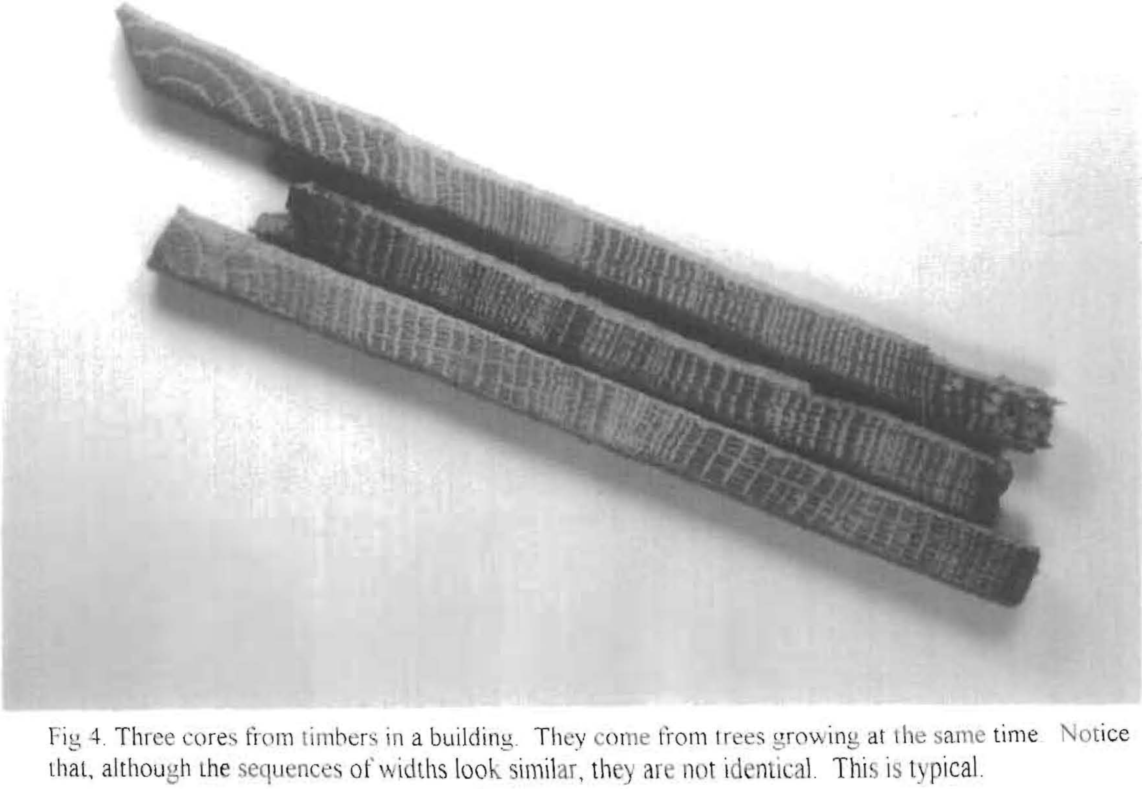


Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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

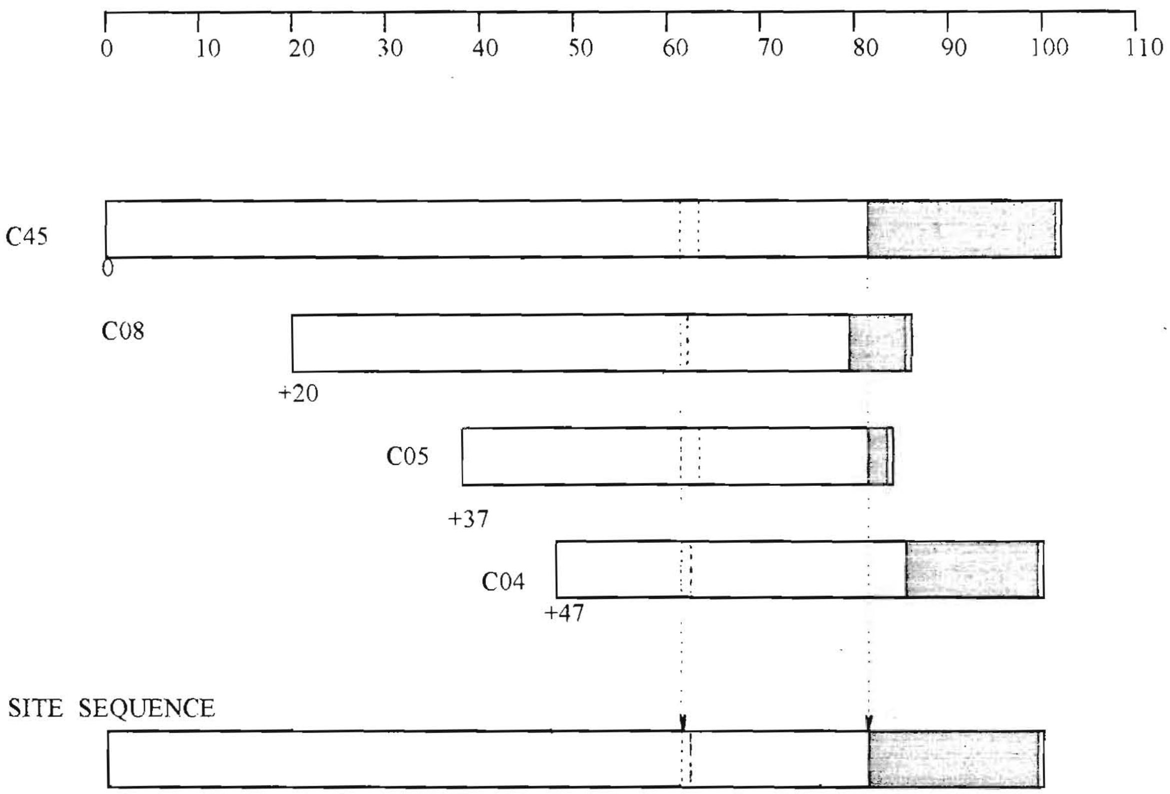


Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.
The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set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

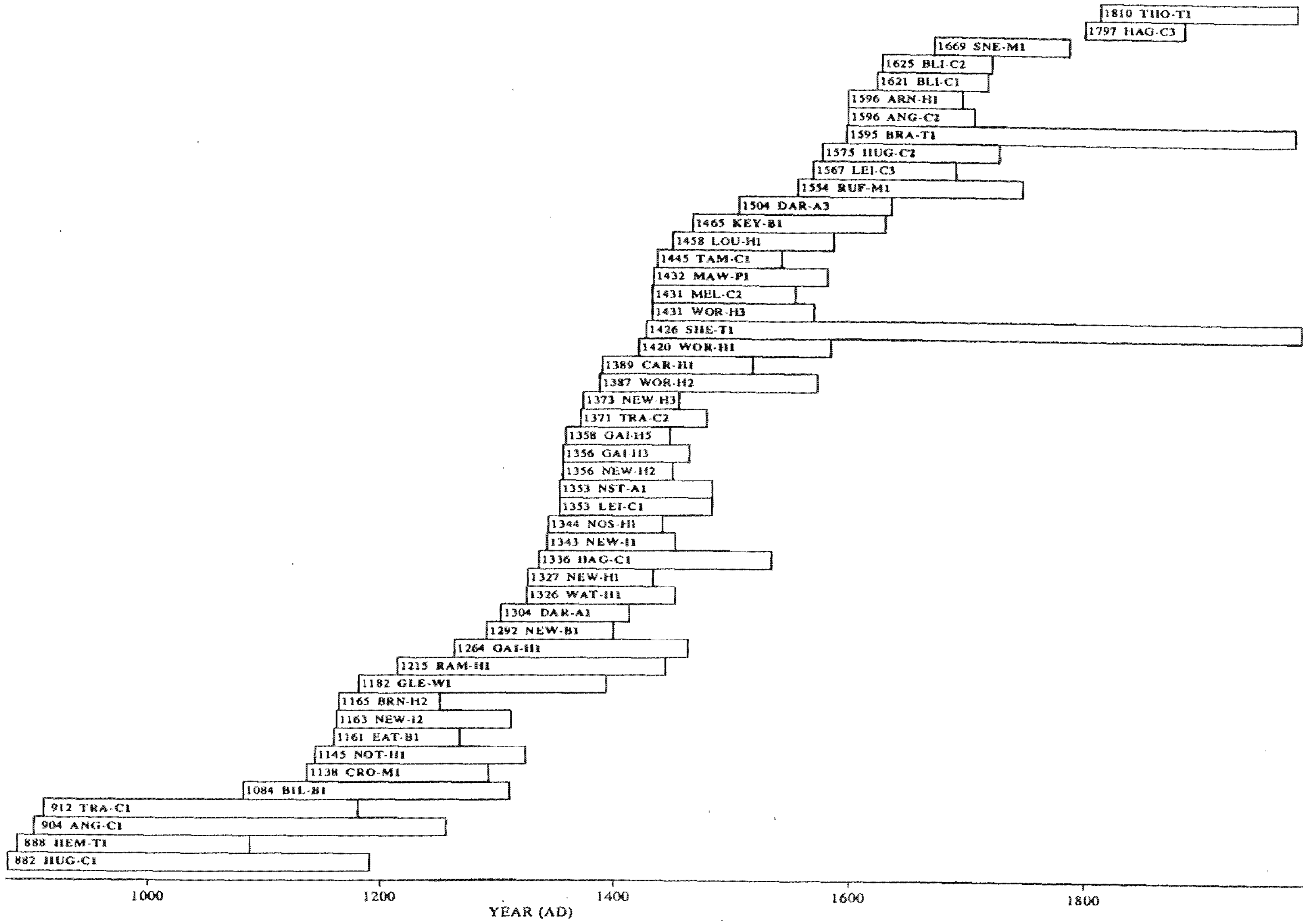


Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

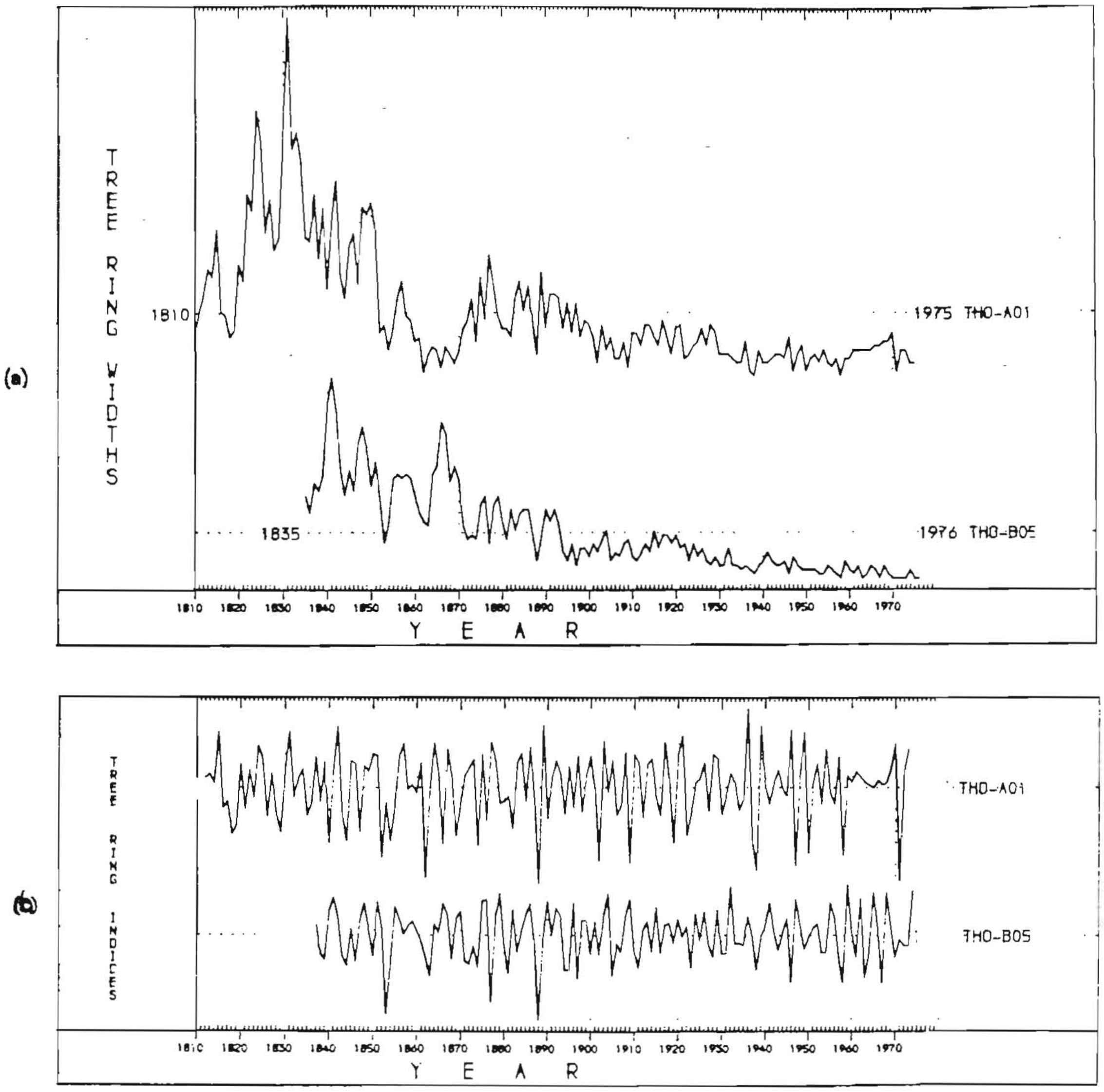


Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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