Ancient Monuments Laboratory
Report 29/99

TREE-RING ANALYSIS OF TIMBERS FROM THE DOWER HOUSE, FAWSLEY PARK, FAWSLEY, NR DAVENTRY, NORTHAMPTONSHIRE

R E Howard
R R Laxton
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Summary

Analysis was undertaken of samples from twenty-nine oak beams at the Dower House, Fawsley. This resulted in the production of two site chronologies. The first has 149 rings and spans the period AD 1427 - 1575. The second site chronology has 176 rings spanning the period AD 1720 - 1895. A number of other samples date individually. Interpretation of the heartwood/sapwood boundaries and the sapwood, where it exists, suggests a range of felling dates are represented. The earliest certain felling date is estimated to be in the range AD 1514 - 1539 which may relate to the initial construction of the Dower House. A number of the dated timbers appear to have been felled in the later-sixteenth century and may represent a major reconstruction or extension; it is possible that this is connected with the visit of Queen Elizabeth the First to the house in AD 1575. There is then a "romantic" repair at the end of the nineteenth-century.

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Introduction

This ruinous grade II listed brick building and scheduled ancient monument stands in a deer park set between the B438 and B407 a few miles south of Daventry in Northamptonshire (SP 570578, see Fig 1). The Manor of Fawsley was bought in AD 1416 by Richard Knightly and held by his descendants until AD 1938. A deer park had been created in the area some time after AD 1331 and this was enlarged during the reign of Elizabeth in the second half of the sixteenth century, the enlargement area being termed the "New Park". The Dower House stands in this enlargement area.

The Dower House began life in the sixteenth century as a brick lodge or stand, the use of brick marking it out as a fashionable up-to-date structure; it is reputedly the earliest brick-built structure in Northamptonshire. Later in the sixteenth century the lodge was extended in stone. The owner responsible for the alteration may have been Richard Knightly who held the estate from AD 1566 to AD 1615. It is known that he entertained Queen Elizabeth there in AD 1575.

The last recorded inhabitant of the Dower House was Anne Devereux, who died there in AD 1703. Although some attempts at maintenance were made it appears to have been a ruin since the eighteenth century. In the nineteenth century further repairs were made but it appears to have been maintained specifically as a ruined building.

Sampling and analysis by tree-ring dating was commissioned by English Heritage. The purpose of this was to inform a programme of grant-aided repairs and consolidation. At the time of sampling (October 1998) the Dower house was scaffolded and partly covered with tarpaulins and boarding, see photograph, Figure 2.

The Laboratory would like to take this opportunity to thank the owner, The Right Honourable Henry Nicolas, 8th Viscount Gage, for granting permission to sample and J Morgan, of John German, for arranging access to the site.

Sampling

A total of twenty-nine different oak timbers was sampled by coring. All these timbers take the form of either door or window lintels, bressumers over large openings, wall lacing timbers or remnants of wedges and blocks set deep within the walls. From the presence of empty peg holes and redundant mortises it is apparent that many of the timbers are reused in their present positions. The building is without a roof, this having decayed in the eighteenth century, and without floor or ceiling beams.

Each sample was given the code FAW-A (for Fawsley site "A") and numbered 01 - 29. The positions of the cores were recorded at the time of sampling on drawings made by the architects Peter Inskip and Peter Jenkins or on a plan made by The Royal Commission on the Historical Monuments of England and supplied by English Heritage. Where no drawing or plan existed a photograph was taken. These diagrams are reproduced here as Figure 3a- 3g. Details of the samples are given in Table 1. Where possible the positions of the samples are recorded by reference to feature numbers on the drawings provided.

Analysis and dating

The twenty-nine samples obtained from this building were prepared by sanding and polishing and their growth-ring widths measured. Where a single core is obtained from a timber this is measured twice and the measurements meaned together. A number of timbers at Fawsley required two or more cores to obtain the optimum number of growth rings. In these cases each core was measured only once and the measurements meaned together. In such cases as this the readings of the same sample have different numbers of rings, sample FAW-A01A/B/C, for example. The data of the measurements of the samples is given at the end of the report.

The measured growth-ring widths of all twenty-nine samples were 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 sixteen samples of the first group cross-matched with each other as shown in the bar diagram, Figure 4. The ring widths from these sixteen samples were combined at their suggested relative offsets to form FAWASQ01, a site chronology of 149 rings. Site chronology FAWASQ01 was successfully cross-matched with a series of relevant reference chronologies for oak, giving it a first ring date of AD 1427 and a last measured ring date of AD 1575. Evidence for this date is given in the t-values of Table 2.

The second group to form at a value of t=4.5 by the Litton/Zainodin grouping procedure consisted of two samples. These two cross-match with each other as shown in the bar diagram, Figure 5. The ring widths from these two samples were combined at their suggested relative offsets to form FAWASQ02, a site chronology of 176 rings. Site chronology FAWASQ02 was successfully cross-matched with a series of relevant reference chronologies for oak, giving it a first ring date of AD 1720 and a last measured ring date of AD 1895. Evidence for this date is also given in the t-values of Table 2.

The two site chronologies thus created, FAWASQ01 and FAWASQ02, were compared with each other but, as expected given their different date spans, there was no cross-matching between them. Each of the two site chronologies was then compared with the remaining eleven ungrouped samples. This process gave low t-value cross-matches between site chronology FAWASQ01 and samples FAW-A08 and FAW-A12. A maximum t-value of 4.3 is found between FAWASQ01 and sample FAW-A08 when the first ring of the sample is at plus 82 years relative to the first ring of the site chronology. A maximum t-value of 3.5 is found between FAWASQ01 and sample FAW-A12 when the first ring of the sample is at minus 17 years relative to the first ring of the site chronology. Given these low t-values, the two samples were not combined with those of the site chronology.

Each of the eleven ungrouped samples was then compared individually with a full range of reference chronologies. This indicated cross-matches and dates for a further three samples, FAW-A08, FAW-A09 and FAW-A12. The t-values of the cross-matches with the reference chronologies of these samples are shown in Table 2. It will be seen from Table 2 that the first ring dates of samples FAW-A08 and FAW-A12, AD 1509 and AD 1410 respectively, are consistent with their relative cross-matching positions against site chronology FAWASQ01, which has a first ring date AD 1427. The dating of these three additional samples indicates the possible relative cross-matching positions between them. There is, however, no satisfactory t-value obtained at such relative off-sets. Because of this, and the low t-value cross-matching of two of the samples with the site chronology, the three additional samples were not combined with those of FAWASQ01.

Interpretation

The bar diagram of Figure 4 shows that there are a number of samples with complete or near complete sapwood, but which have substantially different last measured ring dates. Sample FAW-A05, for example, has a last measured complete sapwood ring date, and therefore a felling date, of AD 1565 while sample FAW-A21 has a last measured complete sapwood ring date of AD 1575. Sample FAW-A02 has a last measured ring date of AD 1542 and has lost, according to observations and notes made at the time of sampling, only a few rings to complete sapwood. It is estimated that the felling date of the timber represented by this sample is *c* AD 1545. Sample FAW-A12 has an estimated felling date in the range AD 1514 - 1539.

The earliest last measured ring date, AD 1455, is found on sample FAW-A09. This sample, however, does not have a heartwood/sapwood boundary and it is thus not possible to estimate its felling date except to say that it is unlikely to be before *c* AD 1470. These felling date ranges are calculated using the usual 95% confidence limits for sapwood on mature oaks from this part of England, 15 to 40 rings. The site has also produced two samples, FAW-A22 and A24, which have a felling date of AD 1895. It is probable that these two samples are a pair . Other pairs of samples probably from the same trees are FAW-A05 and A06, and samples FAW-A17 and A29.

Information, for dated samples with the heartwood/sapwood boundary only, is summarised overpage.

Sample number	Last measured ring date	*Sapwood rings	Felling date or estimated felling date range
FAW-A01	AD 1570	14c	*c* AD 1575
FAW-A02	AD 1542	32c	*c* AD 1545
FAW-A04	AD 1562	41c	*c* AD 1565
FAW-A05	AD 1565	25C	AD 1565
FAW-A06	AD 1548	h/s	AD 1563 - 1588
FAW-A07	AD 1549	h/s	AD 1564 - 1589
FAW-A08	AD 1564	h/s	AD 1579 - 1604
FAW-A12	AD 1499	h/s	AD 1514 - 1539
FAW-A15	AD 1545	h/s	AD 1560 - 1585
FAW-A16	AD 1555	h/s	AD 1570 - 1595
FAW-A17	AD 1540	h/s	AD 1555 - 1580
FAW-A21	AD 1575	28C	AD 1575
FAW-A22	AD 1891	28c	AD 1895
FAW-A24	AD 1895	27C	AD 1895
FAW-A27	AD 1545	h/s	AD 1560 - 1585

*h/s = the heartwood/sapwood boundary is the last ring on sample
c = complete sapwood on timber; all or part lost from sample in coring
C = complete sapwood retained on sample; last ring date is felling date of timber

It is thus apparent that the above are timbers with different felling dates. However, it would appear that most of the timber was felled at slightly different dates in the third quarter of the sixteenth century. The only definite exceptions to this are samples FAW-A02 and FAW-A12 felled earlier in the sixteenth-century, though at different dates, and samples FAW-A22 and FAW-A24, felled in AD 1895.

Conclusion

The tree-ring dating indicates that timbers with different felling dates are present within the building. A few of these timbers were felled in the late-nineteenth century and probably represent repairs of that period, but many others were felled in the sixteenth century. Some of these may represent the original early sixteenth-century construction while others may belong to the alterations made by Richard Knightly in connection with the visit there of Queen Elizabeth in AD 1575. The variation in felling date may equate to re-use of timbers as a result of the nineteenth-century attempts to maintain the building as a ruin by using "authentic" timbers.

The results do not highlight the lodge section in particular as being earlier than the extension, but then only one sample sixteenth-century sample, FAW-A12. is from the lodge; it is, however, the one with the earliest certain felling date range.

Eight timbers remain undated. Six of these have rather few rings, though in fact sufficient for satisfactory analysis. Two samples do have a higher number of rings and the lack of dating may be due to the fact that these are singletons and as such, without very high t-values, any cross-matching is unreliable.

Sample number	Last measured ring date	*Sapwood rings	Felling date or estimated felling date range
FAW-A01	AD 1570	14c	*c* AD 1575
FAW-A02	AD 1542	32c	*c* AD 1545
FAW-A04	AD 1562	41c	*c* AD 1565
FAW-A05	AD 1565	25C	AD 1565
FAW-A06	AD 1548	h/s	AD 1563 - 1588
FAW-A07	AD 1549	h/s	AD 1564 - 1589
FAW-A08	AD 1564	h/s	AD 1579 - 1604
FAW-A12	AD 1499	h/s	AD 1514 - 1539
FAW-A15	AD 1545	h/s	AD 1560 - 1585
FAW-A16	AD 1555	h/s	AD 1570 - 1595
FAW-A17	AD 1540	h/s	AD 1555 - 1580
FAW-A21	AD 1575	28C	AD 1575
FAW-A22	AD 1891	28c	AD 1895
FAW-A24	AD 1895	27C	AD 1895
FAW-A27	AD 1545	h/s	AD 1560 - 1585

*h/s = the heartwood/sapwood boundary is the last ring on sample
c = complete sapwood on timber; all or part lost from sample in coring
C = complete sapwood retained on sample; last ring date is felling date of timber

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Bibliography

Alcock, N W, Warwick University, Howard, R E, Laxton, R R, and Litton, C D, Nottingham University Tree-Ring Dating Laboratory, and Miles, D, 1989 - Leverhulme Cruck Project Results: 1988, List 31 no 1, *Vernacular Architect*, **20**, 43-45

Alcock, N W, Warwick University, Howard, R E, Laxton, R R, and Litton, C D, Nottingham University Tree-Ring Dating Laboratory, and Miles, D, 1990 - Leverhulme Cruck Project Results: 1989, List 35 no 13, *Vernacular Architect*, **21**, 42-44

Alcock, N W, Warwick University, Howard, R E, Laxton, R R, and Litton, C D, Nottingham University Tree-Ring Dating Laboratory, and Miles, D, 1991 - Leverhulme Cruck Project Results: 1990, List 41 nos 3, 12, *Vernacular Architect*, **22**, 45-47

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

Esling, J, Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1989 List 29 no 6b - Nottingham University Tree-Ring Dating Laboratory Results, *Vernacular Architect*, **20**, 39-41

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

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1992 List 44 no 16 - Nottingham University Tree-Ring Dating Laboratory Results, *Vernacular Architect*, **23**, 51-56

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1993 List 48 no 11 - Nottingham University Tree-Ring Dating Laboratory Results, *Vernacular Architect*, **24**, 40-42

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1995 List 60 no 2a - Nottingham University Tree-Ring Dating Laboratory Results, *Vernacular Architect*, **26**, 47-53

Howard, R E, Laxton, R R, and Litton, C D, 1996 List 65 no 5 - Nottingham University Tree-Ring Dating Laboratory Results, *Vernacular Architect*, **27**, 78-81

Howard, R E, Laxton, R R, and Litton, C D, 1997 List 77 nos 1b, 5 - Nottingham University Tree-Ring Dating Laboratory Results: Dendrochronological Dating for English Heritage, *Vernacular Architect*, **28**, 130-132

Howard, R E, Laxton, R R, and Litton, C D, forthcoming - Nottingham University Tree-Ring Dating Laboratory Results: Dendrochronological Dating for English Heritage, *Vernacular Architect,* **29**

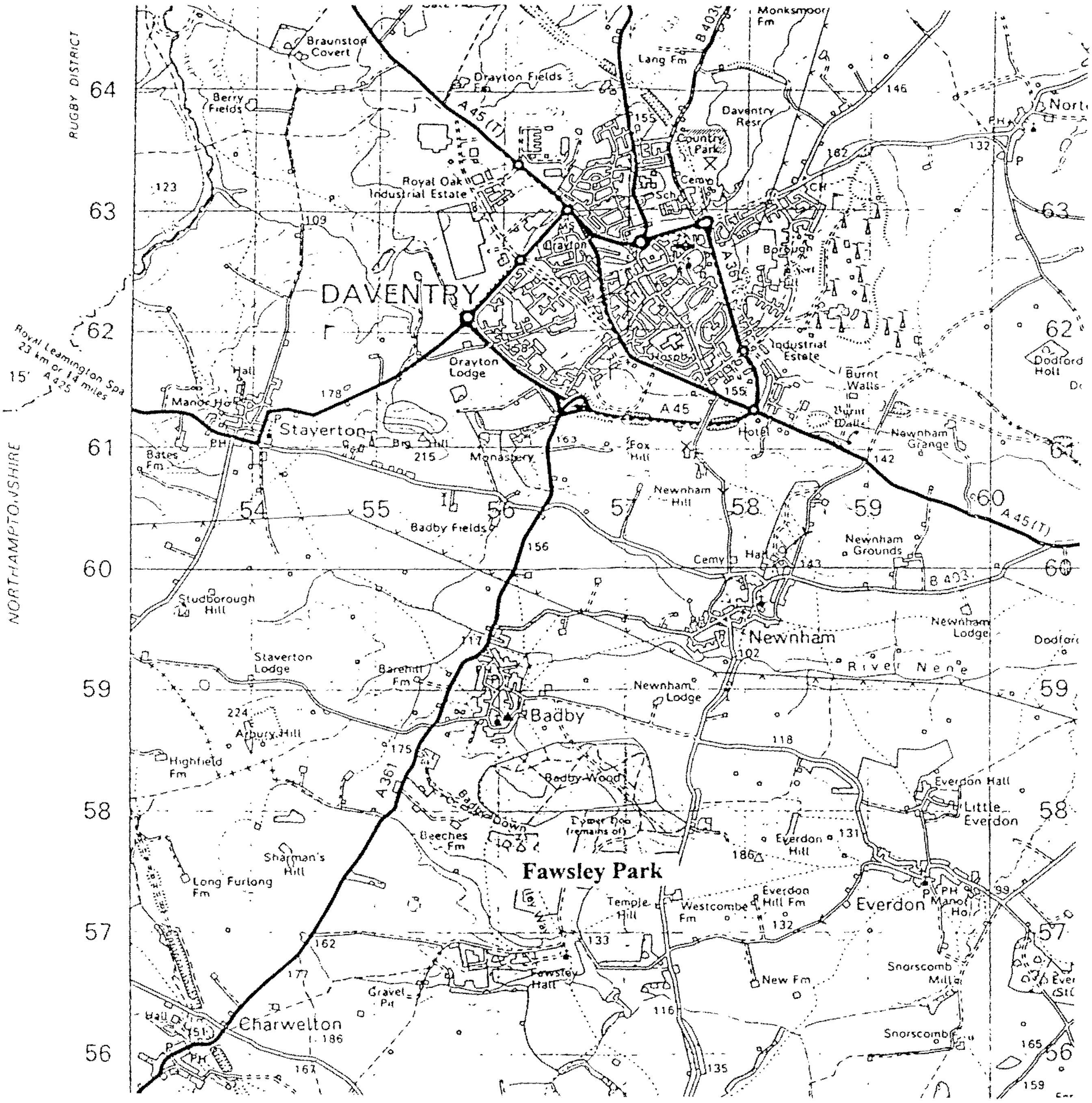
Laxton, R R, and Litton, C D, 1988 An East Midlands Master Tree-ring chronology and its use for dating vernacular buildings, University of Nottingham, Dept of Classical and Archaeol Studies, Monograph Series, **III**

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

Tyers, I, Groves, C, Hillam, J, and Boswijk, G, 1997 List 80 no 58 - Tree-ring Dates from Sheffield University, *Vernacular Architect*, **28**, 138-158

Tyers, I, 1997 unpub computer file *LOND1175*

Figure 1: Map to show general location of Fawsley Park



(based upon the Ordnance Survey 1:50000 map with permission of The Controller of Her Majesty's Stationery Office, ©Crown Copyright).

Figure 2: General view of the Dower House from the south looking north

Figure 3a: Plan of the Dower House to show approximate positions of samples FAW-A01-06 and general location of other samples

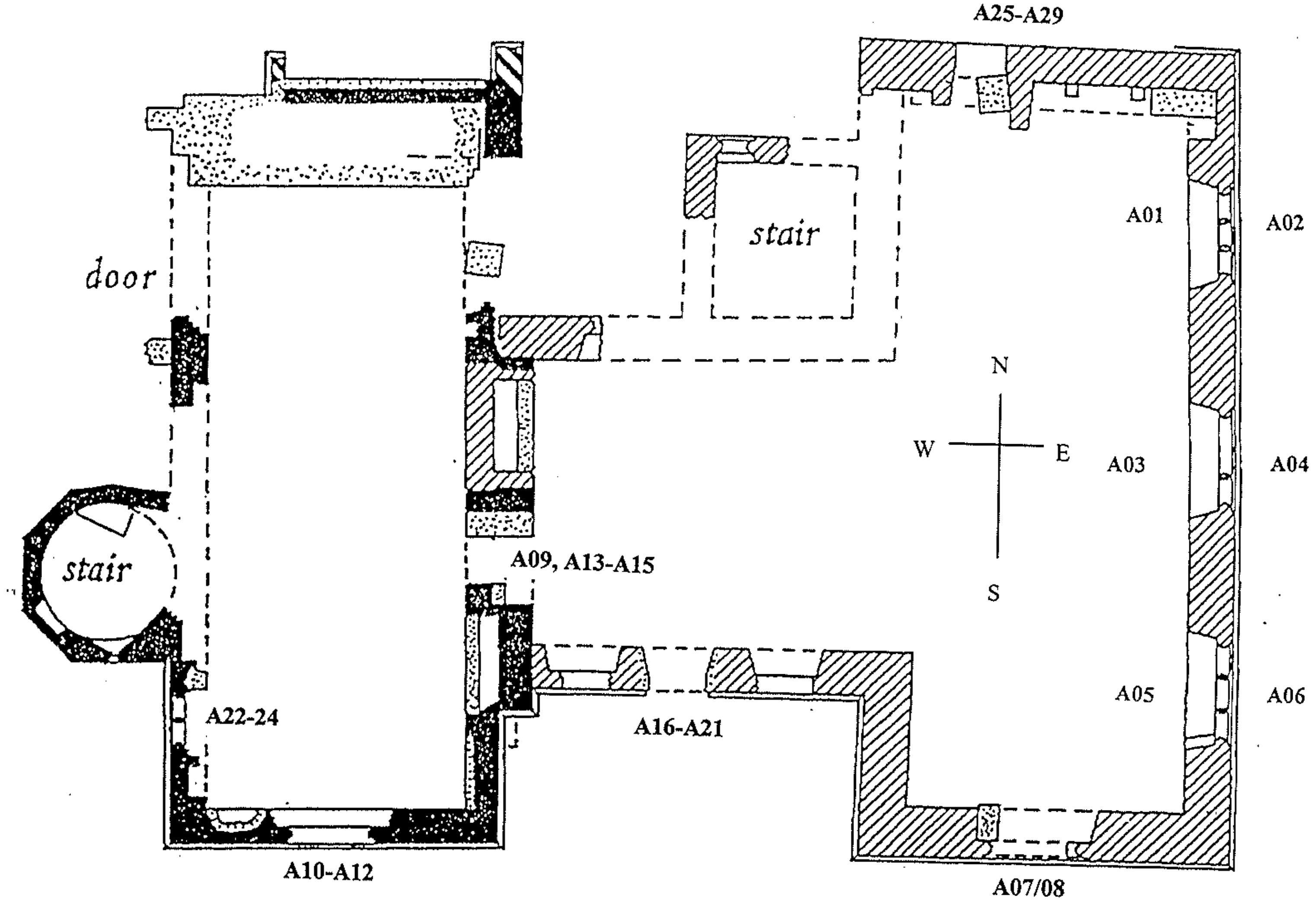


Figure 3b: Drawing to show positions of samples FAW-A07 and FAW-A08 from window 22 in the south wall

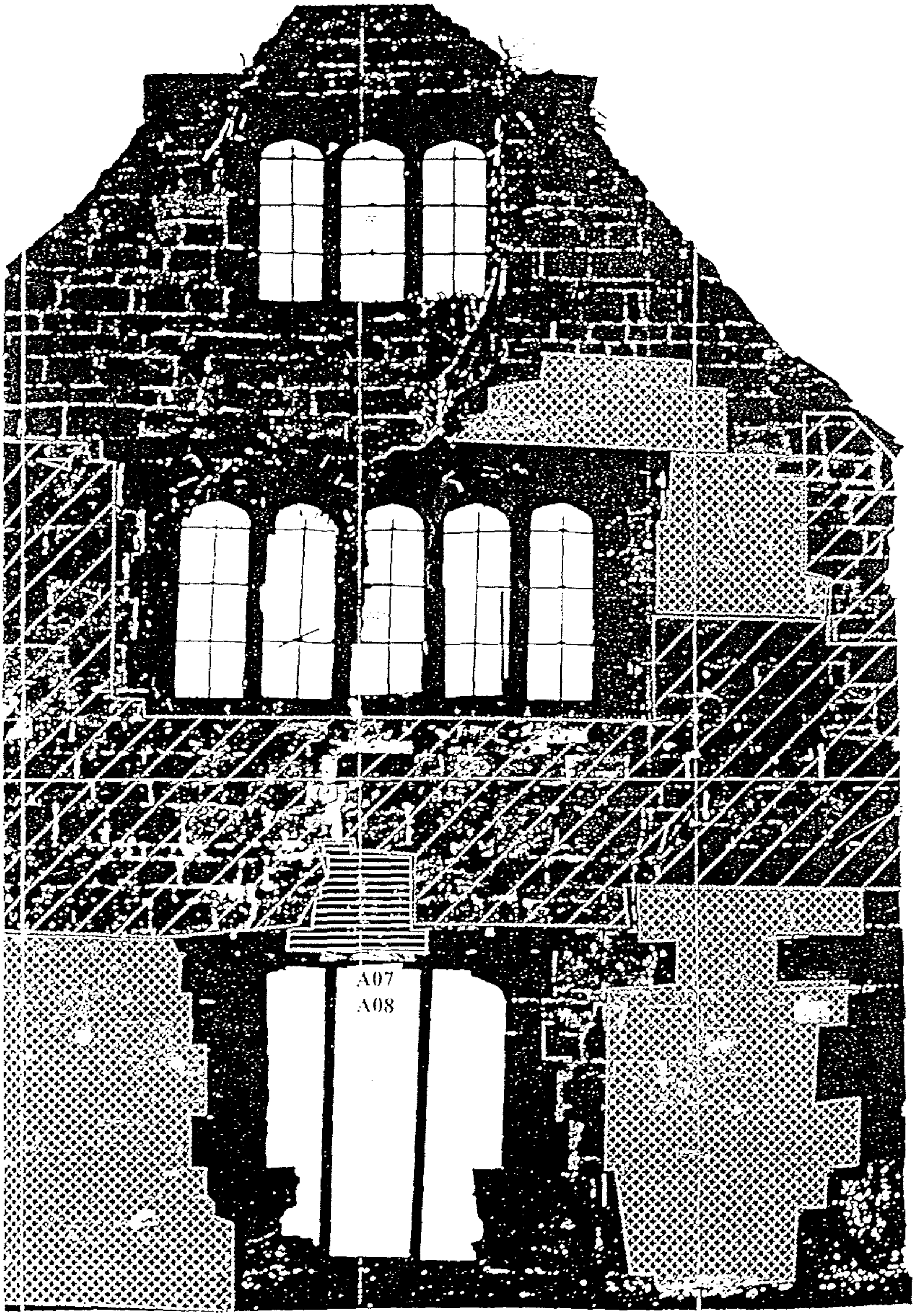


Figure 3c: Drawing to show positions of samples FAW-A10, A11 and A12 from window 13 in the south wall

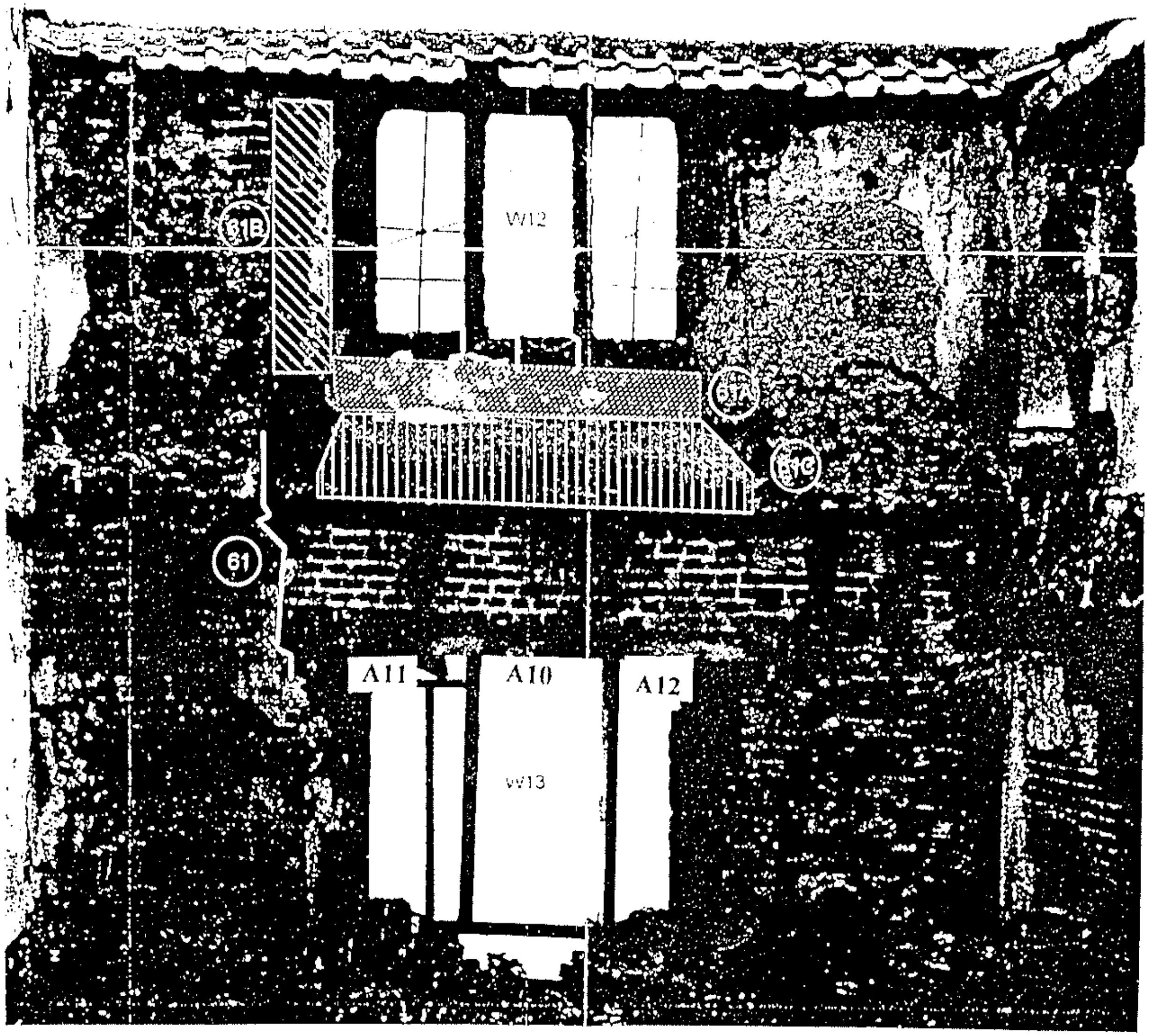


Figure 3d: Drawing to show positions of samples FAW-A09, A13, A14, and A15 from the doorway between north-south party wall

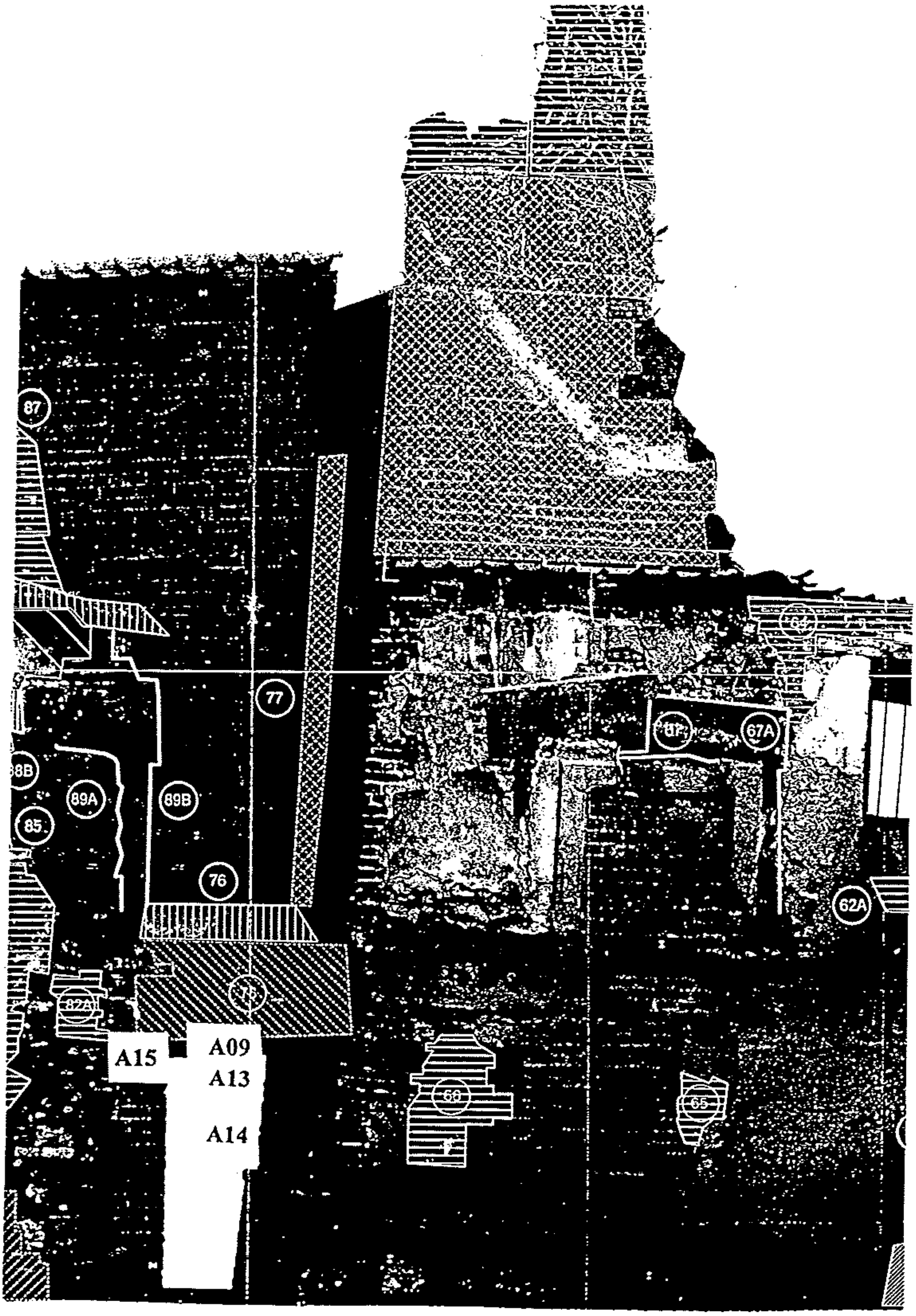


Figure 3e: Drawing to show positions of samples FAW-A16, A17, A18, A19, A20, and A21 from windows 16, 17, and 18 in the south wall

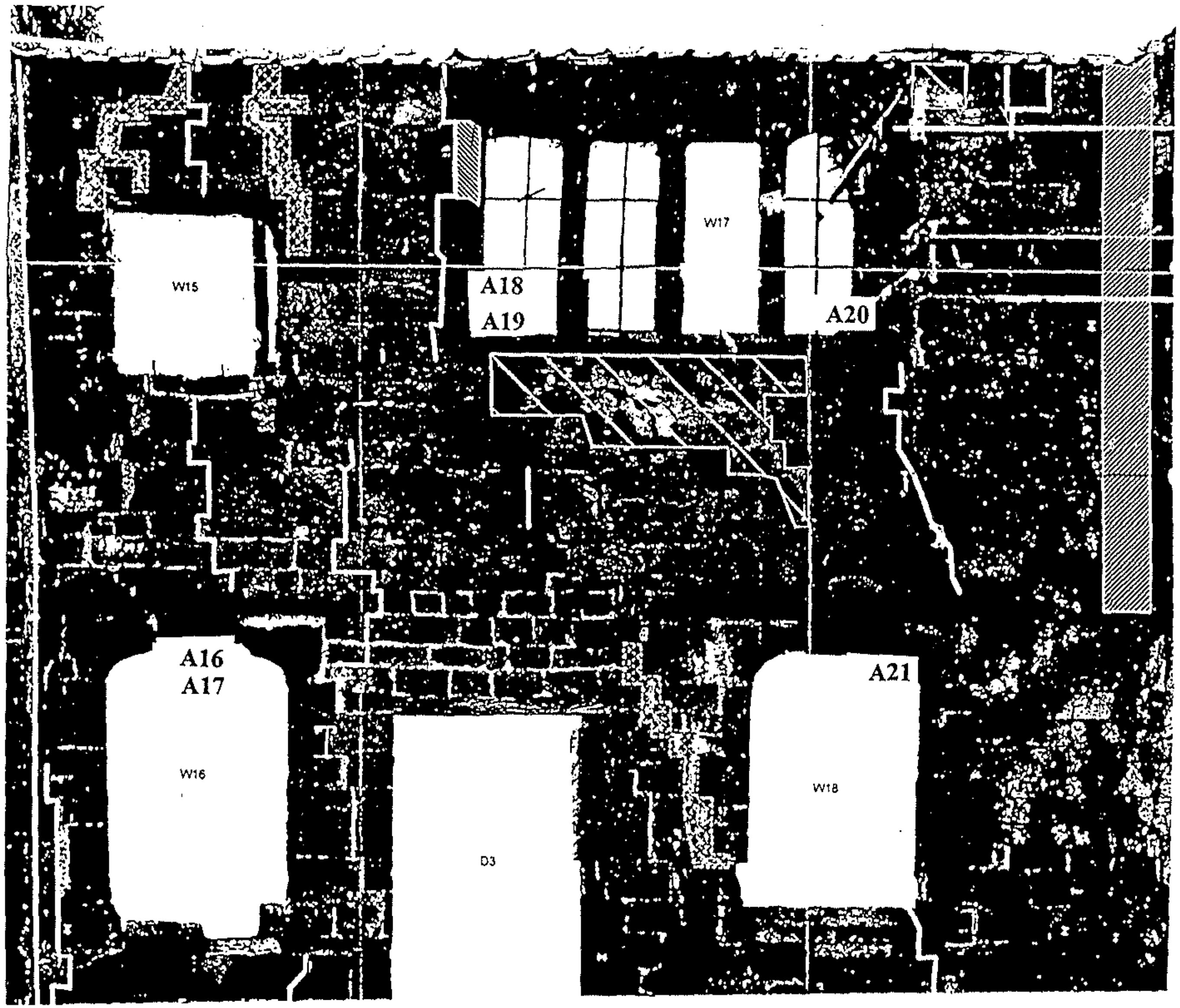


Figure 3f: Drawing to show positions of samples FAW-A22, A23, and A24 from window 10 in the west wall

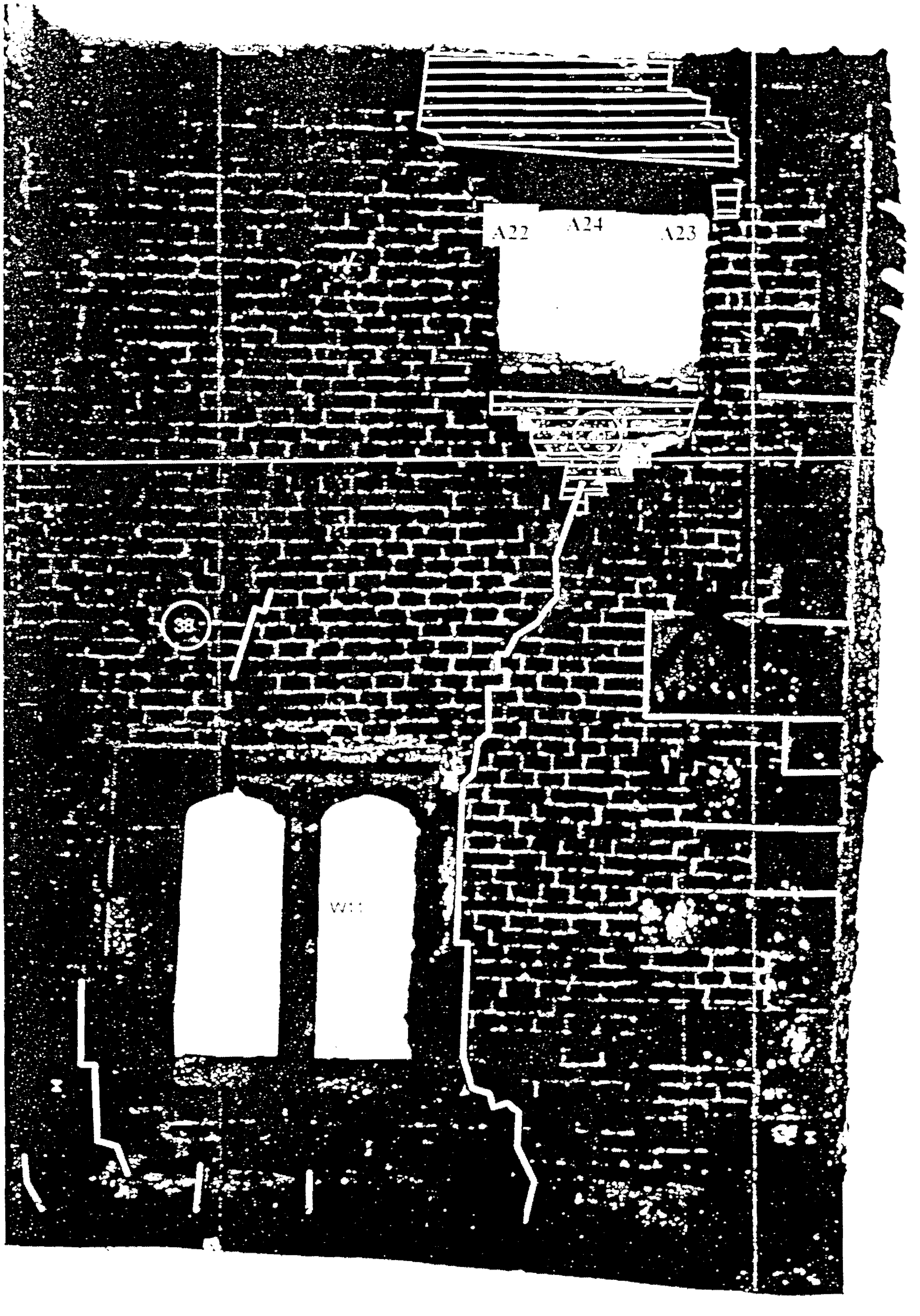


Figure 3g: Photograph to show position of samples FAW-A25, A26, A27, A28, and A29 from timbers in the north wall

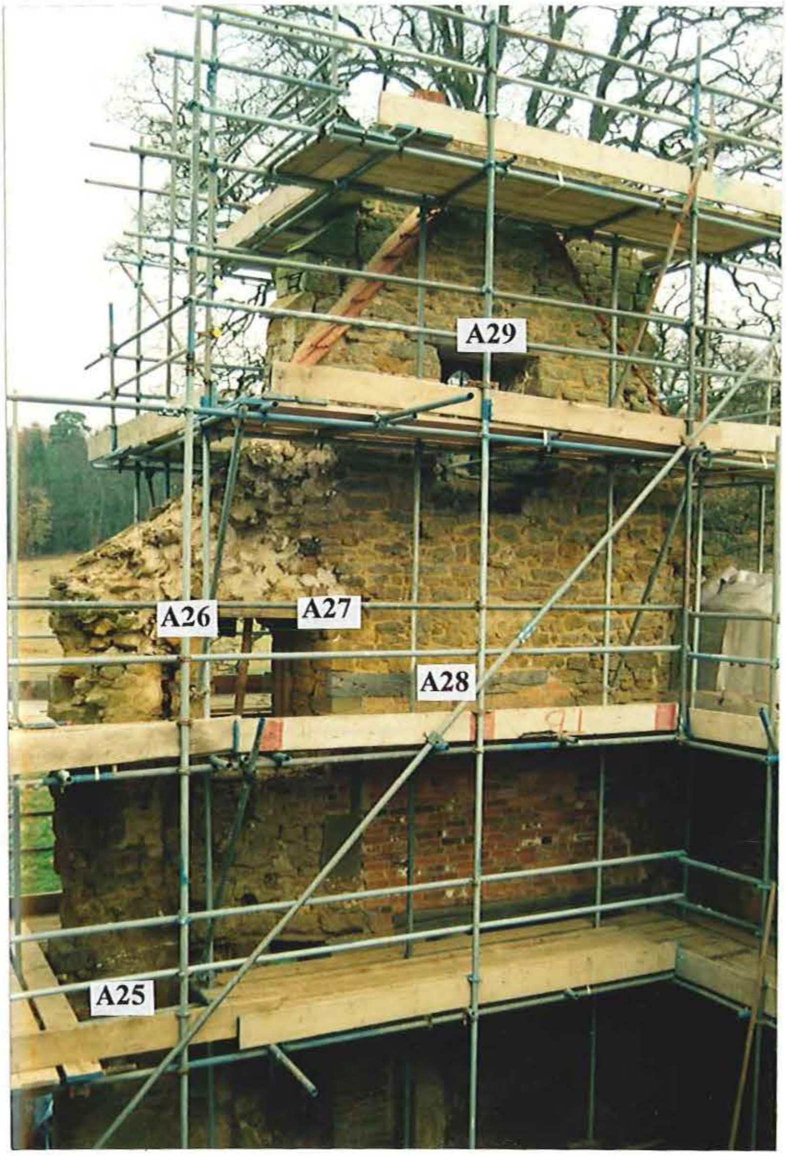
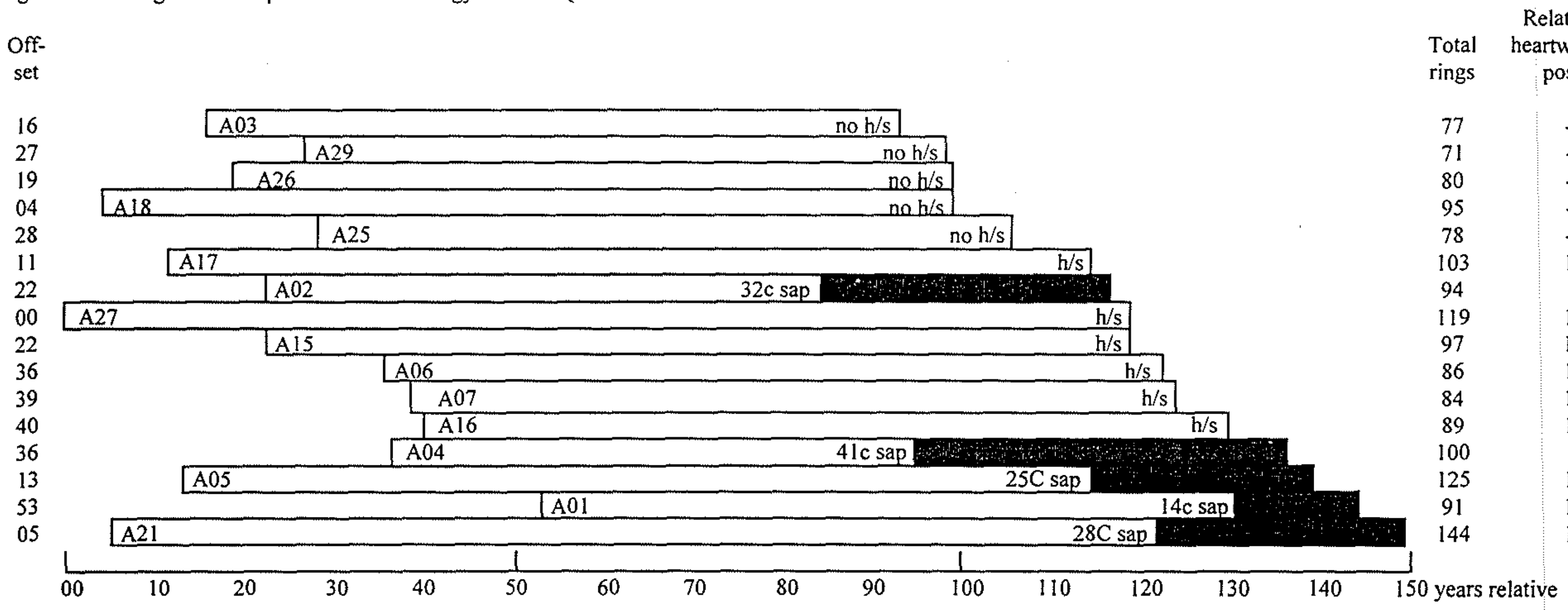
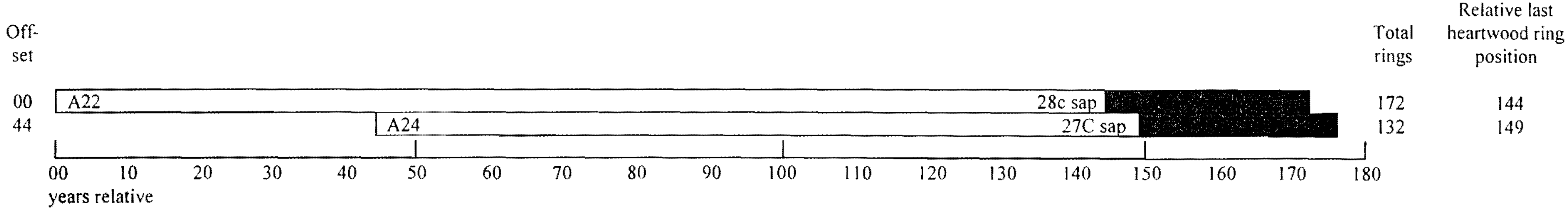


Figure 4: Bar diagram of samples in site chronology FAWASQ01



White bar = heartwood rings, shaded area = sapwood rings
h/s = the heartwood/sapwood boundary is the last ring on the sample
c = complete sapwood on timber; all or part lost from sample in coring
C = complete sapwood retained on sample; last ring date is felling date of timber

Figure 5: Bar diagram of samples in site chronology FAWASQ02



White bar = heartwood rings, shaded area = sapwood rings
c = complete sapwood on timber; all or part lost from sample in coring
C = complete sapwood retained on sample; last ring date is felling date of timber

Table 1: Details of tree-ring samples from the Dower House, Fawsley Park, Fawsley, nr Daventry

Sample no.	Sample location	Total rings	Sapwood rings*	First measured ring date	Last heartwood ring date	Last measured ring date
FAW-A01	Inner lintel, north window, east wall	91	14c	AD 1480	1556	1570
FAW-A02	Outer lintel, north window, east wall	94	32c	AD 1449	1510	1542
FAW-A03	Inner lintel, centre window, east wall	77	no h/s	AD 1443	------	1519
FAW-A04	Outer lintel, centre window, east wall	100	41c	AD 1463	1521	1562
FAW-A05	Inner lintel, south window, east wall	125	25C	AD 1441	1540	1565
FAW-A06	Outer lintel, south window, east wall	86	h/s	AD 1463	1548	1548
FAW-A07	Inner lintel, window 22, south wall	84	h/s	AD 1466	1549	1549
FAW-A08	Outer lintel, window 22, south wall	56	h/s	AD 1509	1564	1564
FAW-A09	East lintel of north-south party wall doorway	94	no h/s	AD 1362	------	1455
FAW-A10	Inner lintel, window 13, south wall	61	no h/s	------	------	------
FAW-A11	East bracket to window 13, south wall	95	h/s	------	------	------
FAW-A12	West bracket to window 13, south wall	90	h/s	AD 1410	1499	1499
FAW-A13	Middle lintel of north-south party wall doorway	54	no h/s	------	------	------
FAW-A14	West lintel of north-south party wall doorway	54	no h/s	------	------	------
FAW-A15	Stub block in north-south party wall	97	h/s	AD 1449	1545	1545
FAW-A16	Outer lintel, window 16, south wall	89	h/s	AD 1467	1555	1555
FAW-A17	Inner lintel, window 16, south wall	103	h/s	AD 1438	1540	1540
FAW-A18	Inner pad-block to west side window 17, south wall	95	no h/s	AD 1431	------	1525
FAW-A19	Outer pad-block to west side, window 17, south wall	55	no h/s	------	------	------

Table 1: continued

Sample no.	Sample location	Total rings	Sapwood rings*	First measured ring date	Last heartwood ring date	Last measured ring date
FAW-A20	Outer pad-block to east side, window 17, south wall	62	no h/s	------	------	------
FAW-A21	Lacing beam/lintel, window 18, south wall	144	28C	AD 1432	1547	1575
FAW-A22	Inner lintel, window 10, west wall	172	28c	AD 1720	1863	1891
FAW-A23	Outer lintel, window 10, west wall	54	no h/s	------	------	------
FAW-A24	Middle lintel, window 10, west wall	132	27C	AD 1764	1868	1895
FAW-A25	Inner lintel, ground-floor window, north wall	78	no h/s	AD 1455	------	1532
FAW-A26	Inner lintel, first-floor window, north wall	80	no h/s	AD 1446	------	1525
FAW-A27	Outer lintel, first-floor window, north wall	119	h/s	AD 1427	1545	1545
FAW-A28	Lacing beam, north wall	71	h/s	------	------	------
FAW-A29	Inner lintel, second-floor window, north wall	71	no h/s	AD 1454	------	1524

*h/s = the heartwood/sapwood boundary is the last ring on sample
c = complete sapwood on timber; all or part lost from sample in coring
C = complete sapwood retained on sample; last ring date is felling date of timber

Table 2: Results of the cross-matching of site chronologies and individual samples against relevant reference chronologies

Reference chronology	Span of chronology	t-value	
Site chronology FAWASQ01 when first ring date is AD 1427 and last ring date is AD 1575			
East Midlands	AD 882 - 1981	8.7	(Laxton and Litton 1988)
MGB-E01	AD 401 - 1981	8.7	(Baillie and Pilcher 1982 unpubl)
Wales and West Midlands	AD 1341 - 1636	8.8	(Siebenlist-Kerner 1978)
MC10---H	AD 1386 - 1585	6.7	(Fletcher 1978)
26 Westgate Street, Gloucester	AD 1399 - 1622	6.7	(Howard *et al* forthcoming)
Manor House, Donington-le-Heath, Leics	AD 1411 - 1618	5.1	(Esling *et al* 1989)
Coats Barn, Cosby, Leics	AD 1426 - 1562	6.6	(Alcock *et al* 1991)
26 Manor Rd, Didcot, Oxon	AD 1415 - 1509	6.2	(Alcock *et al* 1989)
Site chronology FAWASQ02 when first ring date is AD 1720 and last ring date is AD 1895			
East Midlands	AD 882 - 1981	6.6	(Laxton and Litton 1988)
MGB-E01	AD 401 - 1981	6.7	(Baillie and Pilcher 1982 unpubl)
Sherwood Trees, Notts	AD 1426 - 1981	5.1	(Laxton and Litton 1988)
Bradgate Trees, Leics	AD 1595 - 1975	7.4	(Laxton and Litton 1988)
Hagworthingham Church, Lincs	AD 1797 - 1881	5.3	(Laxton and Litton 1988)
Sample FAW-A08 when first ring date is AD 1509 and last ring date is AD 1564			
East Midlands	AD 882 - 1981	3.9	(Laxton and Litton 1988)
MGB-E01	AD 401 - 1981	4.5	(Baillie and Pilcher 1982 unpubl)
Wales and West Midlands	AD 1341 - 1636	4.8	(Siebenlist-Kerner 1978)
MC10---H	AD 1386 - 1585	4.5	(Fletcher 1978)
Coats Barn, Cosby, Leics	AD 1426 - 1562	4.5	(Alcock *et al* 1991)
Astley Castle, Warwicks	AD 1495 - 1627	3.8	(Howard *et al* 1997)
26 Westgate Street, Gloucester	AD 1399 - 1622	4.1	(Howard *et al* forthcoming)
Lodge Park, Aldsworth, Glos	AD 1324 - 1587	3.8	(Howard *et al* 1995)
Sinai Park, Burton on Trent, Staffs	AD 1227 - 1750	3.9	(Tyers *et al* 1997)
Staunton Harold Church, Leics	AD 1508 -1661	3.6	(Howard *et al* 1996)

Table 2: continued

Reference chronology	Span of chronology	t-value	
Sample FAW-A09 when first ring date is AD 1362 and last ring date is AD 1455			
East Midlands	AD 882 - 1981	4.9	(Laxton and Litton 1988)
LOND1175	AD 413 - 1728	3.9	(Tyers 1997)
Breamhill Farm, Calne, Wilts	AD 1353 - 1484	5.2	(Alcock *et al* 1991)
Mercers Hall, Gloucester	AD 1289 - 1541	4.8	(Howard *et al* 1997)
244 Forest Rd, Woodhouse Eaves, Leics	AD 1374 - 1455	5.4	(Alcock *et al* 1990)
Lodge Park, Aldsworth, Glos	AD 1324 - 1587	4.9	(Howard *et al* 1995)
Tusmore Park, Oxon	AD 1359 - 1545	4.1	(Howard *et al* 1992)
Cuttlepool Farm, Solihull, Warwicks	AD 1337 - 1478	4.7	(Howard *et al* 1993)
Sample FAW-A12 when first ring date is AD 1410 and last ring date is AD 1499			
East Midlands	AD 882 - 1981	6.8	(Laxton and Litton 1988)
MGB-E01	AD 401 - 1981	6.4	(Baillie and Pilcher 1982 unpubl)
Wales and West Midlands	AD 1341 - 1636	5.4	(Siebenlist-Kerner 1978)
MC10---H	AD 1386 - 1585	5.5	(Fletcher 1978)
26 Westgate Street, Gloucester	AD 1399 - 1622	4.6	(Howard *et al* forthcoming)
Mercers Hall, Gloucester	AD 1289 - 1541	6.4	(Howard *et al* 1997)
Lodge Park, Aldsworth,, Glos	AD 1324 - 1587	6.7	(Howard *et al* 1995)
Cuttlepool Farm, Solihull, Warwicks	AD 1337 - 1478	5.9	(Howard *et al* 1993)
Sinai Park, Burton on Trent, Staffs	AD 1227 - 1750	5.3	(Tyers *et al* 1997)

Data of measured samples - measurements in 0.01mm units

FAW-A01A 75
143 175 101 135 168 221 284 355 129 90 108 73 65 37 67 118 176 145 134 150
231 184 160 129 112 103 150 92 146 149 140 213 181 171 166 100 91 100 140 129
126 52 34 44 44 61 81 74 64 69 48 82 38 54 44 66 65 71 49 61
73 109 84 89 86 84 91 84 101 84 63 81 58 81 91
FAW-A01B 71
213 182 164 130 111 104 132 92 149 156 136 199 167 183 157 114 94 102 134 134
128 49 40 37 44 50 82 67 72 66 44 86 50 47 50 65 62 62 58 65
70 103 81 94 86 80 99 85 107 81 56 69 62 80 86 96 102 56 83 101
95 121 115 133 111 104 79 101 149 118 132
FAW-A02A 62
153 150 128 120 81 114 154 176 166 137 109 139 173 129 137 107 100 112 99 139
101 133 88 68 69 81 171 135 112 116 63 113 166 116 126 121 99 139 165 150
110 104 73 63 59 65 99 99 57 61 69 73 60 41 47 64 59 88 60 69
79 99
FAW-A02B 80
189 112 122 129 133 167 183 190 120 102 90 92 131 102 83 89 86 90 131 71
62 51 57 63 67 63 72 86 67 66 59 58 71 84 49 51 54 71 46 39
40 53 47 82 65 52 60 65 84 84 72 53 55 59 47 50 73 50 47 52
36 33 40 39 51 40 34 25 39 25 30 27 29 43 34 23 30 39 31 37
FAW-A03A 59
278 288 177 152 121 165 170 155 162 120 107 137 136 159 138 112 126 182 159 165
190 126 131 194 174 204 216 218 180 118 115 146 216 156 122 116 113 140 138 132
137 111 140 166 232 186 193 184 100 113 67 79 99 171 156 122 182 171 157
FAW-A03B 67
109 119 135 166 131 113 134 199 163 162 182 118 135 192 168 207 230 222 197 131
105 156 214 139 141 100 132 127 151 119 130 127 142 153 226 176 181 174 107 92
82 71 105 179 149 105 150 164 154 147 95 86 90 85 90 80 105 100 103 113
145 159 114 138 82 125 135
FAW-A04A 90
141 114 149 95 62 83 73 78 133 83 100 96 113 137 192 160 178 141 94 95
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73 69 65 106 52 81 91 111 47 98 42 53 59 62 64 46 41 36 36 24
24 32 43 33 39 28 26 31 28 32 37 35 30 25 23 28 19 36 26 23
29 23 26 21 20 27 28 21 16 20
FAW-A04B 74
126 81 86 81 81 103 194 187 129 76 46 65 132 90 61 99 89 92 133 99
125 128 133 159 217 171 189 135 95 84 92 113 150 183 114 82 86 108 104 94
91 83 98 124 59 118 99 83 104 121 73 63 73 92 59 83 91 91 55 107
50 55 56 74 72 62 58 39 35 41 46 28 39 56
FAW-A05A 125
133 207 185 146 85 90 129 180 177 125 140 188 88 114 100 79 64 89 110 86
47 29 51 39 85 140 114 63 86 166 207 140 128 185 196 176 99 93 106 109
128 43 44 44 55 81 88 68 64 64 59 53 48 66 78 89 75 82 61 78
108 73 54 66 54 64 53 81 82 74 91 89 76 91 61 48 58 46 94 86
114 109 62 105 74 90 84 99 87 46 90 55 56 67 84 91 74 58 87 104
83 44 42 53 59 78 59 60 35 52 60 52 63 42 41 35 34 35 41 39
30 36 37 28 55
FAW-A05B 125
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53 23 46 33 79 141 109 43 94 159 226 143 127 168 201 189 103 96 99 110
123 37 54 41 59 75 93 66 77 64 57 53 44 68 84 92 80 67 51 72
97 62 70 74 48 62 58 83 76 71 89 89 80 87 66 76 55 51 84 82
127 105 57 106 75 84 84 95 89 48 94 58 50 65 76 92 76 58 79 103
71 43 49 51 63 81 51 65 35 54 62 55 54 50 37 31 33 30 35 28
34 45 32 34 47

FAW-A06A 86
159 97 209 245 161 68 86 179 222 215 215 264 230 237 183 186 191 243 201 91
65 88 130 148 224 207 209 172 169 171 183 214 235 155 139 118 108 123 137 114
124 102 78 84 81 105 124 114 133 147 156 114 94 171 100 104 104 133 174 159
111 130 135 139 123 150 132 83 134 75 58 71 74 104 103 57 75 78 66 33
49 72 86 92 75 83
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75 87 128 154 216 203 225 157 170 172 166 233 239 172 133 117 105 123 123 134
123 100 74 86 77 100 131 117 132 148 173 117 92 155 107 108 98 142 182 143
111 128 122 141 136 147 129 89 136 72 67 74 68 95 107 52 68 83 68 40
58 74 79 98 78 83
FAW-A07A 66
164 63 110 155 138 116 90 131 96 122 138 120 80 104 125 147 74 112 124 130
127 223 144 120 154 115 104 69 111 142 211 138 101 123 106 108 88 110 105 86
96 72 94 113 73 125 83 99 87 75 112 92 89 161 103 132 195 55 99 86
110 111 81 72 52 114
FAW-A07B 72
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86 156 103 145 192 59 101 84 107 113 69 75 50 116 59 59 83 97 82 139
88 113 97 91 36 51 52 57 78 51 65 73
FAW-A08A 54
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223 124 258 165 189 171 282 208 216 214 195 195 245 171 196 182 169 173 139 166
163 173 200 147 192 149 207 214 152 200 221 149 196 299
FAW-A08B 46
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203 204 229 142 195 173 180 161 149 176 179 162 208 150 213 142 199 196 157 205
198 149 173 233 255 165
FAW-A09A 81
221 299 260 153 230 276 201 275 203 206 138 144 155 113 182 215 244 170 132 183
164 142 157 159 193 178 142 130 125 108 75 117 70 62 100 131 126 124 133 122
96 109 110 103 100 76 86 128 80 84 65 76 77 137 66 87 86 102 100 118
93 109 112 68 41 52 43 73 35 49 46 41 53 77 63 51 47 51 60 78
51
FAW-A09B 77
179 126 183 177 153 145 175 183 183 150 114 128 114 80 99 73 75 102 131 120
135 128 121 85 110 112 101 99 76 85 123 86 83 59 75 85 135 84 86 70
93 108 129 83 109 110 76 40 56 48 59 44 41 50 37 55 78 58 53 48
45 67 79 62 71 81 55 39 58 45 55 47 51 48 54 59 63
FAW-A10A 61
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190 249 250 379 277 95 56 74 125 114 121 130 132 102 96 118 154 177 218 200
230 147 309 83 52 50 74 73 109 121 121 129 180 211 199 221 213 236 210 218
219
FAW-A10B 61
139 195 252 295 292 304 268 215 110 59 51 98 102 122 174 190 237 181 196 198
201 257 247 370 269 109 47 82 120 111 132 128 144 95 96 127 153 172 204 209
234 141 297 96 53 50 68 66 121 109 122 127 183 201 206 222 202 235 223 200
226
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89 68 62 76 138 65 67 50 59 42 57
FAW-A11B 77
106 106 145 144 136 165 165 149 241 209 216 169 149 135 152 222 197 155 172 173
173 293 239 228 268 205 201 150 173 219 268 162 143 142 131 138 125 128 127 87
119 77 91 69 64 76 136 66 66 46 62 44 40 73 67 52 61 39 61 55
57 48 54 44 34 31 31 35 35 24 19 39 28 33 30 40 47

FAW-A12A 90
208 230 198 180 193 190 165 161 132 146 218 207 235 369 321 376 259 202 258 267
163 161 252 183 151 164 143 148 141 100 135 154 143 190 222 152 137 129 105 138
102 134 128 115 126 117 141 138 135 99 139 112 105 105 83 108 71 79 75 94
73 82 71 99 84 158 112 94 89 117 136 211 147 156 128 68 64 82 92 85
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FAW-A12B 90
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77 84 77 82 99 149 114 96 85 122 149 194 137 159 125 72 67 84 86 83
131 106 108 129 130 173 212 163 170 208
FAW-A13A 54
327 357 351 281 386 434 211 340 347 300 427 312 255 198 194 178 124 234 221 222
206 166 173 150 178 158 163 205 197 201 161 158 128 95 172 116 94 117 151 134
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FAW-A13B 54
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219 189 177 157 168 161 159 199 193 144 210 173 139 100 171 100 110 115 152 141
138 97 114 121 102 152 180 143 126 120 166 149 154 183
FAW-A14A 54
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FAW-A14B 54
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111 94 144 97 104 102 105 138 132 98 78 80 92 122
FAW-A15A 97
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77 63 82 87 118 126 72 122 85 85 111 103 156 143 106 135 106 104 101 112
99 65 86 68 56 55 56 79 78 81 90 118 74 40 63 64 89
FAW-A15B 97
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86 63 70 94 110 125 68 128 82 82 111 113 151 140 112 128 112 103 104 109
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FAW-A16A 89
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180 210 174 131 138 114 72 101 128 141 143 135 134 158 196 108 137 119 151 186
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37 34 62 102 27 49 45 57 66 104 90 102 87 41 53 61 74 85 176 153
92 96 110 97 79 67 129 77 106 108 133 168 109 127 153 116 112 48 122 104
154 119 120 125 118 62 213 131 136 111 93 60 33 57 37 33 34 31 75 62
33 48 61

FAW-A17B 103
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93 91 114 94 80 71 125 80 107 107 136 170 105 119 157 118 113 53 116 111
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36 41 58
FAW-A18A 95
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395 404 242 176 224 251 160 137 143 201 212 125 131 99 120 170 149 174 250 215
142 56 54 86 127 120 52 99 65 124 159 104 83 100 81 113 223 153 106 92
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48 67 70 64 44 38 29 56 87 65 76 93 33 54 64
FAW-A18B 95
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386 381 221 180 222 263 168 119 141 205 206 127 142 105 112 164 133 168 251 205
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FAW-A19B 55
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105 137 109 137 153 126 103 66 76 82 94 105 156 134 135
FAW-A20A 61
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101 127 144 191 153 137 201 191 104 162 143 170 136 75 85 79 173 105 101 108
271
FAW-A20B 62
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242 215 147 125 65 63 73 67 88 92 86 58 62 208 230 226 172 194 193 144
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123 200
FAW-A21A 144
376 277 168 256 201 211 156 106 171 235 202 209 212 128 133 108 102 125 56 66
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46 59 45 55 87 62 52 68 50 42 56 39 31 43 41 33 24 54 44 37
56 54 57 55 75 60 67 78 70 85 78 60 87 70 77 81 65 60 54 57
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42 53 33 50
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44 45 33 56
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105 89 72 114 96 110 105 84 107 84 100 91 102 131 114 122 130 146 133 122
106 98 125 117 83 60 73 88 98 114 107 78 110 73 96 95 75 93 83 94
83 80 67 80 78 86 80 81 80 75 66 86 80 78 64 57 65 68 69 61

66 60 50 72 63 50 55 70 69 76 69 60 58 82 78 74 67 63 65 65
47 59 69 67 50 56 71 82 77 61 70 59 48 77 78 64 69 62 47 72
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FAW-A22B 172
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125 104 58 108 104 105 119 56 88 74 69 84 87 81 77 70 56 79 91 98
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83 78 71 75 81 86 77 89 79 69 66 83 86 74 70 56 58 72 71 64
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FAW-A24B 132
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FAW-A25A 78
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152 154 102 106 83 154 158 130 132 149 170 260 224 159 163 196 135 157 116 134
189 200 145 137 139 142 139 117 107 111 86 120 109 130 153 96 144 150 140 135
90 132 93 78 90 85 122 112 99 108 76 110 106 122 101 68 101 106
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FAW-A26A 80
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37 42 48 38 71 46 50 43 48 58 67 46 127
FAW-A27B 119
270 296 424 569 390 266 158 121 223 251 234 158 197 211 247 192 167 200 141 113
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56 44 71 95 92 51 60 91 112 133 70 67 67 114 130 106 76 94 130 154
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FAW-A28A 71
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182 94 152 115 161 199 187 143 218 180 264
FAW-A28B 71
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FAW-A29A 71
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181 177 307 217 145 158 131 130 86 85 146 94 84 92 141 169 102 109 151 117
129 69 117 121 137 125 104 120 131 79 155
FAW-A29B 71
152 180 259 189 154 157 171 217 139 117 126 114 92 113 125 151 250 185 153 120
185 225 166 67 86 95 119 179 62 115 104 117 116 149 164 193 216 112 140 121
170 179 288 219 158 156 127 130 92 74 151 94 68 101 141 169 100 122 151 113
124 75 120 120 136 125 100 121 127 67 164

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.

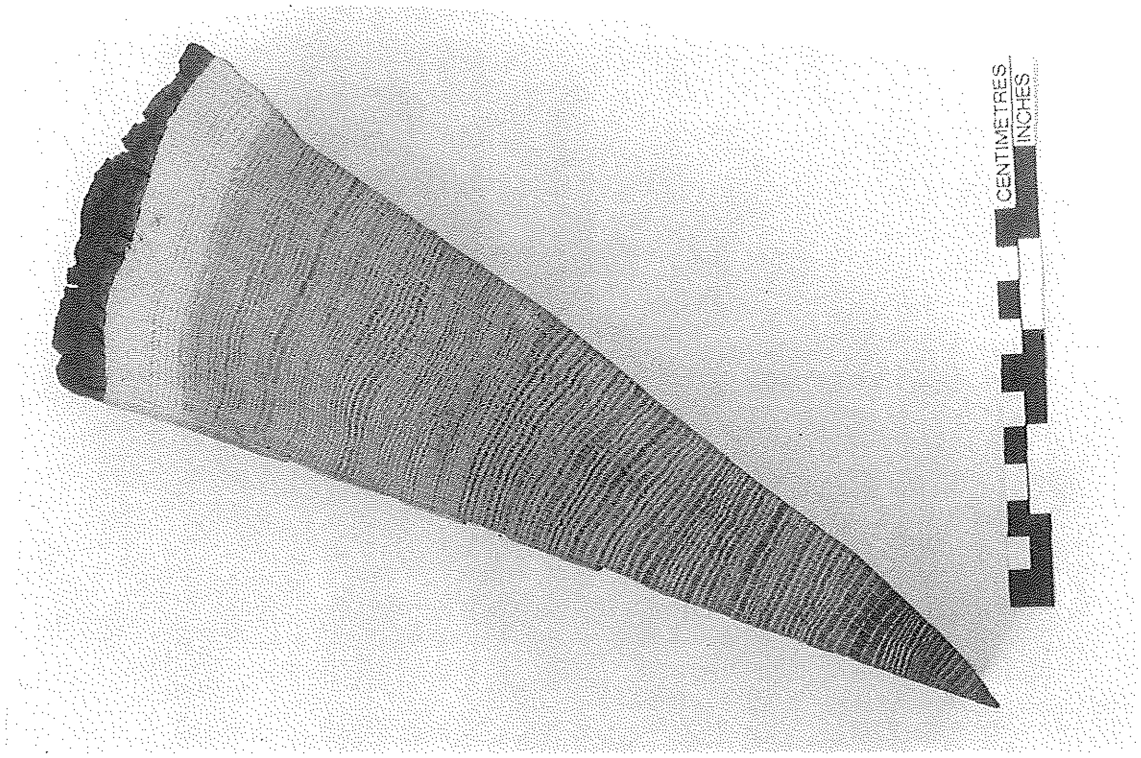

Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

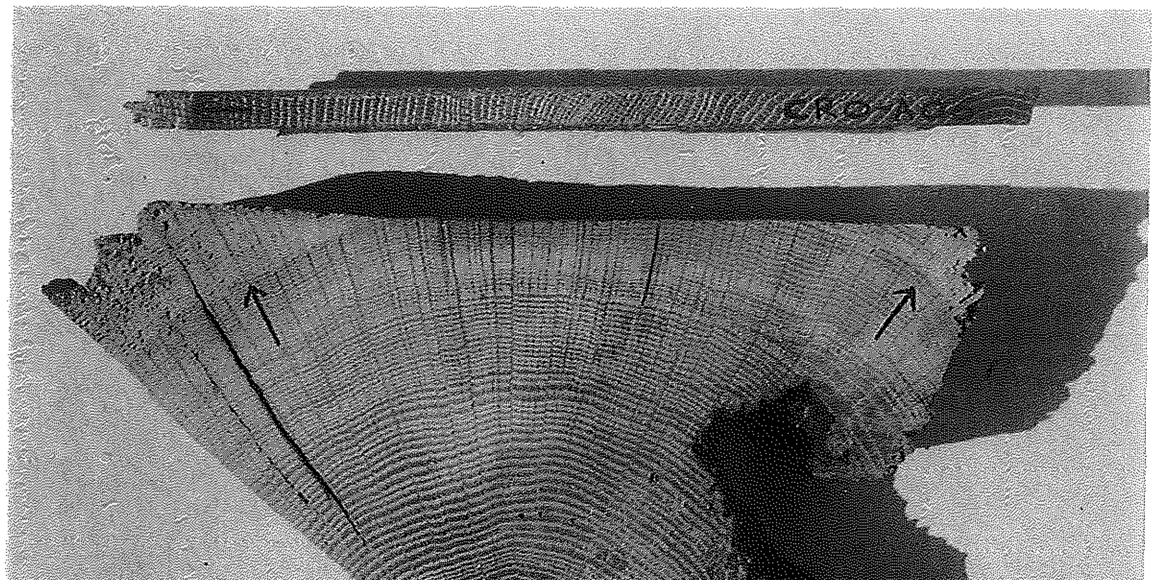

Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners; the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

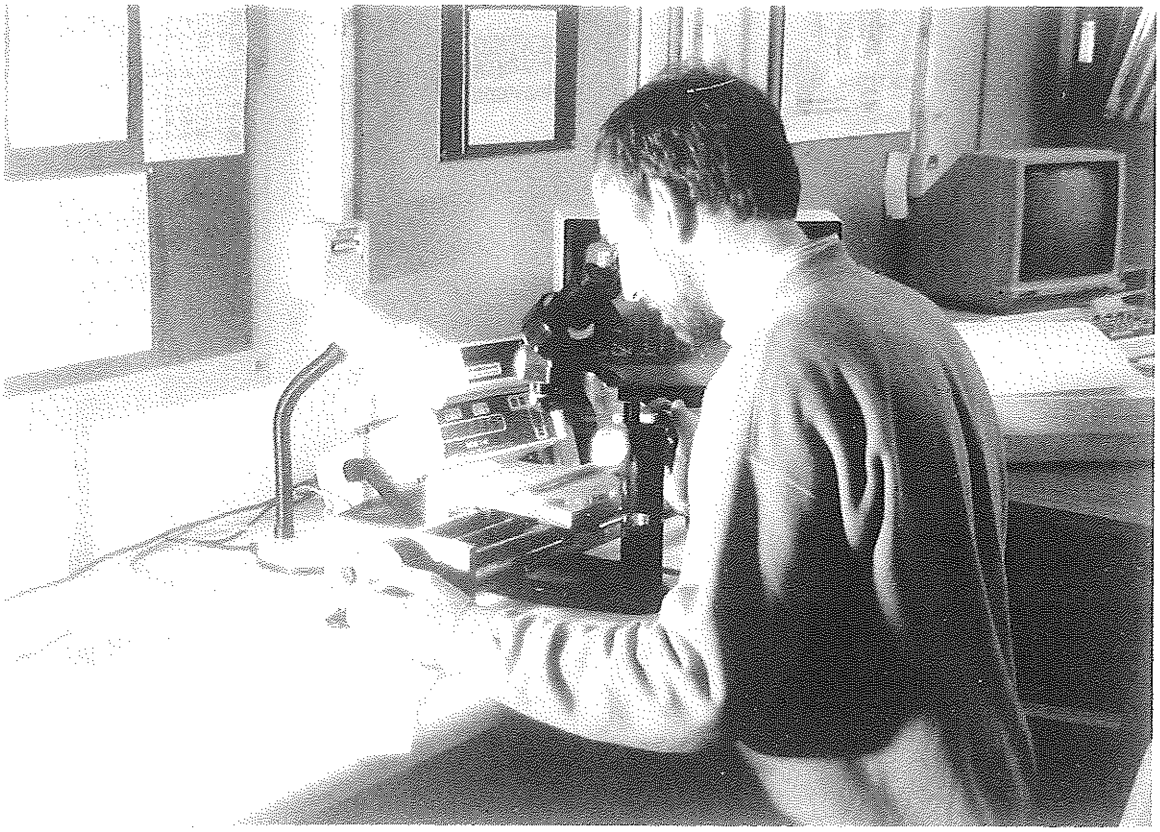

Fig 3. Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measured twice to ensure that an error has not been made. This type of apparatus is needed to process a large number of samples on a regular basis.

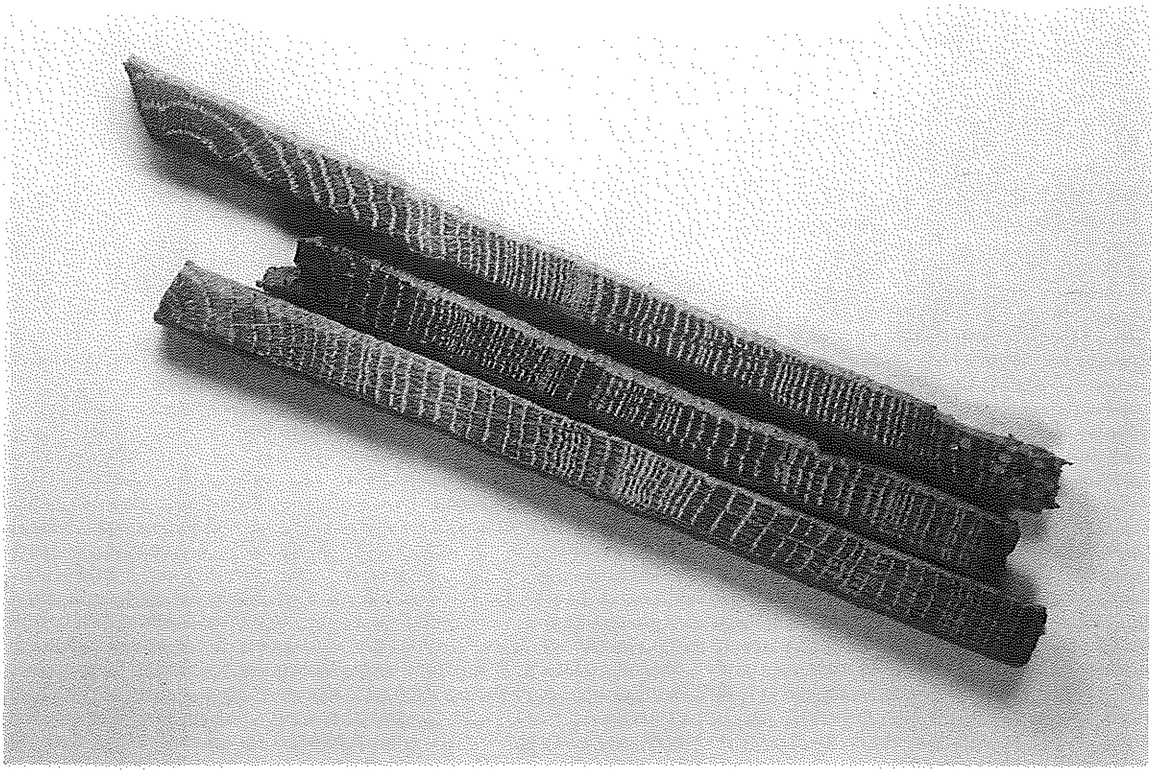

Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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

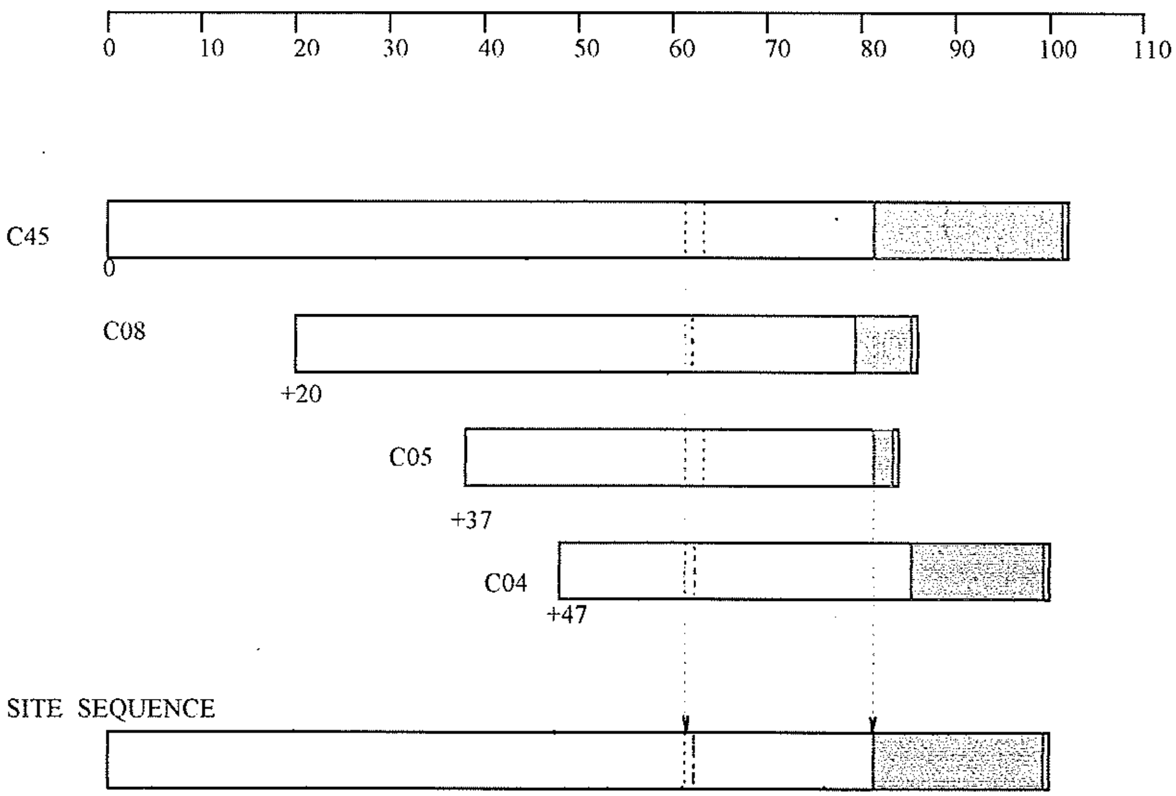

Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.
The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set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

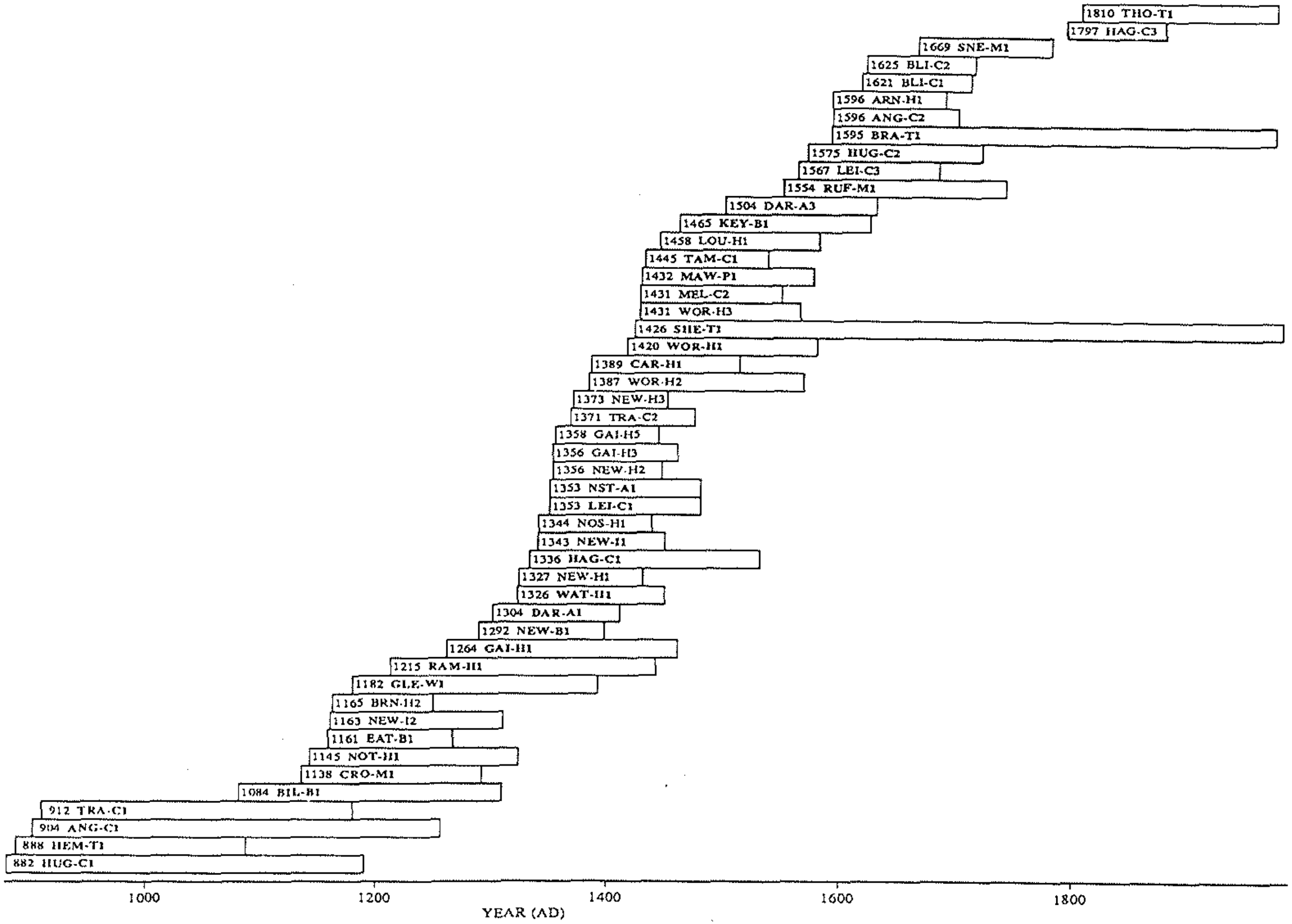

Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

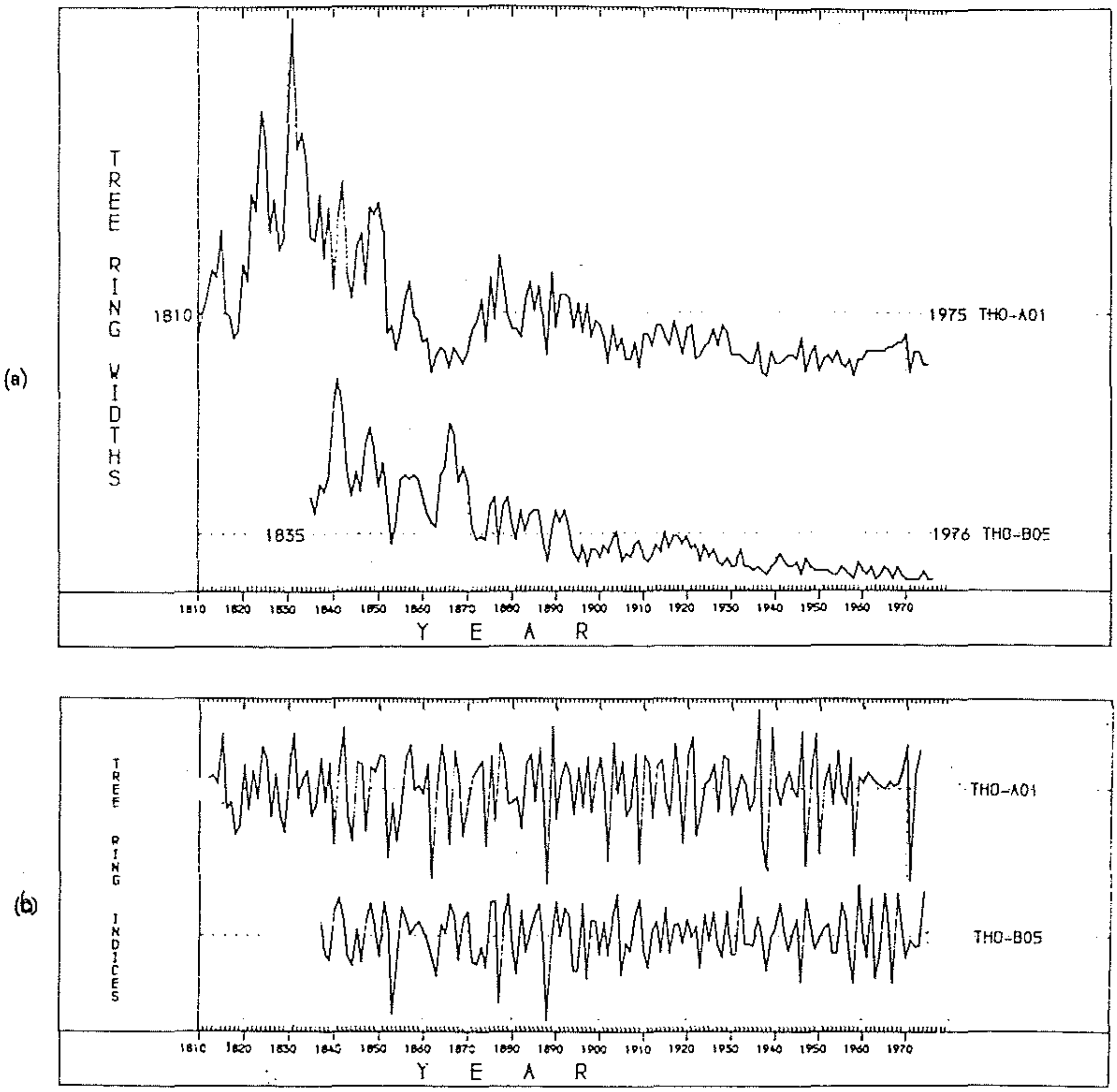

Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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