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ABBEY GATEHOUSE AND NUMBER 1 THE SQUARE, BLANCHLAND, NORTHUMBERLAND
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold, Robert Howard and Matt Hurford

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SUMMARY

Dendrochronological analysis of 29 samples obtained from a range of locations at the Abbey gatehouse and No 1 The Square, Blanchland, has produced a single dated site chronology, comprising 28 samples and having an overall length of 207 rings. These rings can be dated as spanning the years AD 1326–1532.

Interpretation of the sapwood on the dated samples indicates the likelihood that all the timbers were cut as part of a single programme of felling in, or about, AD 1532. Such a date shows that while the lower levels of both the gatehouse and No 1 contain some medieval fabric, possibly of late-fifteenth century date, this may have been remodelled in AD 1532 when the upper floor of No 1 was probably added. Tree-ring analysis would also show that work was undertaken on the Abbey buildings shortly before the dissolution here in AD 1536. A single sample remains ungrouped and undated.

CONTRIBUTORS

Alison Arnold, Robert Howard, and Matt Hurford

ACKNOWLEDGEMENTS

The Laboratories would like to thank Mr and Mrs Lamb of the gatehouse and No 1 The Square for their enthusiasm for this programme of tree-ring analysis and their great cooperation during the disturbance caused by sampling. Their hospitality must also be gratefully acknowledged. The Laboratory would also like to thank Martin Roberts of English Heritage's Newcastle-upon-Tyne office for arranging and assisting with this programme of analysis as well as John Meadows and Isabelle Parsons, of English Heritage's Scientific Dating Section, for commissioning and coordinating the project. Finally, we would like to thank Peter Ryder, buildings archaeologist, for the extensive use of his notes in the introduction section below, and for the use of his plans and drawings in this report.

ARCHIVE LOCATION

Northumberland Historic Environment Record
Northumberland County Council Conservation Team
Environment Directorate
County Hall
Morpeth NE61 2EF

DATE OF INVESTIGATION

2008–9

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INTRODUCTION

Blanchland Abbey (NY 965 503, Figs 1 and 2) was founded as a Norbertine, or premonstratensian, priory in AD 1165 by Walter de Bolbec II, and was a daughter house of a similar abbey at Croxton, Leicestershire. The premonstratensians, or White Canons (from the colour of their habit),were originally founded by Saint Norbert at Premontre near Laon in AD 1120 and followed the strict rule of St Augustine, with supplementary statutes that made their life one of great austerity.

Although the abbey granges at Blanchland were pillaged during the Anglo-Scots wars, particularly during AD 1327, the abbey itself was apparently left unscathed. The abbey was dissolved in AD 1536, reformed in AD 1537, and dissolved again in AD 1539, at which time it was granted to the Bellow and Broxholm families. The estate was later acquired by the Radclyffe family, from whom it passed by marriage to Nicholas Forster. Part of the abbey church was altered and retained for use as a parish church, and the abbot's former residence became the manor house. In AD 1612 it was the residence of Sir Claudius Forster, High Sheriff of Northumberland. In AD 1704 Lord Crewe purchased the estate, and on his death in AD 1721 he left all his properties to be administered in trust for charitable purposes (Lord Crewe's Charity).

Of the abbey buildings, the later-fifteenth-century gatehouse with embattled parapets survives, along with the adjacent, interlinked, house at No 1 The Square, attached to its west side (see basic plan, Fig 3). The gatehouse is an impressive, stone-built, rectangular structure containing a double-height north-south gate passage with a similarly lofty parallel ground-floor chamber, now occupied by the local Post Office, to the west. What was once a single large chamber to the upper floor, possibly associated with some judicial function and reached via an external staircase to the east, has been subdivided into two smaller rooms. Both rooms at this level are currently used as an art gallery and exhibition space (although the western room was at one time the third bedroom of No 1 The Square). This western room is dominated by a large medieval fireplace in the north wall.

No 1 The Square, again with some later-fifteenth century architectural features, is set over three floors; ground, containing the living room and kitchen, first, containing bedroom 1, and second, once used as bedroom 2, but now containing the office and workshop of the art gallery. The roof of this room comprises four shallow-pitched, heavily cambered tiebeam trusses, the trusses carrying single purlins to each pitch. It is believed that the house formed part of the monastic outer court buildings, possibly acting as an almonry.

Although the lower floors of both the gatehouse and No 1 The Square contain similar features of medieval date, the top part of No 1 The Square is clearly later. It is not certain, however, that the lower portions of the gatehouse and No 1 are both of the same, later-fifteenth-century date. It has been suggested that the lower portions were extensively remodelled when the top floor of No 1 was added *c* AD 1500, or that the lower floors of both are of *c* AD 1500, with the top floor of No 1 being added only a few years later in a different fabric.

SAMPLING

Sampling and analysis by dendrochronology of the timbers at the gatehouse and No 1 The Square were requested by Martin Roberts, Historic Buildings Inspector at English Heritage's Newcastle-upon-Tyne office, the primary purpose of this programme being to inform statutory advice. It was hoped that analysis would establish with greater certainty the dates of various elements of the buildings and help determine the possible sequential phases of alteration and change.

Thus, from the timbers available a total of 29 samples was obtained by coring. Each sample was given the code BAG-B (for Blanchland, site 'B') and numbered 01–29. Twelve of these samples, BAG-B01–12, were taken from the roof (Fig 4) of bedroom 2 of No 1 The Square, the room now used as an office, with a further 11 samples, BAG-B13–23, being obtained from the ceiling of bedroom 1 (Fig 5), on the first floor. Four samples, BAG-B24–B27, were taken from the few available ceiling beams of the ground-floor living room (Fig 6), with the final two samples, BAG-B28 and B29, being taken from the two window lintels to the first floor of the west room of the gatehouse (Fig 7), formerly bedroom 3 but now the room used as part of the art gallery. No other suitable timbers were available in any other part of the building, as the accessible timbers were all modern replacements.

The location of samples was noted at the time of coring and marked on the drawings made by Peter Ryder and provided by English Heritage. These are reproduced here as Figures 8a–d. Further details relating to the samples can be found in Table 1, in which the timbers have been located and numbered following the scheme on the drawings provided.

ANALYSIS

Each of the 29 samples obtained was prepared by sanding and polishing and their annual growth-ring widths were measured, the data of these measurements being given at the end of this report. The data of these 29 samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), allowing a single group, comprising 28 samples, to be formed at a minimum value of t=4.4. The samples cross-match with each other as shown, sorted by sample location, in the bar diagram, Figure 9. The 28 cross-matching samples were combined at these indicated offsets to form site chronology BAGBSQ01, this having an overall length of 207 rings.

Site chronology BASGBSQ01 was then compared to an extensive corpus of reference chronologies for oak, matching repeatedly and consistently with a number of these when the date of its first ring is AD 1326 and the date of its last measured ring is AD 1532. The evidence for this dating is given in Table 2.

The single remaining ungrouped sample, BAG-B17, was also compared to the reference chronologies but there was no satisfactory cross-matching and this sample must, therefore, remain undated.

INTERPRETATION

Three of the dated samples, BAG-B14, B18, and B23, in site chronology BAGBSQ01 retain complete sapwood. This means that they each have the last growth ring that the trees they represent produced before they were cut down. In each case the last, complete, sapwood ring, and thus the felling of the trees, is the same at AD 1532.

Two other samples, BAG-B15 and B16, come from timbers which did in fact retain complete sapwood but from which, because of the soft and fragile nature of this part of the wood, small portions were lost during sampling. Observations and notes made at the time would suggest that the lost portions of the cores represent number of rings which, given the last extant sapwood ring date on each sample, would make it very likely that the trees these two samples represent were felled in AD 1532 as well.

Of the remaining samples, the similarity in position of the heartwood/sapwood boundary on those where it exists with the boundary on those with complete sapwood is consistent with the timbers they represent being felled at a similar, if not identical, date, AD 1532. As may be seen from Table 1 and the bar diagram, Figure 9, the heartwood/sapwood boundary on all the samples where it exists varies from relative position 167 (AD 1492) on sample BAG-B04, to relative position 180 (AD 1505) on sample BAG-B22, a variation of only 13 years. Such a small range is indicative of timbers cut as part of a single programme of felling.

Such an interpretation is supported by the fact that many of these samples, both those with, as well as those without, a heartwood/sapwood boundary, cross-match very well with each other, suggesting that the trees utilised grew close to each other in the same copse or stand of woodland. Such a phenomenon would be relatively unlikely were the timbers felled, and each element of the gatehouse constructed, at different times. If the trees had been felled at different times, it is probable that they would have come from different sources and would have thus cross-matched less well.

CONCLUSION

Thus, the evidence of tree-ring dating suggests that all the timbers sampled in this programme of analysis were cut as part of a single episode of felling which took place in, or about, AD 1532 when the top floor on No 1 The Square was probably added.

As intimated above, the level of cross-matching between many of the samples is noticeably high, with several values in excess of t=6.0 being seen, suggesting the source trees were growing in the same woodland. Indeed, given the levels of cross-matching between some samples, it is likely that some timbers were derived from the same tree.

Samples BAG-B03 and B06, for example, cross-match with a value of t=10.3, while samples BAG-B14 and B15 cross-match with a value of t=11.4. The highest cross-match is found between samples BAG-B02 and B05, which cross-match with a value of t=13.7.

Where this source woodland was cannot be identified precisely by dendrochronology (eg Bridge 2000). However, it would appear that the timbers analysed here are likely to have derived from a nearby woodland. As may be seen from Table 2, which lists a short selection of the reference chronologies used to date site sequence BAGBSQ01, the highest t-values, and thus the greatest degree of similarity obtained during the dating of the sequence, is mainly with reference chronologies from other sites in Northumberland and County Durham.

One sample, BAG-B17, remains ungrouped and undated. This sample shows no problems with its annual growth rings, such as distortion or compression, which would make cross-matching and dating difficult, nor is it, with 66 rings, too short for reliable analysis. Indeed, it appears to be a perfectly clear normal sample. It is a common feature or tree-ring analysis, however, for one or more samples not to combine with the main group or to date individually. Sample BAG-B17 is one such example.

BIBLIOGRAPHY

Arnold, A J, Howard, R E, and Litton, C D, 2004 *Tree-ring analysis of timbers from the Moot Hall, Market Place, Hexham,* Centre for Archaeol Rep, 41/2004

Arnold, A J, Howard, R E, and Litton, C D, 2006 *Tree-ring analysis of timbers from Low Harperley Farmhouse, Wolsingham, County Durham,* Engl Heritage Res Dep Rep Ser, 6/2006

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

Bridge, M, 2000 Can dendrochronology be used to indicate the source of oak within Britain? *Vernacular Architect*, 31, 67–72

Hillam, J and Groves C M, 1991 *Tree-ring analysis of oak timbers from Aydon Castle, Corbridge, Northumberland,* Anc Mon Lab Rep, 42/1991

Howard, R E, Laxton, R R, and Litton, C D, 2001a *Tree-ring analysis of timbers from Unthank Hall, Stanhope, County Durham,* Centre for Archaeol Rep, 4/2001

Howard, R E, Laxton, R R, and Litton, C D, 2001b *Tree-ring analysis of timbers from Halton Castle, near Corbridge, Northumberland,* Centre for Archaeol Rep, 96/2001

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1991 List 39 no 10 - Nottingham University Tree-Ring Dating Laboratory: results, *Vernacular Architect,* 22, 40–3

Howard, R E, Laxton, R R, and Litton, C D, Nottingham University Tree-ring Dating Laboratory, Hook R, Thornes, R, Royal Commission on the Historical Monuments of England, 1992 List 47 no 3 - Nottingham University Tree-Ring Dating Laboratory: truncated principal trusses project, *Vernacular Architect,* 23, 59–6

TABLES

Table 1: Details of tree-ring samples from Blanchland Abbey gatehouse and No 1 The Square, Blanchland, Northumberland

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Roof to bedroom 2 (office – second floor level)						
BAG-B01	Truss 1, tiebeam	140	no h/s	1326	------	1465
BAG-B02	North purlin, truss 1–2	105	h/s	1393	1497	1497
BAG-B03	South purlin, truss 1–2	110	no h/s	1377	------	1486
BAG-B04	Truss 2, tiebeam	90	h/s	1403	1492	1492
BAG-B05	North purlin, truss 2–3	75	no h/s	1412	------	1486
BAG-B06	South purlin, truss 2–3	102	no h/s	1386	------	1487
BAG-B07	Ridge beam, truss 2–3	60	h/s	1445	1504	1504
BAG-B08	Truss 3, tiebeam	97	no h/s	1362	------	1458
BAG-B09	North purlin, truss 3–4	96	no h/s	1381	------	1476
BAG-B10	South purlin, truss 3–4	94	no h/s	1389	------	1482
BAG-B11	Truss 4, tiebeam	95	no h/s	1361	------	1455
BAG-B12	South common rafter 3, bay 3	67	h/s	1434	1500	1500
Ceiling to bedroom 1 (first floor level)						
BAG-B13	Ceiling joist 1, bay 1	63	no h/s	1405	------	1467
BAG-B14	Ceiling joist 5, bay 1	127	31C	1406	1501	1532
BAG-B15	Ceiling joist 6, bay 1	102	29c	1424	1496	1525
BAG-B16	Ceiling joist 7, bay 1	107	28c	1421	1499	1527
BAG-B17	Ceiling joist 1, bay 2	66	h/s	------	------	------
BAG-B18	Ceiling joist 2, bay 2	138	37C	1395	1495	1532
BAG-B19	Ceiling joist 4, bay 2	110	no h/s	1357	------	1466
BAG-B20	Ceiling joist 6, bay 2	85	no h/s	1384	------	1468
BAG-B21	Ceiling joist 7, bay 2	88	no h/s	1366	------	1453
BAG-B22	Main ceiling beam 1	93	3	1416	1505	1508
BAG-B23	Main ceiling beam 2	129	29C	1404	1503	1532

Table 1: continued

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Ground floor ceiling (living room)						
BAG-B24	Ceiling beam 1	83	h/s	1411	1493	1493
BAG-B25	Ceiling beam 2	88	h/s	1411	1498	1498
BAG-B26	Ceiling beam 3	110	h/s	1385	1494	1494
BAG-B27	Ceiling beam 4	72	no h/s	1367	------	1438
'Bedroom 3' (west gallery room to first floor)						
BAG-B28	Inner lintel	147	h/s	1354	1500	1500
BAG-B29	Outer lintel	72	no h/s	1380	------	1451

h/s = the heartwood/sapwood ring is the last ring on the sample
c = complete sapwood exists on the timber but all or part of the sapwood has been lost from the sample during coring
C = complete sapwood is retained on the sample; where dated the last measured ring is the felling date of the timber represented

Table 2: Results of the cross-matching of site sequence BAGBSQ01 and relevant reference chronologies when the first-ring date is AD 1326 and the last-ring date is AD 1532

Reference chronology	*t*-value	Span of chronology	Reference
Aydon Castle, Corbridge, Northumberland	10.5		(Hillam and Groves 1991)
Low Harperley Farmhouse, Wolsingham, Co Durham	9.9	AD 1356–1604	(Tyers and Groves 1999 unpubl)
1–2 The College, Cathedral Precinct, Durham	9.6	AD 1364–1531	(Howard *et al* 1992)
Unthank Hall, Stanhope, Co Durham	9.4	AD 1386–1592	(Howard *et al* 2001a)
Halton Castle, Corbridge, Northumberland	8.9	AD 1396–1559	(Howard *et al* 2001b)
35 The Close, Newcastle upon Tyne	8.4	AD 1365–1513	(Howard *et al* 1991)
England Master Chronology	8.4	AD 401–1981	(Baillie and Pilcher 1982 unpubl)
Moot Hall, Hexham, Northumberland	8.3	AD 1341–1539	(Arnold *et al* 2004)

FIGURES

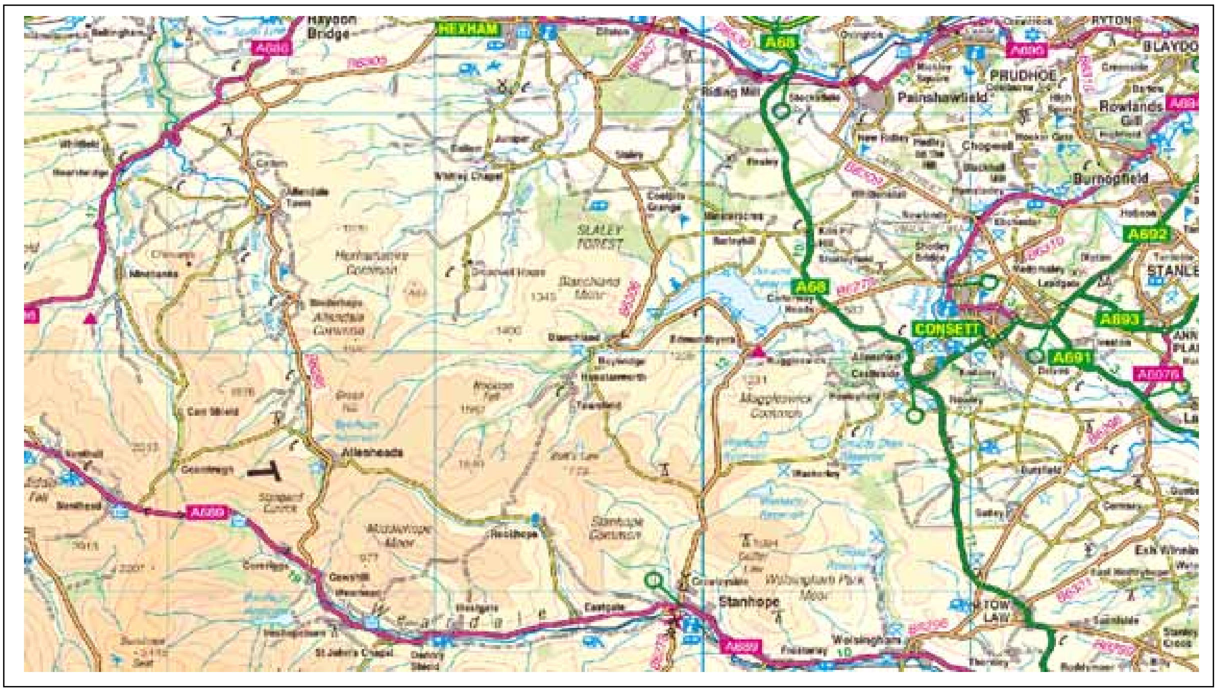


Figure 1: Map to show the location of Blanchland (based on the Ordnance Survey map with permission of the Controller of Her Majesty's Stationery Office, © Crown Copyright)

Figure 2: Map to show the location of Blanchland Abbey gatehouse and No 1 The Square, (based on the Ordnance Survey map with permission of the Controller of Her Majesty's Stationery Office, ©Crown Copyright)

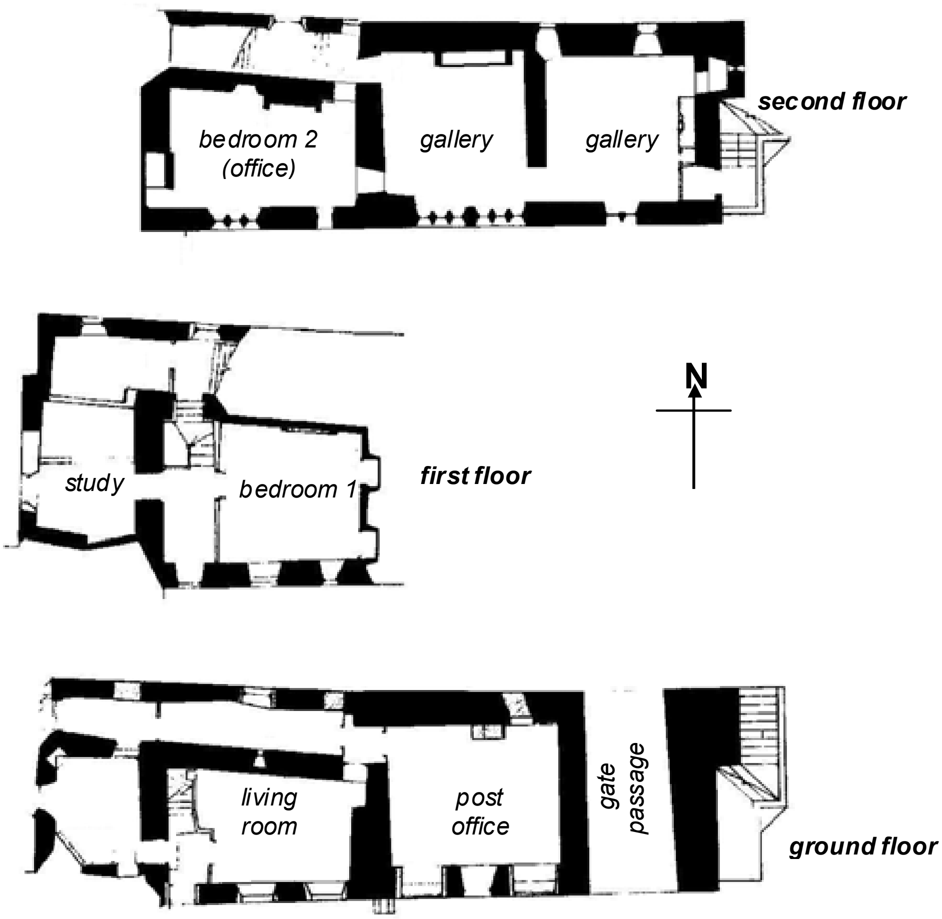


Figure 3: Plan to show layout and arrangement of the gatehouse and No 1 The Square (after Kevin Doonan, Architects)

Figure 4 (top): Ceiling to bedroom 2 (now the office) of No 1 The Square

Figure 5 (bottom): Ceiling to bedroom 1 at first floor level of No 1 The Square

Figure 6 (top): Ground-floor ceiling (living room) room of No 1 The Square

Figure 7 (bottom): Window lintels to west gallery room of the gatehouse (formerly bedroom 3)

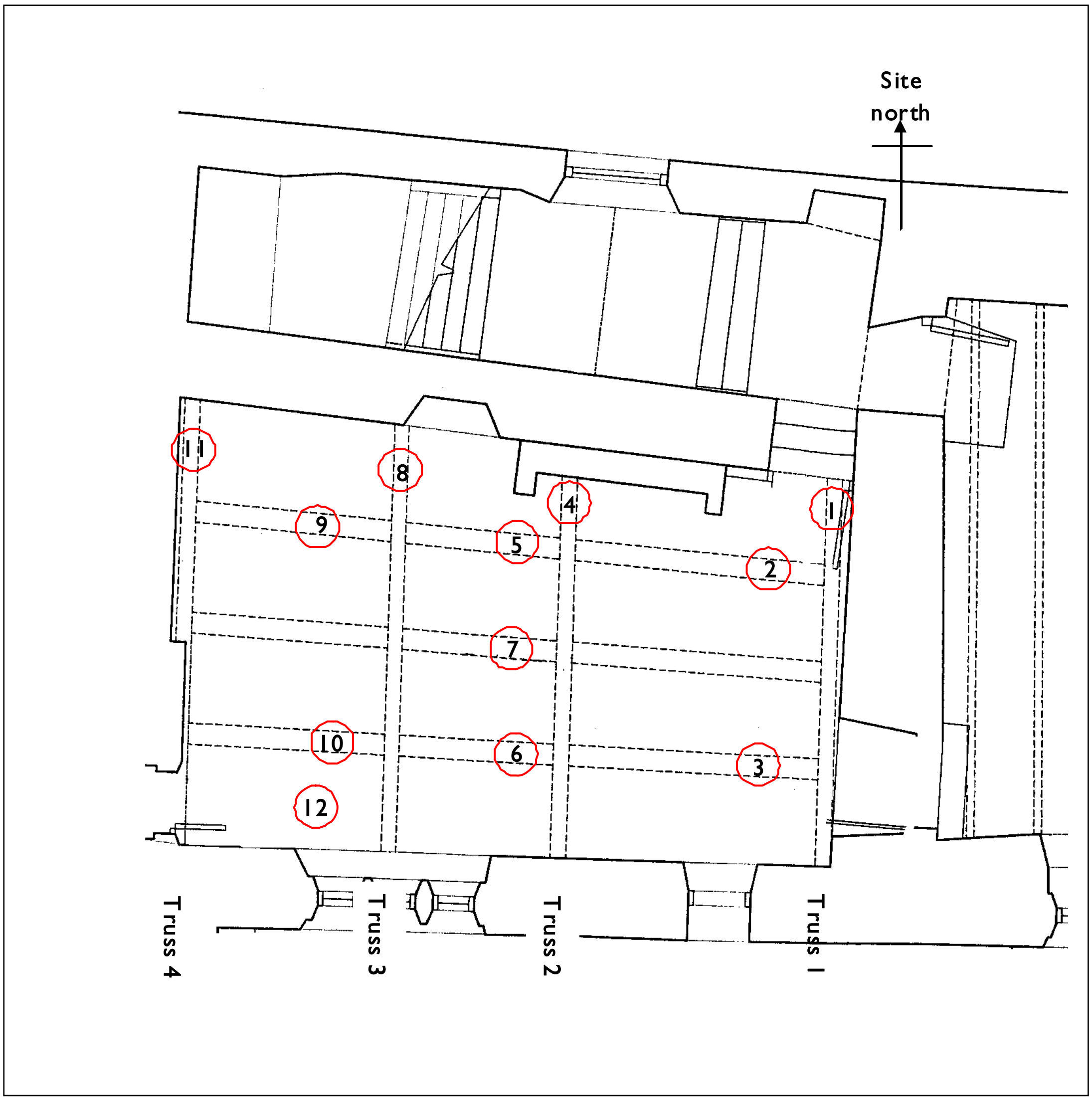


Figure 8a: Plan of roof to bedroom 2 (now the office) to show sampled timbers (after Peter Ryder)

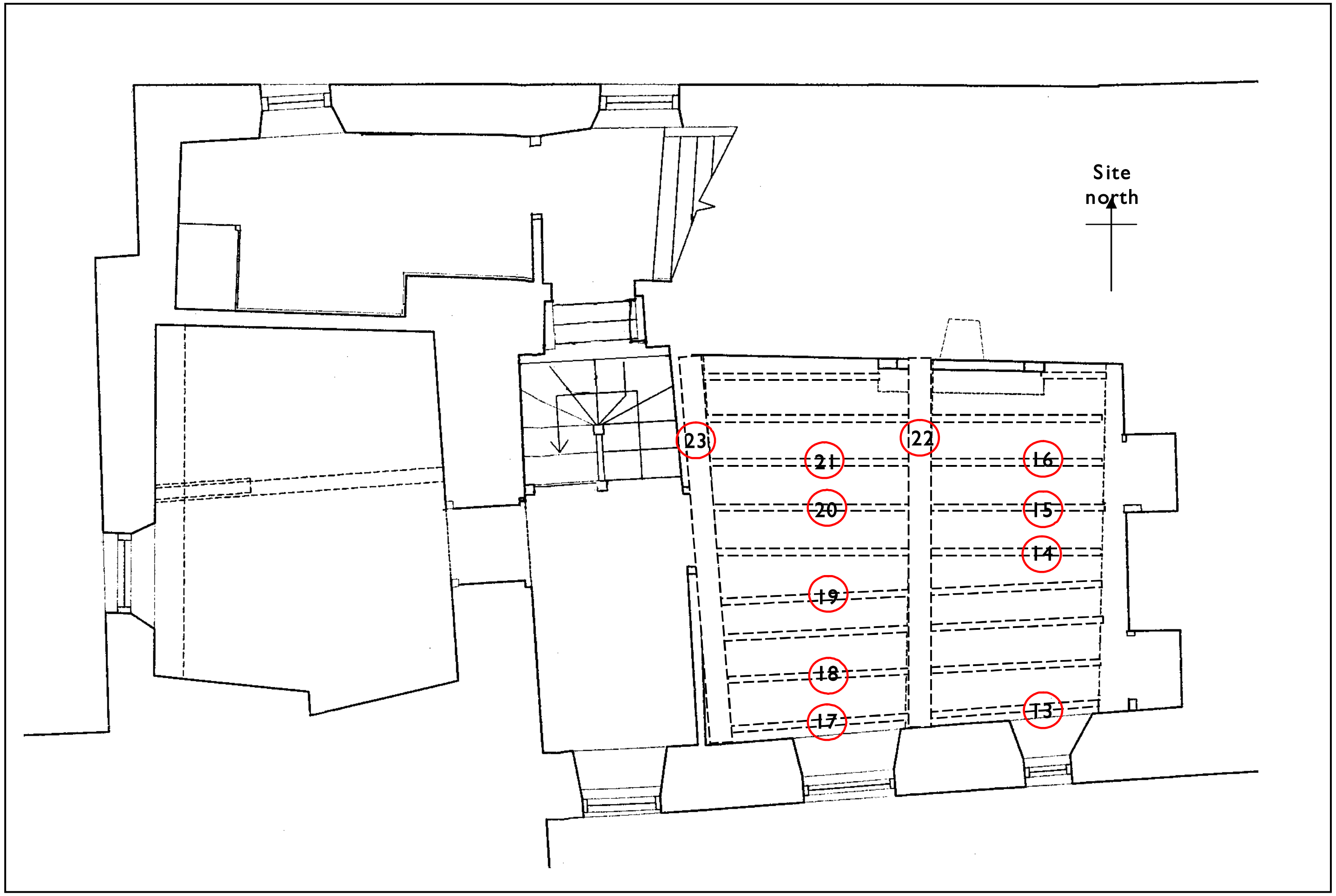


Figure 8b: Ceiling to bedroom 1 (first floor No 1 The Square) to show sampled timbers (after Peter Ryder)

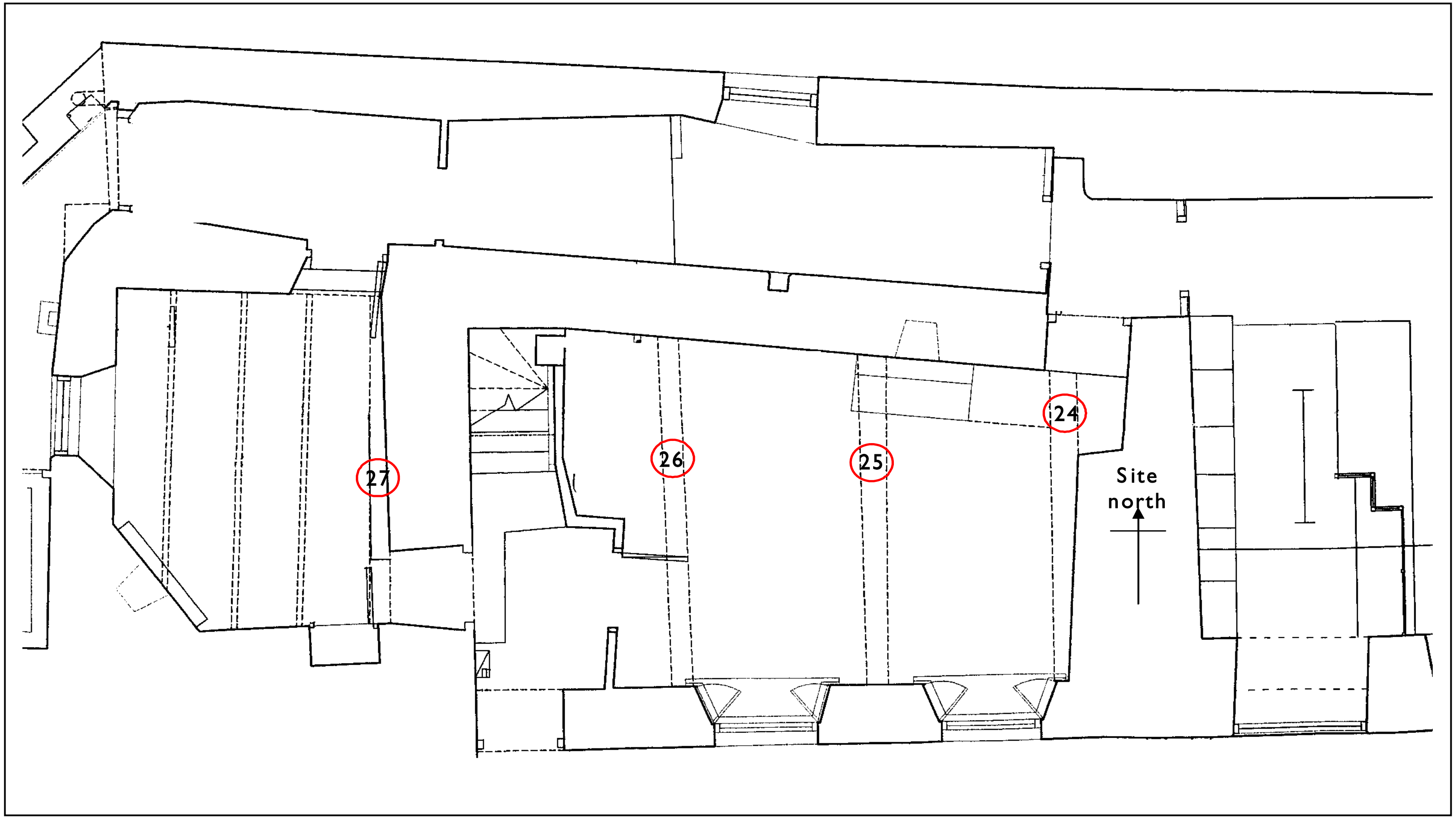


Figure 8c: Ground-floor ceiling (living room No 1 The Square) to show sampled timbers (after Peter Ryder)

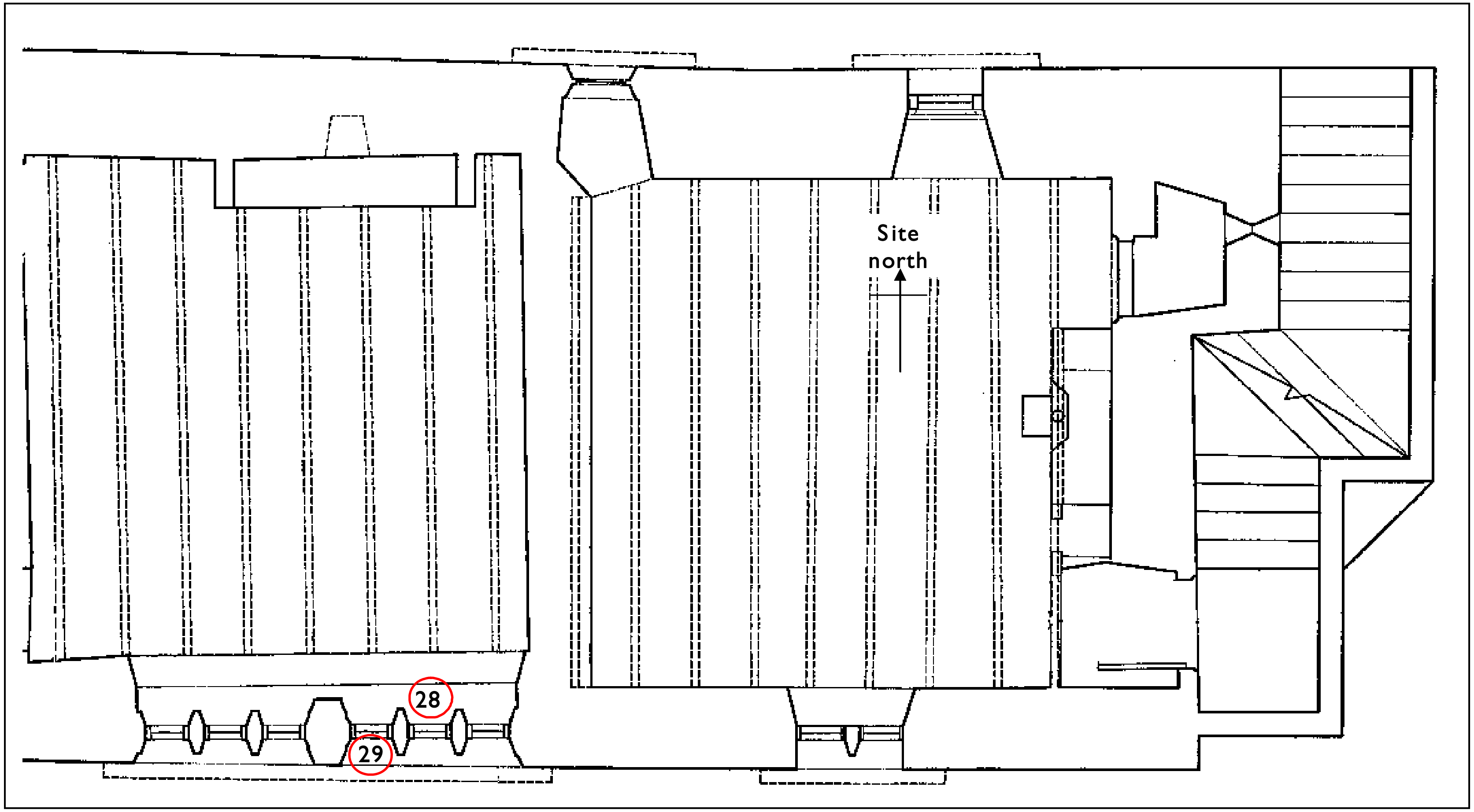
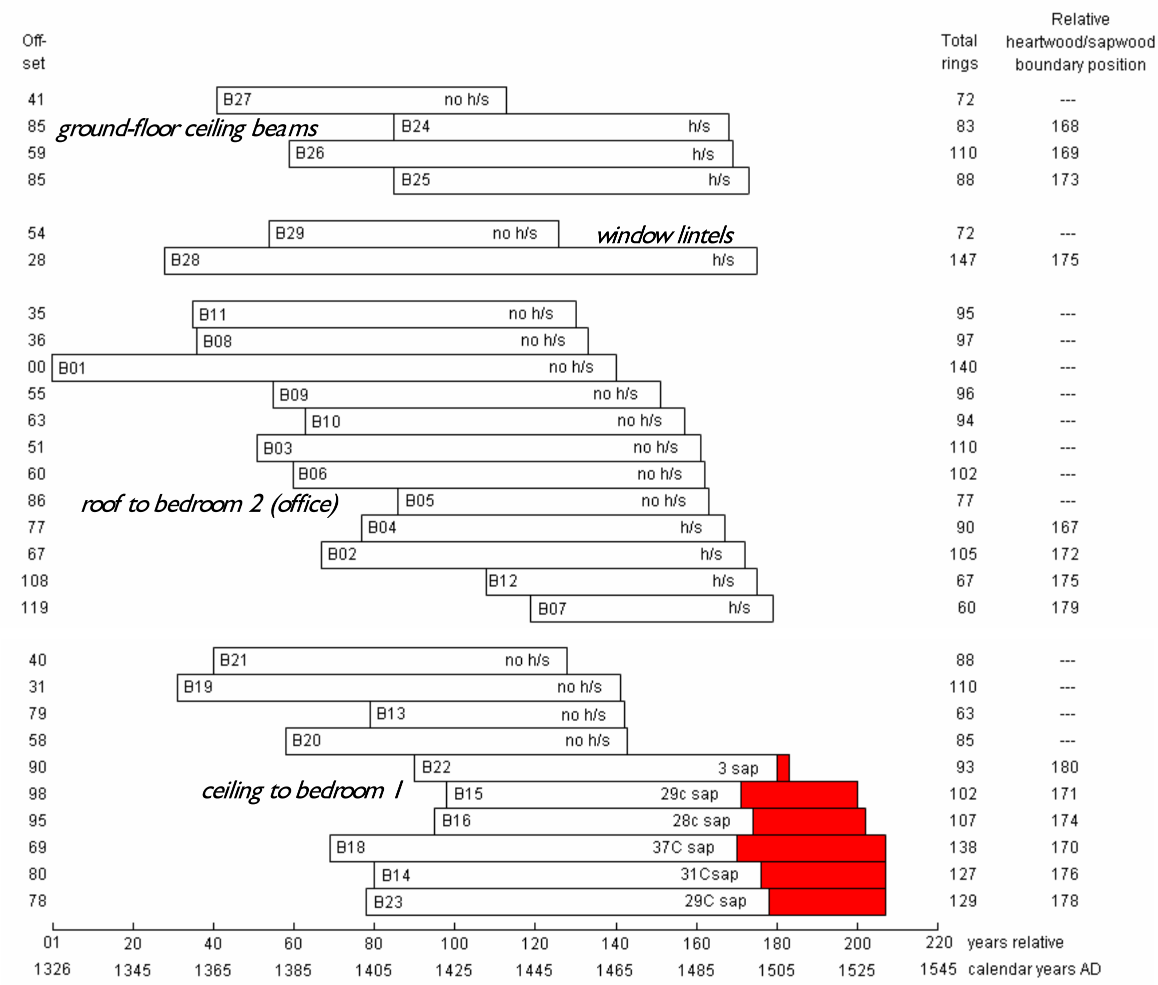


Figure 8d: Bedroom 3 (west gallery room of gatehouse) to show sampled timbers (after Peter Ryder)



Blank bars = heartwood rings, shaded bars = sapwood rings
h/s = heartwood sapwood boundary
c = complete sapwood exists on the timber but all or part of the sapwood has been lost from the sample during coring
C = complete sapwood is retained on the sample; where dated the last measured ring is the felling date of the timber represented

Figure 9: Bar diagram of the samples in site chronology BAGBSQ01 sorted by sample location

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

BAG-B01A 140
97 174 144 161 160 120 138 139 173 198 185 167 178 184 140 170 149 136 136 189
147 105 102 167 127 98 145 143 133 113 90 112 102 128 78 97 89 127 91 111
103 105 117 132 111 87 105 113 149 114 96 83 92 111 94 81 69 77 131 78
90 80 83 79 61 91 68 68 75 75 83 70 94 89 86 95 46 104 67 80
58 57 59 55 45 44 48 65 41 41 43 49 49 39 37 55 33 87 57 54
38 27 31 30 37 32 48 33 36 41 31 30 30 21 22 23 29 26 37 25
27 26 17 20 28 26 26 35 24 27 44 35 30 36 30 26 33 34 34 36
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96 171 146 169 154 110 141 143 165 199 148 157 175 179 140 169 159 153 133 179
145 108 100 165 133 100 149 138 129 110 102 120 116 114 74 118 91 123 90 111
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95 85 73 77 78 85 78 54 80 63 102 62 92 87 78 98 52 105 63 82
60 57 61 54 44 48 39 60 43 40 39 51 49 36 34 47 32 97 57 44
39 27 30 28 37 33 46 33 35 43 35 33 30 21 21 23 27 28 38 26
26 24 20 22 28 24 26 34 26 30 42 36 29 38 29 25 35 34 34 36
BAG-B02A 105
164 154 126 131 110 134 120 119 160 115 218 138 126 80 89 82 62 79 85 110
116 86 106 67 105 86 68 38 76 64 114 100 116 62 36 59 101 117 116 121
122 145 156 120 114 99 99 143 144 144 137 186 199 141 211 207 238 162 201 225
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43 41 91 109 111 95 107 125 112 43 73 91 104 121 171 133 112 123 118 88
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106 106 114 119 121 94 104 87 115 136 118 152 170 154 139 186 143 194 149 151
155 184 149 184 188 165 134 137 118 112 115 127 94 130 116 138 118 80 74 76
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APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

Tree-ring dating, or dendrochronology as it is known, is discussed in some detail in the Laboratory's Monograph, *An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Building* (Laxton and Litton 1988) and *Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates* (English Heritage 1988). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The width of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure A1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths for oaks, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of oak timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring.

If the bark is still on the sample, as in Figure A1, then the date of the last ring will be the date of felling of the oak from which it was cut. There is much evidence that in medieval times oaks cut down for building purposes were used almost immediately, usually within the year or so (Rackham 1976). Hence if bark is present on several main timbers in a building, none of which appear reused or are later insertions, and if they all have the same date for their last ring, then we can be quite confident that this is the date of construction or soon after. If there is no bark on the sample, then we have to make an estimate of the felling date; how this is done is explained below.

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

1. **Inspecting the Building and Sampling the Timbers.** Together with a building historian the timbers in a building are inspected to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can sample *in situ* timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer rings than this, 50 for example, sequences of widths become difficult to match to a unique position within a master sequence of ring widths

and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure A2 has about 120 rings; about 20 of which are sapwood rings – the lighter rings on the outside. Similarly the core has just over 100 rings with a few sapwood rings.

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

Sampling is done by coring into the timber with a hollow corer attached to an electric drill and usually from its outer rings inwards towards where the centre of the tree, the pith, is judged to be. An illustration of a core is shown in Figure A2; it is about 150mm long and 10mm diameter. Great care has to be taken to ensure that as few as possible of the outer rings are lost in coring. This can be difficult as these outer rings are often very soft (see below on sapwood). Each sample is given a code which identifies uniquely which timber it comes from, which building it is from and where the building is located. For example, CRO-A06 is the sixth core taken from the first building (A) sampled by the Laboratory in Cropwell Bishop. Where it came from in that building will be shown in the sampling records and drawings. No structural damage is done to any timbers by coring, nor does it weaken them.

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

All sampling by the Laboratory is undertaken according to current Health and Safety Standards. The Laboratory's dendrochronologists are insured.

Figure A1: A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976

Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

Figure A3: Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measured twice to ensure that an error has not been made. This type of apparatus is needed to process a large number of samples on a regular basis

Figure A4: Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical

2. **Measuring Ring Widths.** Each core is sanded down with a belt sander using medium-grit paper and then finished by hand with flourgrade-grit paper. The rings are then clearly visible and differentiated from each other with a result very much like that shown in Figure A2. The core is then mounted on a movable table below a microscope and the ring-widths measured individually from the innermost ring to the outermost. The widths are automatically recorded in a computer file as they are measured (see Fig A3).

3. **Cross-Matching and Dating the Samples.** Because of the factors besides the local climate which may determine the annual widths of a tree's rings, no two sequences of ring widths from different oaks growing at the same time are exactly alike (Fig A4). Indeed, the sequences may not be exactly alike even when the trees are growing near to each other. Consequently, in the Laboratory we do not attempt to match two sequences of ring widths by eye, or graphically, or by any other subjective method. Instead, it is done objectively (ie statistically) on a computer by a process called cross-matching. The output from the computer tells us the extent of correlation between two sample sequences of widths or, if we are dating, between a sample sequence of widths and the master, at each relative position of one to the other (offsets). The extent of the correlation at an offset is determined by the *t*-value (defined in almost any introductory book on statistics). That offset with the maximum *t*-value among the *t*-values at all the offsets will be the best candidate for dating one sequence relative to the other. If one of these is a master chronology, then this will date the other. Experiments carried out in the past with sequences from oaks of known date suggest that a *t*-value of at least 4.5, and preferably at least 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton and Litton 1988; Laxton *et al* 1988; Howard *et al* 1984–1995).

This is illustrated in Figure A5 with timbers from one of the roofs of Lincoln Cathedral. Here four sequences of ring widths, LIN-C04, 05, 08, and 45, have been cross-matched with each other. The ring widths themselves have been omitted in the bar diagram, as is usual, but the offsets at which they best cross-match each other are shown; eg the sequence of ring widths of C08 matches the sequence of ring widths of C45 best when it is at a position starting 20 rings after the first ring of C45, and similarly for the others. The actual *t*-values between the four at these offsets of best correlations are in the matrix. Thus at the offset of +20 rings, the *t*-value between C45 and C08 is 5.6 and is the maximum found between these two among all the positions of one sequence relative to the other.

It is standard practice in our Laboratory first to cross-match as many as possible of the ring-width sequences of the samples in a building and then to form an average from them. This average is called a site sequence of the building being dated and is illustrated in Figure A5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences of the four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. Thus in Fig A5 if the widths shown are 0.8mm for C45, 0.2mm for C08, 0.7mm for C05, and 0.3mm for C04, then the corresponding width of the site sequence is the average of these, 0.55mm. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

The straightforward method of cross-matching several sample sequences with each other one at a time is called the 'maximal *t*-value' method. The actual method of cross-matching a group of sequences of ring-widths used in the Laboratory involves grouping and averaging the ring-width sequences and is called the 'Litton-Zainodin Grouping Procedure'. It is a modification of the straightforward method and was successfully developed and tested in the Laboratory and has been published (Litton and Zainodin 1991; Laxton *et al* 1988).

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

Quite often some, though not all, of the original outer rings are missing on a timber. The outer rings on an oak, called sapwood rings, are usually lighter than the inner rings, the heartwood, and so are relatively easy to identify. For example, sapwood can be seen in the corner of the rafter and at the outer end of the core in Figure A2, both indicated by arrows. More importantly for dendrochronology, the sapwood is relatively soft and so liable to insect attack and wear and tear. The builder, therefore, may remove some of the sapwood for precisely these reasons. Nevertheless, if at least some of the sapwood rings are left on a sample, we will know that not too many rings have been lost since felling so that the date of the last ring on the sample is only a few years before the date of the original last ring on the tree, and so to the date of felling.

Various estimates have been made and used for the average number of sapwood rings in mature oak trees (English Heritage 1998). A fairly conservative range is between 15 and 50 and that this holds for 95% of mature oaks. This means, of course, that in a small number of cases there could be fewer than 15 and more than 50 sapwood rings. For example, the core CRO-A06 has only 9 sapwood rings and some have obviously been lost over time – either they were removed originally by the carpenter and/or they rotted away in the building and/or they were lost in the coring. It is not known exactly how many sapwood rings are missing, but using the above range the Laboratory would estimate between a minimum of 6 (=15-9) and a maximum of 41 (=50-9). If the last ring of CRO-A06 has been dated to 1500, say, then the estimated felling-date range for the tree from which it came originally would be between 1506 and 1541. The Laboratory uses this estimate for sapwood in areas of England where it has no prior information. It also uses it when dealing with samples with very many rings, about 120 to the last heartwood ring. But in other areas of England where the Laboratory has accumulated a number of samples with complete sapwood, that is, no sapwood lost since felling, other estimates in place of the conservative range of 15 to 50 are used. In the East Midlands (Laxton *et al* 2001) and the east to the south down to Kent (Pearson 1995) where it has sampled extensively in the past, the Laboratory uses the shorter estimate of 15 to 35 sapwood rings in 95% of mature oaks growing in these parts. Since the sample CRO-A06 comes from a house in Cropwell Bishop in the East Midlands, a better estimate of sapwood rings lost since felling is between a minimum of 6 (=15-9) and 26 (=35-9) and the felling would be estimated to have taken place between 1506 and 1526, a shorter period than before. Oak boards quite often come from the Baltic region and in these cases the 95% confidence limits for sapwood are 9 to 36 (Howard *et al* 1992, 56).

Even more precise estimates of the felling date and range can often be obtained using knowledge of a particular case and information gathered at the time of sampling. For example, at the time of sampling the dendrochronologist may have noted that the timber from which the core of Figure A2 was taken still had complete sapwood but that some of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 20mm, a reasonable estimate can be made of the number of sapwood rings lost, say 12 to 15 rings in this case. By adding on 12 to 15 years to the date of the last ring on the sample a good tight estimate for the range of the felling date can be obtained, which is often better than the 15 to 35 years later we would have estimated without this observation. In the example, the felling is now estimated to have taken place between AD 1512 and 1515, which is much more precise than without this extra information.

Even if all the sapwood rings are missing on a sample, but none of the heartwood rings are, then an estimate of the felling-date range is possible by adding on the full compliment of, say, 15 to 35 years to the date of the last heartwood ring (called the heartwood/ sapwood boundary or transition ring and denoted H/S). Fortunately it is often easy for a trained dendrochronologist to identify this boundary on a timber. If a timber does not have its heartwood/sapwood boundary, then only a *post quem* date for felling is possible.

5. Estimating the Date of Construction. There is a considerable body of evidence collected by dendrochronologists over the years that oak timbers used in buildings were not seasoned in medieval or early modern times (English Heritage 1998; Miles 1997, 50–5). Hence, provided that all the samples in a building have estimated felling-date ranges broadly in agreement with each other, so that they appear to have been felled as a group, then this should give an accurate estimate of the period when the structure was built, or soon after (Laxton *et al* 2001, fig 8; 34–5, where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storage before use, or if there is evidence the oak came from abroad (eg Baltic boards), then some allowance has to be made for this.

6. Master Chronological Sequences. Ultimately, to date a sequence of ring widths, or a site sequence, we need a master sequence of dated ring widths with which to cross-match it, a Master Chronology. To construct such a sequence we have to start with a sequence of widths whose dates are known and this means beginning with a sequence from an oak tree whose date of felling is known. In Figure A6 such a sequence is SHE-T, which came from a tree in Sherwood Forest which was blown down in a recent gale. After this other sequences which cross-match with it are added and gradually the sequence is 'pushed back in time' as far as the age of samples will allow. This process is illustrated in Figure A6. We have a master chronological sequence of widths for Nottinghamshire and East Midlands oak for each year from AD 882 to 1981. It is described in great detail in Laxton and Litton (1988), but the components it contains are shown here in the form of a bar diagram. As can be seen, it is well replicated in that for each year in this period there are several sample sequences having widths for that year. The master is the average of these. This master can now be used to date oak from this area and from the surrounding areas where the climate is very similar to that in the East Midlands. The Laboratory has also constructed a master for Kent (Laxton and Litton 1989). The method the Laboratory uses to construct a master sequence, such as the East Midlands and Kent, is completely objective and uses the Litton-Zainodin grouping procedure (Laxton *et al* 1988). Other laboratories and individuals have constructed masters for other areas and have made them available. As well as these masters, local (dated) site chronologies can be used to date other buildings from nearby. The Laboratory has hundreds of these site sequences from many parts of England and Wales covering many short periods.

7. Ring-Width Indices. Tree-ring dating can be done by cross-matching the ring widths themselves, as described above. However, it is advantageous to modify the widths first. Because different trees grow at different rates and because a young oak grows in a different way from an older oak, irrespective of the climate, the widths are first standardized before any matching between them is attempted. These standard widths are known as ring-width indices and were first used in dendrochronology by Baillie and Pilcher (1973). The exact form they take is explained in this paper and in the appendix of Laxton and Litton (1988) and is illustrated in the graphs in Figure A7. Here ring-widths are plotted vertically, one for each year of growth. In the upper sequence of (a), the generally large early growth after 1810 is very apparent as is the smaller later growth from about 1900 onwards when the tree is maturing. A similar phenomenon can be observed in the lower sequence of (a) starting in 1835. In both the widths are also changing rapidly from year to year. The peaks are the wide rings and the troughs are the narrow rings corresponding to good and poor growing seasons, respectively. The two corresponding sequence of Baillie-Pilcher indices are plotted in (b) where the differences in the immature and mature growths have been removed and only the rapidly changing peaks and troughs remain, that are associated with the common climatic signal. This makes cross-matching easier.

t-value/offset Matrix

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

Bar Diagram

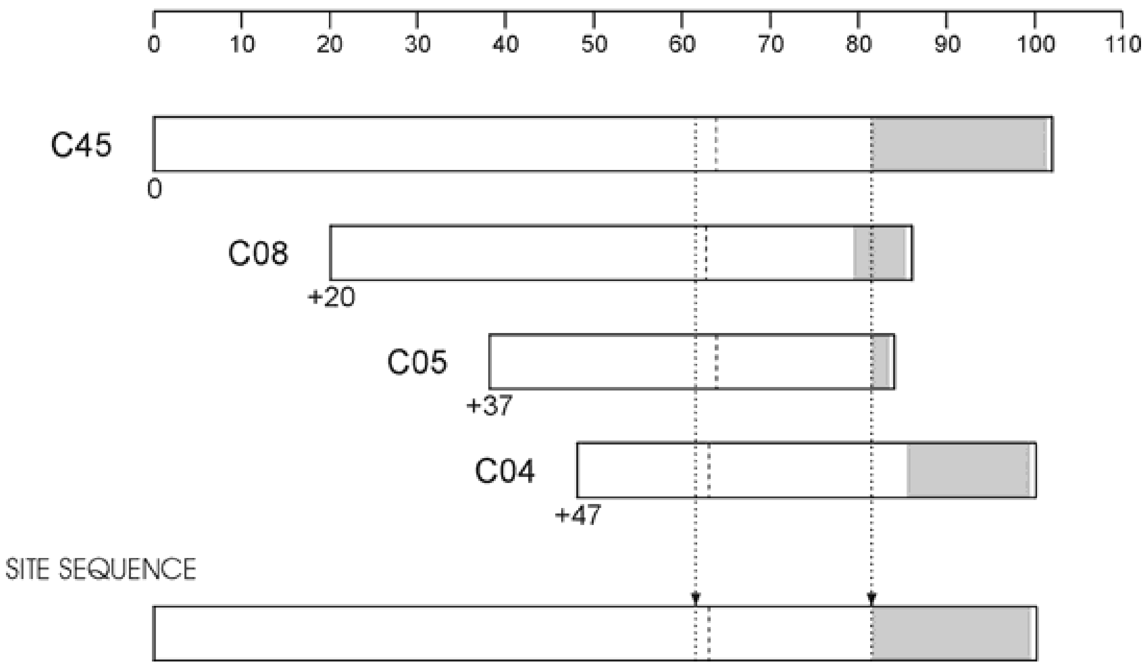


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

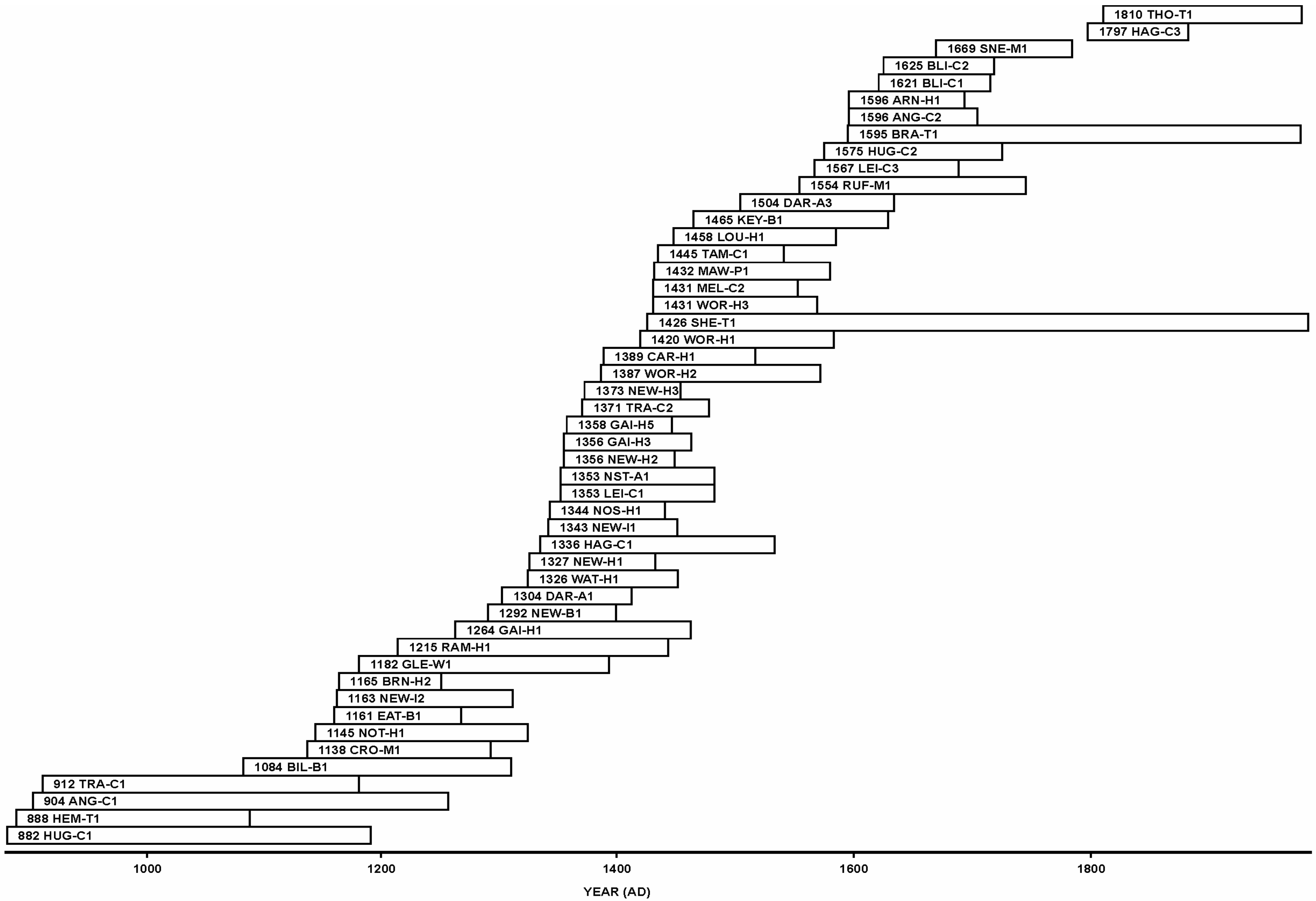
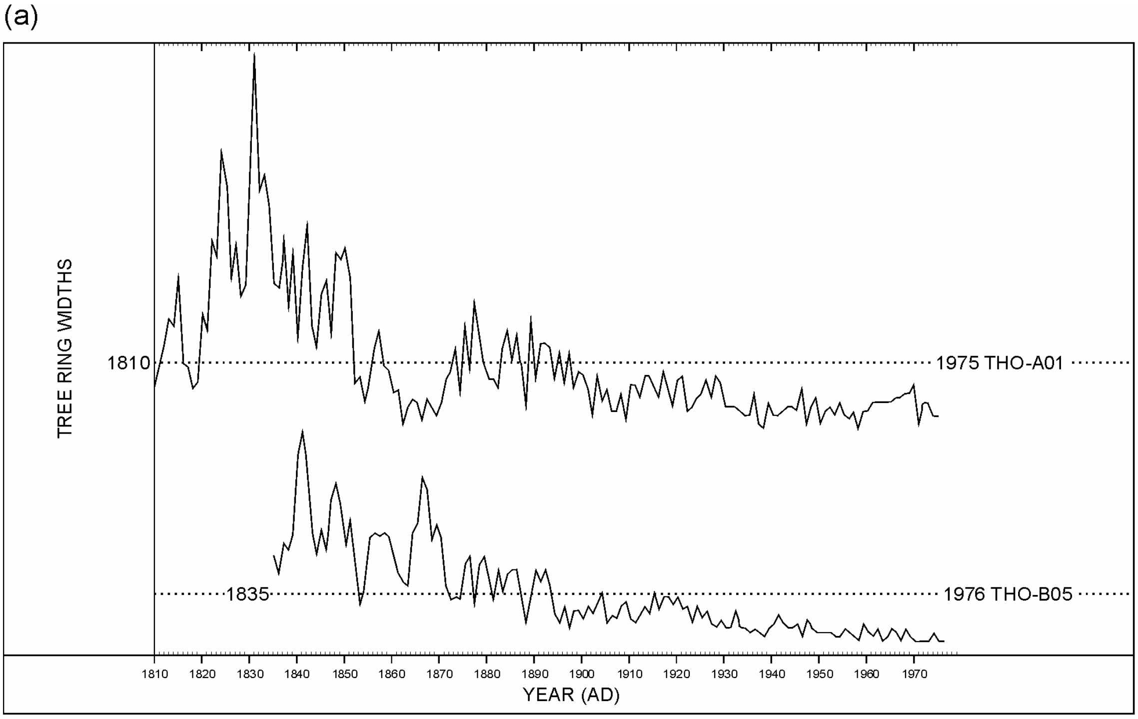


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

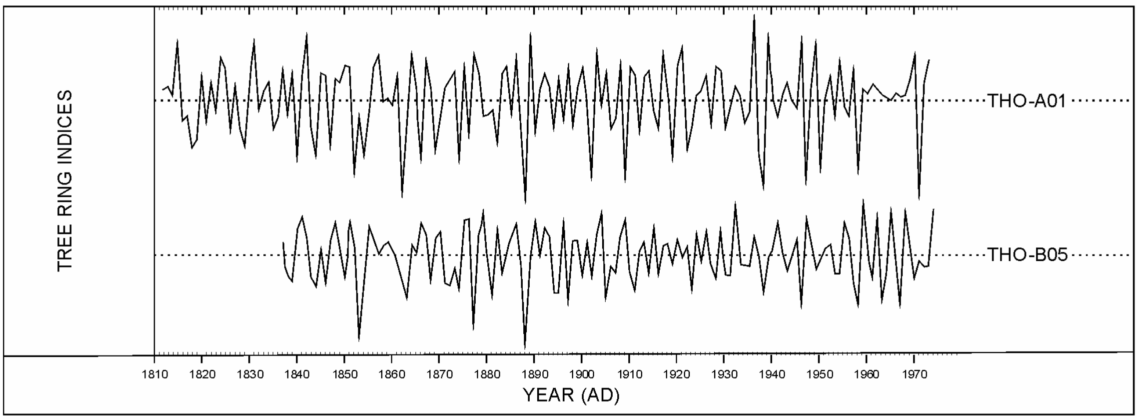


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree are wider than the later ones of the older tree in both sequences

Figure A7 (b): The Baillie-Pilcher indices of the above widths

The growth trends have been removed completely

References

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

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

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

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

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

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

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

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

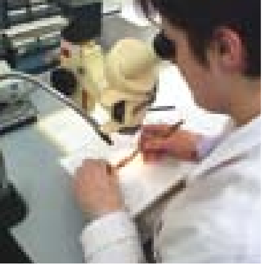
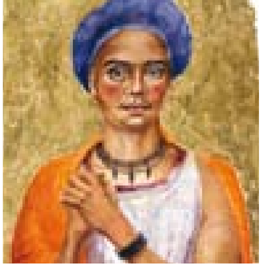
Laxton, R R, Litton, C D, and Howard, R E, 2001 *Timber: Dendrochronology of Roof Timbers at Lincoln Cathedral*, Engl Heritage Res Trans, 7

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

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

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

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



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