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WOOD BARN, FAIRFIELD HOUSE, STOGURSEY, SOMERSET

TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

INTERVENTION
AND ANALYSIS

ENGLISH HERITAGE

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SUMMARY

Analysis undertaken on samples from Wood Barn resulted in the construction of a single site sequence. This site sequence, FRFBSQ01, contains 18 samples and spans the period AD 1561–1771.

Interpretation of the sapwood suggests construction of the main barn and associated pentice occurred soon after the felling of the timbers utilised in AD 1726; a single bay extension to the south with associated pentice, thought to be slightly later, contains timber felled in AD 1768 and AD 1771.

CONTRIBUTORS

Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS

The Laboratory would like to thank Lady Gass for facilitating access and for her assistance during sampling. Jenny Chesher, English Heritage Inspector of Historic Buildings and Areas, provided the survey of the building, from which the drawings are used to locate samples. Thanks are also given to Cathy Tyers and Shahina Farid of the English Heritage Scientific Dating Team for commissioning the analysis and their advice and assistance throughout the production of this report.

ARCHIVE LOCATION

Somerset Historic Environment Record
Somerset Heritage Centre
Brunel Way
Langford Mead
Norton Fitzwarren
Taunton
TA2 6SF

DATE OF INVESTIGATION

2013

CONTACT DETAILS

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CONTENTS

INTRODUCTION

Wood Barn on the Fairfield estate is located some distance from other estate buildings and is accessed from a track which was formerly a drive leading to the house (Figs 1 and 2). A survey of Wood Barn was undertaken by the Somerset Vernacular Building Research Group (Chesher *et al* 2008). The original barn is aligned north-east/south-west (north-south for the purpose of this report) and consists of seven bays with off-centre opposing doors; the southern three bays have a floor and are divided off from the rest of the barn by a stone wall. This wall does not continue at first-floor level. An open fronted pentice extends the full length of the south-east wall. To the east of the original barn is a large, fully enclosed yard which also had an open-fronted animal shelter along its north wall. To the south of the barn is a two-storey, single-room extension with external stone steps. There is a further substantial addition to the south, which may also have been floored at its south end. To the east of this, extending southwards, is another large yard formerly with an open-fronted range to its north and west (Fig 3).

The original barn is timber-framed on a blue lias stone plinth. The framing consists of principal posts extending down from the roof trusses, with intermediate posts and two straight, diagonal braces running from the sole plate to the wall-plate in each bay. The roof structure consists of principal rafters with tiebeams and trenched purlins (Fig 4). Additional posts with cross-bracing have been inserted at a later date (Fig 5).

The roof of the southern extension is a much coarser construction with three tiebeams resting on wall plates, collars, and queen posts to the middle truss (Fig 6).

The pentice, which once extended along the east wall of the original barn and southern extension, was open-fronted and supported on oak posts set on blue lias straddles (Fig 7).

The original barn and integral pentice is thought to date to the later eighteenth century and is thought to have been floored and extended at its southern end in the first half of the nineteenth century.

SAMPLING

A dendrochronological survey was requested by Jenny Chesher, English Heritage Inspector of Historic Buildings and Areas, to provide independent dating evidence for the building and to establish a developmental framework for the barn.

A total of 25 timbers from the main barn, the single-bay southern extension, and their associated pentices was sampled by coring. Each sample was given the code FRF-B and numbered 1–25. The location of all samples was noted at the time of sampling and has been marked on Figures 8–15. Further details relating to the samples can be found in Table 1.

The later posts and framing of the main barn were fast-grown and unsuitable for tree-ring dating and so sampling of these timbers was abandoned after coring of two of them (FRF-B15 and FRF-B16).

ANALYSIS AND RESULTS

Three samples, one from the later phase of the main barn and two from the southern extension roof, had too few rings for secure dating and so were discarded prior to measurement. The remaining 22 samples were prepared by sanding and polishing and their growth ring-widths measured; the data of these measurements are given at the end of the report. All samples were then compared with each other by the Litton/Zainodin grouping programme (see Appendix).

Eighteen samples matched each other and were combined at the relevant offset positions to form FRFBSQ01, a site sequence of 211 rings (Fig 16). This site sequence was compared against a series of relevant reference chronologies for oak where it was found to span the period AD 1561–1771. The evidence for this dating is given in Table 2.

Attempts to date the ungrouped samples were unsuccessful and hence all remain undated.

INTERPRETATION

Twelve of the samples taken from the primary phase of the main barn and associated pentice have been successfully dated (Fig 17). Two of the dated samples, FRF-B04 and FRF-B06, have complete sapwood and the last-measured ring date of AD 1726, the felling date of the timbers represented. Seven further samples have the heartwood/sapwood boundary ring, the dates of which are broadly contemporary and suggestive of a single felling. The average heartwood/sapwood boundary ring date is AD 1707, allowing an estimated felling date to be calculated for the seven timbers represented to within the range AD 1722–47, consistent with these timbers also having been felled in AD 1726. The remaining three dated samples do not have the heartwood/sapwood boundary but with last-measured heartwood ring dates of AD 1643 (FRF-B11), 1646 (FRF-B14), and AD 1665 (FRF-B10) they have *terminus post quem* felling dates of AD 1658, AD 1661, and AD1680, respectively. Samples FRF-B11 and FRF-B14 match each other at t=10.7, a value high enough to suggest that the two beams represented were potentially cut from the same tree. Generally, the overall level of cross-matching of these three samples with the rest of the timber from the main barn and associated pentice is such to suggest a coherent group of timbers, and that these three timbers were also likely to have been felled in AD 1726.

Six samples taken from the southern extension and its associated pentice have been dated (Fig 17). Two of these (FRF-B21 and FRF-B17) have complete sapwood. Sample FRF-B21, taken from a post of truss 9 has the last-measured ring date of AD 1768, whilst FRF-B17, from the tiebeam of truss 9, has the last-measured ring date of AD 1771, the felling dates of the timbers represented. Two other samples, one from a wall plate and one from a purlin of the pentice have similar heartwood/sapwood boundary ring dates to each other, the average of which is AD 1741, giving an estimated felling date range for the two timbers represented of AD 1762–81, consistent with these timbers also having been felled in the late AD 1760s or early AD 1770s. This felling date range allows for sample FRF-B19 having a last-measured ring date of AD 1761 with incomplete sapwood.

The two other dated samples, common rafters from the associated pentice, have been dated but do not have the heartwood/sapwood boundary. With last-measured heartwood ring dates of AD 1691 (FRF-B24) and AD 1709 (FRF-B25) these would be estimated to have *terminus post quem* felling dates of AD 1706 and AD 1724, respectively. Sample FRF-B25 matches FRF-B24 and FRF-B17 (felled AD 1771) particularly well at t=9.3 and 9.1, respectively, which might suggest all three are likely to have been felled at the same time.

Felling date ranges have been calculated using the estimate that mature oak trees in this region have 15–40 sapwood rings.

DISCUSSION

Dendrochronological research has successfully dated timbers from the main barn, the single-bay extension, and from the pentices associated with each element.

Primary timbers of the main barn and associated pentice are now known to have been felled in AD 1726 and therefore likely that construction of both elements occurred soon after. This is somewhat earlier than the previously suggested date of the later eighteenth century.

The extension and its associated pentice were thought to date to the first half of the nineteenth century. It is now known that they contain timber dated to AD 1768 and AD 1771 with construction likely to have been in the later eighteenth century, again somewhat earlier than previously thought.

The reference chronology against which site sequence FRFBSQ01 matches most closely is that constructed from the timbers at Fairfield House (Table 2). These match each other at t=11.6; such a high level demonstrates that the same woodland source was almost certainly utilised for both buildings.

It is unfortunate that the majority of the timbers associated with a later phase of the main barn were found to be unsuitable for sampling, and the one suitable sample taken could not be dated. In addition to the usual difficulties in dating single samples, this sample is likely to belong to the late-nineteenth century, a period for which there is relatively little reference data available for the Somerset area

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TABLES

Table 1: Details of samples from Wood Barn, Fairfield House, Stogursey, Somerset

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Phase 1						
Main barn						
FRF-B01	West stud 2, bay 2	83	12	1638	1708	1720
FRF-B02	West sole plate, bay 3	81	05	1634	1709	1714
FRF-B03	East stud 2, bay 5	124	11	1597	1709	1720
FRF-B04	Tiebeam, truss 6	154	18C	1573	1708	1726
FRF-B05	East wall post, truss 6	147	06	1567	1707	1713
FRF-B06	East principal rafter, truss 6	121	22C	1606	1704	1726
FRF-B07	Tiebeam, truss 7	137	h/s	1570	1706	1706
FRF-B08	Tiebeam, truss 8	69	--	----	----	----
Pentice						
FRF-B09	Tie, truss 4	103	h/s	1600	1702	1702
FRF-B10	Principal rafter, truss 4	105	--	1561	----	1665
FRF-B11	Tie, truss 6	83	--	1561	----	1643
FRF-B12	Principal rafter, truss 6	120	h/s	----	----	----
FRF-B13	Tie, truss 7	80	h/s	1627	1706	1706
FRF-B14	Tie, truss 8	83	--	1564	----	1646
Phase 2						
Main barn						
FRF-B15	West post, truss 2	NM	--	----	----	----
FRF-B16	West post, truss 3	68	20C	----	----	----
South extension						
FRF-B17	East wall post, truss 9	148	35C	1624	1736	1771
FRF-B18	East wallplate	54	26C	----	----	----
FRF-B19	West wallplate	179	17	1583	1744	1761

Table 1: (cont)

FRF-B20	Tiebeam, truss 9	NM	--	----	----	----
FRF-B21	Tiebeam, truss 10	88	35C	1681	1733	1768
FRF-B22	Tiebeam, truss 11	NM	--	----	----	----
Pentice						
FRF-B23	Purlin	150	h/s	1589	1738	1738
FRF-B24	Common rafter, 11	74	--	1618	----	1691
FRF-B25	Common rafter, 12	92	--	1618	----	1709

*NM = not measured

**h/s = heartwood/sapwood boundary is the last-measured ring

C = complete sapwood retained on sample, last measured ring is the felling date

Table 2: Results of the cross-matching of site sequence FRFBSQ01 and relevant reference chronologies when the first-ring date is AD 1561 and the last-measured ring date is AD 1771

Reference chronology	*t*-value	Span of chronology	Reference
Fairfield House, Stogursey, Somerset	11.6	AD 1316–1484	Arnold and Howard 2013
Church Farm House, Ockbrook, Derbyshire	6.8	AD 1560–1672	Arnold and Howard 2009
Worcester Cathedral, Worcester, Worcestershire	6.8	AD 1484–1772	Arnold *et al* 2003
Poltimore House, Poltimore, Devon	6.7	AD 1534–1725	Arnold *et al* 2005
Bretby Hall, Bretby, Derbyshire	6.4	AD 1494–1719	Howard *et al* 1999
Wren Wing, Easton Neston, Northamptonshire	6.3	AD 1468–1686	Arnold *et al* 2008
1–5 Bridge Street, Bideford, Devon	6.2	AD1484–1706	Arnold and Howard 2012 unpubl

FIGURES

Figure 1: Map to show the general location of Stogursey, circled. © Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900

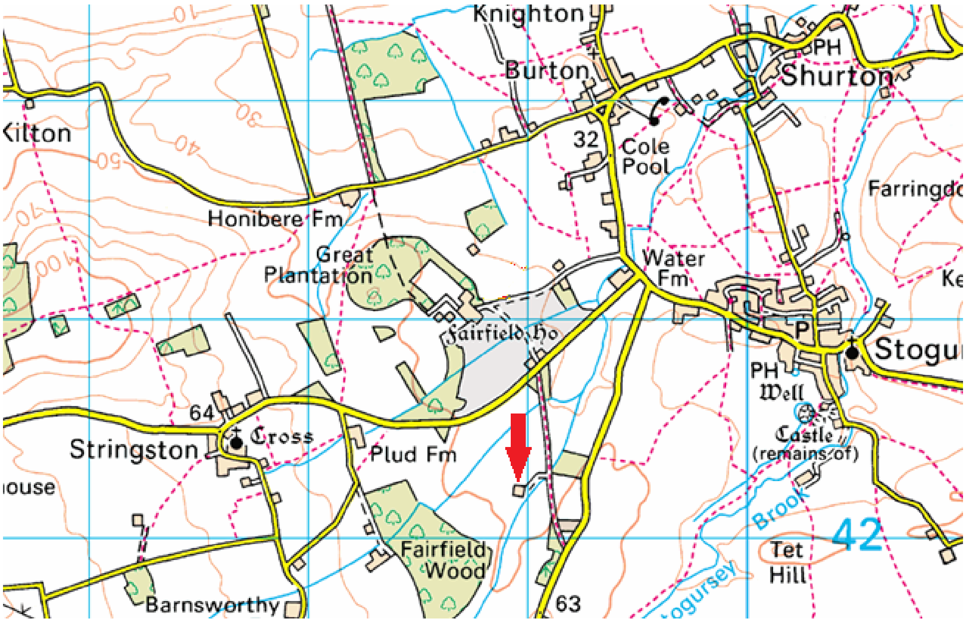

Figure 2: Location of Wood Barn, Stogursey, Somerset, arrowed. © Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900.

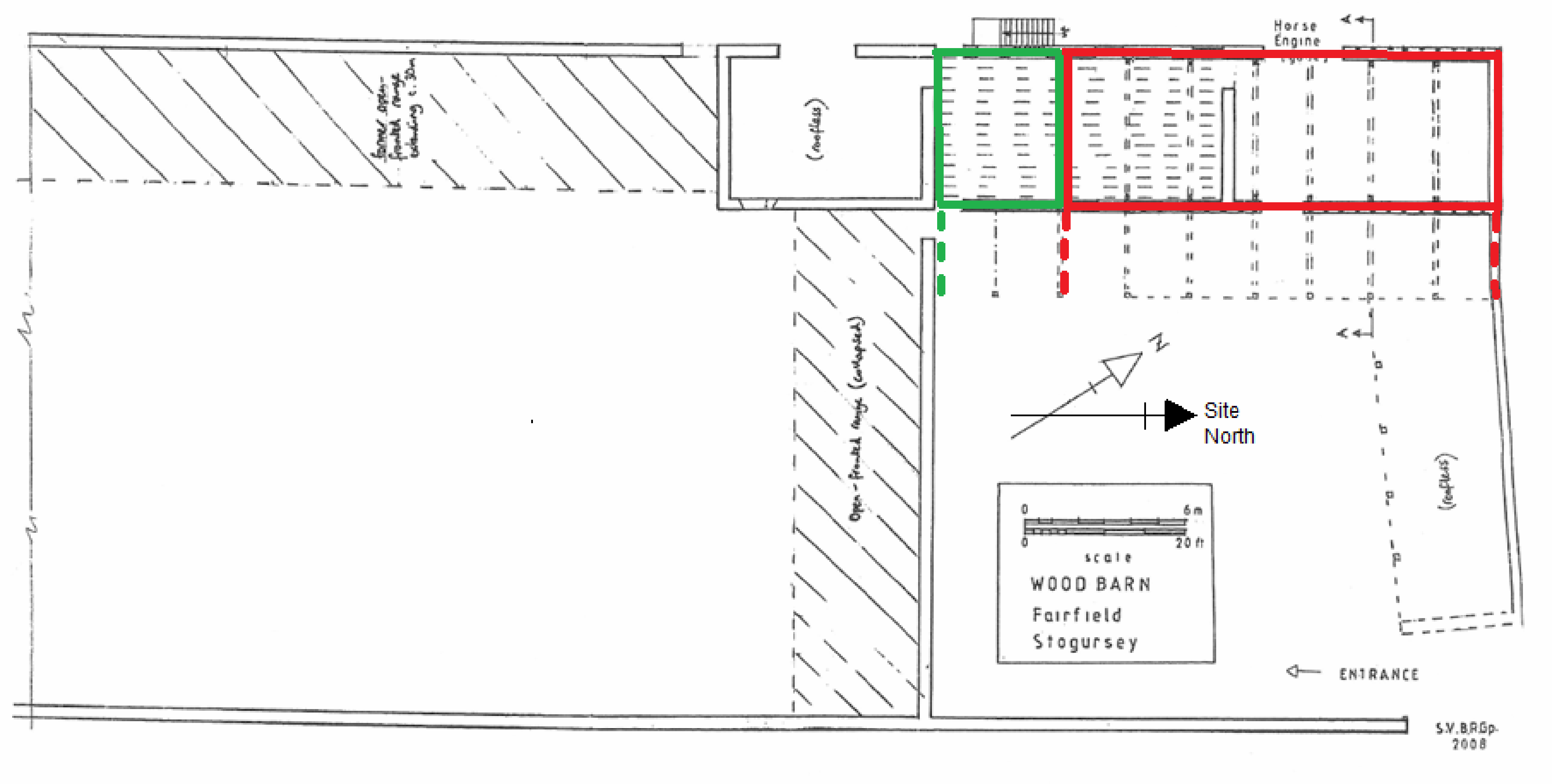

Figure 3: Plan of Wood Barn; main barn and pentice in red and extension and pentice in green (Chesher et al 2008)

Figure 4: Main barn roof, looking north-east (Alison Arnold)

Figure 5: Main barn, later posts and bracing, from the west (Alison Arnold)

Figure 6: South extension, truss 10, from the south-west (Alison Arnold)

Figure 7: Main barn pentice, looking north-east (Alison Arnold)

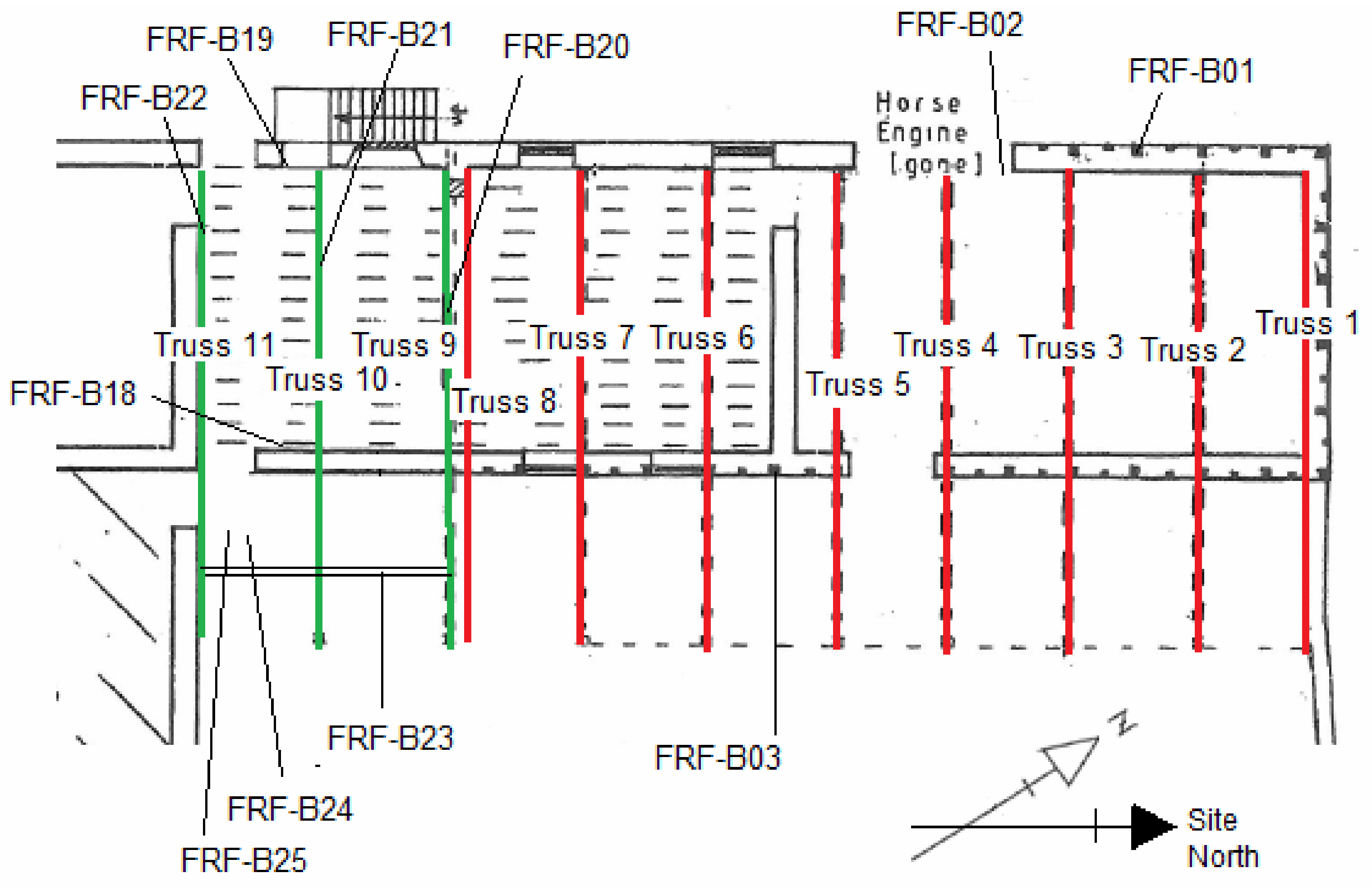

Figure 8: Plan of the barn and extension, showing the location of samples FRF-B01–03, and FRF-B18–25 (Chesher et al 2008)

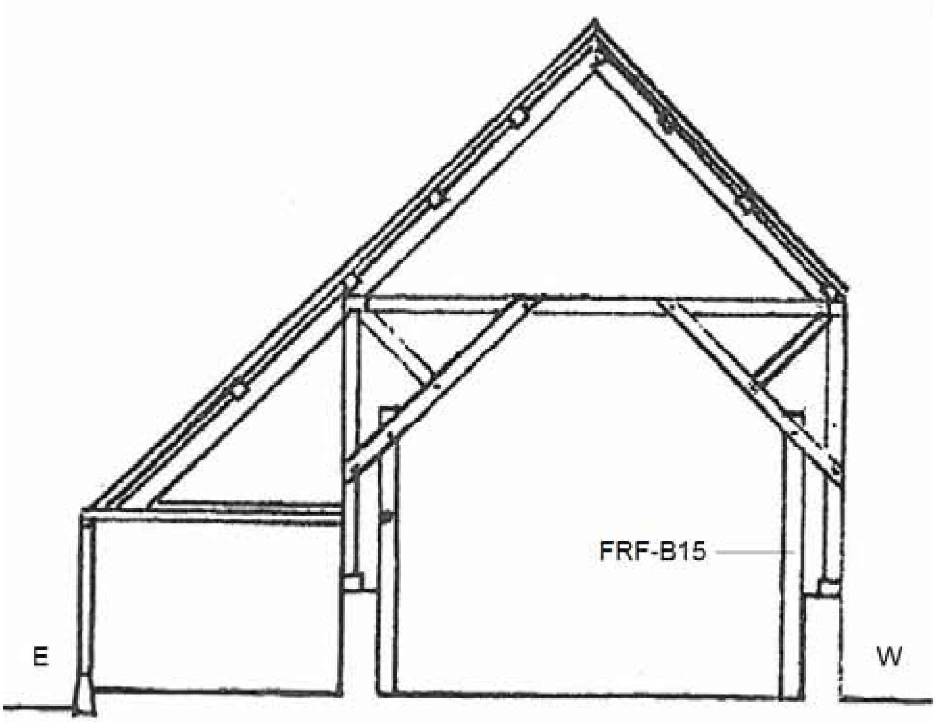

Figure 9: Truss 2, showing the location of sample FRF-B15 (Chesher et al *2008)*

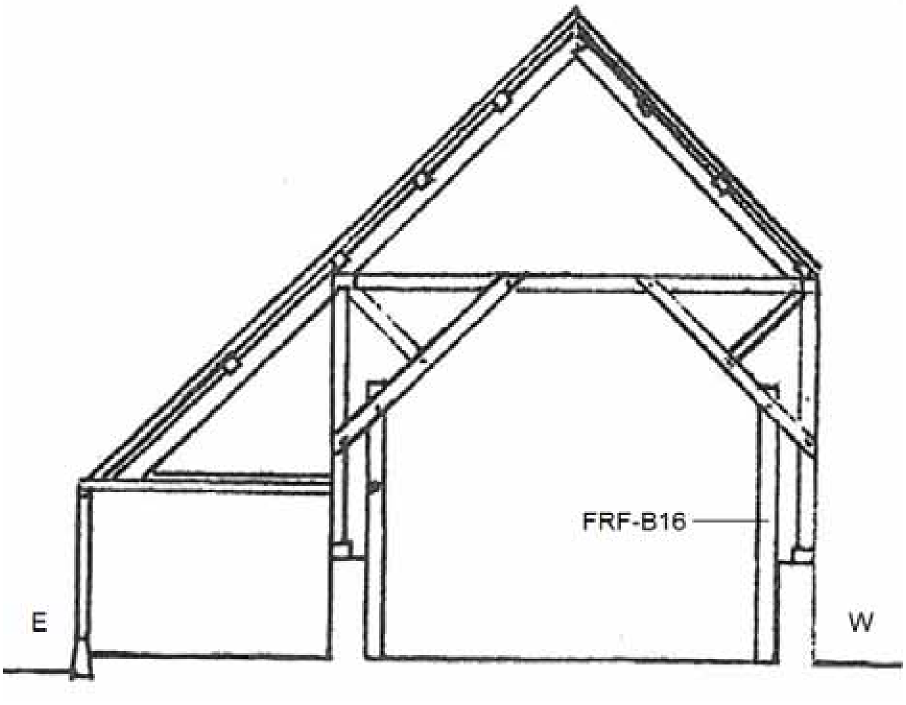

Figure 10: Truss 3, showing the location of sample FRF-B16 (Chesher et al *2008)*

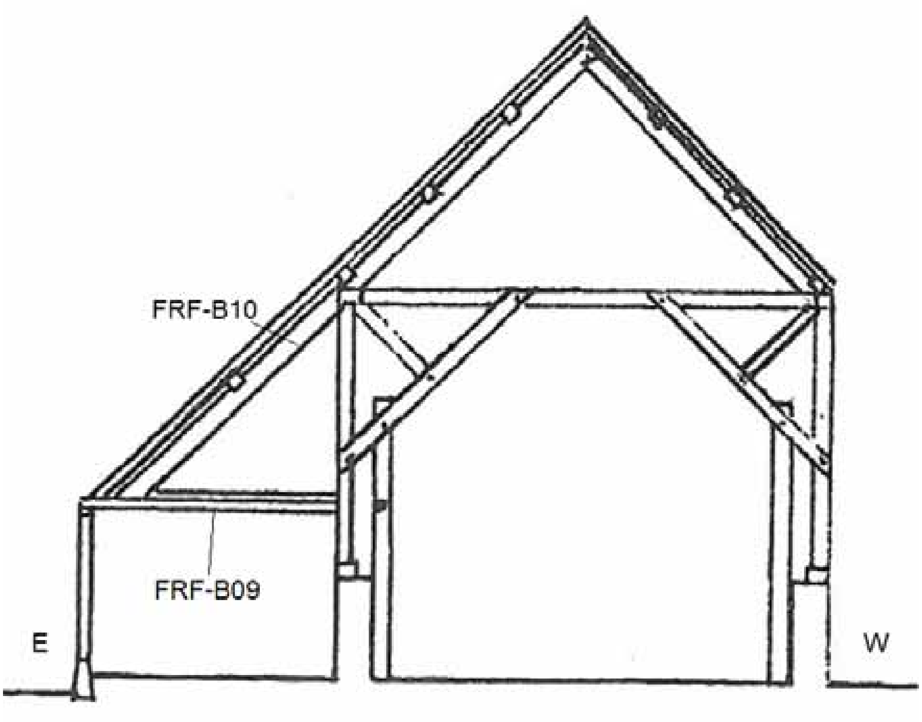

Figure 11: Truss 4, showing the location of samples FRF-B09 and FRF-B10 (Chesher et al *2008)*

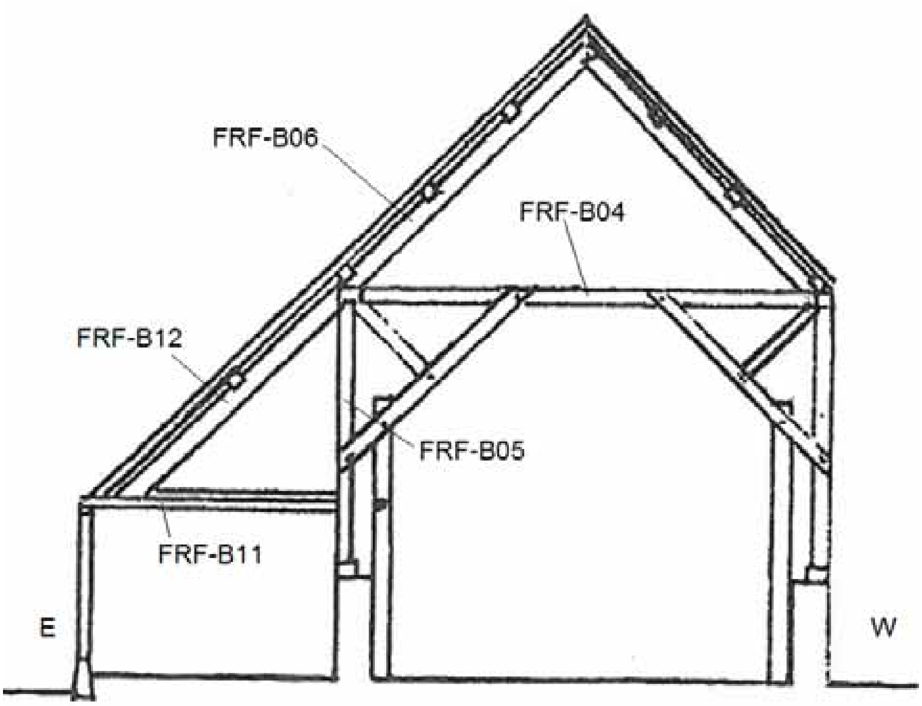

Figure 12: Truss 6, showing the location of samples FRF-B04–06 and FRF-B11–12 (Chesher et al *2008)*

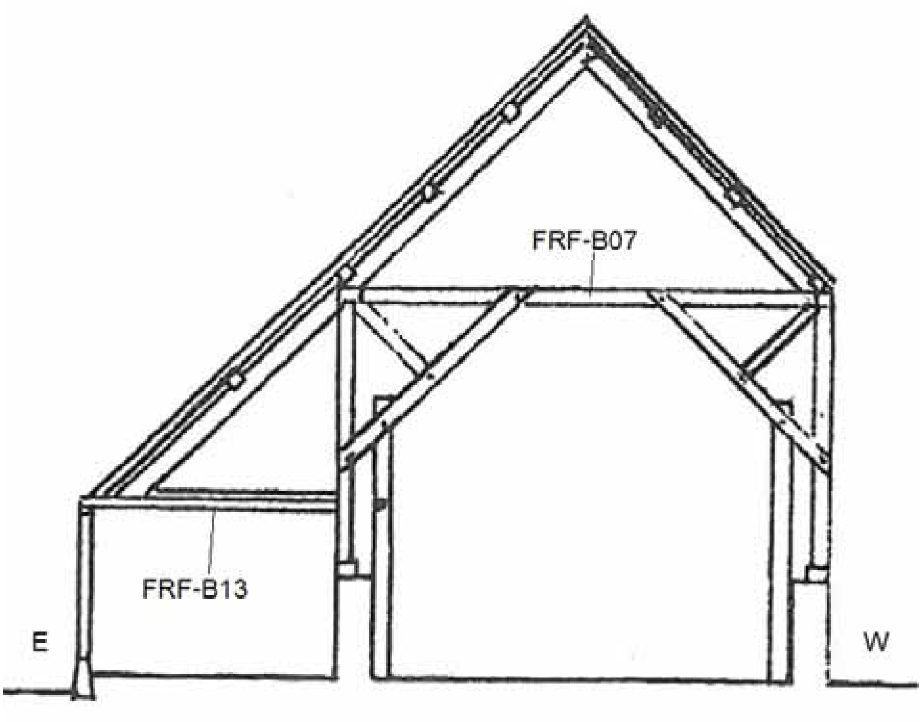

Figure 13: Truss 7, showing the location of samples FRF-B07 and FRF-B13 (Chesher et al *2008)*

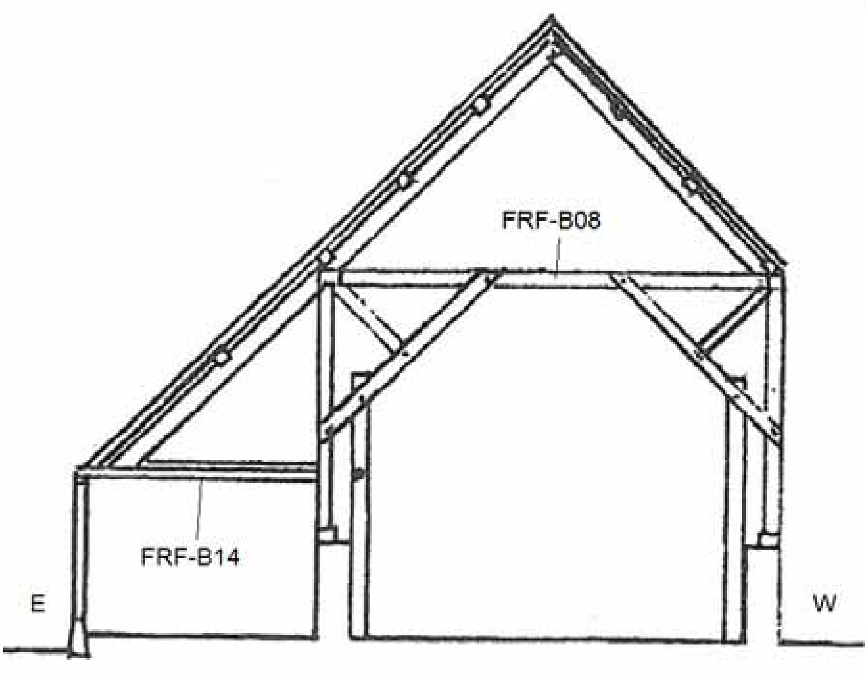

Figure 14: Truss 8, showing the location of samples FRF-B08 and FRF-B14 (Chesher et al *2008)*

Figure 15: Photograph to show the location of sample FRF-B17, from the west (Alison Arnold)

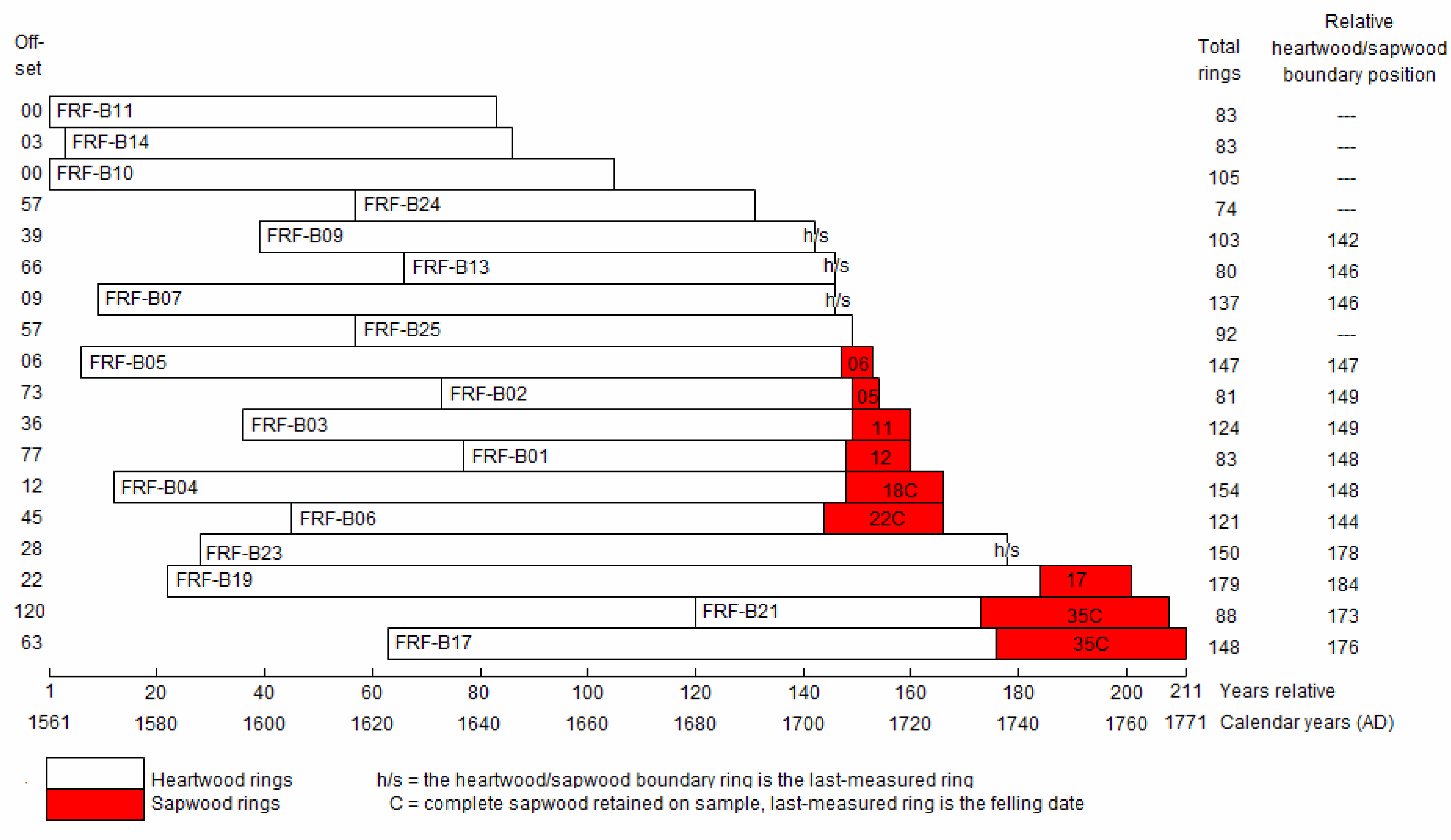

Figure 16: Bar diagram of samples in site sequence FRFBSQ01

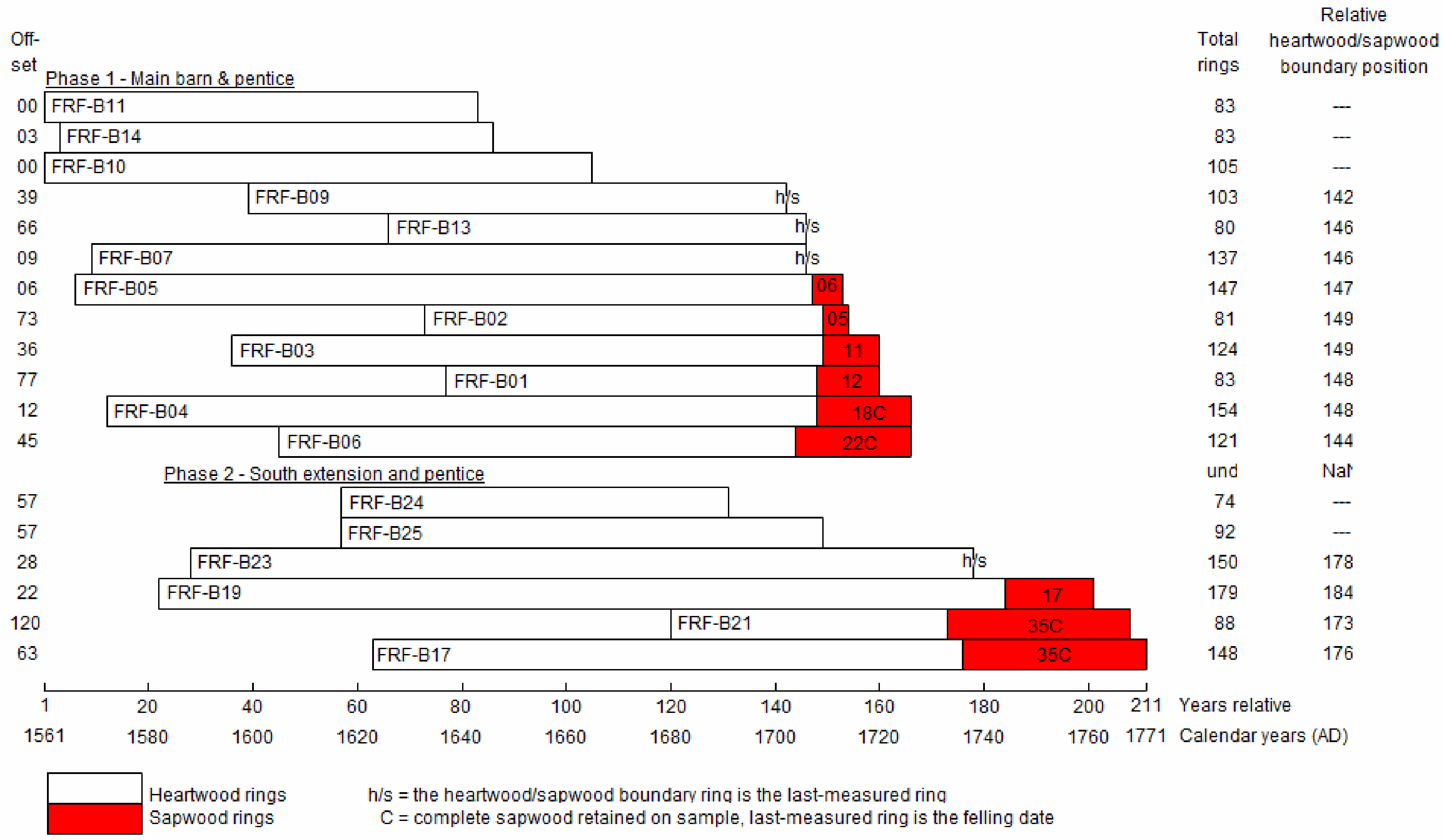

Figure 17: Bar diagram of dated samples, sorted by area

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

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FRF-B01A 83
 373 246 296 253 132 192 147 148 189 101  84  81  75 120 147 123 154 274 202 174
 152 135 173 241 260 225 245 247 282 188 309 300 168 191 166 242 212 162 102 135
 210 167 335 301 476 303 261 154 246 199 200 142 183 290 166 211 145 156 303 294
 252 197 182 165 162 240 324 140  91  76  70  82  53  55  69  74  85  76  91  59
  80  70  54
FRF-B01B 83
 380 243 300 240 125 192 143 147 199 100  83  76  70 130 156 117 149 279 217 184
 149 138 167 240 255 224 255 249 282 195 314 304 156 191 169 247 211 160 102 136
 211 168 334 300 475 304 270 155 239 199 203 142 184 288 174 212 148 153 302 285
 258 196 184 163 160 239 330 140  87  81  66  80  55  55  67  78  82  81  90  56
  73  78  64
FRF-B02A 81
 121 130  90 155 230 131 138 122  76  80  53  47 123  71  63  30  26  28  59 114
 163 205 221 186 229 129 226 216 163 228 223 230 214 268 258 214 234 207 240 198
 172  91  82 162 165 135 138 126 170 113 223  95 125  83 126 146 160 113  89  78
 118 163 165 138 105 102  67  98  63 104 363 198 123 148 113 297 107 170 241 365
 157
FRF-B02B 81
 121 123  96 160 233 107 117 128  83  71  53  54 113  77  58  35  26  28  55 110
 150 199 233 194 221 130 222 215 149 240 212 227 214 267 253 208 235 208 234 188
 183  93  76 158 165 146 124 131 173 115 218 107 118  82 122 152 169 103  85  89
 118 159 164 131 106  97  67  88  68 101 366 180 123 152 121 279 116 166 232 377
 153
FRF-B03A 124
 126 142 127  84 112 105 106 108  92 115  77 151  96 117  98  94  93 103  75  77
 123 121 125  96 102 115  74  67  78 102 124 123 111 100  56  56  76  62  59  65
  96 142 112 118 106  92  72  87  93 101  99 125 106  74  90  79  90 151 144 102
  89  82  91 167 159 118 150 152 167 150 199 201 176 134 190 112 184 126 143 106
 143 118 117 125 110 122 111  96  74 163 179 124 138 133 134 136  66  96 137 196
 177 108 100 121 157 129 267 295 140 159 249 185 187 151 155 189 177 140 121 229
 141 118 158 171
FRF-B03B 124
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 158 108  94 123 158 132 255 300 145 157 260 186 181 151 152 182 181 148 138 194
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FRF-B04A 154
 260 232 299 275 333 256 299 244 228 258 287 397 349 242 200 265 306 217 260 269
 174 201 194 225 201 151 117 137  93 114 184 172 111 135 177 175 202 183 207  90
 112 106 128 126 109 142 116 186 136 127  90  63  67 136  84 100 116 112 101 139
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FRF-B04B 154
 264 230 270 289 320 244 296 249 214 255 286 396 354 252 193 271 309 190 264 249
 172 202 204 216 190 153 107 136  94 115 169 170 106 127 194 178 193 179 212  83
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FRF-B06B 121
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FRF-B07B 137
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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 1998). 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

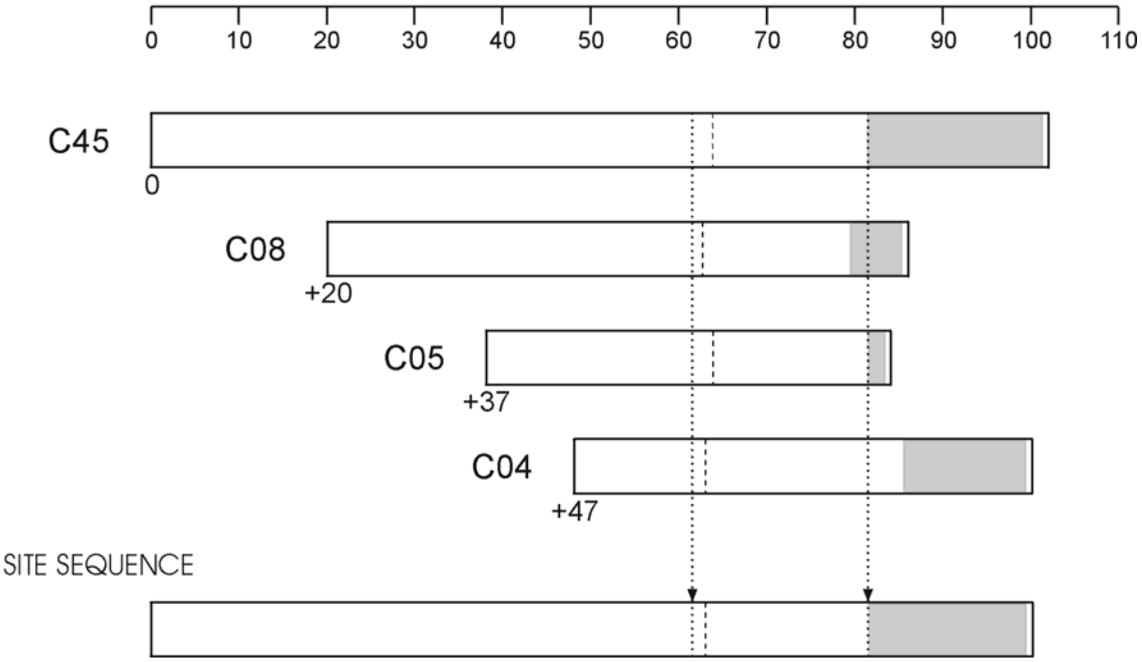


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

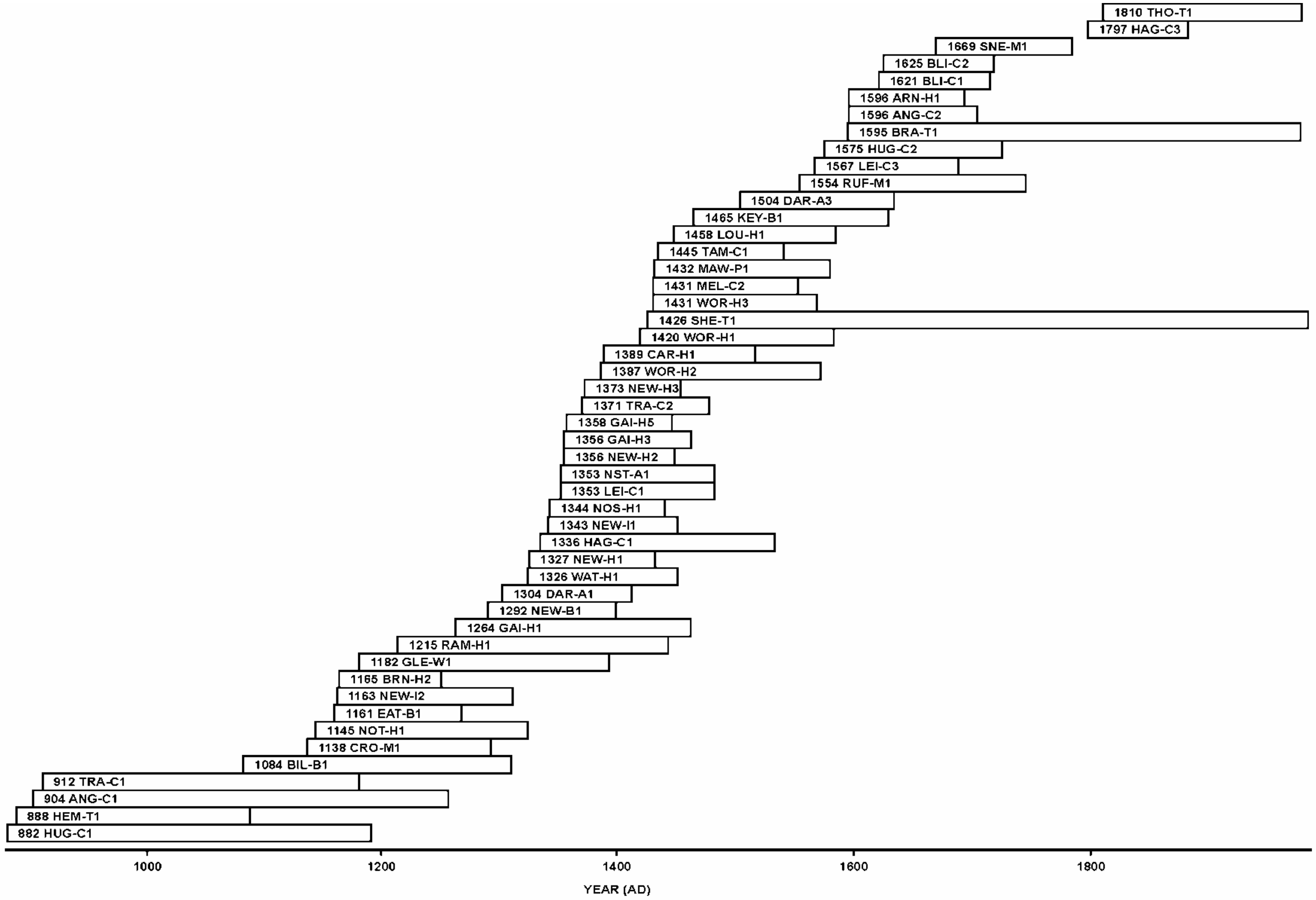
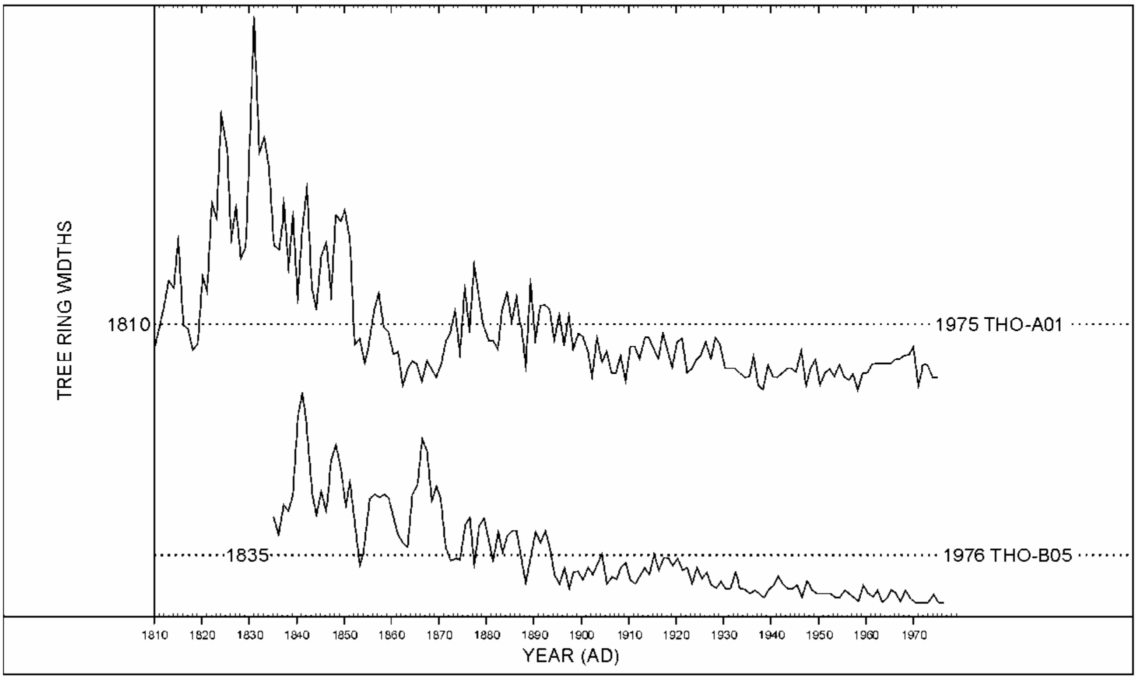


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

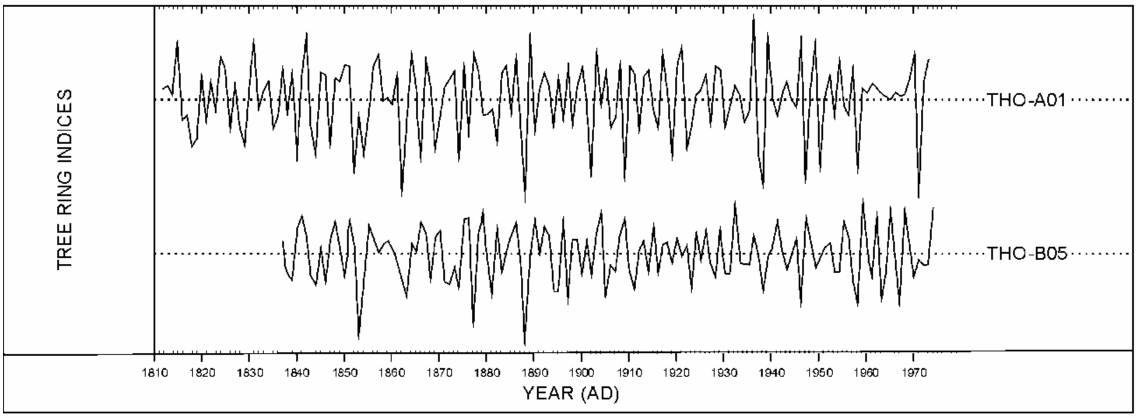


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

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