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BLACK MIDDENS BASTLE, GREENHAUGH, NORTHUMBERLAND
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

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SUMMARY
Analysis was undertaken on eight samples from the small number of timbers available at Black Middens bastle, Greenhaugh. Unfortunately, there was no conclusive cross-matching between any of the samples, and a site chronology could not be formed. None of the samples could be dated individually, despite their being compared to a large corpus of reference chronologies for oak. This site must, therefore, remain undated.

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CONTENTS

INTRODUCTION

Black Middens bastle is situated overlooking Black Burn, in the remote scenic regions between Hadrian's Wall and the Scottish border. It is sited approximately 10km west of the A68 trunk road as it passes close to Otterburn in Northumberland (NY 7731 8999, Figs 1 and 2). According to the listed building description (www.imagesofengland.org.uk), from which this introduction is taken, the bastle (Figs 3 and 4) is rectangular in plan, measuring 10.4m east–west by 7.3m north–south, the walls, of large, roughly squared, blocks laid in irregular courses up to 1.4m thick, and standing to a height of approximately 8.0m at the gable ridge. Larger, better-squared stones are used for the dressings.

The building, which is now roofless, illustrates the usual arrangement of its type as a two-storey structure with steeply pitched gables, possibly dating from the late-sixteenth century or early-seventeenth century. There are two doorways in the south wall leading to the lower rooms (Fig 4). Both of these, however, are eighteenth-century replacements of original doorways, and are wider than the original doors would have been. The original ladder access to the upper floor has been replaced by an external staircase to an original doorway. The site is an example of the rarer type of bastle in which the ground floor had a timber ceiling rather than one of vaulted stone. Black Middens is a Scheduled Ancient Monument and is also a Grade II* listed building under English Heritage guardianship.

THE TIMBERS

At the time of a survey in 1979, a larger number of timbers were present at Black Middens bastle, the joists of a first-floor frame, door lintels and surrounds, and roof frames (though almost certainly later replacements), along with the remains of three raised cruck trusses. However, 30 years on, there are now only a few beams remaining. These comprise stub blades of the three raised cruck trusses, buried high in the north wall (Fig 5), four, short, horizontal beams in the south-west corner, possibly supporting corbelling for a first-floor fireplace (Fig 6), and three lintels to each of the two ground-floor doorways.

It is likely that only the stub blades of the three raised cruck trusses and possibly the horizontal beams in the south-west corner are in their original positions (and these latter not certainly so). The other timbers, the lintels, have probably been salvaged from this building, or possibly another building altogether, and reset in their present locations during either eighteenth- or nineteenth-century alterations, or possibly during stabilisation and conservation works of the early 1980s.

SAMPLING

Sampling and analysis by tree-ring dating of timbers within Black Middens was requested by Martin Roberts, Historic Buildings Inspector based at English Heritage's Newcastle office, in an attempt to obtain a date for this structure. It was hoped that tree-ring analysis would not only determine its construction date with greater accuracy and reliability, but also establish how much of the extant timber might be original.

Thus, from the small number of suitable oak timbers available, a total of eight samples was obtained. Each sample was given the code BKM-A (for Black Middens, site 'A') and numbered 01–08. Of these eight samples, one, BKM-A01, is a cross-sectional slice believed to have been obtained from a timber during the early-1980s conservation works. The timber function and its location were not recorded at this time. A further three samples, BKM-A02–A04, were taken as cores from the three *in-situ* stub blades, with the remaining samples, BKM-A05–A08, being obtained as cores from the four horizontal beams in the south–west corner.

Other timbers were in theory available for sampling, these being the three door lintels to each of the two ground-floor rooms. However, apart from showing some evidence for reuse in their present positions, such as small mortices for window mullions, the timbers also tended to be broad and thin, and to be set deeply into the stonework above. As such, following the earlier assessment, it was agreed that such timbers were unlikely to provide usable samples, or meaningful results.

Where possible, the exception being the previously obtained sample BKM-A01, the positions of these samples were marked at the time of sampling on drawings made in 1979 by Plowman Craven and Associates, architects, and provided by English Heritage. These are reproduced here as Figures 7a/b. Details of the samples are given in Table 1. In this report the rear of the building is taken to face north (in actuality north-east), and the front, with its doorways and stairs, to face south, the gable ends facing east and west. The trusses and other timbers have been numbered from site west to site east.

ANALYSIS

Each of the eight samples obtained was prepared by sanding and polishing and the width of its annual growth rings were measured. The data of these measurements are given at the end of this report. The data of these eight samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix). None of the samples, however, conclusively cross-matched with each other. Each sample was, therefore, compared individually with a full series of reference chronologies for oak. There was again no satisfactory cross-matching and all the samples must, therefore remain undated for the moment.

INTERPRETATION AND CONCLUSION

None of the eight samples obtained from this site has dated, and it is thus not possible to give a felling date for any of the timbers cored. This is perhaps slightly unusual, in that all the samples have more than the minimum of 54 rings required for analysis, and two of them have over 100 rings. Although the rings on a few of the samples are quite narrow, they show no signs of compression or distortion which might make cross-matching and dating difficult.

It is possible, though this cannot be proven by tree-ring dating, that the lack of cross-matching between individual samples is caused by each timber being of a different date, with the growth rings they contain sharing no, or insufficient, overlap. Such a phenomenon would in effect make each sample a 'singleton' and while such samples can sometimes be dated, particularly where they have high numbers of rings, this is often much more difficult than with well-replicated data from several cross-matching samples. Such a situation is perhaps more likely at Black Middens, where it would appear that some timbers may have been salvaged and reset during the conservation works.

It is possible too that the timbers used at Black Middens are from an area, and or a time period, for which there is presently little reference material available with which the samples can be compared. It may only be when further samples and data is obtained from this region that the Black Middens samples might be dated.

TABLES

Table 1: Details of tree-ring samples from Black Middens bastle, near Gatehouse, Greenhaugh, Northumberland

Sample number	Sample location	Total rings	Sapwood rings*	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
BKM-A01	Unknown timber	71	h/s	------	------	------
BKM-A02	West cruck blade (north wall)	136	h/s	------	------	------
BKM-A03	Middle cruck blade (north wall)	55	h/s	------	------	------
BKM-A04	East cruck blade (north wall)	55	h/s	------	------	------
BKM-A05	West lateral beam	80	no h/s	------	------	------
BKM-A06	Middle lateral beam	67	no h/s	------	------	------
BKM-A07	East lateral beam	104	no h/s	------	------	------
BKM-A08	East–west longitudinal beam	86	h/s	------	------	------

*h/s = the heartwood/sapwood ring is the last ring on the sample

FIGURES

Figure 1: location of Black Middens bastle, Northumberland (circled)

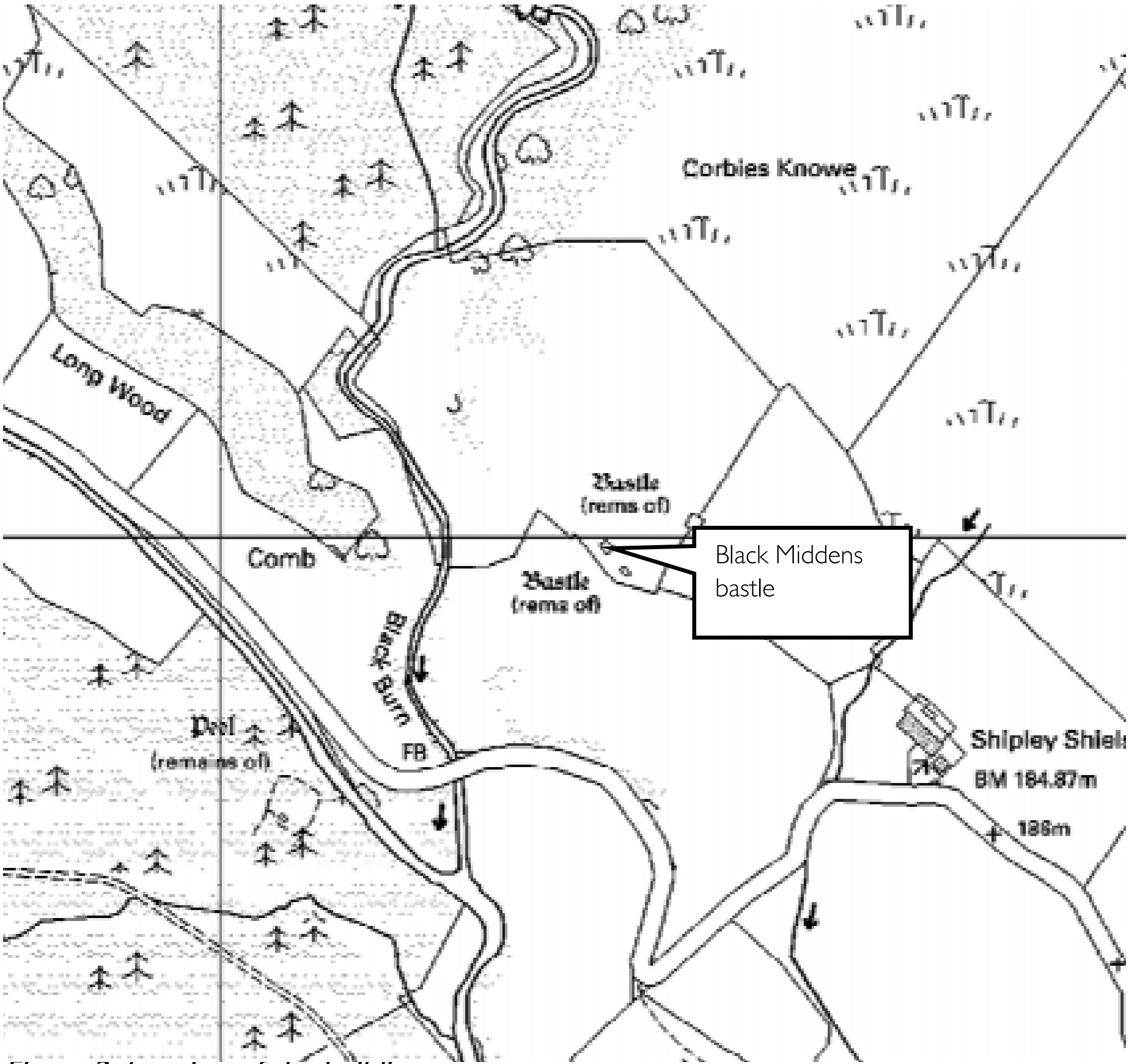


Figure 2: location of the building

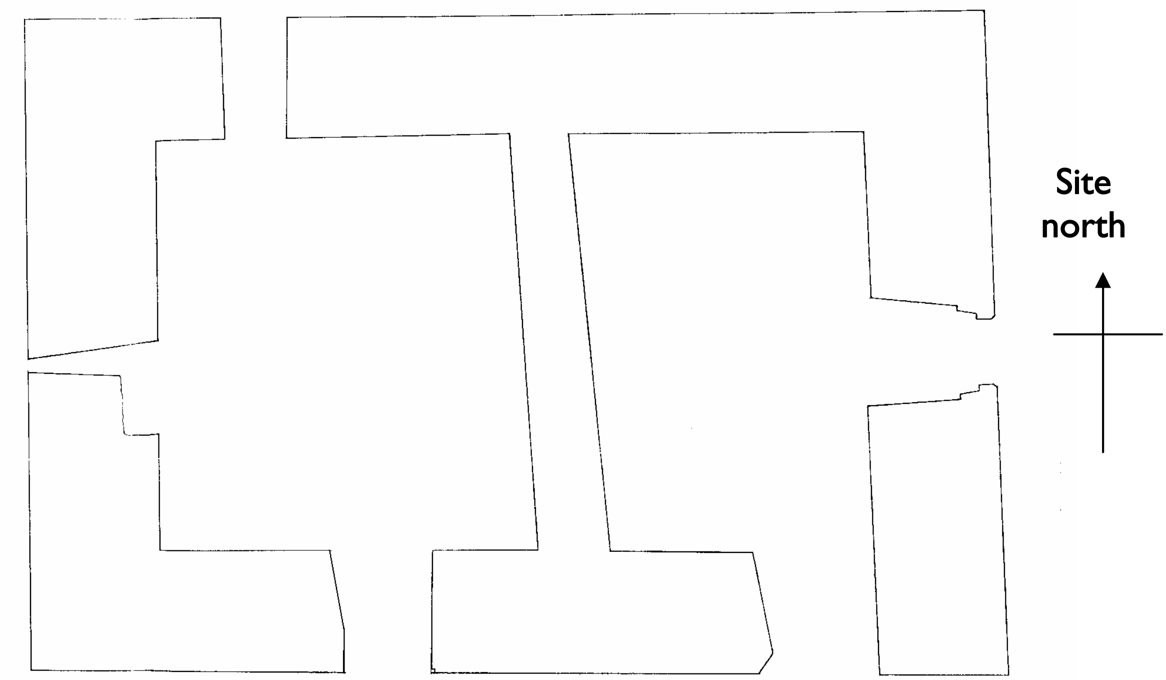


Figure 3: Simple plan of Black Middens bastle at ground floor level (after Plowman Craven & Associates, architects)

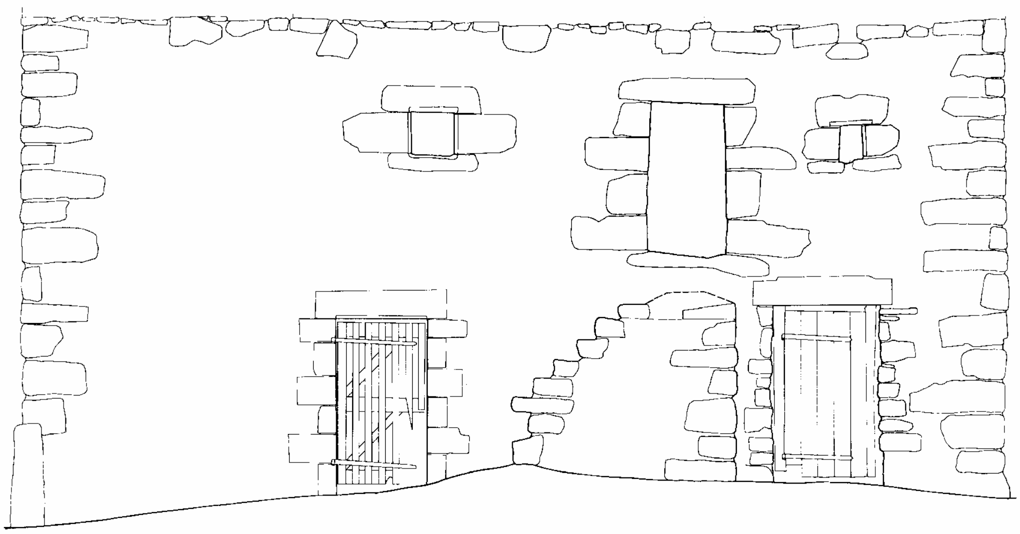


Figure 4: South elevation of Black Middens bastle (after Plowman Craven & Associates, architects)

Figure 5: North wall, interior, to show stub remains of the three raised cruck blades

Figure 6: South wall, interior, to show beams in the south–west corner

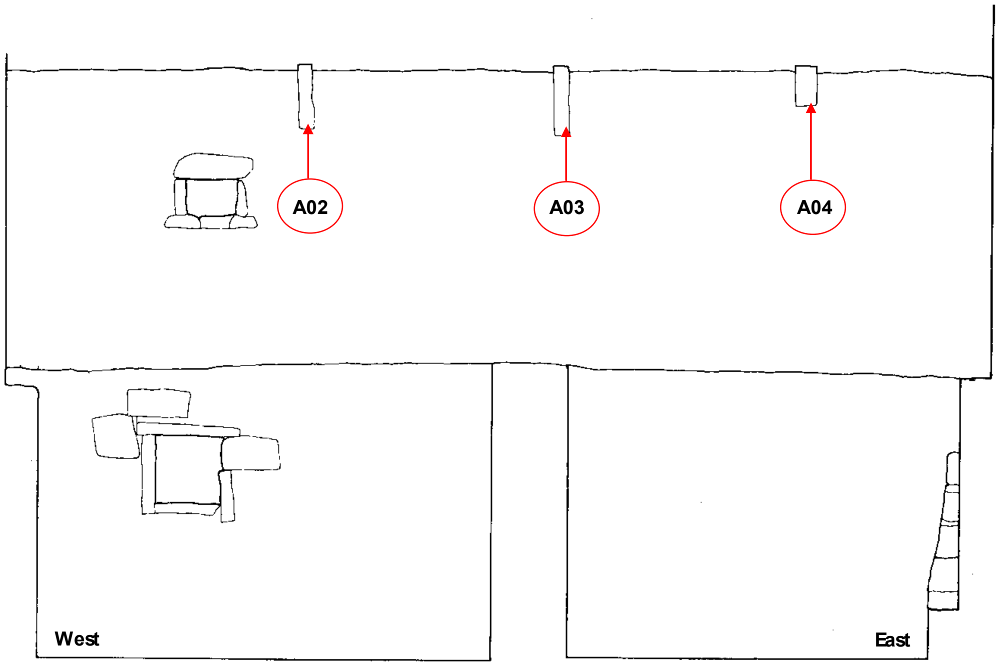


Figure 7a: Drawing of north wall interior to show sample locations (after Plowman Craven & Associates, architects)

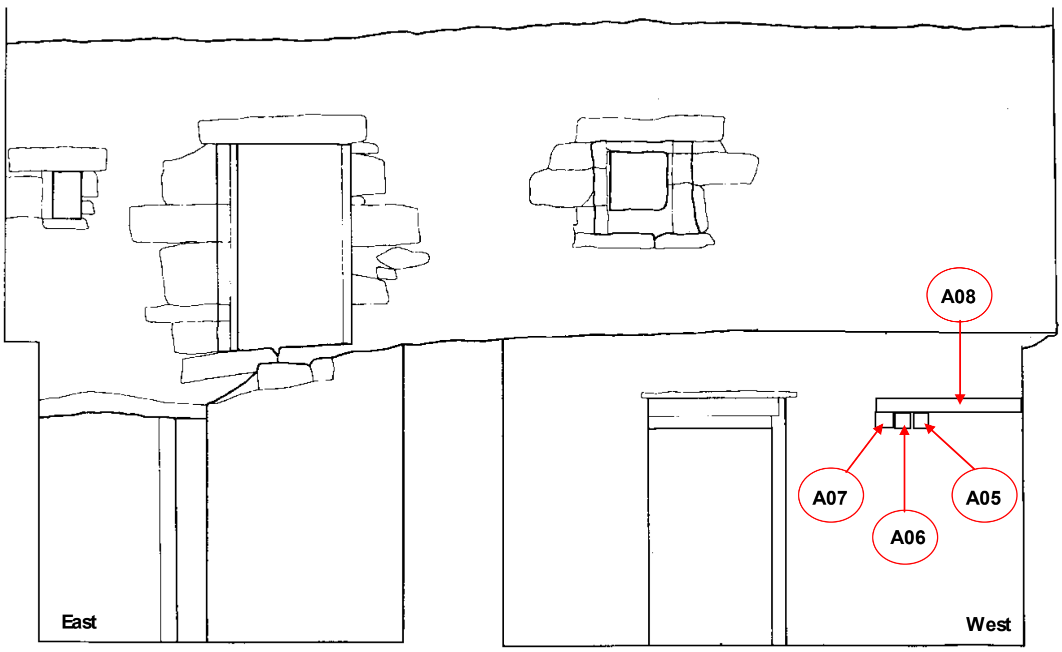


Figure7b: Drawing of south wall interior to show sample locations (after Plowman Craven & Associates, architects)

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

BKM-A01A 71
146 68 77 87 127 155 118 156 116 153 135 190 206 158 173 164 142 168 190 206
167 225 231 193 223 202 187 204 185 183 178 205 223 191 211 222 251 185 193 150
218 246 226 305 260 296 289 195 158 159 232 232 212 174 159 198 145 113 200 271
251 240 141 162 159 220 133 170 114 149 215
BKM-A01B 71
136 148 68 71 58 109 93 121 88 102 94 156 190 162 144 167 182 129 175 176
155 162 175 165 181 193 147 112 111 88 98 122 129 98 99 106 95 78 83 76
116 146 164 239 185 180 168 155 121 149 175 204 192 168 185 166 109 92 151 252
215 205 153 126 211 204 103 123 101 157 193
BKM-A02A 136
22 23 18 14 17 19 26 38 47 34 43 28 62 74 58 72 62 64 50 44
51 55 76 73 79 64 51 48 33 64 66 53 60 59 50 54 56 70 47 41
20 51 52 45 33 38 44 36 39 38 31 39 40 43 44 49 46 39 57 41
34 26 35 52 53 59 45 38 90 59 65 50 59 87 80 54 39 36 25 20
32 17 29 37 37 69 68 69 62 86 62 69 103 81 73 67 88 91 92 81
67 73 68 71 55 64 87 92 137 189 141 96 79 69 65 91 136 237 163 155
199 194 150 172 165 172 150 154 118 106 74 63 81 146 198 196
BKM-A02B 136
19 17 16 14 21 19 28 40 43 42 33 33 56 63 62 64 67 60 49 56
43 58 71 74 68 55 59 36 42 61 64 64 64 64 56 54 63 68 47 49
29 45 52 49 27 43 41 35 40 37 35 40 39 39 46 48 45 38 60 40
29 30 35 52 50 63 46 46 67 58 60 55 56 86 85 52 46 34 24 20
32 18 23 40 42 61 69 73 61 86 53 69 102 76 81 73 84 85 99 75
80 73 68 60 68 69 76 98 126 194 140 98 71 69 63 97 129 241 161 153
212 199 167 181 166 168 149 152 117 111 61 63 84 162 179 194
BKM-A03A 55
187 292 308 271 197 163 252 298 274 229 310 265 302 163 175 202 168 399 385 283
316 328 234 297 424 518 372 318 431 357 374 305 313 378 321 333 270 195 277 194
304 303 234 256 368 281 325 261 360 371 355 333 359 173 173
BKM-A03B 55
184 272 297 290 207 165 230 301 264 218 327 282 299 173 178 208 180 404 372 280
319 295 258 289 440 520 345 329 407 379 388 311 335 388 311 317 294 174 270 200
266 327 216 247 358 289 299 259 402 379 338 356 348 179 164
BKM-A04A 55
283 246 239 328 278 397 345 209 233 179 299 168 235 155 204 159 186 245 225 124
238 260 294 255 226 166 209 231 179 245 196 214 197 168 158 206 310 308 410 315
296 390 346 387 360 205 300 311 289 289 397 294 238 460 225
BKM-A04B 55
339 225 238 293 268 376 380 210 240 167 286 164 226 166 201 147 182 242 214 134
243 257 301 252 229 176 193 233 183 220 218 200 210 168 160 209 307 299 408 332
294 384 349 396 362 200 301 317 283 296 377 278 251 444 225
BKM-A05A 80
261 149 213 284 154 166 159 140 118 139 113 146 126 154 162 136 115 79 101 99
94 114 81 94 72 106 119 134 159 119 104 141 81 65 55 42 57 67 46 67
60 96 89 68 84 103 96 118 83 83 76 63 63 61 49 49 52 73 55 52
58 45 49 62 50 59 57 52 55 38 54 58 49 48 51 46 41 42 47 40

BKM-A05B 80
258 149 215 286 160 163 156 147 116 140 110 141 125 153 164 137 116 88 99 100
96 111 83 95 78 102 124 138 154 119 107 136 79 59 54 46 58 68 48 68
70 88 87 70 79 102 95 112 74 87 76 63 62 66 48 52 47 72 58 56
51 51 44 57 51 57 50 59 53 44 55 50 57 45 49 43 42 41 46 38
BKM-A06A 67
119 146 113 126 136 226 160 128 131 134 119 113 98 84 106 96 114 126 96 102
92 81 89 101 84 109 73 68 69 79 61 69 63 74 81 95 98 103 94 103
98 112 96 137 113 122 87 92 108 97 70 95 109 84 96 89 126 94 100 90
89 109 79 82 79 99 107
BKM-A06B 67
126 153 112 129 130 225 151 132 134 138 118 104 95 86 101 98 99 126 103 107
97 81 95 95 75 107 76 67 65 80 64 79 61 69 82 101 93 106 96 99
102 111 94 132 113 121 98 81 105 92 69 91 113 83 95 79 125 96 100 96
81 109 77 85 77 93 106
BKM-A07A 104
86 45 51 63 59 78 56 58 68 54 58 62 48 74 54 58 63 56 52 59
43 62 67 76 75 78 83 82 84 84 80 90 83 72 76 67 69 77 69 61
70 65 76 78 85 71 84 80 88 95 73 79 75 84 84 82 87 62 57 84
64 65 66 53 52 70 78 95 134 134 116 128 122 158 123 125 99 115 108 118
93 94 153 140 163 209 263 208 190 198 252 236 237 136 161 121 163 183 194 230
231 256 244 202
BKM-A07B 104
82 57 60 57 68 61 59 69 64 52 57 66 37 71 42 56 70 60 62 54
42 55 68 64 71 75 79 81 82 80 75 87 82 74 76 60 68 68 67 66
63 59 69 86 90 66 74 82 81 103 55 79 68 90 82 79 78 70 63 82
62 69 67 57 53 64 84 94 114 145 117 129 132 148 130 111 102 110 118 104
102 98 145 142 168 211 258 209 174 195 258 237 242 141 167 118 151 175 189 204
227 248 241 209
BKM-A08A 86
130 95 87 242 173 175 165 122 61 47 102 112 135 151 147 128 93 97 95 69
108 62 70 55 59 57 81 140 83 107 121 133 132 143 121 109 102 93 94 101
195 197 260 206 120 59 83 119 131 189 196 141 141 105 93 73 135 170 318 180
176 158 78 59 57 87 164 116 100 81 103 57 59 66 93 128 100 75 68 69
68 63 74 61 86 114
BKM-A08B 86
106 93 157 232 197 162 163 132 70 56 98 119 130 156 149 126 107 90 105 62
110 71 69 53 66 60 85 128 96 108 123 142 129 155 115 108 108 103 99 100
172 218 255 200 135 66 79 117 118 174 150 145 120 103 80 68 140 151 284 159
186 181 74 71 59 117 164 129 87 83 111 64 52 69 103 118 93 82 66 73
77 52 70 73 92 114

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	

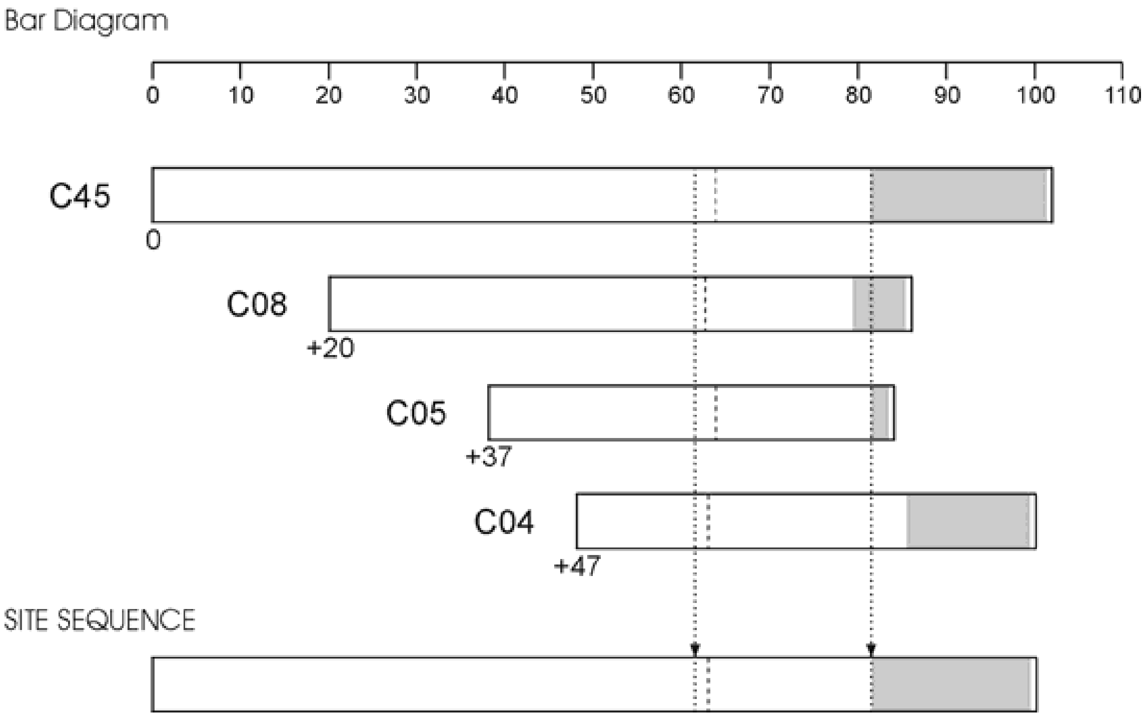


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

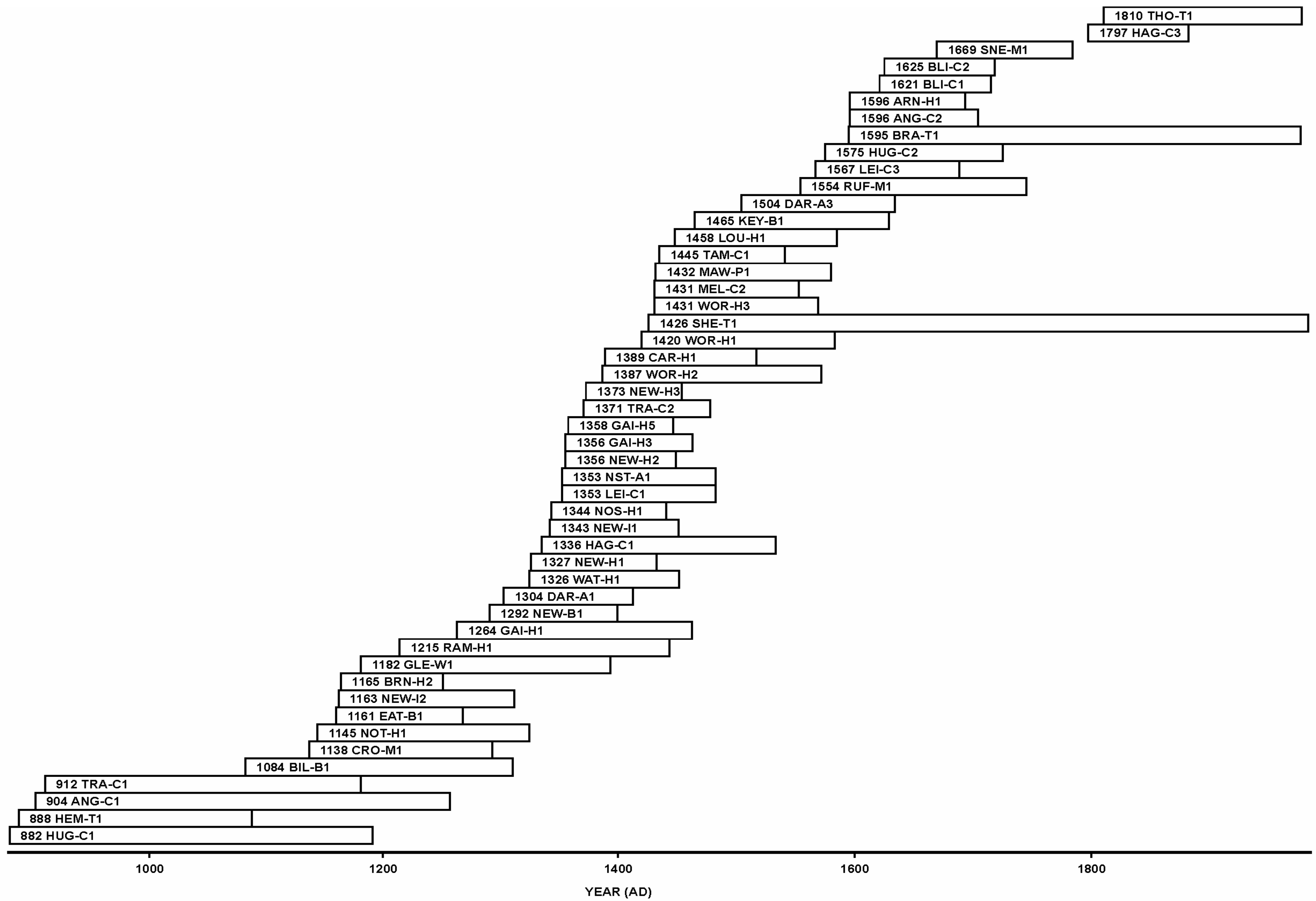
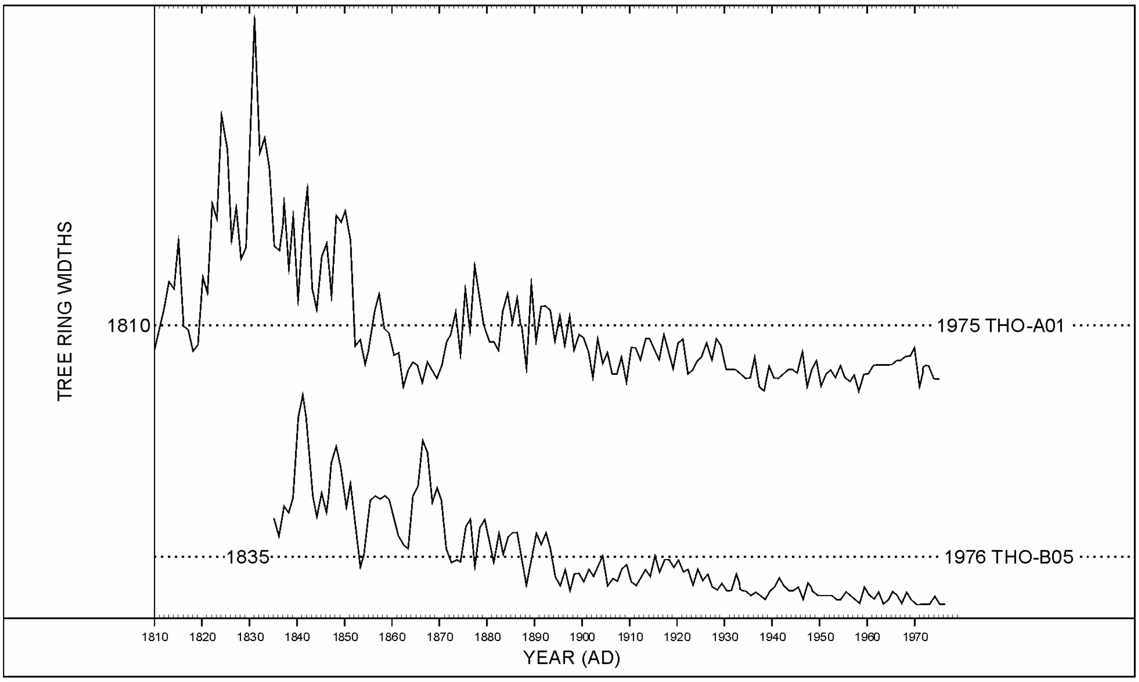


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

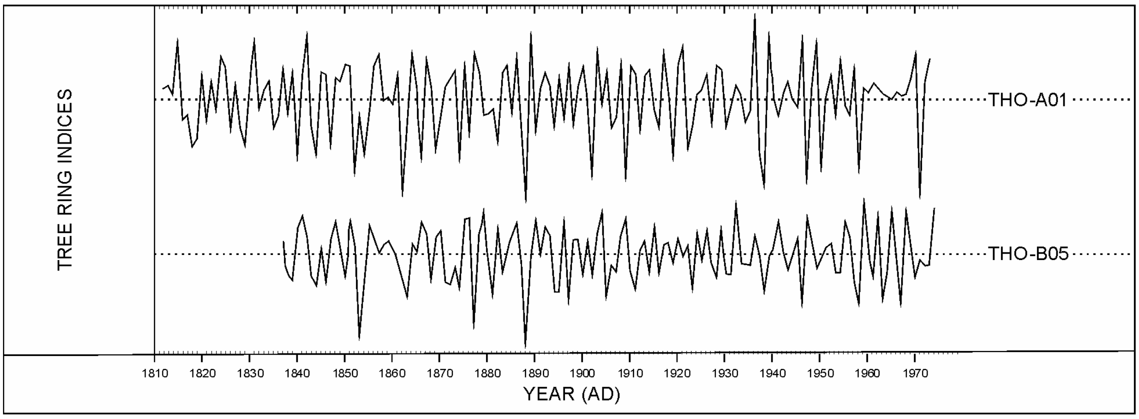


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

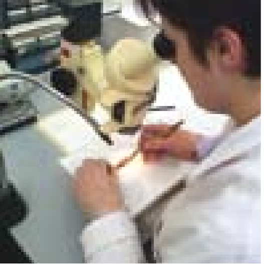
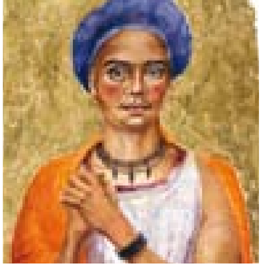
Laxton, R R, Litton, C D, and Howard, R E, 2001 *Timber: Dendrochronology of Roof Timbers at Lincoln Cathedral*, Engl Heritage Res Trans, 7

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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