

Ancient Monuments Laboratory  
Report 62/1999

TREE-RING ANALYSIS OF TIMBERS  
FROM UPPER HARDRES BARN,  
HARDRES COURT, UPPER HARDRES,  
KENT

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Summary

Seven samples from Upper Hardres barn were analysed by tree-ring dating. This analysis produced a single site chronology consisting of two samples, with 111 rings. Although this site chronology was compared with a full range of relevant reference chronologies, there was no satisfactory cross-matching. Each of the five remaining ungrouped samples was also compared with a full range of relevant reference chronologies, but again there was no satisfactory cross-matching. This site must therefore remain undated

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## TREE-RING ANALYSIS OF TIMBERS FROM UPPER HARDRES BARN, HARDRES COURT, UPPER HARDRES, KENT

### Introduction

Upper Hardres barn is a grade II\* listed building near Petham, about five miles south of Canterbury (TR 152508, see Fig 1). It is a substantial building believed to date from the late-fifteenth to early-sixteenth centuries. It has nine bays of aisled-truss construction, being about 150 feet long by about 33 feet wide. Internal evidence suggests that at one time the barn was at least one bay longer. Only the southernmost five bays remain to full height, the trusses here having unbraced crown-posts, jowled main-posts from which spring slightly curved braces to the collars, and passing braces to the base of the aisle posts.

The other bays to the north have had a mezzanine floor inserted. The form of the trusses in these bays is different from those five to the south. In these crown-posts are not used and the passing shores are replaced by braces from the upper part of the main posts to aisle-ties. An illustrative example of the two different trusses is provided in Figure 2. The roof is hipped at both ends.

Sampling and analysis by tree-ring dating was commissioned by English Heritage. The purpose of this was to establish with greater certainty the dating of this building at risk and to promote and inform the progress of repair.

### Sampling

This building has been the subject of a substantial fire, which destroyed a large number of smaller timbers and made the site difficult, though not impossible, to examine. Although it contained a substantial quantity of very large timbers, it could be seen quite clearly that the vast majority of it was extremely wide-ringed and quite unsuitable for analysis by dendrochronology. Thus, in the whole building only seven timbers could be found that had sufficient rings for satisfactory analysis.

Each of these seven timbers was sampled by coring. Each sample was given the code HRD-A (for Hardres, site "A") and numbered 01-07. The location of the cores was recorded at the time of sampling on plans provided by English Heritage, reproduced here as Figure 3. Details of the samples are given in Table 1.

### Analysis

Each sample was prepared by sanding and polishing and the growth-ring widths of all seven samples measured. The data of these measurements are given at the end of the report. The growth-ring widths of the seven samples were compared with each other by the Litton/Zainodin grouping procedure (see appendix). At a minimum t-value of 4.5 one group of two samples, HRD-A01 and A07, formed, cross-matching as shown in the bar diagram, Figure 4.

The growth-ring widths of these two samples were combined at these relative off-set positions to form HRDASQ01, a site chronology of 111 rings. Site chronology HRDASQ01 was compared with a series of relevant reference chronologies for oak, but there was no satisfactory cross-matching at any position.

Site chronology HRDASQ01 was compared with the five remaining ungrouped samples, but there was no further satisfactory cross-matching. Each of these five ungrouped samples was compared individually with the full range of relevant reference chronologies, but again there was no satisfactory cross-matching.

This site must, therefore, remain undated. This lack of cross-matching and dating may in part be due to the rather wide and complacent nature of the growth rings, which may have little climatic signature. It may be significant that two other buildings from Upper Hardres which had been sampled some time ago also remain undated. Perhaps the source of the timber in this area is from a micro-climate not represented in the current reference or other site chronologies.

Table 1: Details of samples from Upper Hardres Barn, Hardres Court, Upper Hardres, Kent

Sample no.	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
HRD-A01	East post, truss D	111	h/s	-----	-----	-----
HRD-A02	North brace from east post truss D to aisle plate	119	22C	-----	-----	-----
HRD-A03	South brace from west post truss D to aisle plate	74	h/s	-----	-----	-----
HRD-A04	West post, truss C	109	h/s	-----	-----	-----
HRD-A05	East post truss C	72	h/s	-----	-----	-----
HRD-A06	East post, truss A	107	h/s	-----	-----	-----
HRD-A07	West post, truss A	54	h/s	-----	-----	-----

\*h/s = the heartwood/sapwood boundary is the last ring on the sample  
 C = complete sapwood is retained on sample

Figure 1: Map to show general location of Upper Hardres

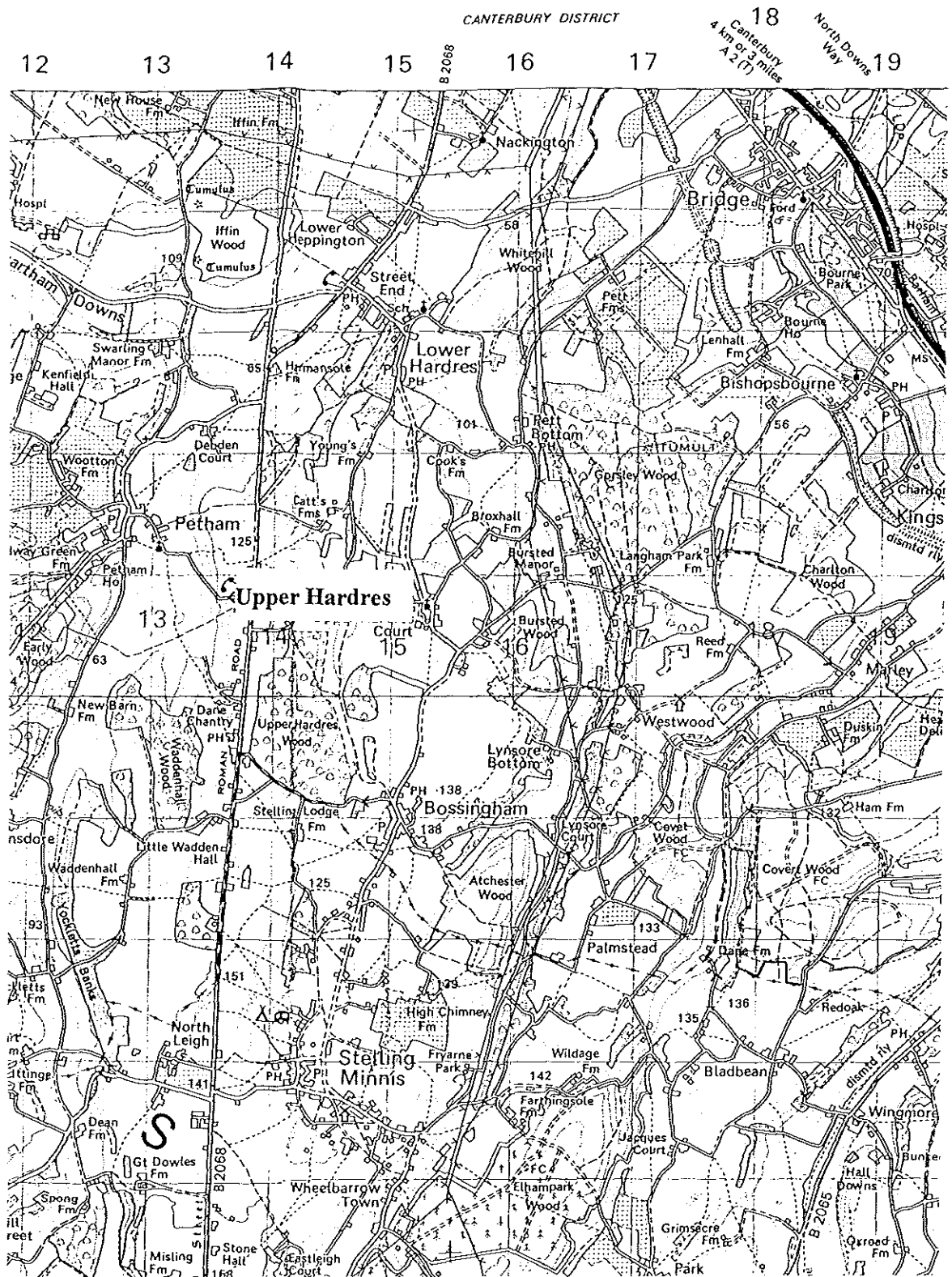


Figure 2: Illustrative examples of two trusses, truss A above, truss F below

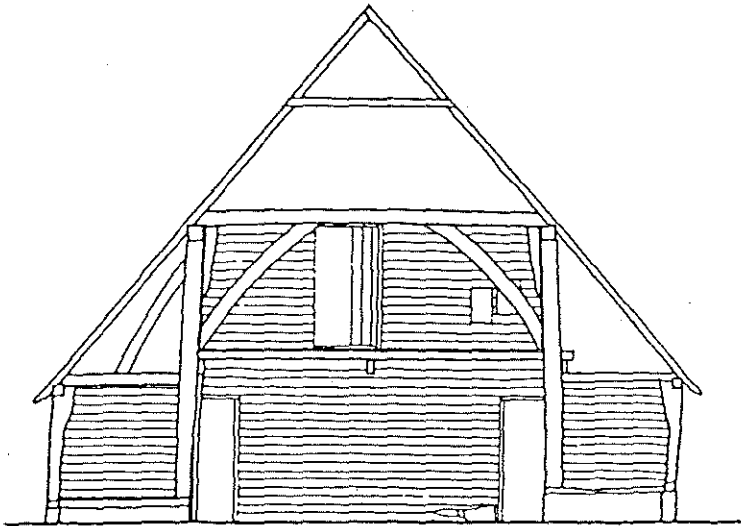
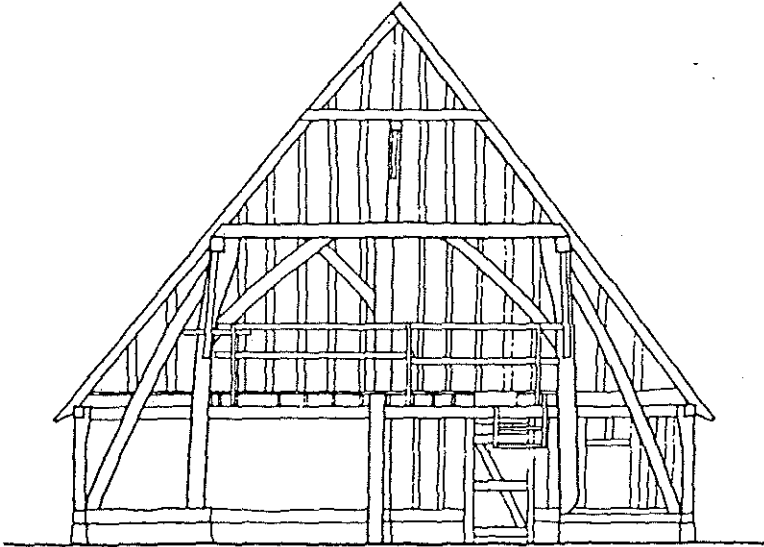


Figure 3: Plan to show position of samples

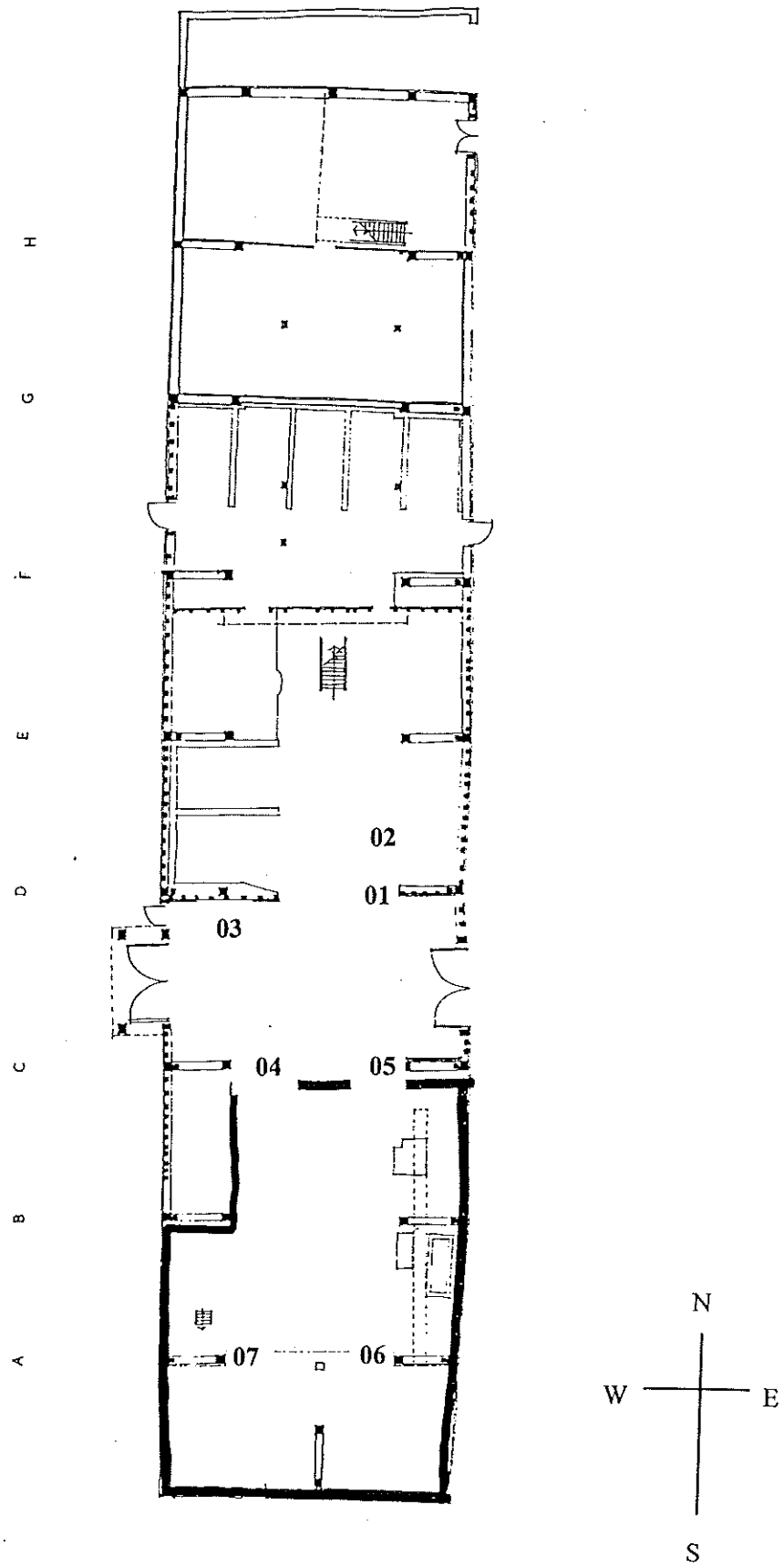
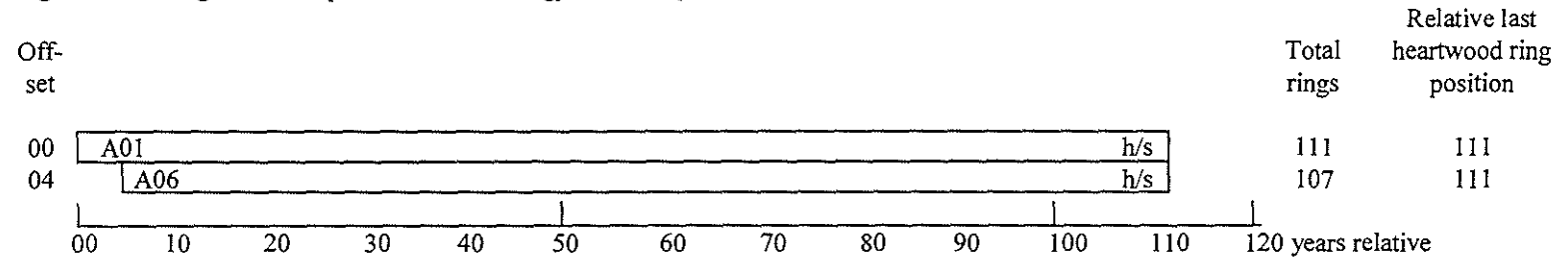




Figure 4: Bar diagram of samples in site chronology HRDASQ01



White bars = heartwood rings

h/s = heartwood/sapwood boundary is last ring on sample

Data of measured samples - measurements in 0.01mm units

HRD-A01A 111

303 330 289 290 207 208 195 152 122 96 111 109 96 32 45 110 144 148 153 130  
163 163 224 267 155 168 140 154 132 128 139 100 98 121 106 126 151 136 176 281  
206 179 172 196 75 134 152 86 108 79 98 94 112 130 118 149 129 92 191 226  
185 181 176 203 196 225 206 228 212 194 192 210 100 60 42 75 77 68 74 73  
58 70 75 97 73 76 140 156 211 155 164 179 194 119 176 158 121 148 179 196  
194 202 199 138 116 167 129 117 119 109 131

HRD-A01B 111

299 350 312 301 206 196 197 153 107 91 107 112 79 44 38 118 160 121 148 128  
140 170 214 266 151 166 140 154 128 147 150 104 98 120 99 124 138 148 180 277  
212 178 173 194 72 133 159 91 107 77 86 97 114 122 125 159 186 120 202 180  
186 173 182 203 190 237 220 240 200 195 186 203 75 59 59 75 76 84 65 77  
66 71 73 91 68 88 131 163 177 169 158 164 184 119 169 154 136 145 178 211  
192 204 194 147 98 159 124 116 118 116 144

HRD-A02A 119

249 367 190 165 183 124 88 140 143 169 127 130 169 122 148 165 219 300 200 256  
174 240 266 85 71 64 78 122 132 119 130 77 110 106 68 72 72 97 141 117  
101 90 108 167 121 181 175 137 91 39 43 39 47 68 58 54 62 95 73 124  
86 86 129 134 202 181 235 197 125 196 214 146 208 127 192 159 99 131 116 195  
192 185 170 161 156 141 204 182 199 131 108 121 85 105 130 171 182 170 157 200  
165 192 129 161 232 106 158 144 142 148 159 175 125 157 159 156 104 116 141

HRD-A02B 119

144 359 192 157 186 129 82 141 134 164 124 136 166 115 168 178 207 302 203 254  
177 226 270 93 69 60 82 116 123 121 131 75 121 106 64 65 80 92 140 122  
105 85 119 164 122 213 156 134 83 44 42 42 45 70 56 56 69 94 66 130  
86 85 119 127 213 186 220 211 130 192 206 136 224 123 179 168 98 128 121 196  
179 193 174 158 162 135 205 186 194 134 97 128 83 97 134 174 180 168 153 195  
148 197 125 161 230 131 142 139 157 142 153 167 125 165 158 148 104 123 155

HRD-A03A 74

309 231 287 291 258 338 468 375 377 325 274 283 385 468 220 272 425 304 268 70  
49 54 120 110 134 129 286 177 65 45 59 58 76 144 131 210 202 175 188 281  
170 50 45 53 59 78 87 111 89 101 92 99 132 204 292 140 168 135 160 240  
171 200 258 128 227 298 277 223 186 581 523 361 237 235

HRD-A03B 74

323 245 281 283 285 314 459 363 365 319 275 284 422 449 212 256 426 290 264 76  
40 69 112 107 140 128 288 171 54 54 61 57 78 149 133 205 208 174 183 284  
166 58 40 49 67 75 83 116 86 102 85 91 124 212 276 161 165 143 153 239  
174 189 251 141 225 308 268 218 193 582 516 386 228 253

HRD-A04A 109

375 135 331 230 334 272 191 186 267 284 248 214 185 225 165 210 217 175 222 57  
68 61 89 142 103 85 119 137 49 39 58 110 92 96 84 98 108 93 165 146  
159 123 41 37 33 62 58 65 93 72 43 79 81 146 171 127 180 139 127 109  
89 54 45 39 77 49 69 61 88 122 98 90 151 152 111 155 148 121 183 171  
124 150 50 55 42 54 56 53 55 79 76 115 98 124 89 116 104 120 116 114  
96 163 126 168 142 200 146 158 151

HRD-A04B 109

364 141 332 236 329 275 196 198 276 288 258 215 177 229 163 204 217 180 207 64  
73 70 86 136 107 92 125 134 48 45 68 92 77 86 74 108 94 90 165 144  
169 121 42 37 32 58 63 64 96 68 44 75 86 144 153 140 172 136 139 100  
88 56 42 44 76 53 65 61 89 122 102 94 141 144 118 152 164 116 184 167  
119 147 57 47 41 61 50 56 47 78 86 112 90 132 81 102 106 111 103 115  
103 158 131 147 129 198 159 150 179

HRD-A05A 72

56 85 92 420 309 336 241 126 119 139 339 319 222 200 182 99 99 39 57 88  
98 75 75 52 41 48 30 59 61 49 41 110 101 94 92 109 121 133 213 136  
216 255 182 107 71 73 92 83 87 83 85 101 88 103 93 145 213 200 114 224  
314 326 239 196 174 186 212 426 336 361 366 420

HRD-A05B 72

58 91 87 444 293 342 247 134 119 153 340 316 222 199 182 105 109 39 59 76  
95 86 74 51 50 46 35 43 50 41 44 113 97 98 102 118 128 136 185 121  
203 278 199 116 73 74 79 96 86 83 90 96 89 103 97 152 211 200 113 223  
342 314 235 205 176 178 207 408 286 359 367 389

HRD-A06A 107

286 210 187 208 141 111 100 90 72 45 48 103 175 176 190 225 189 198 265 299  
184 209 144 160 118 126 147 121 103 120 119 106 136 114 124 161 179 163 161 194  
94 102 133 88 103 79 96 75 106 143 146 172 160 140 154 204 198 189 190 189  
206 287 225 213 167 135 163 197 101 71 41 67 70 81 79 91 74 77 93 101  
82 76 79 109 130 148 119 141 149 143 125 106 110 119 147 161 163 194 172 109  
98 130 116 110 101 101 116

HRD-A06B 107

247 220 198 204 136 106 101 90 66 49 41 103 220 157 205 189 192 184 247 268  
198 202 146 153 122 135 153 116 106 117 133 103 137 108 116 173 166 169 152 174  
92 112 125 87 95 87 94 82 105 154 138 161 179 121 153 202 194 194 186 202  
220 294 230 214 156 148 161 194 99 67 43 66 75 82 77 88 72 84 92 105  
83 70 80 109 137 139 123 142 162 134 131 101 113 111 159 157 162 192 170 118  
96 122 118 102 109 87 122

HRD-A07A 54

418 169 85 182 280 236 181 177 193 267 231 228 196 178 171 207 160 176 265 273  
301 289 486 367 338 294 288 269 316 406 282 273 307 271 195 270 234 174 183 187  
217 195 175 170 181 191 157 237 303 284 267 301 495 362

HRD-A07B 54

448 182 68 187 279 245 170 180 210 256 232 200 191 172 180 201 168 178 272 270  
288 278 458 367 316 297 272 202 304 383 278 279 300 284 210 256 219 179 176 194  
246 190 176 170 178 167 180 261 268 285 284 303 478 358

## APPENDIX

### Tree-Ring Dating

#### The Principles of Tree-Ring Dating

Tree-ring dating, or *dendrochronology* as it is known, is discussed in some detail in the Laboratory's Monograph, '*An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Buildings*' (Laxton and Litton 1988b) and, for example, in *Tree-Ring Dating and Archaeology* (Baillie 1982) or *A Slice Through Time* (Baillie 1995). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The *width* of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure 1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring.

If the bark is still on the sample, as in Figure 1, then the date of the last ring will be the date of felling of the oak from which it was cut. There is much evidence that in medieval times oaks cut down for building purposes were used almost immediately, usually within the year or so (Rackham 1976). Hence if bark is present on several main timbers in a building, none of which appear reused or are later insertions, and if they all have the same date for their last ring, then we can be quite confident that this is the date of construction. If there is no bark on the sample, then we have to make an estimate of the felling date; how this is done is explained below.

#### The Practice of Tree-Ring Dating at the University of Nottingham Tree-Ring dating Laboratory

1. *Inspecting the Building and Sampling the Timbers.* Together with a building historian we inspect the timbers in a building to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can sample *in situ* timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer rings than this, 50 for example, sequences of widths become difficult to match to a unique position within a master sequence of ring widths and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure 2 has about 120 rings; about 20 of which are sapwood rings. Similarly the core has just over 100 rings.

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

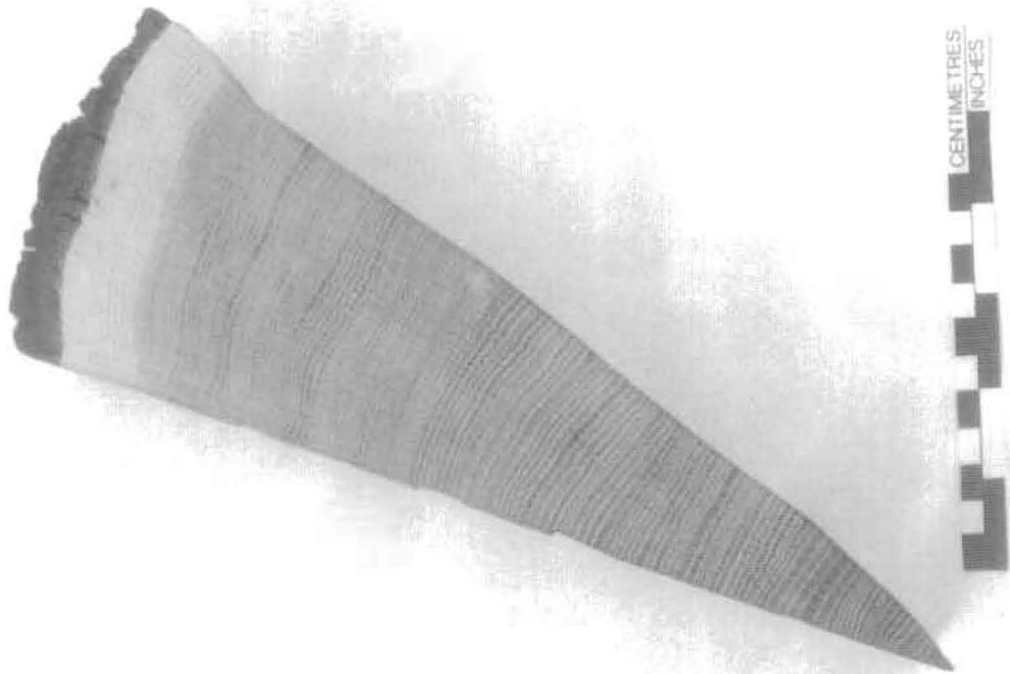


Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

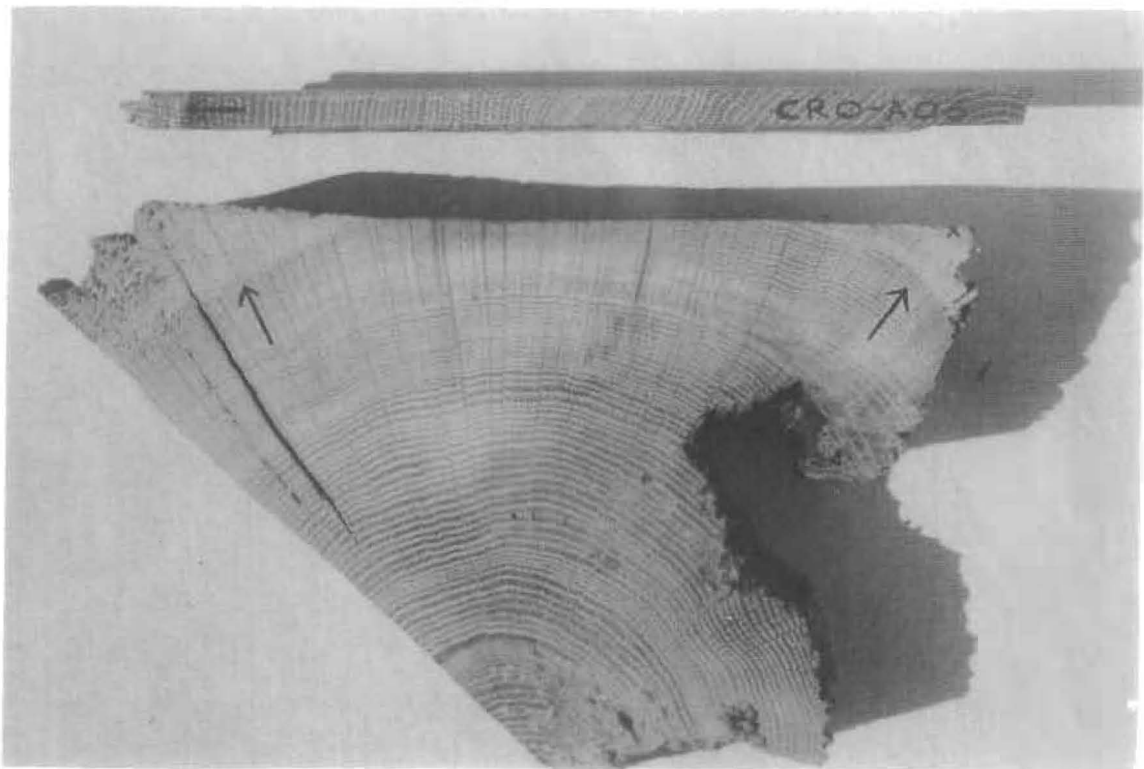


Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.



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

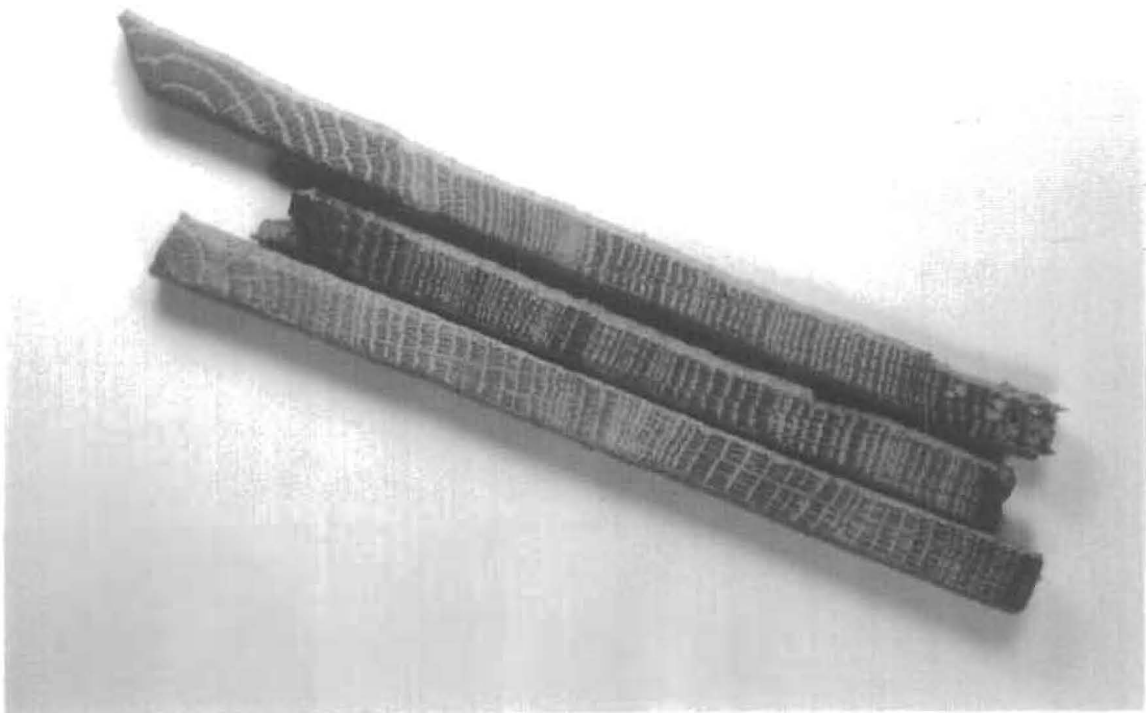


Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

Sampling is done by coring into the timber with a hollow corer attached to an electric drill and usually from its outer rings inwards towards where the centre of the tree, the pith, is judged to be. An illustration of a core is shown in Figure 2; it is about 15cm long and 1cm diameter. Great care has to be taken to ensure that as few as possible of the outer rings are lost. This can be difficult as these outer rings are often very soft (see below on sapwood). Each sample is given a code which identifies uniquely which timber it comes from, which building it is from and where the building is located. For example, CRO-A06 is the sixth core taken from the first building (A) sampled by the Laboratory in Cropwell Bishop. Where it came from in that building will be shown in the sampling records and drawings. No structural damage is done to any timbers by coring, nor does it weaken them.

During the initial 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 is insured with the CBA.

- 2. Measuring Ring Widths.** Each core is sanded down with a belt sander using medium-grit paper and then finished by hand with flourgrade-grit paper. The rings are then clearly visible and differentiated from each other with a result very much like that shown in Figure 2. The core is then mounted on a movable table below a microscope and the ring-widths measured individually from the innermost ring to the outermost. The widths are automatically recorded in a computer file as they are measured (see Fig 3).
- 3. Cross-matching and Dating the Samples.** Because of the factors besides the local climate which may determine the annual widths of a tree's rings, no two sequences of ring widths from different oaks growing at the same time are exactly alike (Fig 4). Indeed, the sequences may not be exactly alike even when the trees are growing near to each other. Consequently, in the Laboratory we do not attempt to match two sequences of ring widths by eye, or graphically, or by any other subjective method. Instead, it is done objectively (ie statistically) on a computer by a process called cross-matching. The output from the computer tells us the extent of correlation between two sample sequences of widths or, if we are dating, between a sample sequence of widths and the master, at each relative position of one to the other (offsets). The extent of the correlation at an offset is determined by the *t-value* (defined in almost any introductory book on statistics). That offset with the maximum *t-value* among the *t-values* at all the offsets will be the best candidate for dating one sequence relative to the other. If one of these is a master chronology, then this will date the other. Experiments carried out in the past with sequences from oaks of known date suggest that a *t-value* of at least 4.5, and preferably 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton *et al* 1988a,b; Howard *et al* 1984 - 1995).

This is illustrated in Fig 5 with timbers from one of the roofs of Lincoln Cathedral. Here four sequences of ring widths, LIN- C04, 05, 08, and 45, have been cross-matched with each other. The ring widths themselves have been omitted in the *bar-diagram*, as is usual, but the offsets at which they best cross-match each other are shown; eg. C08 matches C45 best when it is at a position starting 20 rings after the first ring of 45, and similarly for the others. The actual *t-values* between the four at these offsets of best correlations are in the matrix. Thus at the offset of +20 rings, the *t-value* between C45 and C08 is 5.6 and is the maximum between these two whatever the position of one sequence relative to the other.

It is standard practice in our Laboratory first to cross-match as many as possible of the sequences of the samples in a building and then to form an average from them. This average is called a site sequence of the building being dated and is illustrated in Fig 5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences from four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

This straightforward method of cross-matching several sample sequences with each other one at a time is called the 'maximal t-value' method. The actual method of cross-matching a group of sequences of ring-widths used in the Laboratory involves grouping and averaging the ring-width sequences and is called the 'Litton-Zainodin Grouping Procedure'. This was developed and tested in the Laboratory and has been published (Litton and Zainodin 1991; Laxton *et al* 1988a). To illustrate the difference between the two approaches with the above example, consider sequences C08 and C05. They are the most similar pair with a t-value of 10.4. Therefore, these two are first averaged with the first ring of C05 at +17 rings relative to C08 (the offset at which they match each other). This average sequence is then used in place of the individual sequences C08 and C05. The cross-matching continues in this way gradually building up averages at each stage eventually to form the site sequence.

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

Quite often some, though not all, of the original outer rings are missing on a timber. The outer rings on an oak, called sapwood rings, are usually lighter than the inner rings, the heartwood, and so are relatively easy to identify. For example, they can be seen in two upper corners of the rafter and at the outer end of the core in Figure 2. More importantly for dendrochronology, the sapwood is relatively soft and so liable to insect attack and wear and tear. The builder, therefore, may remove some of the sapwood for precisely for these reasons. Nevertheless, if at least some of the sapwood rings are left on a sample, we will know that not too many rings have been lost since felling. Thus in these circumstances the date of the present last ring is at least close to the date of the original last ring on the tree, and so to the date of felling.

Various estimates have been made for the average number of sapwood rings in a mature oak. One estimate is 30 rings, based on data from living oaks. So, in the case of the core in Figure 2 where 9 sapwood rings remain, this would give an estimate for the felling date of 21 ( $= 30 - 9$ ) years later than of the date of the last ring on the core. Actually, it is better in these situations to give an estimated range for the felling date. Another estimate is that in 95% of mature oaks there are between 15 and 50 sapwood rings. So in this example this would mean that the felling took place between 6 ( $= 15 - 9$ ) and 41 ( $= 50 - 9$ ) years after the date of the last ring on the core and is expected to be right in at least 95% of the cases (Hughes *et al* 1981; see also Hillam *et al* 1987).

Data from the Laboratory has shown that when sequences are considered together in groups, rather than separately, the estimates for the number of sapwood can be put at between 15 and 40 rings in 95% of the cases with the expected number being 25 rings. We would use these estimates, for example, in calculating the range for the common felling date of the four sequences from Lincoln Cathedral using the average position of the heartwood/sapwood boundary (Fig 5). These new estimates are now used by us in all our publications except for timbers from Kent and Nottinghamshire where 25 and between 15 to 35 sapwood rings, respectively, is used instead (Pearson 1995).

More precise estimates of the felling date and range can often be obtained using knowledge of a particular case and information gathered at the time of sampling. For example, at the time of sampling the dendrochronologist may have noted that the timber from which the core of Figure 2 was taken still had complete sapwood. Sapwood rings were only lost in coring, because of their softness. By measuring in the timber the depth of sapwood lost, say 2 cm., a reasonable estimate can be made of the number of sapwood rings missing from the core, say 12 to 15 rings in this case. By adding on 12 to 15 years to the date of the last ring on the sample a good tight estimate for the range of the felling date can be obtained, which is often better than the 15 to 40 years later we would have estimated without this observation.



**T-value/Offset Matrix**

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

**Bar Diagram**

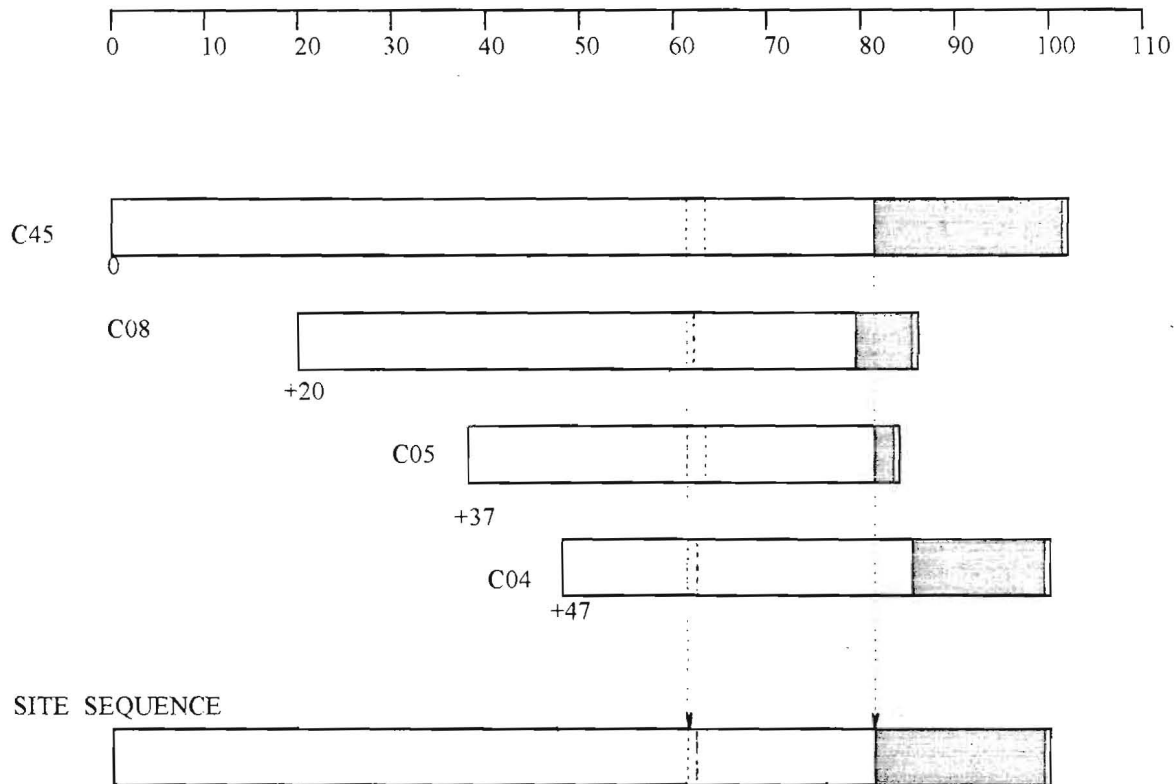


Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set at relative positions (*offsets*) to each other at which they have maximum correlation as measured by the *t-values*.

The *t-value offset* matrix contains the maximum t-values below the diagonal and the offsets above it.

Thus, the maximum t-value between C08 and C45 occurs at the offset of +20 rings and the t-value is then 5.6.

The *site sequence* is composed of the average of the corresponding widths, as illustrated with one width.

Even if all the sapwood rings are missing on all the timbers sampled, an estimate of the felling date is still possible in certain cases. For provided the original last heartwood ring of the tree, called the heartwood/sapwood boundary (H/S), is still on some of the samples, an estimate for the felling date of the group of trees can be obtained by adding on the full 25 years, or 15 to 40 for the range of felling dates.

If none of the timbers have their heartwood/sapwood boundaries, then only a *post quem* date for felling is possible.

5. **Estimating the Date of Construction.** There is a considerable body of evidence in the data collected by the Laboratory that the oak timbers used in vernacular buildings, at least, were used 'green' (see also Rackham (1976)). Hence provided the samples are taken *in situ*, and several dated with the same estimated common felling date, then this felling date will give an estimated date for the construction of the building, or for the phase of construction. If for some reason or other we are rather restricted in what samples we can take, then an estimated common felling date may not be such a precise estimate of the date of construction. More sampling may be needed for this.
6. **Master Chronological Sequences.** Ultimately, to date a sequence of ring widths, or a site sequence, we need a master sequence of dated ring widths with which to cross-match it, a Master Chronology. To construct such a sequence we have to start with a sequence of widths whose dates are known and this means beginning with a sequence from an oak tree whose date of felling is known. In Fig 6 such a sequence is SHE-T, which came from a tree in Sherwood Forest which was blown down in a recent gale. After this other sequences which cross-match with it are added and gradually the sequence is 'pushed back in time' as far as the age of samples will allow. This process is illustrated in Fig 6. We have a master chronological sequence of widths for Nottinghamshire and East Midlands oak for each year from AD 882 to 1981. It is described in great detail in Laxton and Litton 1988b, but the components it contains are shown here in the form of a bar diagram. As can be seen, it is well replicated in that for each year in this period there are several sample sequences having widths for that year. The master is the average of these. This master can now be used to date oak from this area and from the surrounding areas where the climate is very similar to that in the East Midlands. The Laboratory has also constructed a master for Kent (Laxton and Litton 1989). The method the Laboratory uses to construct a master sequence, such as the East Midlands and Kent, is completely objective and uses the Litton-Zainodin grouping procedure (Laxton *et al* 1988a). Other laboratories and individuals have constructed masters for other areas and have made them available. As well as these masters, local (dated) site chronologies can be used to date other buildings from nearby. The Laboratory has hundreds of these site sequences from many parts of England and Wales covering many short periods.
7. **Ring-width Indices.** Tree-ring dating can be done by cross-matching the ring widths themselves, as described above. However, it is advantageous to modify the widths first. Because different trees grow at different rates and because a young oak grows in a different way from an older oak, irrespective of the climate, the widths are first standardized before any matching between them is attempted. These standard widths are known as ring-width indices and were first used in dendrochronology by Baillie and Pilcher (1973). The exact form they take is explained in this paper and in the appendix of Laxton and Litton (1988b) and is illustrated in the graphs in Fig 7. Here ring-widths are plotted vertically, one for each year of growth. In the upper sequence (a), the generally large early growth after 1810 is very apparent as is the smaller generally later growth from about 1900 onwards. A similar difference can be observed in the lower sequence starting in 1835. In both the widths are also changing rapidly from year to year. The peaks are the wide rings and the troughs are the narrow rings, hopefully corresponding to good and poor growing seasons, respectively. The two corresponding sequences of Baillie-Pilcher indices are plotted in (b) where the differences in the early and late growths have been removed and only the rapidly changing peaks and troughs remain only associated with the common climatic signal and so make cross-matching easier.

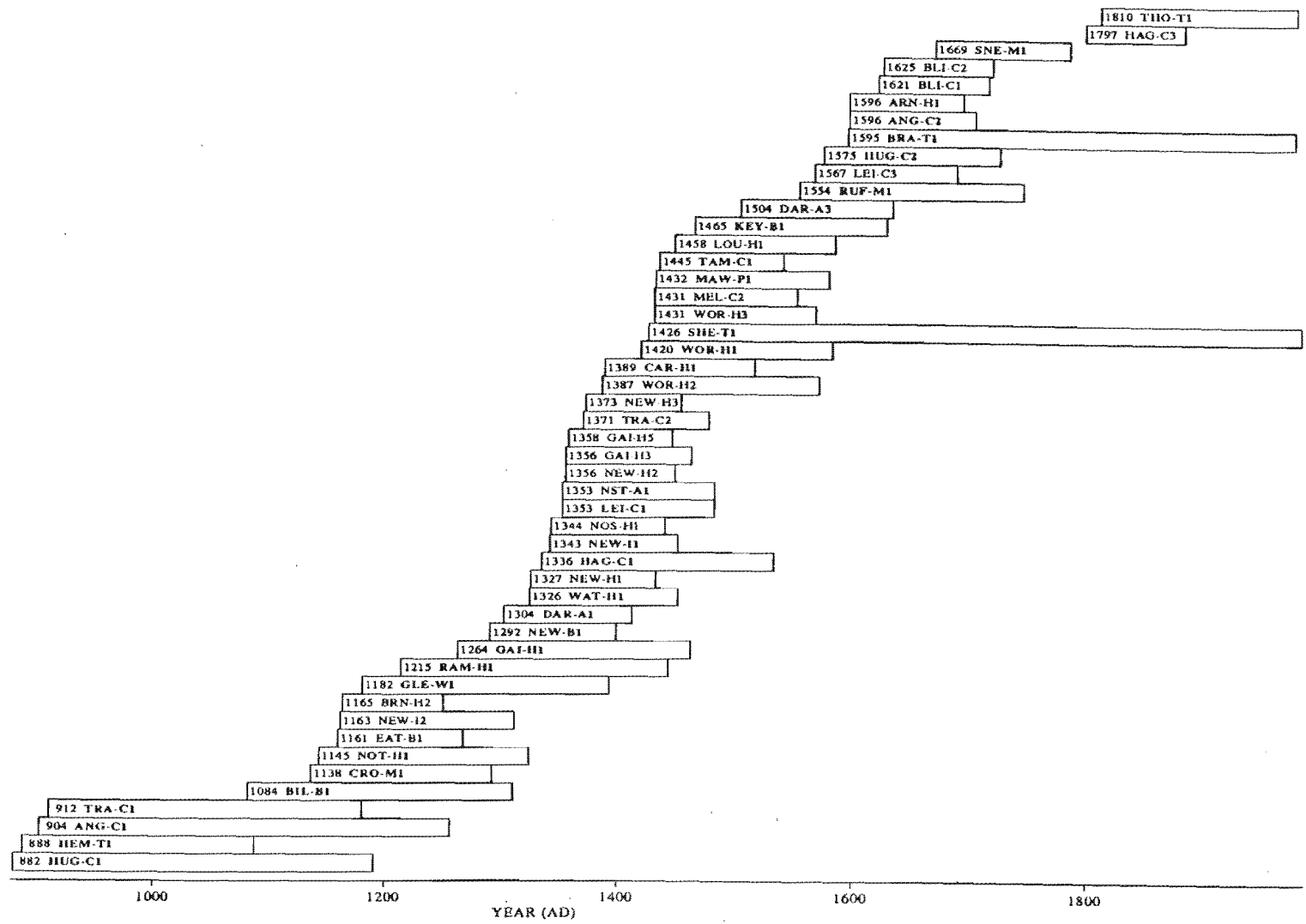


Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

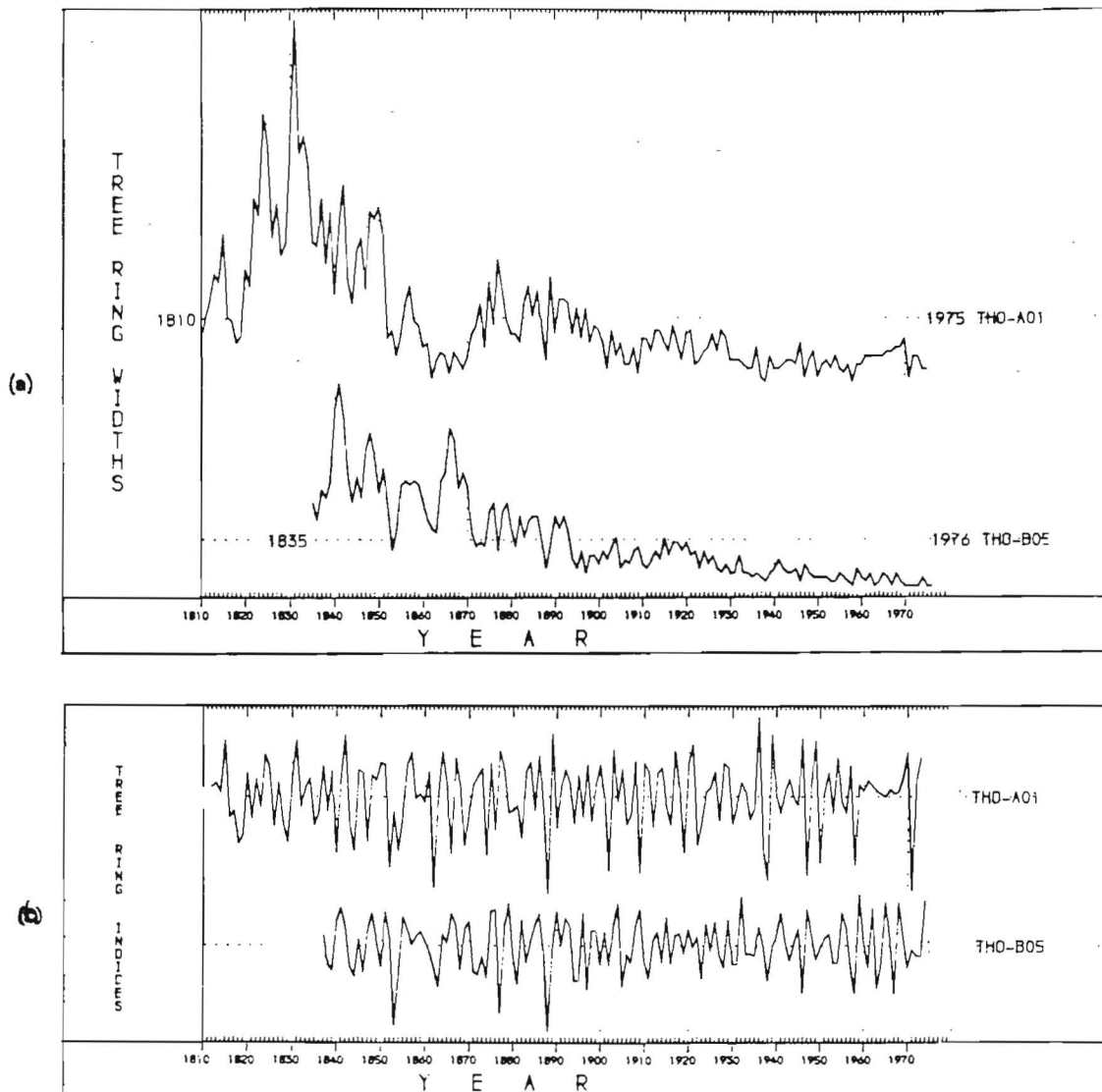


Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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

(b) The *Baillie-Pilcher indices* of the above widths. The growth-trends have been removed completely.

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