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95 HIGH STREET, COLESHILL, WARWICKSHIRE
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

INTERVENTION
AND ANALYSIS

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TREE-RING ANALYSIS OF TIMBERS

Alison Arnold and Robert Howard

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SUMMARY
Dendrochronological analysis was undertaken on three samples taken from roof timbers of this building, resulting in the construction and dating of a single site sequence. Site sequence CLHASQ01 contains two samples and spans the period AD 1322–1436, with felling thought to have occurred in *circa* AD1456.

CONTRIBUTORS
Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS
The Laboratory would like to thank Jerome Tait of English Heritage's Designation Department and William Mason of Latham Mason Conservation for arranging access and for their on-site advice. Thanks are also given to the staff at the Coleshill branch of the HSBC for their assistance and patience whilst sampling was undertaken. The building description and drawings used to locate the samples were taken from Bob Meeson's survey of the building. The Scientific Dating Team at English Heritage and Cathy Tyers of the Sheffield University Dendrochronology Laboratory were, as always, a great help throughout the production of this report.

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CONTENTS

INTRODUCTION

The building known as 95 High Street, Coleshill (Figs 1–3; SP 2000 8908), retains the remains of a medieval two-bay wing which is aligned parallel to the street with a long range to the rear. The first-floor chamber of this wing was originally open to the clasped-purlin roof. The rear range also retains the remains of a clasped purlin roof but this has mostly been replaced by 'modern' softwood timbers.

The roof

The roof of the two-bay wing comprises two close-studded gable trusses and a central open arch-braced collar truss. The gable trusses supported a single tier of clasped side purlins; those on the east side of the building remain *in situ* but those to the west side have been altered.

The south gable truss consists of a tiebeam supporting eight struts which are tenoned into the collar, and probably (although not visible) V-struts above the collar (Fig 4). There are surviving cusped wind-braces within this first bay on the south side. The east wall-post of the central truss has a Tudor ogee moulding, which follows the inner face of an extended jowl, and continues along the curved arch-brace up to the collar. Again, there are V-struts above the collar (Fig 5). Unusually, the side purlins were threaded across the junction between the arch-brace and the collar, with the principal rafter laid across these timbers. The north gable truss comprises tiebeam, six extant studs rising up to the collar, and V-struts. The principal rafters are reduced in scantling above the clasped purlin joints. The east purlin is *in situ*, whereas that on the west side is now propped over a block of wood (Meeson 2010).

SAMPLING

Sampling was requested by Jerome Tait, English Heritage Designation Department, to inform the potential listing of the building.

Surface examination of the growth pattern of the timbers had shown that the majority of them were derived from relatively fast-grown trees but it was hoped that several would have sufficient growth rings for secure dating. Unfortunately, after careful selection and sampling of what were thought to be the most suitable timbers it became clear that the majority of the samples gained were going to have less than the required minimum number of growth rings and sampling was halted.

A total of eight timbers was sampled, five of which subsequently proved to be unsuitable for analysis due to having too few growth rings. Each sample was given the code CLH-A (for Coleshill) and numbered 01–08. The location of samples was noted at the time of sampling and has been marked on Figures 6–8. Further details relating to the samples can be found in Table 1.

ANALYSIS AND RESULTS

The three suitable 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. These samples were compared with each other by the Litton/Zainodin grouping procedure (see Appendix).

Samples CLH-A01 and CLH-A07 matched each other and were combined at the relevant offset positions to form CLHASQ01, a site sequence of 115 rings (Fig 9). This site sequence was compared against a series of relevant reference chronologies for oak, where it was found to match consistently and securely at a first-ring date of AD 1322 and a last-measured ring date of AD 1436. The evidence for this dating is given by the *t*-values in Table 2.

One of these samples (CLH-A01) was taken from a timber which had complete sapwood but unfortunately a large portion of the sapwood broke off during the coring process. This sample has the last-measured ring date of AD 1436; there are 19 sapwood rings on the portion which broke off but as the two pieces cannot be joined with complete confidence it is possible that a ring has been lost between the two parts, giving a felling date of *c* AD 1456. The second dated sample does not have the heartwood/sapwood boundary ring but with a last-measured heartwood ring date of AD 1403 it is possible that this is also from a timber felled in *c* AD 1456.

Attempts to date the remaining, ungrouped sample by individually comparing it against the reference chronologies were unsuccessful and it remains undated.

All felling date ranges have been calculated using the estimate that 95% of mature oak trees in this area have between 15 and 40 sapwood rings.

DISCUSSION

Prior to tree-ring analysis being undertaken the dating of this building was purely on stylistic grounds. Clasped purlin roofs have a long history with known examples dating from the first half of the fourteenth century to the second half of the sixteenth century. It had been suggested that this example dated to before AD 1500 rather than after (Meeson 2010).

It is now known that this roof contains at least two timbers felled in *c* AD 1456. Given that these timbers, both collars, appear integral to the roof and neither show any sign of reuse or later insertion it is possible that this mid-fifteenth century date relates to the construction of the roof as a whole.

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TABLES

Table 1: Details of tree-ring samples from 95 High Street, Coleshill, Warwickshire

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
CLH-A01	Collar, south gable truss	102	10+*c*19NM	1335	1426	1436
CLH-A02	West principal rafter, south gable truss	NM	--	----	----	----
CLH-A03	Stud 1, south gable truss	NM	--	----	----	----
CLH-A04	East principal rafter, central truss	NM	--	----	----	----
CLH-A05	West principal rafter, central truss	NM	--	----	----	----
CLH-A06	Collar, central truss	54	08	----	----	----
CLH-A07	Collar, north gable truss	82	--	1322	----	1403
CLH-A08	East purlin, central truss – north gable truss	NM	--	----	----	---

*NM = not measured

** +*c*xxNM = this sample was taken from a timber with complete sapwood but a portion of the sapwood broke off during sampling; it may be that one or two rings have been lost.

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Table 2: Results of the cross-matching of site sequence CLHASQ01 and relevant reference chronologies when the first-ring date is AD 1322 and the last-ring date is AD 1436

Reference chronology	*t*-value	Span of chronology	Reference
Sinai Park, Staffordshire	7.6	AD 1227–1750	Tyers 1997
East Midlands	6.7	AD 882–1981	Laxton and Litton 1988
The Commandery, Worcester, Worcestershire	6.6	AD 1284–1473	Arnold *et al* 2006
Halesowen Abbey (barn), Dudley, West Midlands	6.6	AD 1310–1535	Arnold and Howard 2008
11/3 Main Street, Newton Linford, Leicestershire	6.5	AD 1319–1457	Alcock *et al* 1990
Abbots Lodge, Ledbury, Herefordshire	6.3	AD 1274–1519	Arnold and Howard 2009
Kingswood Abbey Gatehouse, Gloucestershire	6.1	AD 1307–1428	Arnold *et al* 2003

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FIGURES

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

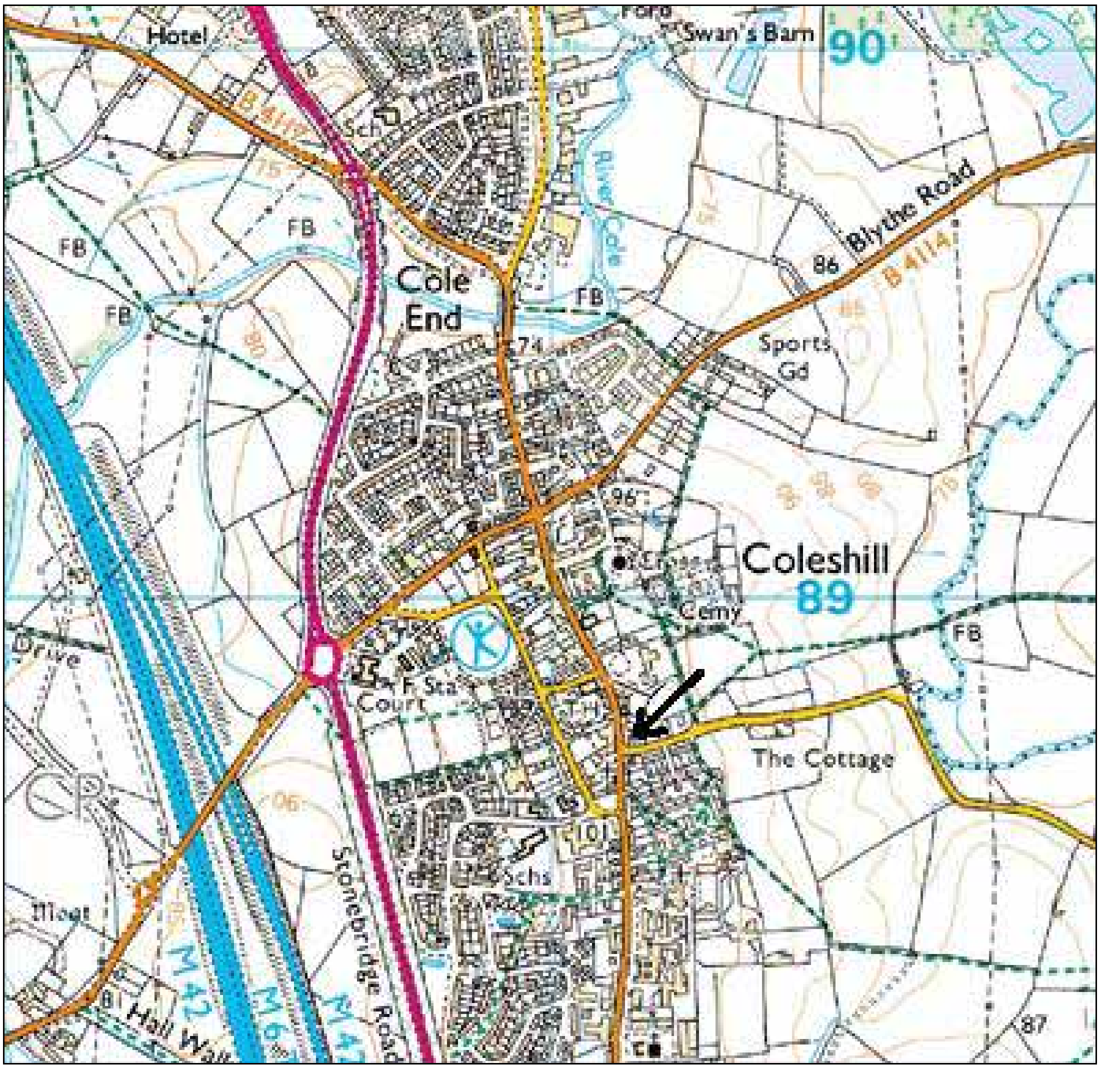

Figure 2: Map to show the approximate location of 95 High Street, Coleshill, arrowed (based on the Ordnance Survey map, with permission of the Controller of Her Majesty's Stationery Office, ©Crown Copyright)

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Figure 3: Map to show 95 High Street, hashed, (based on the Ordnance Survey map, with the permission of the Controller of Her Majesty's Stationery Office, ©Crown Copyright)

Figure 4: South gable truss (north face)

Figure 5: Central truss (south face)

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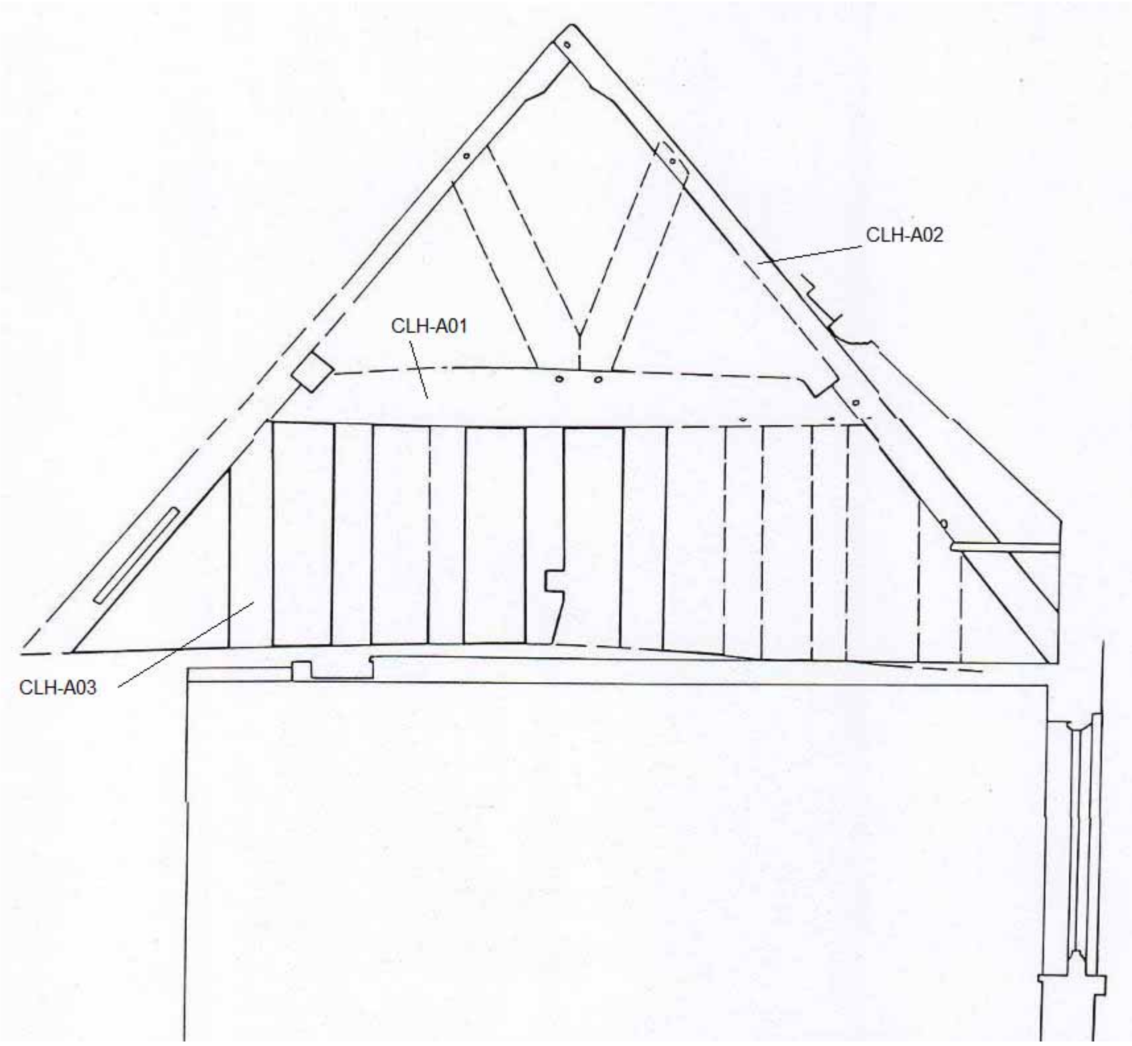


Figure 6: South gable truss (north face); showing the location of samples CLH-A01–03 (Bob Meeson)

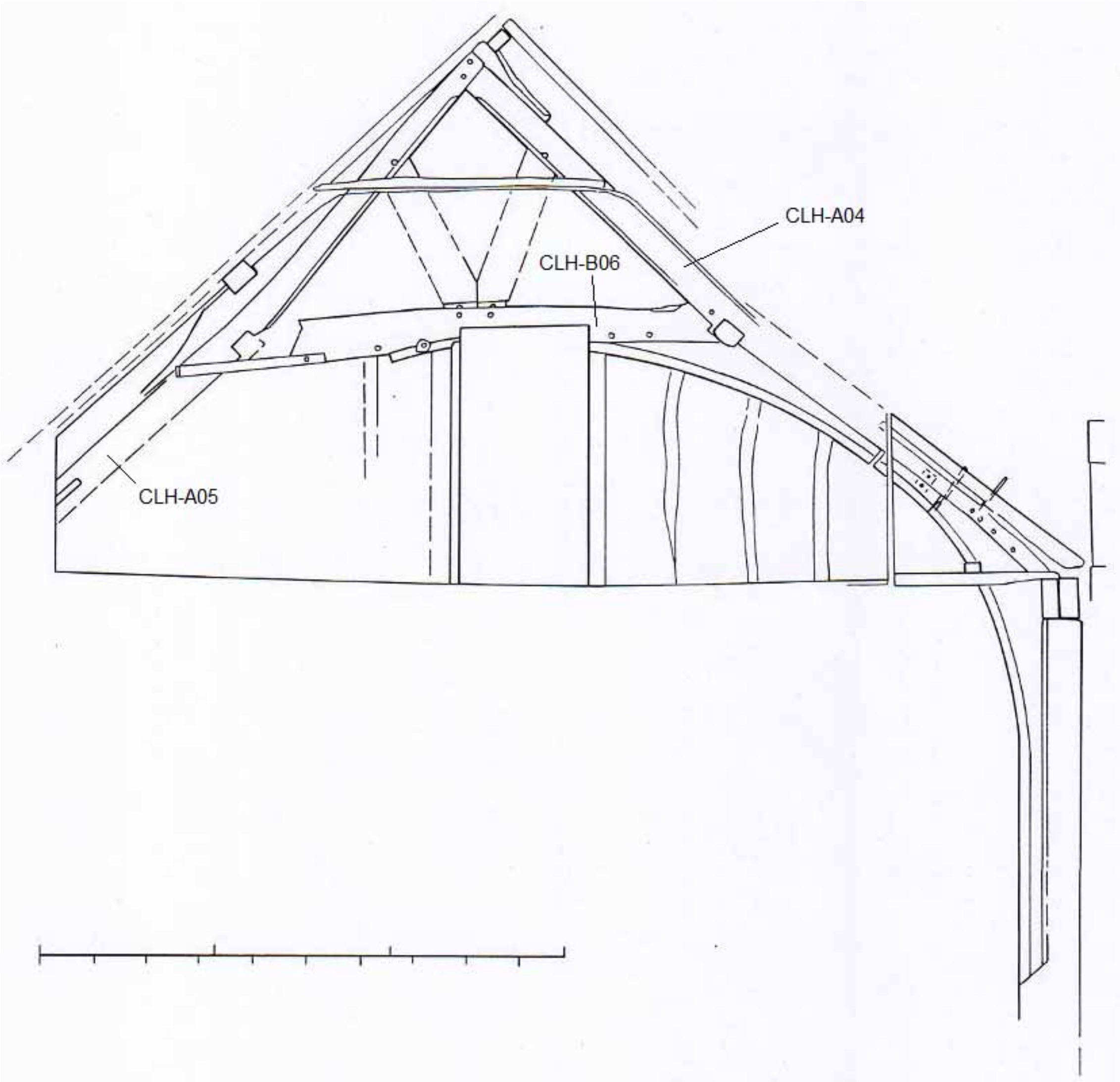


Figure 7: Central truss (south face); showing; showing the location of samples CLH-A04–06 (Bob Meeson)

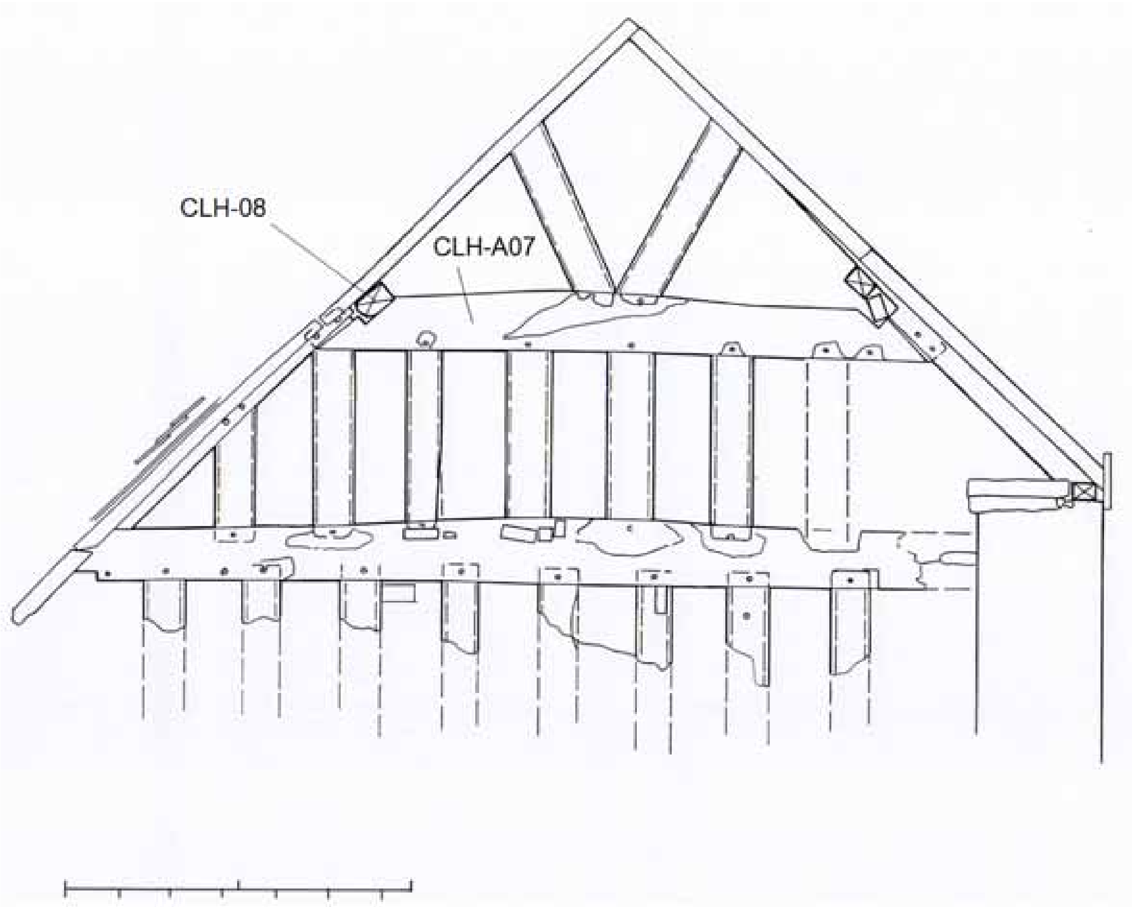


Figure 8: North gable truss (north face); showing the location of samples CLH-A07 and CLH-A08 (Bob Meeson)

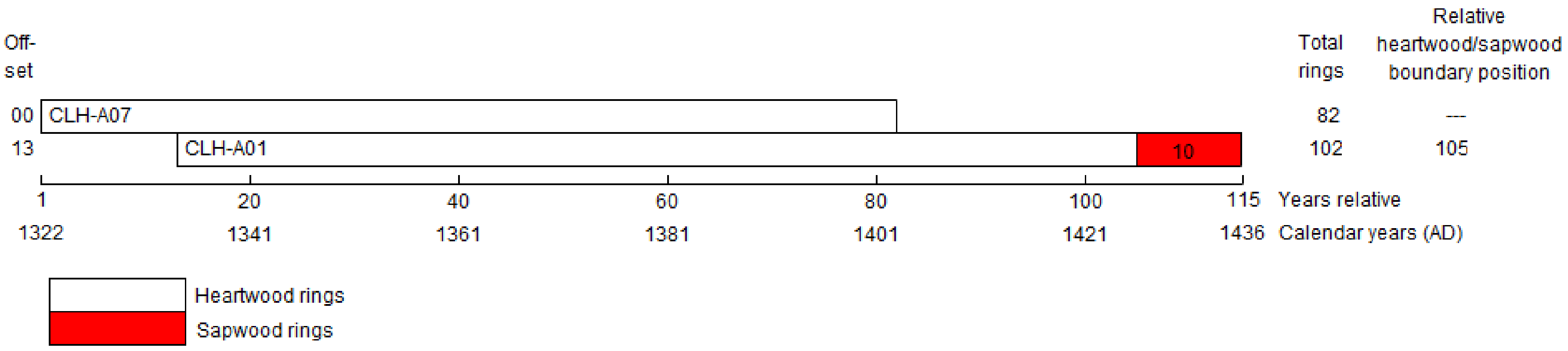


Figure 9: Bar diagram of samples in site sequence CLHASQ01

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

CLH-A01A 102
400 365 320 355 429 366 385 269 211 113 190 127 178 193 234 153 192 137 170 161
159 129 141 134 125 92 120 108 167 129 93 56 98 150 189 105 81 55 69 83
64 63 78 91 111 84 69 89 51 62 79 127 132 114 108 64 72 55 86 81
87 104 82 77 102 139 83 101 139 113 132 118 124 137 150 104 111 160 196 172
214 176 123 108 91 174 165 181 243 213 189 98 94 99 141 181 154 216 107 125
78 75
CLH-A01B 102
399 362 296 355 441 372 378 280 207 112 191 137 175 195 236 144 179 156 178 158
178 125 142 135 120 98 119 121 173 134 94 67 95 160 165 137 72 54 65 72
65 61 71 109 107 73 91 78 56 54 83 135 119 102 98 71 69 56 82 82
92 100 83 84 102 142 94 93 140 113 127 120 129 133 156 104 106 165 206 171
206 177 125 105 94 177 168 192 241 213 185 107 89 104 139 186 157 207 113 118
78 87
CLH-A06A 54
335 265 115 369 375 282 353 204 136 219 287 407 194 109 72 135 101 106 225 160
367 338 402 289 188 174 141 166 254 279 189 197 131 119 124 87 122 167 254 172
252 245 188 173 211 273 300 229 284 263 254 283 240 328
CLH-A06B 54
331 270 115 379 385 275 352 211 135 218 292 400 197 108 78 118 115 106 218 164
364 339 396 288 187 185 139 161 243 277 198 190 130 109 122 90 102 171 238 185
246 259 188 178 205 270 287 219 261 260 246 267 269 299
CLH-A07A 82
360 493 239 214 167 196 234 200 258 271 228 233 244 370 444 398 465 508 269 315
342 487 287 336 231 193 256 362 232 291 221 245 235 138 215 298 212 323 204 136
201 216 252 192 128 209 237 273 192 237 329 504 421 316 349 321 354 300 159 115
180 111 76 87 245 190 216 130 85 60 55 84 77 85 96 78 80 106 78 78
73 187
CLH-A07B 82
371 494 243 217 168 194 231 205 258 269 228 214 237 379 438 451 475 526 265 289
338 475 321 339 229 198 266 375 241 259 210 256 238 142 215 296 207 316 207 139
207 214 252 189 135 213 248 272 201 247 321 491 423 312 349 319 357 321 162 124
174 102 77 90 254 193 209 126 82 58 56 82 80 80 101 66 93 104 80 73
76 155

APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

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

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

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

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

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

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

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

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

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

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

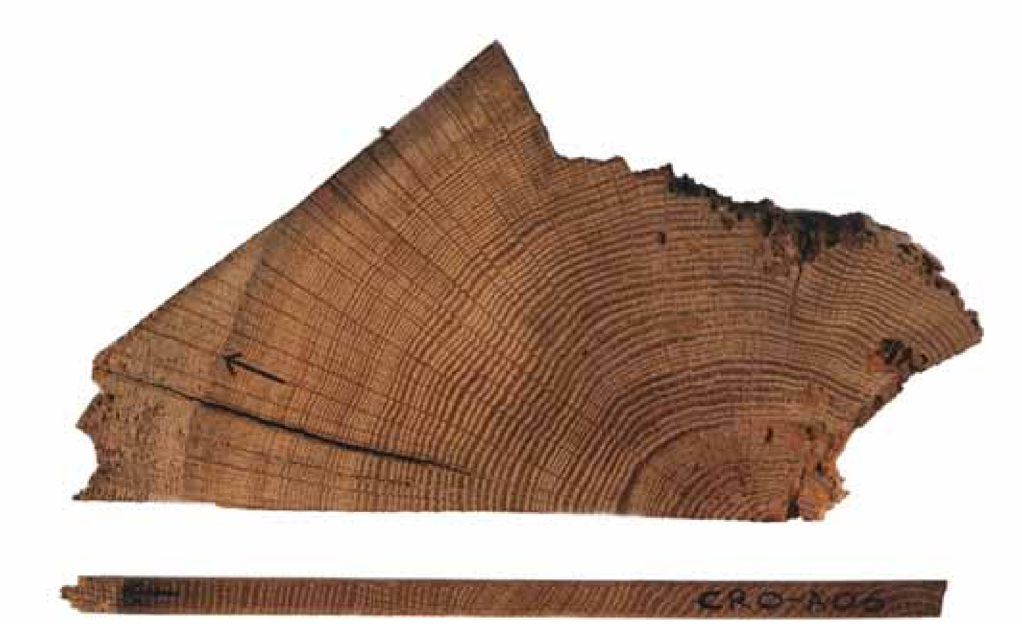


Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

t-value/offset Matrix

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

Bar Diagram

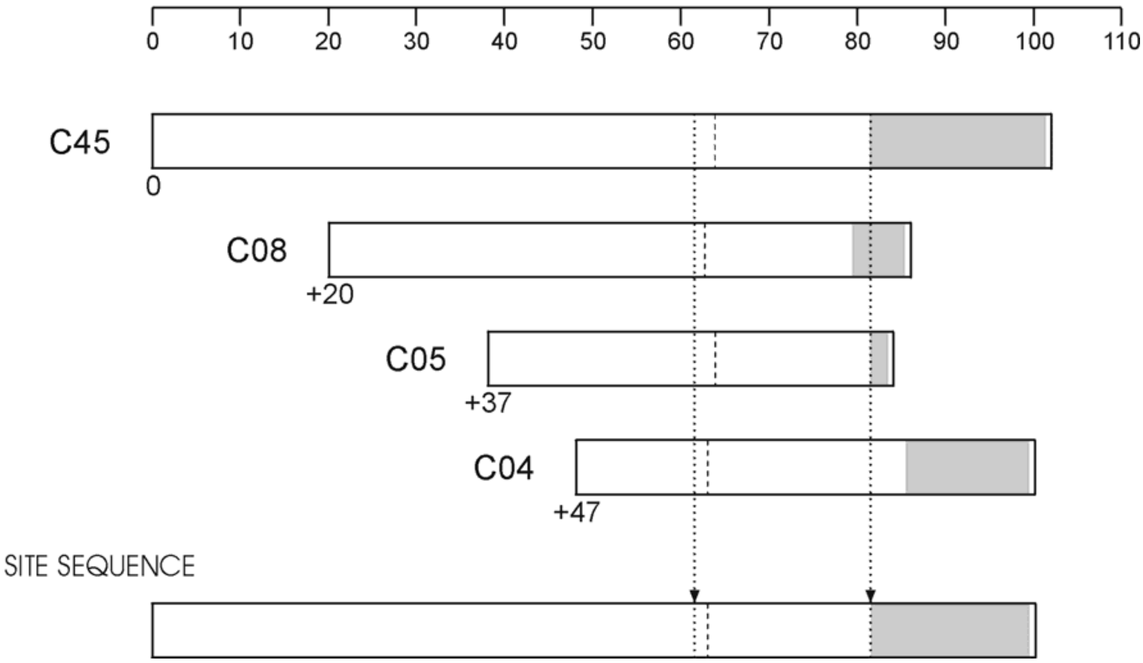


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

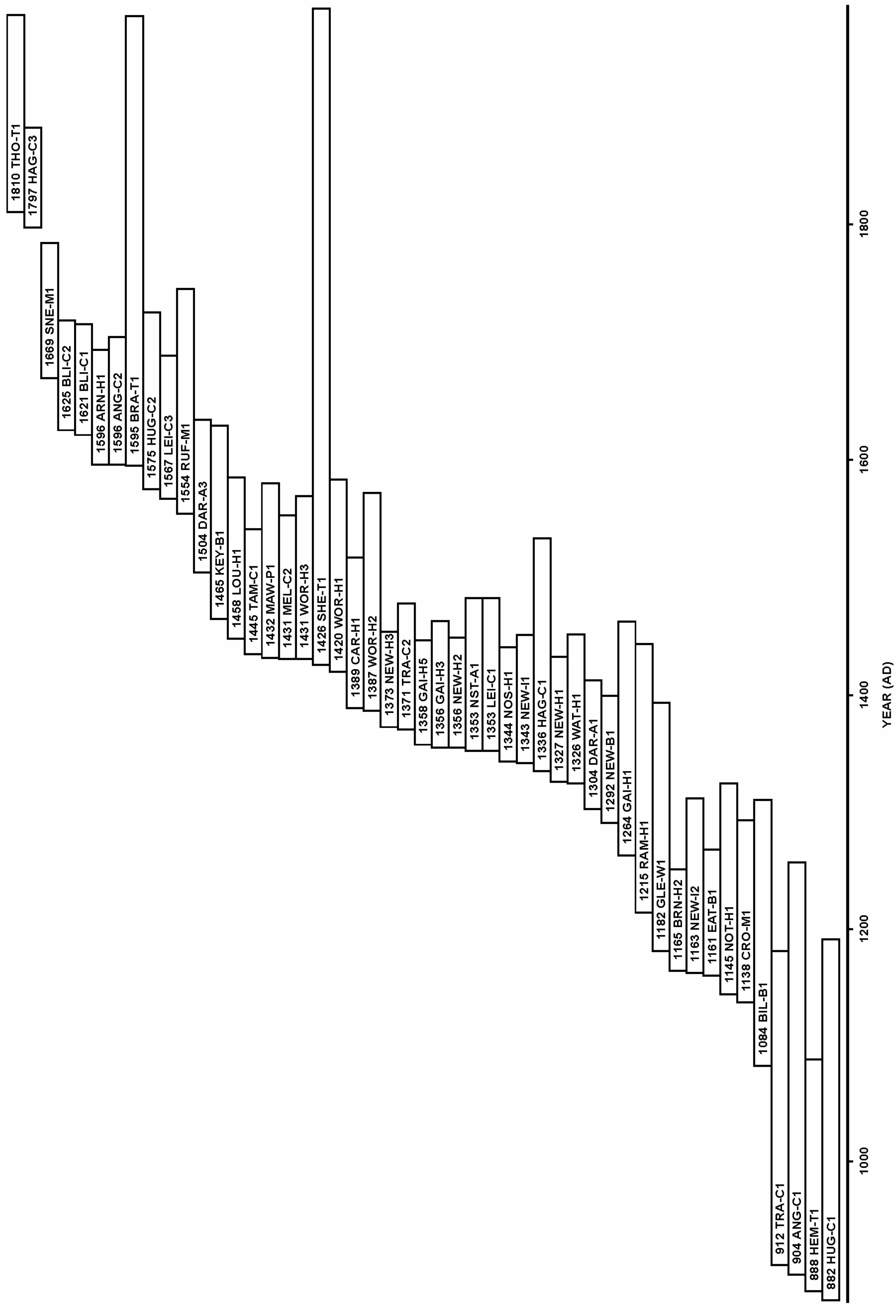
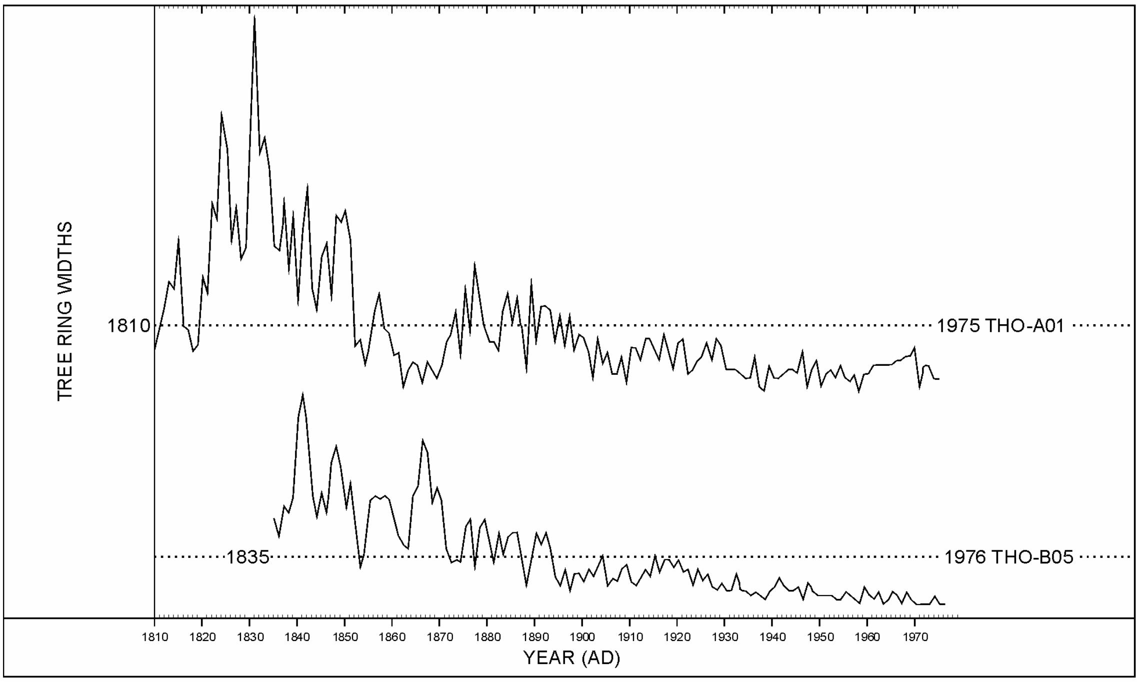


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

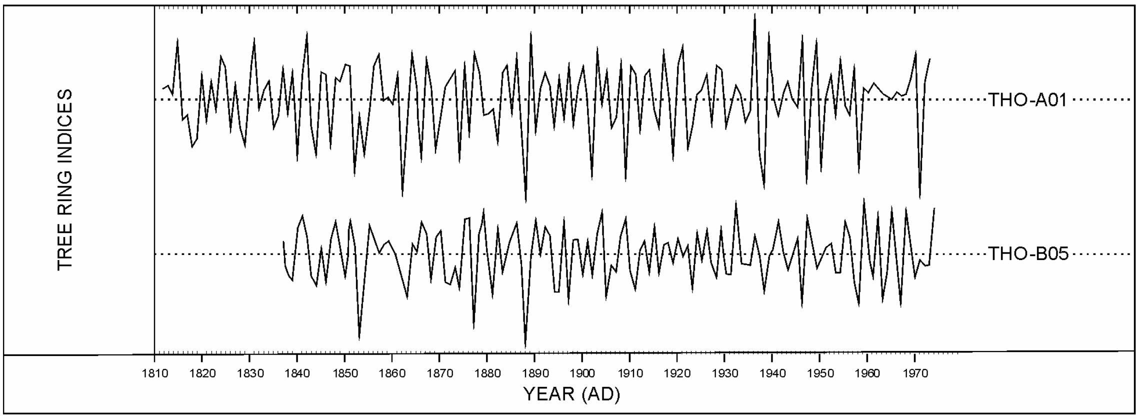


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

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

The growth trends have been removed completely

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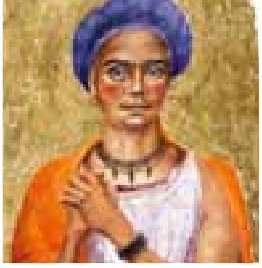


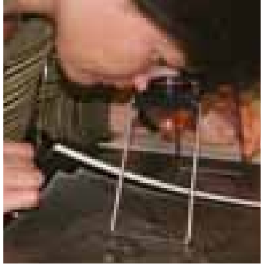


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