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ST MARY'S CHURCH, SARNESFIELD, HEREFORDSHIRE
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

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SUMMARY

Dendrochronological analysis was undertaken on samples taken from the nave roof at this church. Two samples grouped and were combined to form site sequence SARASQ01. Attempts to date this site sequence and the remaining ungrouped samples were unsuccessful and all remain undated.

CONTRIBUTORS

Alison Arnold and Robert Howard

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The Laboratory would like to thank Mr Roger Marshall, the church fabric officer, for his assistance with access. Figures 6–9 were provided by Chris Miners, Historic Buildings Architect at English Heritage's Birmingham office. Thanks are also given to Dr Peter Marshall for all his help with the figures used to illustrate this report.

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INTRODUCTION

The Grade-I listed Church of St Mary at Sarnesfield, near Kington (Figs 1 and 2; SO 375 509) is thought to have its origins in the twelfth century, with the nave and south aisle believed to date to this time. The three-stage west tower was added in the thirteenth century, followed by the chancel and south chapel in the fourteenth century (Fig 3). Alterations and renovations at the church were undertaken in *c* AD 1870 and AD 1907.

Roofs

The nave roof is of seven bays and has seven trusses of major and intermediate type. The four major trusses have curved struts which run from the tiebeam to the principal rafter. The intermediate trusses have arch braces which run from the principal rafter to the collar. There is a single, threaded purlin to each slope. Below the purlins are cusped wind-braces forming trefoil-headed patterns (Fig 4). This roof is believed to date to the fifteenth century.

The south aisle is of two bays and has cusped and cambered ties which form trefoils with the principal rafters. The ties are supported by curved braces. An intermediate collar truss rests on arch braces. It has cusped barge-boards and lower range of wind-braces. The listing description describes this roof as being nineteenth century, but it is thought to contain some medieval timbers.

The chancel roof has collar and tiebeam trusses with lower wind-braces. Although believed to be restored, this roof is thought to have its origins in the medieval period.

The porch roof consists of trusses with principal rafters, collars, and arch braces. Alternate trusses have cusped collar and principals forming trefoil patterns. There is a single set of threaded purlins, beneath which are cusped windbraces (Fig 5). This roof was also thought to be fifteenth-century.

The date of the south transept roof is unclear, there has been significant renovation work in this area, with both the north and south walls of the transept being modern.

The above description in largely based on the Listed Building Description (www.imagesofengland.org.uk).

AIMS AND OBJECTIVES

Sampling and analysis by tree-ring dating was commissioned and funded by English Heritage. It was requested by Chris Miners, Historic Buildings Architect at English Heritage's Birmingham office, to inform a programme of grant-aided repairs.

It was hoped to ascertain the construction date for the nave, chancel, and porch roofs and to identify any surviving medieval timbers in the south aisle and south transept roofs.

SAMPLING

Upon initial surface inspection of the timbers, the majority could be seen to have a relatively wide ring pattern, making it unlikely that they would have sufficient rings for secure dating. On the basis of this surface examination, sampling was not undertaken within the roofs of the chancel, porch, south aisle, and south transept. However, within the timbers of the nave roof it was thought there might be some with just enough rings and so the decision was taken to sample this marginal material. With the strength of the local network of reference chronologies, it was felt that there was a reasonable chance of successful dating.

As such, nine of the most promising timbers were sampled, with the resultant samples being given the code SAR-A (Sarnesfield) and numbered 01–09. The position of all samples was noted at the time of sampling and has been marked on Figures 6–9. Further details relating to each sample can be found in Table 1. The trusses have been numbered from east to west (Fig 3).

ANALYSIS AND RESULTS

Four of the samples had too few rings to make secure dating a possibility, and so these were rejected prior to measurement. The remaining five 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 then compared with each other by the Litton/Zainodin grouping procedure (see Appendix).

At a value of t=5.9, two samples matched each other and were combined at the relevant offset positions to form SARASQ01, a site sequence of 50 rings (Fig 10). Attempts to date this site sequence by comparing it against a series of relevant reference chronologies for oak did not result in a secure match and, therefore, SARASQ01 remains undated. Attempts to individually date the remaining ungrouped samples by comparing them against the reference material proved unsuccessful and these are also undated.

DISCUSSION

Prior to tree-ring analysis being undertaken on the timbers of the nave roof, it had been dated stylistically to the fourteenth or fifteenth century. In this instance, dendrochronological analysis has proved unsuccessful, with no timbers being dated.

Although disappointing, these results are perhaps not surprising given the relative shortness of the ring sequences of these samples and the poor intra-site matching. It is regrettable that site sequence SARASQ01 could not be securely dated, but this site sequence is short, with only 50 rings, and is poorly replicated, containing only two samples. It is well-recognised that the longer and better replicated a site sequence, the greater the chance of successful dating.

Table 1: Details of tree-ring samples from St Mary's Church, Sarnesfield, Herefordshire

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
SAR-A01	South principal rafter, truss 2	57	--	----	----	----
SAR-A02	Tiebeam, truss 2	50	h/s	----	----	----
SAR-A03	North principal rafter, truss 3	NM	--	----	----	----
SAR-A04	South principal rafter, truss 3	NM	--	----	----	----
SAR-A05	North raking strut, truss 3	NM	--	----	----	----
SAR-A06	South raking strut, truss 3	59	--	----	----	----
SAR-A07	Tiebeam, truss 5	50	h/s	----	----	----
SAR-A08	North principal rafter, truss 5	NM	--	----	----	----
SAR-A09	Tiebeam, truss 7	58	--	----	----	----

*NM = not measured

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

FIGURES

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

Figure 2: Map to show the location of St Mary's Church (based on the Ordnance Survey map with permission of the Controller of Her Majesty's Stationery Office, ©Crown Copyright)

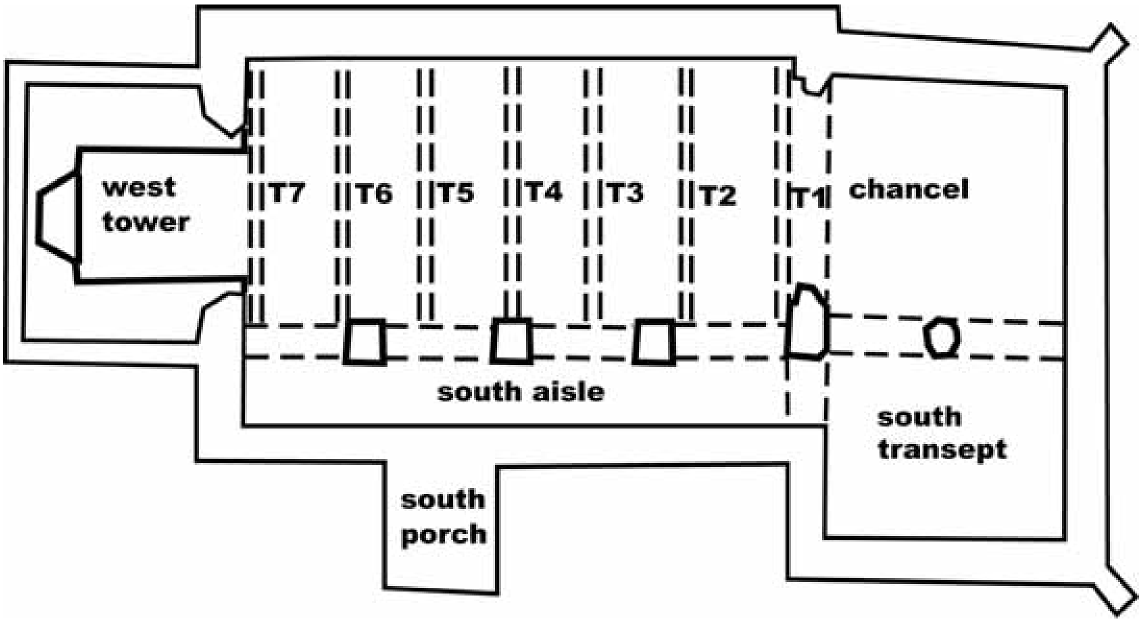


Figure 3: St Mary's Church, ground-floor plan, showing the truss positions in the nave (after RCHME)

Figure 4: Nave roof, truss 3 in foreground (photograph taken from Truss 4)

Figure 5: Porch roof, looking north

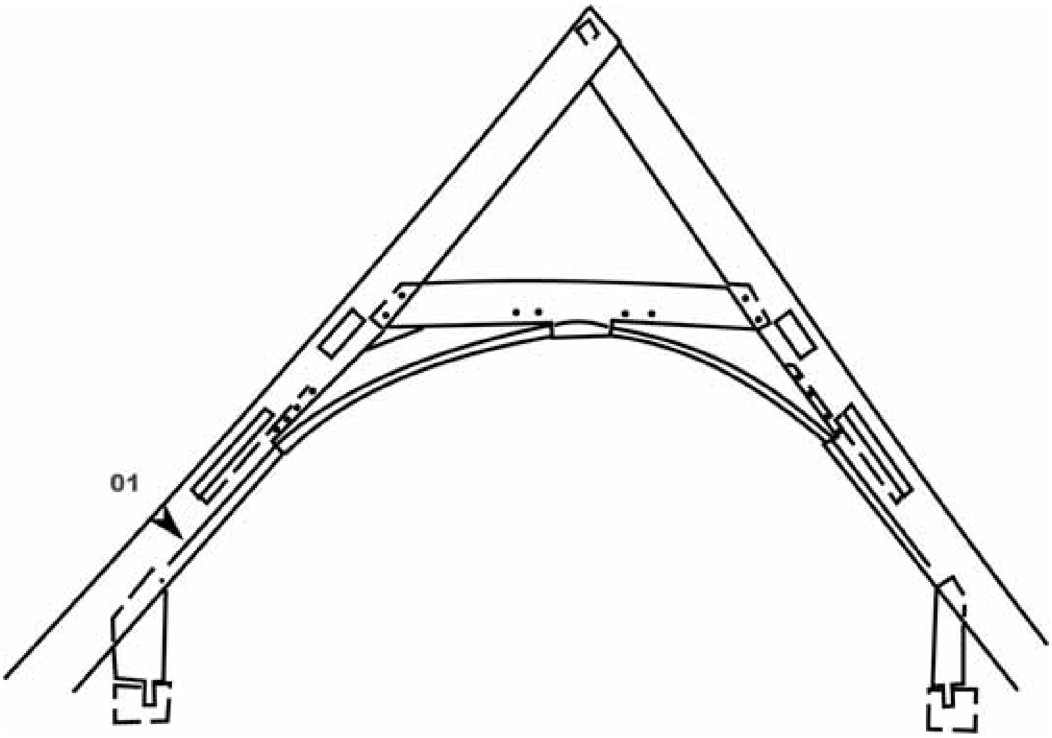


Figure 6: St Mary's Church, truss 2 east face, showing the location of sample SAR-A01

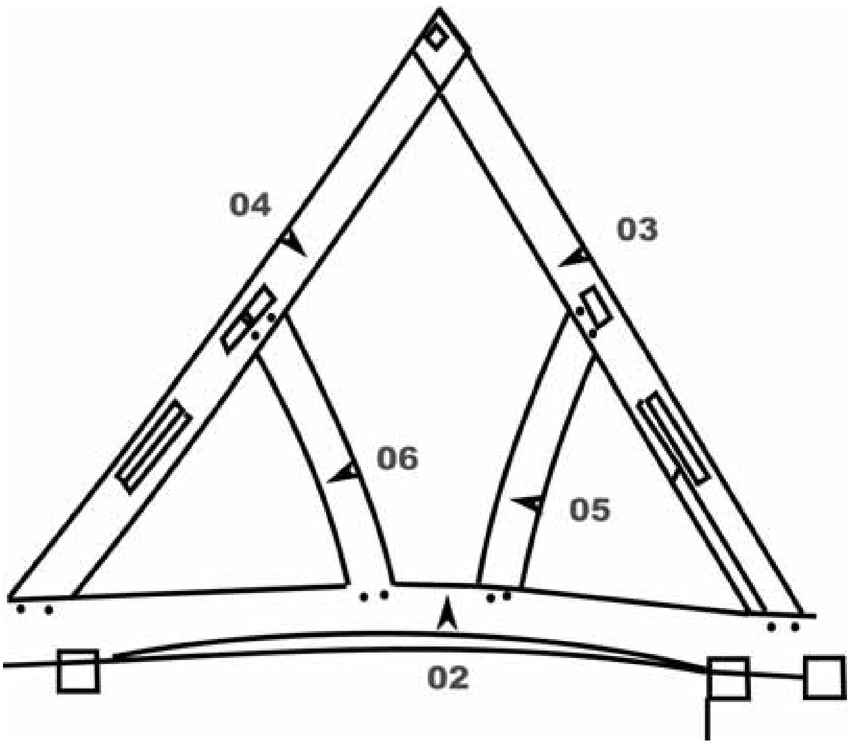


Figure 7: St Mary's Church, truss 3 east face, showing the location of samples SAR-A02–06

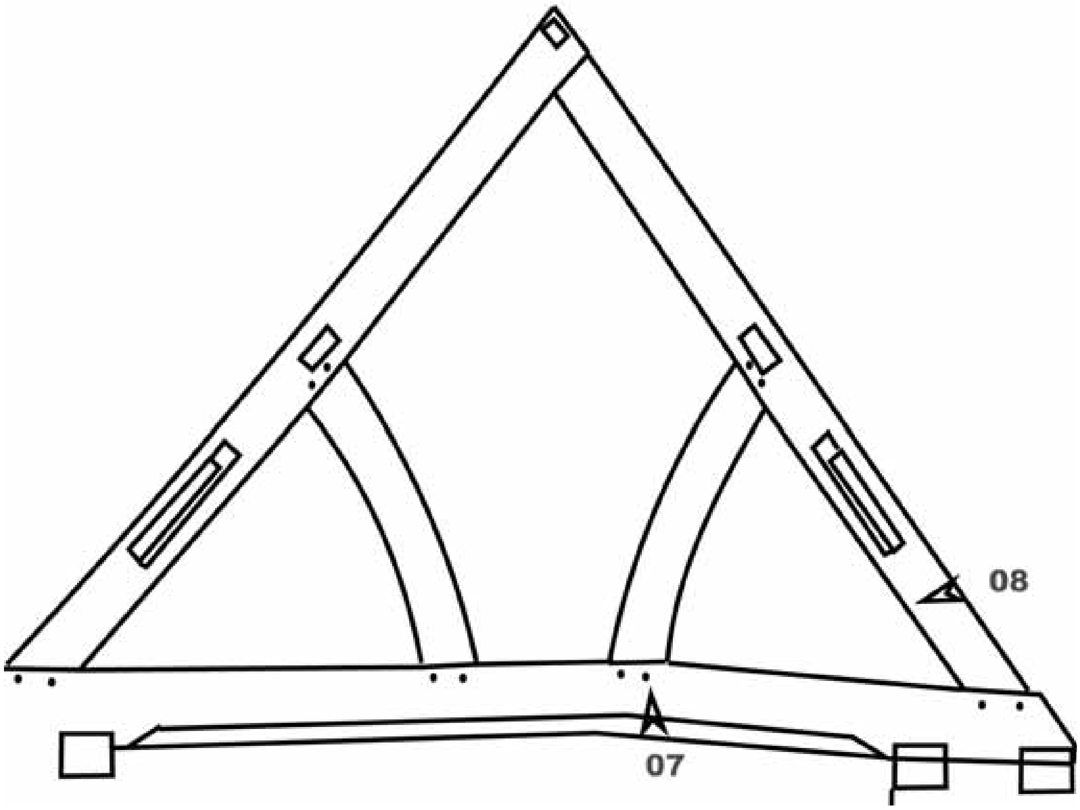


Figure 8: St Mary's Church, truss 5 east face, showing the location of samples SAR-A07 and SAR-A08

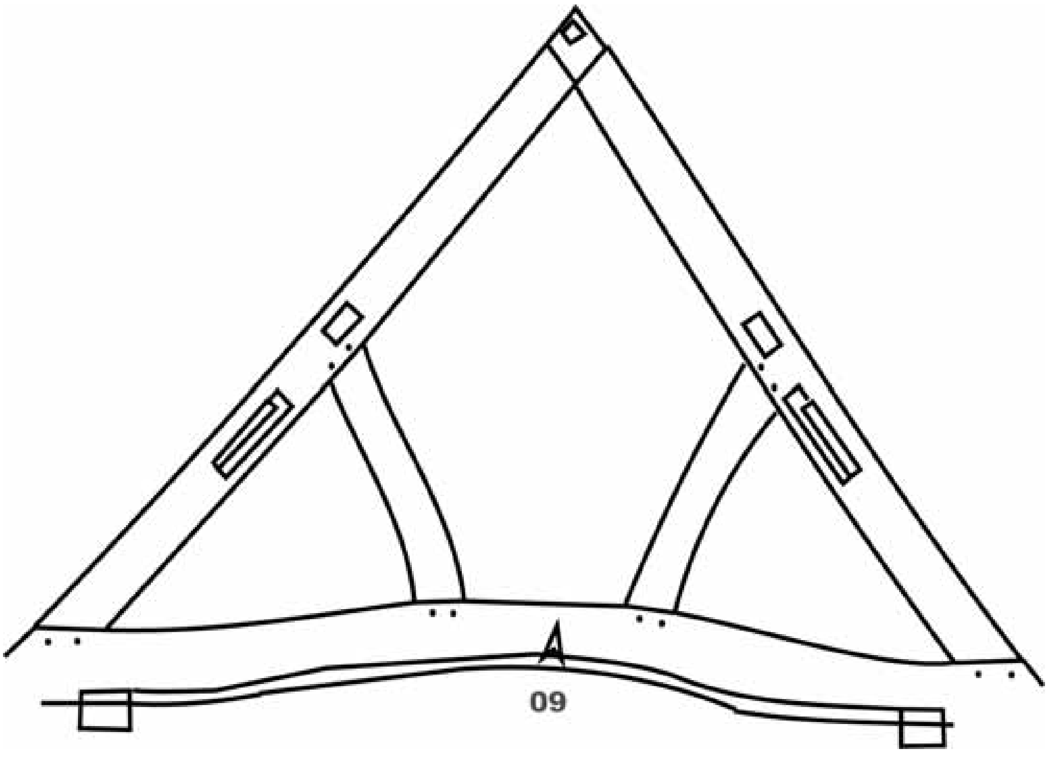


Figure 9: St Mary's Church, truss 7 east face, showing the location of sample SAR-A09

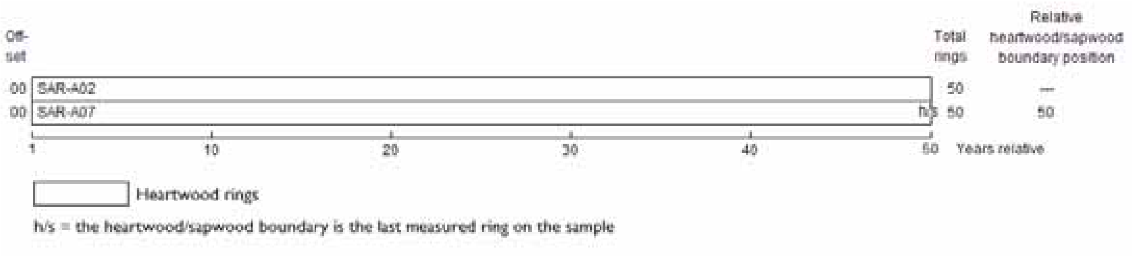


Figure 10: Bar diagram of samples in undated site sequence SARASQ01

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

SAR-A01A 57
220 225 352 306 326 349 306 358 352 316 410 481 498 404 388 412 398 319 354 454
307 365 377 351 267 315 283 402 133 71 89 202 202 206 214 106 117 178 133 203
198 247 158 126 83 110 75 97 52 94 127 104 84 104 278 445 475
SAR-A01B 57
214 222 347 318 387 324 316 361 350 325 388 484 493 410 381 405 406 318 354 452
307 366 382 351 264 328 284 416 133 71 88 204 203 213 212 104 123 179 135 203
197 253 157 126 83 109 76 90 63 91 120 116 76 110 275 444 476
SAR-A02A 50
316 511 468 351 324 411 410 402 201 323 361 385 407 372 219 287 280 251 194 294
316 241 332 258 326 391 228 179 293 248 315 186 237 321 479 402 327 343 428 425
413 282 275 224 247 200 321 250 220 243
SAR-A02B 50
379 501 452 347 327 403 408 399 204 311 392 389 404 395 218 291 287 254 193 294
312 239 316 258 339 377 237 180 292 251 307 178 244 290 485 391 320 346 430 433
431 275 286 218 252 200 318 259 216 254
SAR-A06A 59
103 78 99 130 138 154 172 140 158 124 139 174 152 119 99 123 161 196 228 308
286 253 365 281 301 398 322 262 272 325 253 210 439 352 354 335 284 298 282 272
265 157 186 218 380 377 211 207 233 267 308 301 241 249 236 336 191 164 107
SAR-A06B 59
100 99 98 128 155 173 154 137 171 111 115 177 169 115 101 125 161 203 243 313
290 246 362 291 297 379 305 271 276 303 252 209 437 341 362 333 282 304 275 273
262 152 192 234 377 366 207 206 243 260 312 295 233 243 234 337 189 164 115
SAR-A07A 50
484 438 497 419 421 558 448 412 191 359 389 362 386 367 265 232 307 282 222 240
292 180 294 239 275 242 197 201 235 186 248 183 144 128 244 258 236 214 184 205
228 216 227 222 186 171 182 201 146 160
SAR-A07B 50
483 441 498 416 422 564 450 418 196 356 390 354 402 369 263 241 313 275 213 245
288 181 308 236 272 246 193 206 235 191 249 179 144 132 248 259 233 212 187 197
230 221 229 227 194 168 181 189 153 160
SAR-A09A 58
149 248 291 331 342 431 432 352 149 171 222 271 222 237 190 251 172 232 312 191
188 128 214 251 200 224 150 203 225 255 261 242 263 224 189 104 97 66 82 77
102 147 143 129 124 105 180 298 244 176 192 155 221 194 206 215 162 104
SAR-A09B 58
190 242 287 340 335 429 434 362 216 155 193 347 262 188 202 244 179 238 311 203
195 130 219 257 207 209 154 205 213 247 273 247 279 221 170 116 84 67 83 80
94 149 139 135 107 120 182 311 232 183 188 161 215 197 211 210 164 92

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	

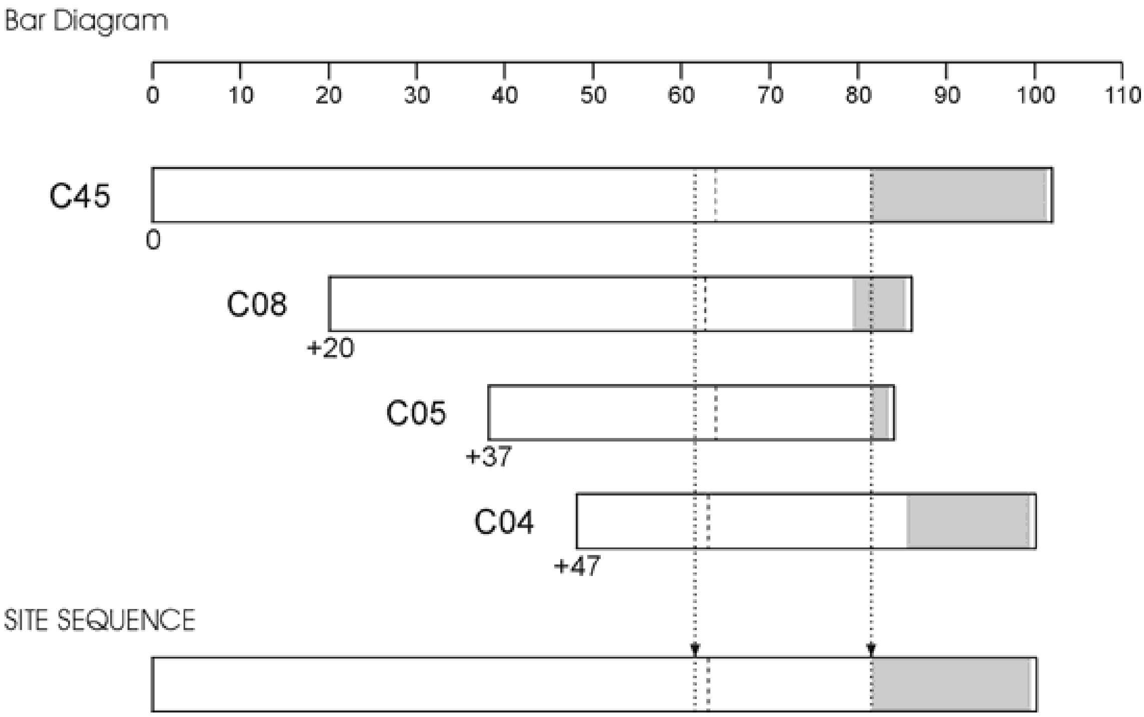


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

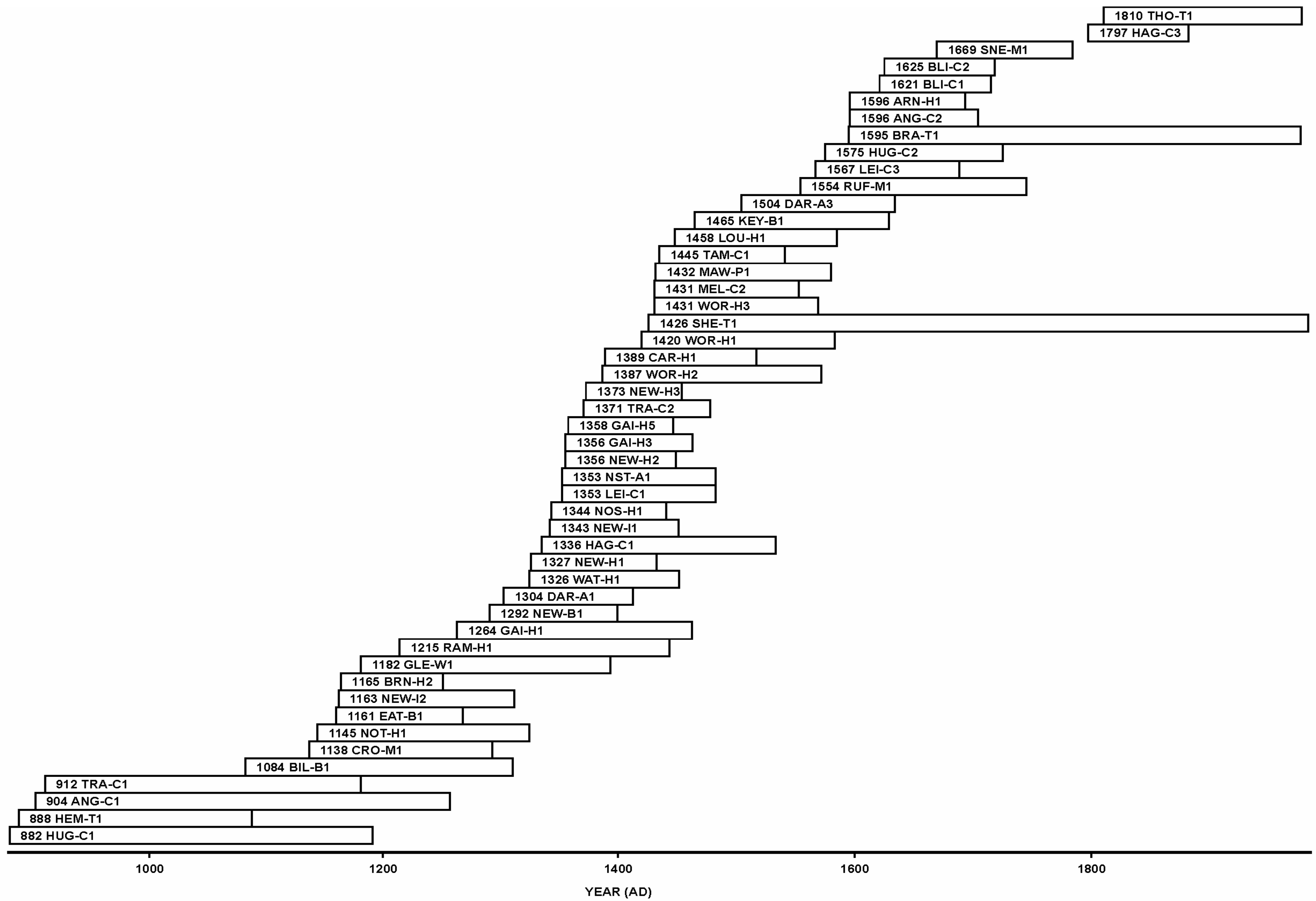
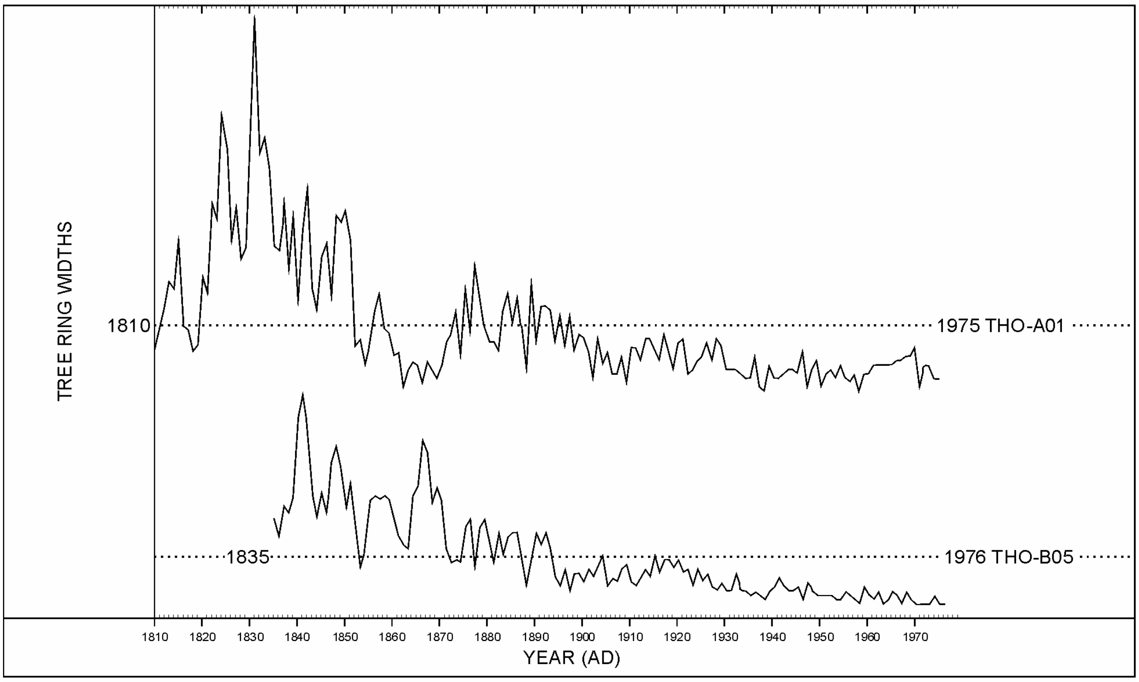


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

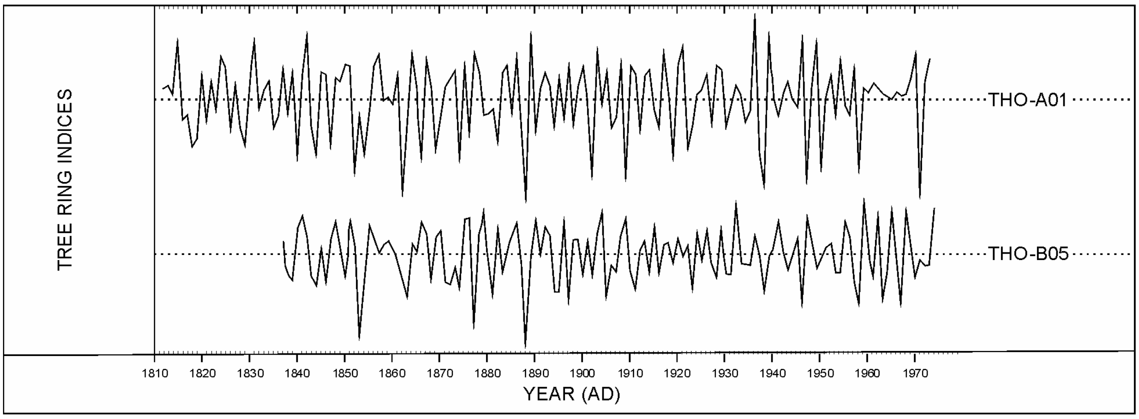


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

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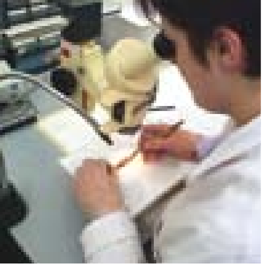
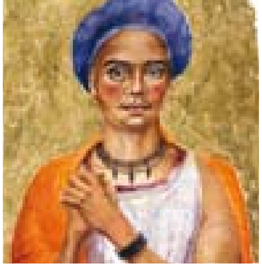



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