Ancient Monuments Laboratory Report 16/98

TREE-RING ANALYSIS OF TIMBERS FROM 10 THE CLOSE, LICHFIELD, STAFFORDSHIRE

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## Summary

Dendrochronological analysis was undertaken of samples from nineteen oak timbers in the roof and attic space of 10 The Close, Lichfield. This resulted in the production of a single site chronology of 61 rings composed of samples from three attic floor joists. Although the site chronology is short and the t-values are lower than we would like, this is dated as spanning the period AD 1384 -1444. Interpretation of the sapwood on the samples would indicate that the timbers of this phase have an estimated felling date in the range AD 1453 -1478. The medieval and post-medieval roof trusses remain undated.

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# TREE-RING ANALYSIS OF TIMBERS FROM 10 THE CLOSE, LICHFIELD, STAFFORDSHIRE

## **Introduction**

10 The Close, Lichfield (SK 114097, see Fig 1) is a small single-bayed building of two storeys, with a cellar and attics under a gabled plain-tiled roof. Within the present structure are the remains of a once larger timber-framed building. Much of the original framing has been removed and the remainder on the lower floors is hidden beneath later coverings. The only substantial intact part of the original structure is the roof of the remaining single bay. The roof of this portion of the building contains two original trusses and a more recent jettied gable truss, identified from east to west as trusses C, A, and B respectively (see Fig 2).

Truss A, the original eastern truss, has a slightly cambered tiebeam and collar with principal rafters. It is infilled with vertically set close studding and was originally closed (see Fig 3).

Truss B, the western truss, is of quite different design. It has only a tiebeam, a central stud rising to the collar, and principal rafters (see Fig 4). This intermediate truss was also closed. There are additional peg holes visible in the soffits of the principal rafters that would have taken the base tenons of wind-braces supporting purlins to the west. There are also pegged mortises that would have taken the end tenons of those purlins.

Truss C, the more recent jettied gable truss, is positioned about one metre in front of truss A, the original eastern truss. Truss C is infilled with a panel of vertically-set close studs, to either side of which are close set diagonal studs, herring-bone style (see Fig 5).

The attic contains a floor supported on a series of north-south joists. It is not clear whether they are continuous between the north and south wall frames or are jointed on top of a partition frame of the first-floor rooms below. The joists to the north of the party wall have plain chamfer stops, whilst those to the south do not. These joists are simply lodged onto the top of the wall-plates. The joists have been cut through to allow for the insertion of stairs into the attic and it can be seen that here they have grooves cut into their sides to take floor boards. It is possible that the floor is primary though this is not certain.

Sampling and tree-ring analysis were commissioned by English Heritage with a view to determining the date of the two, or possibly three, phases. These were represented by the timbers of the original trusses, A and B, the timbers of the later jettied refronting, truss C, and the joists of the attic floor.

The Laboratory would like to thank Richard Morriss for allowing us to use much of his description and his plans. These have been taken from his much fuller interim report (Morriss 1997).

The Laboratory would also like to thank Mr Robert Sharpe for allowing free access to the site and for his help and co-operation during sampling.

## Sampling 5 1 1

A total of nineteen oak timbers from the roof space was sampled by coring. Each sample was given the code LIT-A (for Lichfield, site "A") and numbered 01 - 19. Eight samples, LIT-A01 - 08, were obtained from the timbers of the original trusses, trusses A and B. These were believed to be of late medieval date. A further four samples, LIT-A09 - 12, were obtained from joists of the attic floor whose phasing was uncertain. Finally, seven samples, LIT-A13 - 19 were obtained from the timbers of truss C, the post-medieval jettied refronting of the building. It was noted at the time of



Figure 1: Map to show general location of The Close

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sampling that many of the timbers appeared to have wide growth-rings and this limited the number of potential samples, particularly from truss B. Where timbers are shown on the drawings made by Richard Morris and provided by English Heritage, the positions of the cores were recorded at the time of sampling, see Figures 3, 4, and 5. It was not possible to record some of the sample positions on these drawings.

#### Analysis and dating

## Stage 1

All nineteen samples were prepared by sanding and polishing. At this stage one sample, LIT-A14 was seen to have only thirty rings and it was not measured. One sample, LIT-A06 was composed of two sections of core taken in an attempt to obtain the maximum number of rings from the timber The remaining samples were measured and those with more than fifty-four rings, that is with sufficient rings for satisfactory analysis, were compared with each other by the Litton/Zainodin grouping procedure (see Appendix). At a value of t=4.5 two samples, LIT-A10 and 11, cross-matched with each other at the off-sets shown in Figure 6. At these off-sets the relative positions of the heartwood/sapwood boundaries are consistent with timbers having the same felling date. Because of this and the satisfactory cross-matching, the ring-widths from these two samples were combined at these relative off-sets to form LITASQ01, a site chronology of 60 rings.

Site chronology LITASQ01 was successfully cross-matched with a series of relevant reference chronologies for oak, giving a first ring date of AD 1385 and a last measured ring date of AD 1444. Evidence for this dating is given by the t-values of Table 2.

Site chronology LITASQ01 was then compared with the remaining seventeen ungrouped samples. This indicated satisfactory cross-matches with a further single sample, LIT-A12, with a t-value of 9.0. The relative off-sets of these three samples are shown in the bar diagram in Figure 7. The ring-widths from these three samples were combined at these relative offsets to form LITASQ02, a site chronology of 61 rings.

Site chronology LITASQ02 was successfully cross-matched with a series of relevant reference chronologies for oak, giving a first ring date of AD 1384 and a last measured ring date of AD 1444. Evidence for this dating is given by the t-values of Table 3. Site chronology LITASQ02 was then compared with the remaining sixteen ungrouped samples.

It would have been possible to cross-match a further sample with site chronology LITASQ02 to produce a new site chronology, LITASQ03. In turn it may have been possible to cross-match a further sample with this thus producing a fourth site chronology and so on. This course of analysis was undertaken, but each cross-match was with a low t-value. Furthermore, there appeared to be no consistency for the heartwood/sapwood boundary from timbers of what was believed to be the same phase. It was felt that this course of analysis was unsatisfactory and inadvisable to report what might be spurious results.

## <u>Stage 2</u>

The remaining sixteen ungrouped samples were then compared individually with a series of relevant reference chronologies for oak. Particular attention was paid to samples possible crossmatch with the reference chronologies at positions suggested by their dating relative to site chronology LITASQ02 and its successors as discussed above. There was, however, no satisfactory cross-matches between samples and reference chronologies at any position and thus no confirmation of the possible site chronologies constituted in stage 1, above. In part this must be attributed to the fact that the samples have too few rings to allow dating with conviction.

## **Conclusion**

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It will be seen that only one element of the building, the joists of the attic floor, can be tentatively dated. If the dating is accepted it would suggest that the timbers represented by these samples were felled in the range AD 1453 to 1478 This felling date is based on the usual 95% confidence limit for sapwood on mature oaks from England being in the range 15 to 40 rings.

Table 1: Details of tree-ring samples from 10 The Close, Lichfield, Staffordshire

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Sample no.	Sample location	Total rings	Sapwood rings*	First measured ring date	Last heartwood ring date	Last measured ring date
	Medieval trusses (A and B)					
LIT-A01	North principal rafter, truss A	67	12			
LIT-A02	South principal rafter, truss A	59	h/s	ATT 10- 00- 00- 00- 00-		
LIT-A03	North purlin, truss A - B	54	no h/s			
LIT-A04	Low stud no. 3 from north, truss A	73	12			
LIT-A05	Upper stud no. 2 from north, truss A	58	13			
LIT-A06	Upper stud no.4 from north, truss A	77	h/s			
LIT-A07	South principal rafter, truss B	47	no h/s	10.40 to 10 10 10		
LIT-A08	Common rafter, north slope A - B	40	h/s	Vin. (19. 19. 19. 19. 19.		<i>p</i>
	Floor joists					
LIT-A09	No.3 from truss B	54	h/s			
LIT-A10	No.5 from truss B	54	h/s	1385	1438	1438
LIT-A11	No.4 from truss B	58	07 ·	1387	1437	1444
LIT-A12	No.1 from truss B	45	no h/s	1384	APT 107 304 106 304	1428

## Table 1: continued

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Sample no.	Sample location	Total rings	Sapwood rings*	First measured ring date	Last heartwood ring date	Last measured ring date
·	Post-medieval truss C					
LIT-A13	North main stud post	47	14	at bit means an w		
LIT-A14	South main stud post	30	h/s			*****
LIT-A15	South common rafter, truss A - C	47	h/s			<b>10.00</b> 10.00 10.00
LIT-A16	North strut no.2	74	18			
LIT-A17	North common rafter, truss A - C	50	13		*****	******
LIT-A18	North strut no.1	53	no h/s			*****
LIT-A19	North strut no.3	68	h/s			

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



## Figure 2: 10 The Close, Lichfield; identification of trusses

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Figure 3: Truss "A" showing sample locations

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Figure 5: Truss "C" showing sample locations

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White bar = heartwood rings, shaded area = sapwood rings h/s = the heartwood/sapwood boundary is the last ring on sample

## Table 2: Results of the cross-matching of site chronology LITASQ01 and relevant reference chronologies when first ring date is AD 1385 and last ring date is AD 1444

Reference Chronology	Span of chronology	t-value	
East Midlands	AD 882 - 1981	4.4	(Laxton and Litton 1988)
British Isles	AD 401 - 1981	3.1	(Baillie and Pilcher 1982 unpubl)
Wales and West Midlands	AD 1341 - 1636	5.2	(Siebenlist-Kerner 1978)
MC10H	AD 1386 - 1585	4.6	(Fletcher 1977 pers comm)
Old Bakehouse, Long Crendon, Bucks	AD 1384 - 1440	4.5	(Alcock et al 1990)
Well Cottage, Steeple Claydon, Bucks	AD 1365 - 1444	3.8	(Alcock et al 1990)
Old Hall, Church Broughton, Derbys	AD 1368 - 1467	3.5	(Howard et al 1993)



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White bar = heartwood rings, shaded area = sapwood rings h/s = the heartwood/sapwood boundary is the last ring on sample

## Table 3: Results of the cross-matching of site chronology LITASQ02 and relevant reference chronologies when first ring date is AD 1384 and last ring date is AD 1444

Reference Chronology	Span of chronology	t-value	
East Midlands	AD 882 - 1981	4.9	(Laxton and Litton 1988)
British Isles	AD 401 - 1981	3.6	(Baillie and Pilcher 1982 unpubl)
Wales and West Midlands	AD 1341 - 1636	5.7	(Siebenlist-Kerner 1978)
MC10H	AD 1386 - 1585	5.0	(Fletcher 1977 pers comm)
Old Bakehouse, Long Crendon, Bucks	AD 1384 - 1440	4.9	(Alcock et al 1990)
Well Cottage, Steeple Claydon, Bucks	AD 1365 - 1444	4.3	(Alcock et al 1990)
Old Hall, Church Broughton, Derbys	AD 1368 - 1467	4.1	(Howard et al 1993)

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## APPENDIX

## **Tree-Ring Dating**

## The Principles of Tree-Ring Dating

Tree-ring dating, or *dendrochronology* as it is known, is discussed in some detail in the Laboratory's Monograph, 'An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular 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.



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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.



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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 inspecton 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	$\backslash$	+17	+27
C05	5.2	10.4		+10
C04	5.9	3.7	5.1	$\geq$





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 These standard widths are known as ring-width indices and were first used in attempted. 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 ringwidths 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.

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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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