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Summary

Twenty-seven samples from the "rigging loft" building, plus twelve samples from the undercroft of the separate, though adjacent, chapel of the Trinity House complex in Newcastle upon Tyne, were analysed by tree-ring dating. This analysis produced three site chronologies, and the dating of a further single sample.

The first site chronology, NWCASQ01, consists of ten samples and has 128 rings spanning the period AD 1397 to AD 1524. All samples are from the roof of the rigging loft and indicate that the present roof is a replacement of the original medieval one, being made of timber felled in AD 1524.

The second site chronology is made up of five samples, four from the chapel undercroft and one from the ground-floor ceiling of the rigging loft. It has 234 rings spanning the years AD 950 to AD 1183. One timber from the chapel undercroft was certainly felled in AD 1183 and it is possible that the other four were felled at the same time. However, it is equally possible that some of the timbers have different felling dates, though one is unlikely to have been felled later that AD 1209. These samples are possibly reused in their present location. However if they are in their original position they would represent the remains of a very early pre-chapel building on the site.

A third site chronology, NWCASQ03, consists of 3 samples from the rigging loft roof. It has 82 rings but it cannot be dated.

A single sample, NWC-ASQ18, from the ground-floor ceiling of the rigging loft was also dated. This has 69 rings spanning AD 1381 to AD 1436. The timber represented was felled in AD 1436.

Keywords
Dendrochronology
Standing Building

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TREE-RING ANALYSIS OF TIMBERS FROM THE RIGGING LOFT AND CHAPEL UNDERCROFT, TRINITY HOUSE, BROAD CHARE, NEWCASTLE UPON TYNE, TYNE AND WEAR

Introduction

Trinity House, Newcastle (NZ 253640; Figs 1 and 2), comprises a number of distinct, separate, buildings all grouped around a courtyard. The buildings range in date from the medieval period to the early nineteenth century and include Dog Bank Building, otherwise known as the "rigging loft" after a former use, a chapel, hall, school room, board room, and almshouses. Surveys of Trinity House have previously been undertaken and include McCombie (1985) and Ryder (2001 unpubl).

The earliest extant document relating to the site is dated to AD 1524, being made by the Guild of the Blessed Trinity. This states that in AD 1505 the site had consisted of a messuage with cellars, and a garden with appurtenances in Broad Chare, and that a building once known as Dalton's Place stood here. It was upon this site that the chapel, hall, almshouses etc were to be built.

The AD 1524 documents refer to earlier deeds of sale, now lost, which would put the existence of the site and possibly Dog Bank Building itself as early as AD 1421. The AD 1524 document also states that lofts were added on the north side of the curtilage and above the cellars of Dog Bank Building. It is not clear here whether "above" is used in the sense of directly over the lower rooms of Trinity House, or lying adjacent to, but higher up the low hill upon which Dog Bank Building stands. Archaeological excavations have shown that the area where the Trinity House complex now stands was possibly part of the river Tyne at least as late as the twelfth century. If this interpretation is true it is unlikely that buildings stood here at that time (Ryder pers comm.).

From AD 1530 the Guild start to keep account books and the history of the rest of the site is well known from these sources. These describe amounts expended in maintenance, repair, and further building. They also give a description of the rooms and their uses, and amounts paid for the benefit of the poor housed within. Of these the purchase of coal for heating, and of soap for washing, are common features.

It is with two parts of the Trinity House complex in particular, Dog Bank Building and the chapel undercroft that this report is particularly concerned.

The buildings

Dog Bank Building – the "rigging loft"

Dog Bank Building, or the "rigging loft", is the best preserved medieval structure on the site. It comprises a three storeyed parallelogram block enclosing the north side of the courtyard. On the basis of the stylistic evidence of the stonework, window and door openings etc, and on the basis of the original steep pitch of the roof, deduced from survey work, the building is believed to be of early fourteenth-century date.

The present lower-pitched roof of the rigging loft is believed to be a later, probably sixteenth-century, replacement of the original. This present roof is of five full bays plus a further half-bay at each end in consequence of the parallelogram plan of the building (Fig 3). It consists of six trusses with slender king-posts, some of the king posts having braces rising to the square set ridge; coupled common rafters are to be found between each truss. The principal rafters carry double purlins to each pitch.

There are no timbers to be seen on the second floor of the rigging loft and whilst large timbers are visible on the first floor these had too few rings for satisfactory analysis by dendrochronology. The ceiling of the ground floor, however, consists of five large principal transverse beams supporting numerous smaller common joists (Fig 4). The principal beams are substantial timbers and it is believed that they are possibly original although other interpretations suggest that they are later insertions, possibly of seventeenth-century date. One of them, beam number four, counting from the east, is of some sort of softwood, and may in fact be nineteenth or even twentieth century in date. A further beam, number three, is spliced to another timber at its northern end very close to where it runs into the north wall. Some of the principal beams are supported by timber posts, beam number two for example to north and south end, and number three at its south end only. The posts are largely buried in the walls and apart from one are difficult to access. The ends of some of the other principal transverse beams are supported by metal posts.

It is believed that the common joists which the main principal beams support are all reused, or at least not in their original positions. This is because none of the common joists are jointed into the principal beams and all are cut off where they meet the principals; the ends of the common joists sometimes slightly overlap side-by-side with each other on the principal beams. Some of these common joists have redundant mortices also. There is thus appears to be considerable evidence of possible alteration to the ceiling timbers and hence considerable uncertainty as to its date.

The chapel undercroft

The documentary evidence shows that the chapel building, separate but adjacent to the rigging loft, was founded in AD 1505. However, recent repair and restoration at the chapel has revealed what are believed to be early wooden timbers. The ground-floor room, or undercroft, of the chapel, contains a large axial spine-beam in its western half, the beam being in three sections joined by scarfs (Fig 5).

The spine-beam is supported at its mid-point by a timber Samson post. The post has straight braces rising on its east and west sides, post and braces rising to a horizontal "bolster" beam, on the same line as, and supporting, the spine-beam. To the west end of the undercroft the spine-beam continues to a stone cross-wall where it is supported by a slightly curved brace or bracket. At the east end the spine-beam runs into the brick wall of an internal partition where again there is a curved bracket. None of these timbers show any architectural or structural evidence for being reused in their present location.

In the eastern half of the undercroft the spine-beam is missing altogether, but excavation of the floor revealed the shaped stone plinth for a second Samson post. The undercroft also has three window openings. Each of these has at least three and sometimes four closely set timber lintels.

Sampling

Sampling and analysis by tree-ring dating of the two buildings of Trinity House described in the introduction above, the rigging loft and the chapel undercroft, were commissioned by English Heritage. The purpose of this was to assist in informing listed Building Consent proposals and establish a possible sequential development and alteration of the site. It was hoped that dendrochronological dating would provide dating of otherwise undocumented buildings on the site to inform forthcoming repairs and contribute to site interpretation. It was further hoped that tree-ring dating would also help in the construction of regional roof typologies.

For the rigging loft sampling was to concentrate firstly on the roof to establish whether or not this replacement dated to the sixteenth-century, and secondly on the timbers of the ceiling of the ground floor. The purpose of the latter was to determine which of the timbers might be later replacements and which, if any, may be of medieval date and possibly belong to the original medieval structure.

It was hoped that sampling of timbers from the chapel undercroft would determine whether or not they dated from its foundation in AD 1505, or whether they belonged to some earlier, pre-chapel, structure.

Thus, after on-site discussions and in conjunction with the English Heritage brief, a total of twenty-seven core samples was obtained from the rigging loft. Each of these samples from the rigging loft was given the code NWC-A (for Newcastle, site "A"), and numbered 01 – 27. A further twelve samples were obtained from the chapel undercroft. To help distinguish these from the first batch these were given the code NWC-B (for Newcastle, site "B"), and numbered 01 – 12. This sampling information can be summarised thus:

Sample numbers	Sample location
NWC-A01 – 17	Rigging loft roof
NWC-A18 – 20	Rigging loft, principal transverse beams, ground-floor ceiling
NWC-A21 – 27	Rigging loft, common joists, ground-floor ceiling
NWC-B01 – 12	Chapel undercroft

Although the common joists of the ground-floor ceiling of the rigging loft show evidence of possible reuse, they appeared to contain a large number of rings and, particularly important, they retained complete sapwood. It was hoped that if these were sampled and be dated, and could be reliably cross-matched with samples from known original *in-situ* timbers from the site then they might provide precise dating for the felling of the timber. At the very least it was felt that they might provide local tree-ring data from the Newcastle area.

The positions of these samples are marked on plans drawn for the occasion by Peter Ryder, or made by him earlier and provided by English Heritage. These are reproduced here as Figures 3 - 5. Details of the samples are given in Table 1. In this report the bays and trusses have been numbered and described from east to west, or from north to south as appropriate.

The Laboratory would like to take this opportunity to thank Captain Shipley, Master of Trinity House, for his help in accessing the site during sampling. We would also like to thank Martin Roberts of the English Heritage North-east Regional Office in Newcastle for arranging site access. In particular we would like to thank Peter Ryder, recording archaeologist, who helped assess the possible phasing of the timbers, quickly provided drawings used in this report, and kindly provided his notes and information used in the introduction above.

Analysis

All thirty-nine samples from the three areas of Trinity House were prepared by sanding and polishing and their annual growth-ring widths measured. Analysis then proceeded in stages. In the first stage the samples were analysed in separate groups according to their sampling location, the rigging loft roof, the ground-floor ceiling beams, and the chapel undercroft. However, in this first stage only groups of samples were compared with the reference chronologies, no attempt was yet made to date any remaining ungrouped individuals. In the second stage the samples from all three areas were brought together and compared with each other as a single group of thirty-nine. Any further site chronologies thus created were then dated by comparison with the reference chronologies for oak, compared with each other, and then compared with any remaining ungrouped samples. Only once this was completed was each remaining ungrouped sample compared individually with the reference chronologies.

As a result of this process, at a minimum *t*-value of 4.5, three groups of samples could be formed. The ten samples of the first group, all from the rigging loft roof, cross-matched with each other, as shown in the bar diagram Figure 6, to form a single site chronology, NWCASQ01, of length 128 rings. Site chronology NWCASQ01 was compared with a series of relevant reference chronologies for oak, giving it a first ring date of AD 1397 and a last measured ring date of AD 1524. Evidence for the dating of site chronology NWCASQ01 is given in the *t*-values of Table 2.

Eight of the ten samples in the site chronology retain complete sapwood, that is, they have the last growth ring that the tree from which they were taken produced before it was felled. In each case the last complete sapwood ring date is the same, AD 1524.

The second group of five samples to form cross-matched with each other as shown in the bar diagram of Figure 7. These samples were combined at these relative positions to form site chronology NWCASQ02 of length 234 rings. When compared with the reference chronologies this site chronology has a first ring date of AD 950 and a last measured ring date of AD 1183. Evidence for this dating is given in the *t*-values of Table 3. One sample in this site chronology, NWC-B04, retains complete sapwood, this last ring being dated to AD 1183. However, it is not certain whether this represents the felling date of all the other timbers represented by this site chronology.

As will be seen from the bar diagram of Figure 7 the site chronology NWCASQ02 is made up of five samples. Four of them, NWC-B03, B04, B05, and B06, are from sections of the central spine-beam and bolster of the chapel undercroft, with the fifth, NWC-A25, being from a joist from the ground-floor ceiling of the rigging loft. The *t*-values of the cross-matching between the individual samples are shown in Table 4. It will be seen from this that the highest *t*-value is between samples from the two different areas, NWC-A25, from the ground-floor ceiling of the rigging loft and sample NWC-B03, from the chapel undercroft.

It may be seen from the cross-matching of site chronology NWCASQ02, that the reference chronologies used in Table 3, apart from HARTLEPOOL, are not particularly local to north-east England; only those from Carlisle and Scotland might be considered so. The others are from different parts of the country especially the Midlands and eastern England. A chronology from Wales is also represented. The need to use wider-ranging reference material may be due to the early date of the material represented by NWCASQ02, there being virtually no early reference chronologies available for north-east England.

The third site chronology to be formed consists of two samples, NWC-A03 and A14 from the rigging loft roof, plus one, NWC-A20, from the ground-floor ceiling. The relative positions of these are shown in the bar diagram of Figure 8. The three samples were combined at these positions to form site chronology NWCASQ03 with eighty-two rings and compared with a full range of reference material. It could not, however, be dated.

The three site chronologies were compared with each other, and with the remaining ungrouped samples. There was, however, no further satisfactory cross-matching. Each individual ungrouped sample was then compared with the reference chronologies. This indicated a date for one sample only, NWC-A18, from a principal beam in the ground-floor ceiling of the rigging loft. This has a first ring date of AD 1381 and a last, complete sapwood, ring date of AD 1449. Evidence for this date is given in the *t*-values of Table 5.

Each of the samples in the undated site chronology NWCASQ03 was also compared individually with a full range of reference chronologies. Again, however, there was no satisfactory dating

Interpretation

Analysis by dendrochronology has produced three site chronologies. The first, NWCASQ01, consisting of ten samples from the roof of the rigging loft, is 128 rings long and spans the period AD 1397 – AD 1524. Interpretation of the sapwood suggests that the majority of the timbers in the roof were cut as a single felling in AD 1524.

A second site chronology, NWCASQ02, has 234 rings and is dated as spanning the period AD 950 – AD 1183. It consists of four samples from the chapel undercroft, one of which (NWC-B04), has complete sapwood with a last measured ring date of AD 1183, and one sample from a joist in the ground-floor ceiling of the rigging loft. If it is accepted that the timbers represent trees cut in a single operation, then their felling date would be AD 1183.

However, such an interpretation is not certain because three of the samples, NWC-B03, B05, and B06, do not have the heartwood/sapwood boundary, and one sample, NWC-A25, which does, is from a different location. It is possible that we have here timbers from a similar, or indeed the same, source with slightly different felling dates. If we were to estimate the felling date of sample NWC-A25 alone, with its heartwood/sapwood boundary date of AD 1159, this would be in the range AD 1174 – AD 1209. Such an estimated felling date range is based on a 95% confidence limit for the amount of sapwood on mature oaks from this part of England as being in the range 15 –

50 rings. It will be noted that the felling date of the tree represented by sample NWC-B04, AD 1183, lies well within this range.

Having thus addressed the possibility of multi-phase timbers, it is more probable that the timbers are of one phase of felling, given the use of most of the timbers as part of a single feature, the central spine-beam, and their degree of internal cross-matching

A third site chronology, consisting of three samples from the rigging loft roof and 82 rings long, could not be dated, nor could, individually, its component samples.

Of the remaining individual samples only one, NWC-A18, from a principal beam of the ground-floor ceiling of the rigging loft could be dated. Retaining the last complete sapwood ring it represents a tree felled in AD 1449.

A number of samples remain ungrouped and undated.

Conclusion

From the analysis it would appear that the majority of the timbers of the rigging loft roof are made up of trees with a single felling date, AD 1524, and that, as believed, the roof is a later replacement of the original. These trees must represent the work described in the document of AD 1524, referring to the addition of lofts above the cellars belonging to Trinity House and on the north side of the curtilage. It is now obvious that these were directly above the cellars and not higher up the hill.

The ceiling of the ground floor of the rigging loft has at least two timbers with different felling dates. One timber, a main principal beam and represented by sample NWC-A18, is from a tree felled in AD 1449. The second timber, a joist and represented by sample NWC-A25, is from a tree possibly felled in AD 1183, and almost certainly felled between AD 1174 and AD 1209. The relationship of the very early date for this timber with the building is difficult to interpret apart from the probability that it is a timber reused from some other, much earlier building; likewise the timber with the AD 1449 felling date. It is possible that this may be a timber belonging to the medieval building on the site, possibly that once known as Dalton's place, but, being a single sample this is impossible to prove and no such conclusion should by inferred from it.

The chapel undercroft contains a small number of timbers that were probably felled in AD 1183 at least one timber, represented by sample NWC-B04, certainly was. If the archaeological interpretation that this area was part of the river in the twelfth century, when at least some of the timbers used in the undercroft were felled, is correct it would be very unlikely that a building could have stood here and the spine-beam represents reused timbers. However, if the archaeological interpretation is not correct it is possible that the spine beam represents part of a very early, pre-chapel, structure on this site.

An unusual feature of this site is the number of samples that not only fail to date, but fail to cross-match with each other. This is particularly a feature of the samples from the ground-floor ceiling of the rigging loft, which were especially sampled for this, and the chapel undercroft. In the former there are three ungrouped and undated samples with over 100 rings. Although the ungrouped and undated samples from the undercroft are shorter, they are still long enough for satisfactory tree-ring dating.

There is no particular reason why there might be any difficulty with these. The ring-widths of some of the samples are slightly narrow, but not unusually so. One wonders whether many of the timbers represented, apparently being reused here, are from multiple sources and of multiple dates. The proximity of the site to the late medieval quay-side may make the import of timbers a greater possibility. There is no positive evidence of this on dendrochronological grounds, but it might lead to the use of timber from disparate sources. In any case, these samples will be assessed again as part of a forthcoming collective analysis of all material from north-east England.

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Table 1: Details of samples from Trinity House, Broad Chare, Newcastle upon Tyne

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Rigging loft roof					
NWC-A01	Tiebeam, truss 1	70	18C	AD 1455	AD 1506	AD 1524
NWC-A02	South principal rafter, truss 1	46	19C	------	------	------
NWC-A03	South common rafter 5, bay 1	75	no h/s	------	------	------
NWC-A04	Tiebeam, truss 2	66	18C	------	------	------
NWC-A05	South common rafter 2, bay 2	71	no h/s	AD 1419	------	AD 1489
NWC-A06	North common rafter 2, bay 2	65	6	AD 1451	AD 1509	AD 1515
NWC-A07	North lower purlin, truss 2 – 3	54	no h/s	------	------	------
NWC-A08	Tiebeam, truss 3	107	27C	AD 1418	AD 1497	AD 1524
NWC-A09	South common rafter 1, bay 3	103	no h/s	------	------	------
NWC-A10	North common rafter 2, bay 3	75	17C	AD 1450	AD 1507	AD 1524
NWC-A11	North lower purlin, truss 3 – 4	55	16C	AD 1470	AD 1508	AD 1524
NWC-A12	South common rafter 1, bay 4	70	23C	------	------	------
NWC-A13	North principal rafter, truss 4	64	17C	AD 1461	AD 1507	AD 1524
NWC-A14	South common rafter 3, bay 5	58	h/s	------	------	------
NWC-A15	North principal rafter, truss 5	101	19C	AD 1424	AD 1505	AD 1524
NWC-A16	South principal rafter, truss 5	128	19C	AD 1397	AD 1505	AD 1524
NWC-A17	North upper purlin, truss 5 – 6	85	18C	AD 1440	AD 1506	AD 1524

Table 1: continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Rigging loft ground-floor ceiling					
NWC-A18	Principal transverse beam 2	69	13C	AD 1381	AD 1436	AD 1449
NWC-A19	Principal transverse beam 3	41	15C	------	------	------
NWC-A20	Principal transverse beam 5	82	23C	------	------	------
NWC-A21	Common joist 5, bay 2	143	23C	------	------	------
NWC-A22	Common joist 9, bay 2	78	h/s	------	------	------
NWC-A23	Common joist 8, bay 2	63	16C	------	------	------
NWC-A24	Common joist 5, bay 3	49	19C	------	------	------
NWC-A25	Common joist 3, bay 4	152	h/s	AD 1008	AD 1159	AD 1159
NWC-A26	Common joist 5, bay 5	107	26C	------	------	------
NWC-A27	Common joist 10, bay 5	109	23C	------	------	------
	Chapel undercroft					
NWC-B01	East bracket	73	h/s	------	------	------
NWC-B02	Central Samson post	106	h/s	------	------	------
NWC-B03	Central spine-beam, east section	100	no h/s	AD 1007	------	AD 1106
NWC-B04	Central spine-beam, west section	181	30C	AD 1003	AD 1153	AD 1183
NWC-B05	Central spine-beam, middle section	112	no h/s	AD 950	------	AD 1061
NWC-B06	"Bolster" beam at Samson post	130	no h/s	AD 976	------	AD 1105
NWC-B07	West brace to Samson post	101	44C	------	------	------
NWC-B08	East brace to Samson post	45	no h/s	------	------	------
NWC-B09	Outer lintel, window 1	58	h/s	------	------	------
NWC-B10	Middle lintel, window 1	51	no h/s	------	------	------
NWC-B11	Inner lintel, window 2	71	h/s	------	------	------
NWC-B12	Inner lintel, window 3	55	h/s	------	------	------

*h/s = the heartwood/sapwood boundary is the last ring on the sample
C = complete sapwood retained on sample, last measured ring date is felling date of tree

Table 2: Results of the cross-matching of site chronology NWCASQ01 and relevant reference chronologies when first ring date is AD 1397 and last ring date is AD 1524

Reference chronology	Span of chronology	*t*-value	
Ingleby Greenhow, N Yorks	AD 1429 – 1563	8.5	(Howard *et al* 1993)
The College, Cathedral Precinct, Durham	AD 1364 – 1531	7.8	(Howard *et al* 1992a)
Old Queen's Head, Sheffield, S Yorks	AD 1370 – 1498	6.6	(Howard *et al* 1992b)
Kepier Hospital, Durham	AD 1304 – 1522	6.5	(Howard *et al* 1996)
Nether Levens Hall, Cumbria	AD 1395 – 1541	6.5	(Howard *et al* 1991)
East Midlands	AD 882 – 1981	6.0	(Laxton and Litton 1988)
England	AD 401 – 1981	5.8	(Baillie and Pilcher 1982 unpubl)
Witton Hall, Witton Gilbert, Co Durham	AD 1395 – 1475	5.5	(Howard *et al* 1996)

Table 3: Results of the cross-matching of site chronology NWCASQ02 and relevant reference chronologies when first ring date is AD 950 and last ring date is AD 1183

Reference chronology	Span of chronology	*t*-value	
HARTLEPOOL	AD 851 – 1212	11.0	(Hillam 1983)
Scotland	AD 946 – 1975	3.8	(Baillie 1977)
East range, Carlisle Guildhall, Cumbria	AD 976 – 1382	5.1	(Howard *et al* 1994a)
Brecon Cathedral	AD 996 – 1227	4.7	(Howard *et al* 1994b)
East Midlands	AD 882 – 1981	7.5	(Laxton and Litton 1988)
England	AD 401 – 1981	4.2	(Baillie and Pilcher 1982 unpubl)
St Hugh's Choir, Lincoln Cathedral	AD 882 – 1191	7.0	(Laxton and Litton 1988)
Angel Choir, Lincoln Cathedral	AD 912 – 1248	6.7	(Howard *et al* 1985)

Table 4: *t*-value off-set matrix to show cross-matching between individual component samples of site chronology NWCASQ03

	B03	B04	B05	B06	A25
B03		4	57	31	-1
B04	4.5		53	27	-5
B05	6.7	5.7		-26	-58
B06	6.3	4.5	3.3		-32
A25	7.4	4.6	4.2	5.5	

Off-sets above diagonal, *t*-values below diagonal

Table 5: Results of the cross-matching of sample NWC-A18 and relevant reference chronologies when first ring date is AD 1381 and last ring date is AD 1449

Reference chronology	Span of chronology	*t*-value	
Beamish, Co Durham	AD 1342 – 1441	8.0	(Howard *et al* 1990 unpubl)
Seaton Holme, Easington, Co Durham	AD 1375 – 1489	6.3	(Howard *et al* 1988 unpubl)
Choir roof, Durham Cathedral	AD 1346 – 1458	6.1	(Howard *et al* 1992a)
Byers Garth, Sherburn, Durham	AD 1330 – 1448	5.8	(Howard *et al* 1995)
Witton barn, Witton Gilbert, Co Durham	AD 1342 – 1441	5.6	(Howard *et al* 1996)
The Close, Newcastle upon Tyne	AD 1365 – 1513	5.1	(Howard *et al* 1991)
England	AD 401 – 1981	4.9	(Baillie and Pilcher 1982 unpubl)
East Midlands	AD 882 – 1981	4.4	(Laxton and Litton 1988)

Figure 1: Map to show general location of Trinity House

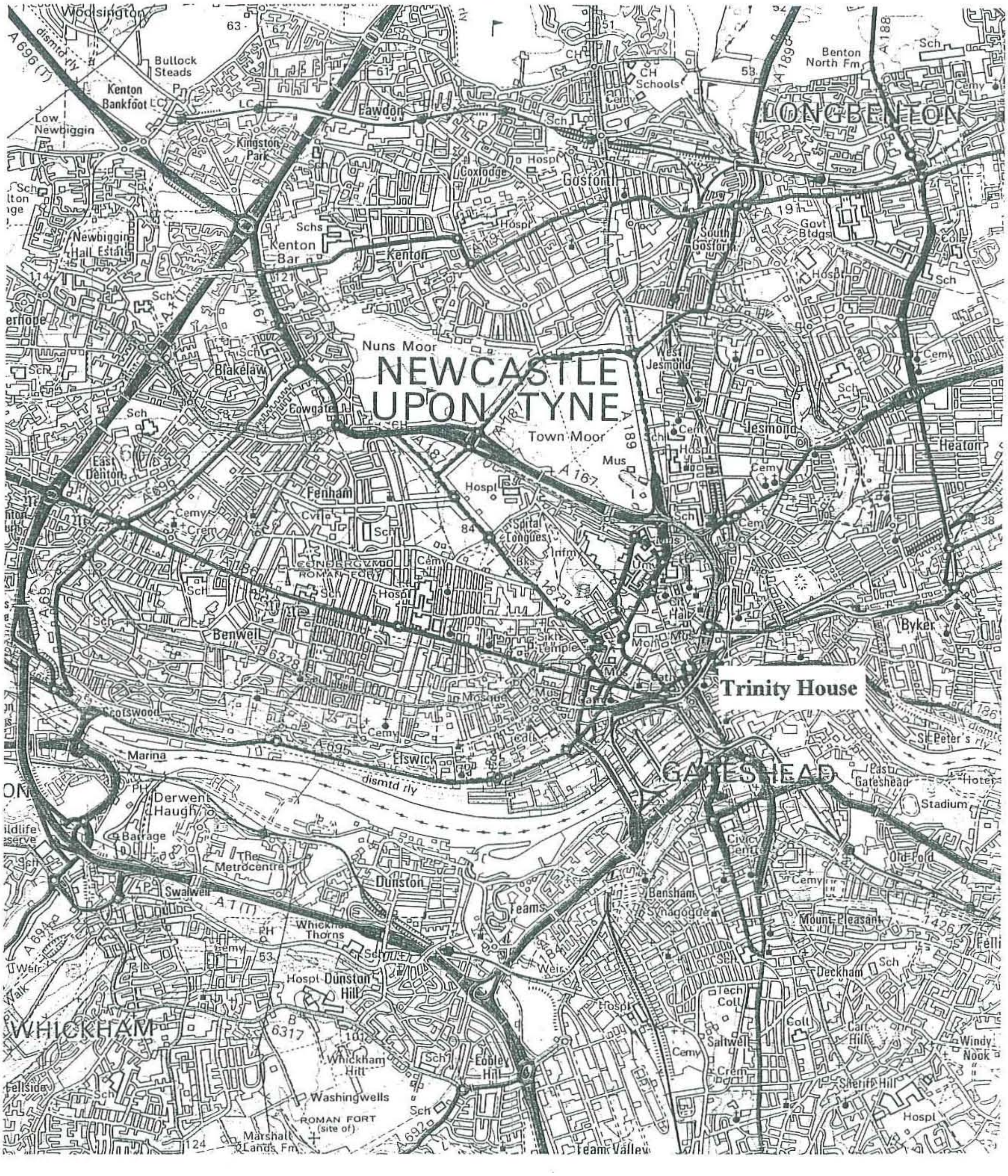


Figure 2: Map to show specific location of the rigging loft (128) and the chapel undercroft (131) at Trinity House

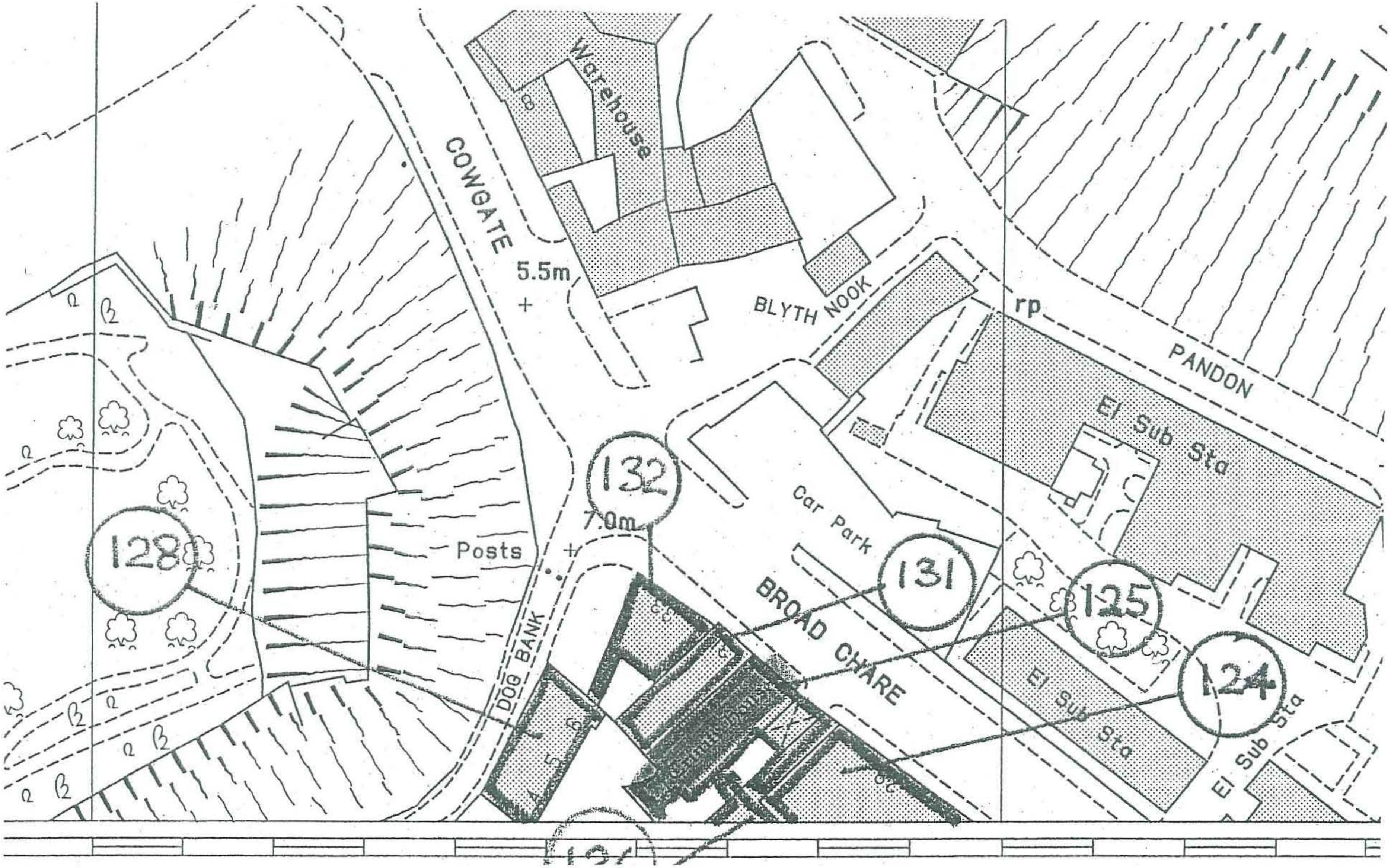


Figure 3: Plan to show sampled timbers from the rigging loft roof (based on sketch drawing made at time of sampling by Peter Ryder)

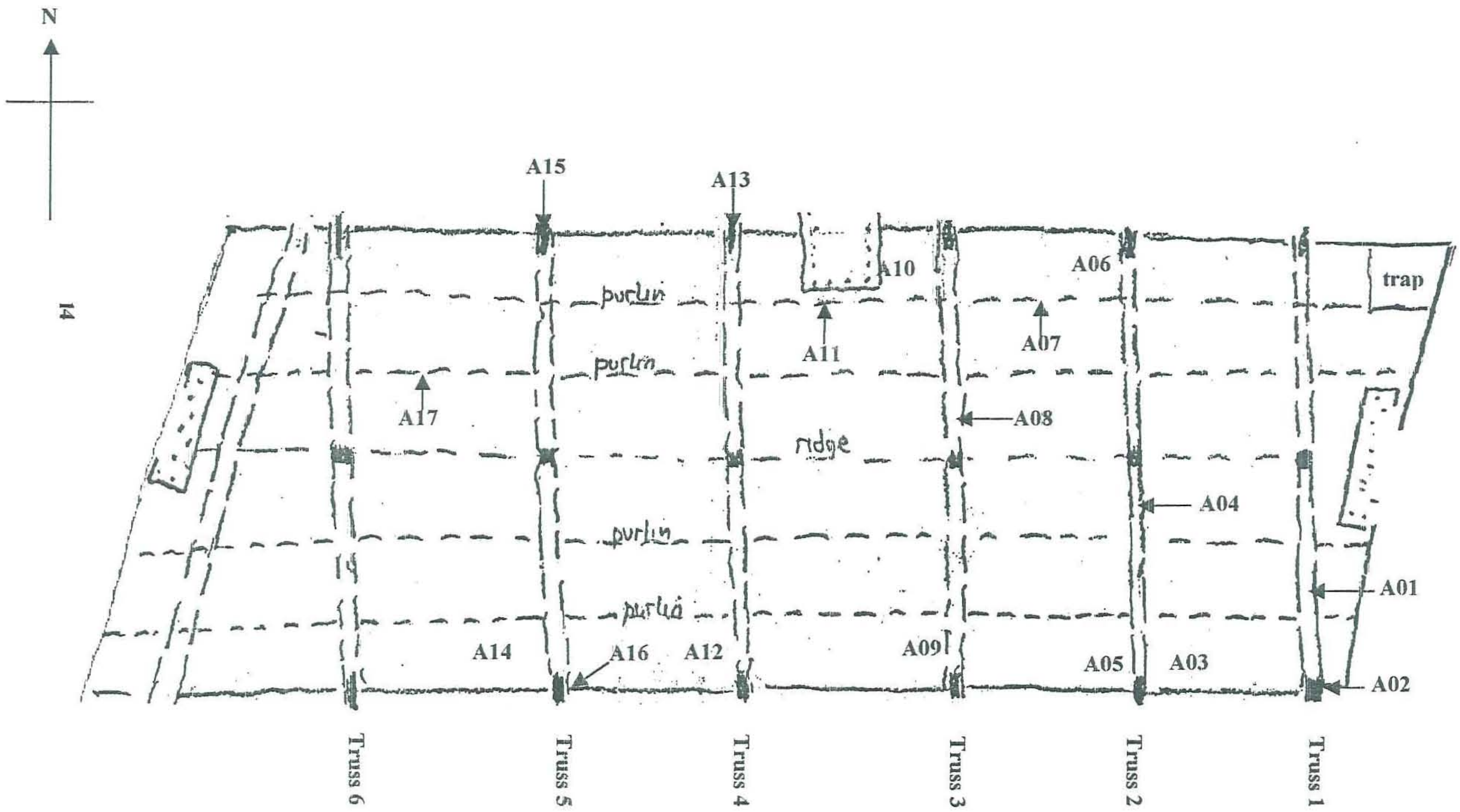


Figure 4: Sketch diagram to show sampled timbers from the rigging loft ground-floor ceiling (based on architectural drawing)

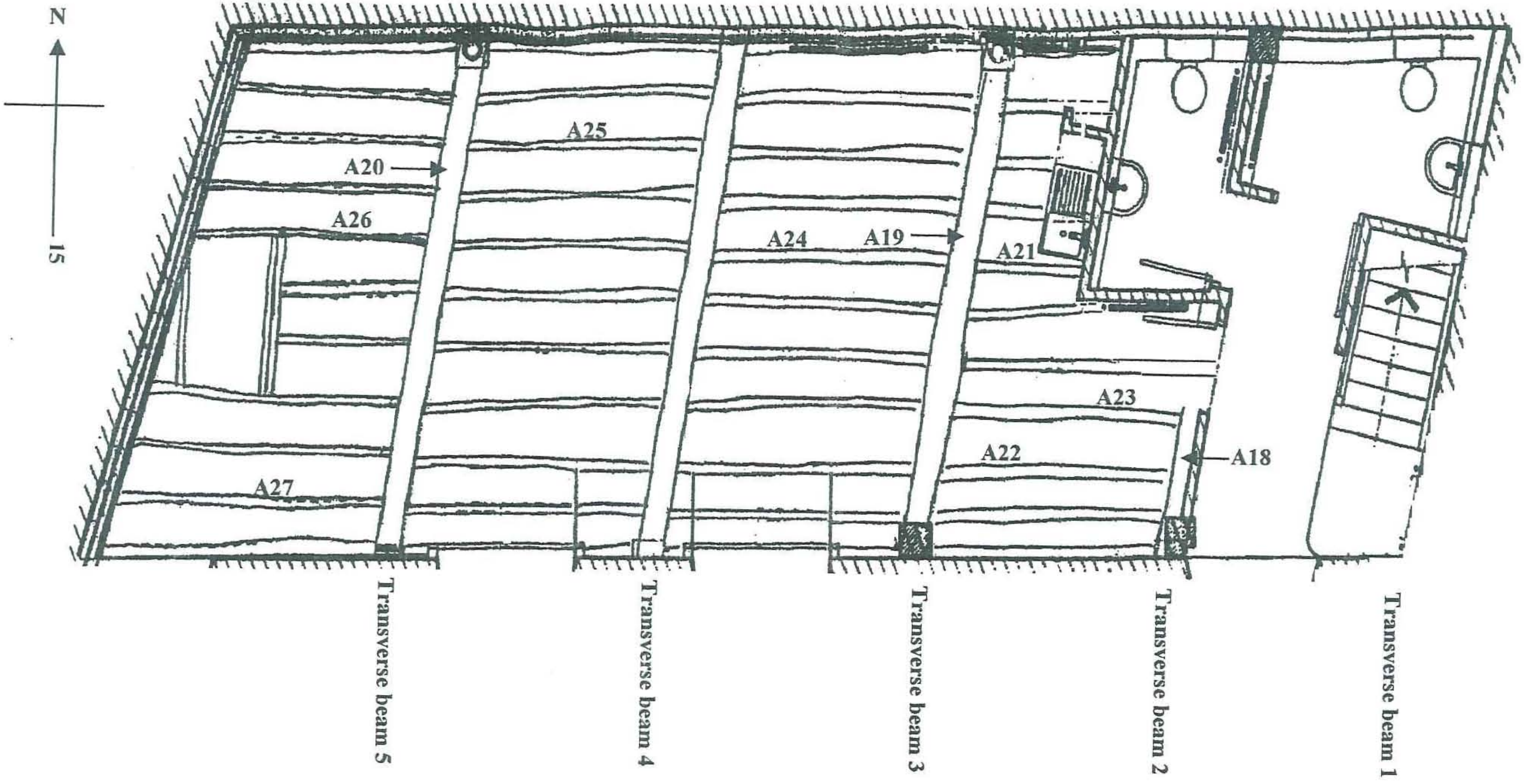


Figure 5: Drawing to show sampled timbers from the chapel undercroft. Samples B09 – B12 from window lintels not shown (based on survey drawing by Peter Ryder)

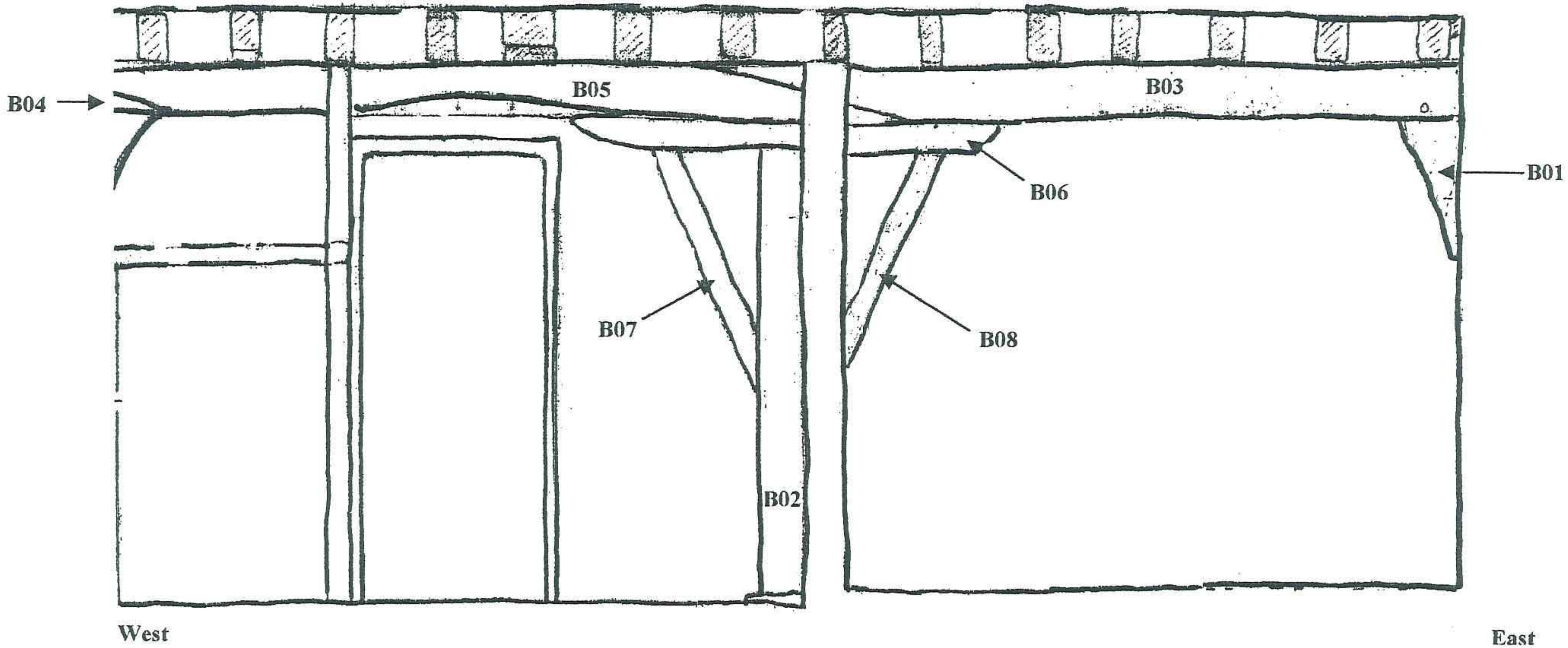
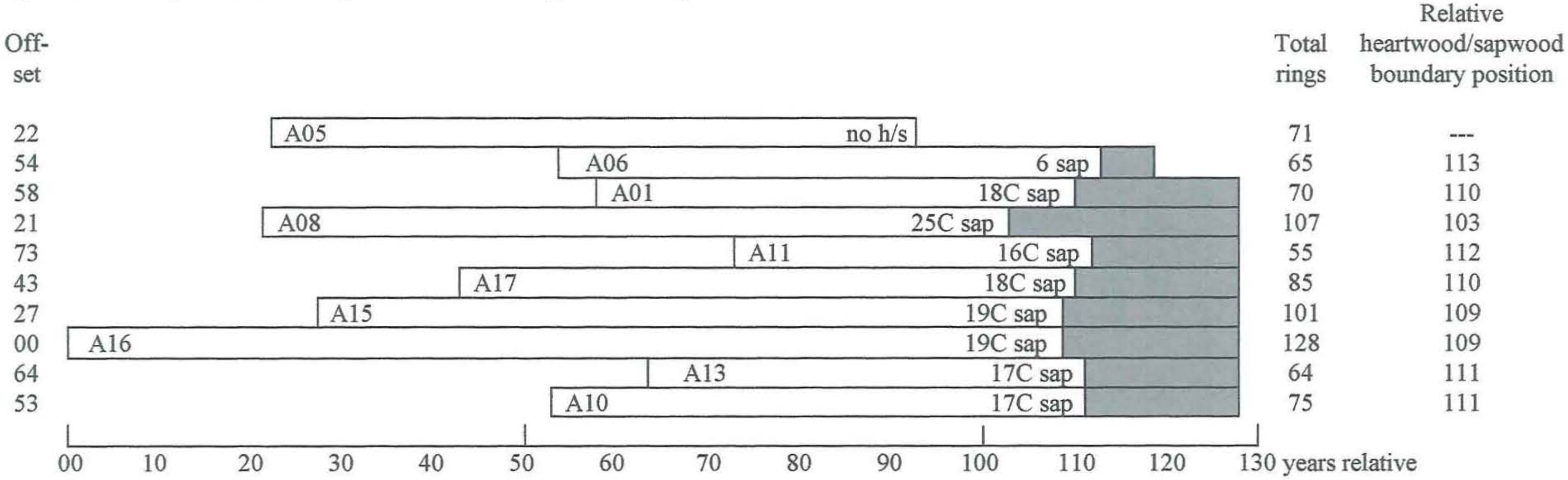


Figure 6: Bar diagrams of the samples in site chronology NWCASQ01



White bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample
C = complete sapwood retained on sample

Figure 7: Bar diagrams of the samples in site chronology NWCASQ02

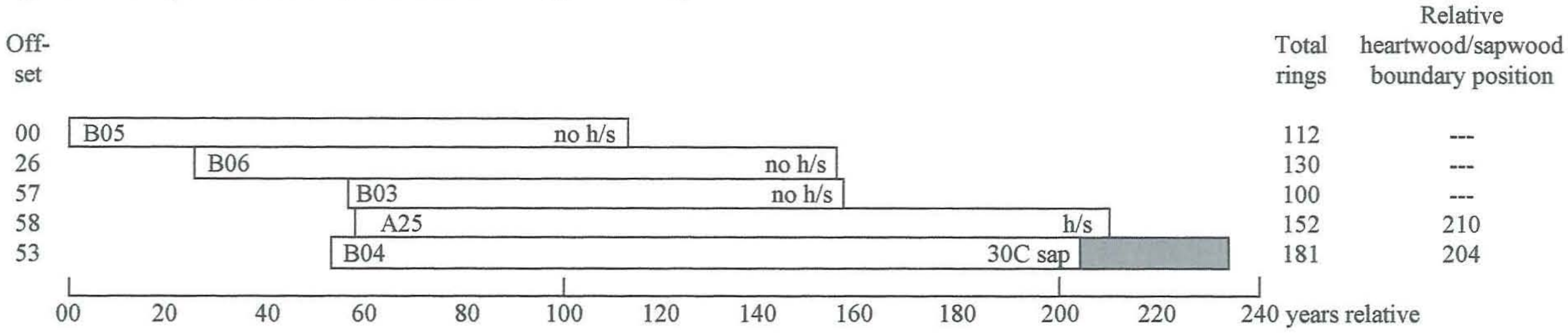
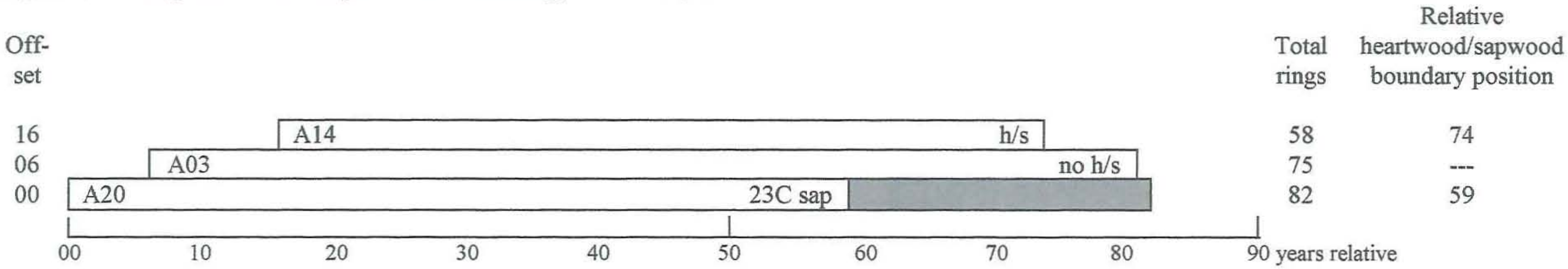


Figure 8: Bar diagrams of the samples in site chronology NWCASQ03



White bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample
C = complete sapwood retained on sample

Data of measured samples measurements in 0.01 mm units

NWC-A01A 70
258 367 419 304 310 304 303 338 268 286 223 230 293 275 284 340 284 270 189 103
109 161 234 206 223 183 201 126 111 191 190 287 424 264 252 204 92 120 119 182
220 268 224 195 180 121 71 72 116 240 222 178 151 181 292 195 182 261 251 169
155 141 160 194 147 132 76 86 67 126
NWC-A01B 70
239 364 441 312 305 313 316 330 274 266 222 216 280 282 270 357 306 265 204 121
107 165 203 200 203 202 208 123 116 209 137 289 424 260 246 211 92 122 119 172
223 264 237 188 179 114 73 72 115 238 218 181 140 192 300 191 167 267 256 169
153 139 162 195 137 149 71 87 62 122
NWC-A02A 46
257 140 114 77 243 244 190 307 377 168 130 110 65 65 128 164 157 213 164 196
217 172 112 160 162 227 200 174 142 208 151 145 123 85 101 139 152 143 119 146
112 98 116 165 64 108
NWC-A02B 46
263 142 117 78 233 251 197 310 363 161 130 116 66 70 127 168 153 209 166 197
229 146 107 146 154 219 177 153 146 211 146 141 127 88 100 135 135 164 104 149
111 96 118 153 69 101
NWC-A03A 75
206 205 267 275 266 232 286 169 291 224 217 218 184 272 279 221 148 184 197 178
164 149 199 175 189 180 129 125 97 145 137 162 180 154 130 131 159 139 131 179
146 156 175 101 105 145 140 123 95 89 107 168 134 151 191 232 209 187 136 155
144 139 141 143 173 147 147 185 112 161 130 159 158 146 168
NWC-A03B 75
197 201 273 272 258 236 270 200 299 226 203 220 184 277 262 238 149 183 195 170
164 154 199 175 186 178 122 111 102 161 144 142 192 163 121 141 153 133 143 181
149 166 162 98 109 145 143 112 98 87 101 164 137 158 193 244 205 188 133 151
145 145 132 138 180 143 161 194 106 146 124 156 165 153 169
NWC-A04A 66
428 344 422 355 232 294 232 329 337 308 372 356 331 118 79 121 150 221 219 195
143 133 185 184 203 317 218 226 164 188 256 293 226 269 194 163 130 104 131 108
121 147 225 149 137 192 169 125 106 128 192 196 180 98 136 176 128 162 116 104
106 137 126 65 124 192
NWC-A04B 66
428 343 440 354 250 265 284 323 338 318 392 359 326 90 124 96 161 238 241 196
149 131 198 176 222 289 227 241 164 185 258 291 268 268 183 153 136 104 118 119
139 135 237 134 131 196 187 104 107 115 190 181 181 110 128 164 129 151 117 105
110 134 133 73 122 181
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154 171 172 144 161 185 205 107 160 155 128 107 143 154 160 202 137 183 186 149
141 150 158 137 157 122 135 149 173 189 164 165 146 151 125 108 133 139 171 140
151 105 150 133 146 147 136 148 179 133 159
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149 133 152 127 151 131 133 149 167 196 158 161 147 149 127 114 134 137 166 146

158 121 140 134 142 154 124 143 181 139 157
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163 179 166 195 169
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165 163 194 172 164
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132 146 90 64 72 104 111 114 94 66 102 132 127 114 82 119 98 120 97 100
114 87 83 94 104 162 210
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110 91 84 90 102 144 168
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175 157 224
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155 163 203
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198 224 216 232
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222 177 191 223 165 137 144 153 194
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222 182 183 218 158 145 154 153 194
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372

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330 271 252 235 306 234 239 338 218
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102 116 173 126 152 171 168 123 87 92 135 150
NWC-A26A 107
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142 119 115 116 100 118 95 71 84 82 79 92 116 79 76 76 81 103 113 114
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NWC-A26B 107
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84 105 106 167 137 131 96

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84 86 84 70 72 88 99 106 96
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NWC-B01A 73
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111 113 123 159 210 144 123 140 126 107 112 114 81 79 75 59 79 80 100 134
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126 103 106 70 73 74 61 100 96 93 78 86 104 72 81 59 67 100 109 95
90 86 80 72 57 71 73 87 95 93 95 117
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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 Figure1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring..

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

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

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

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

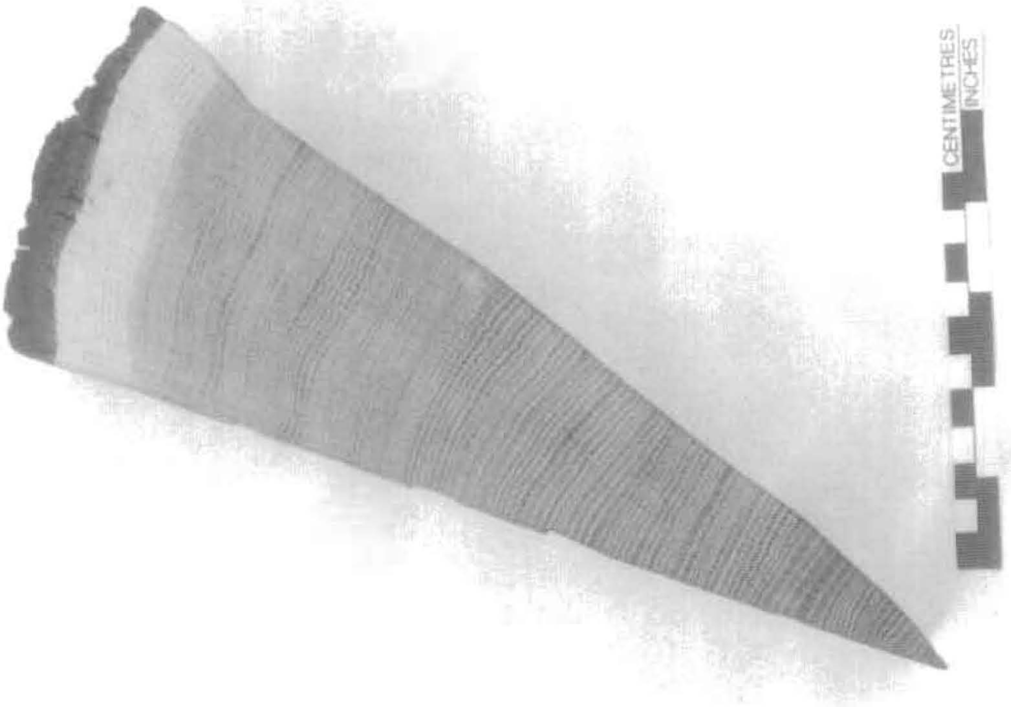


Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

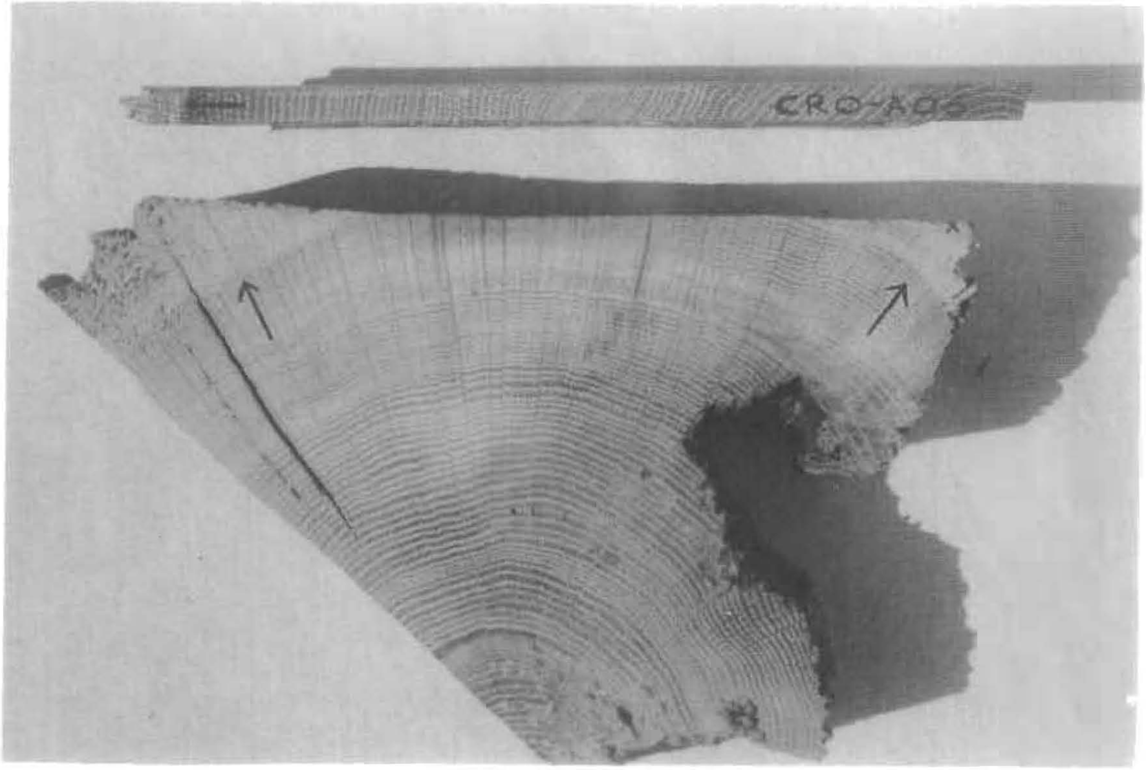


Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

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

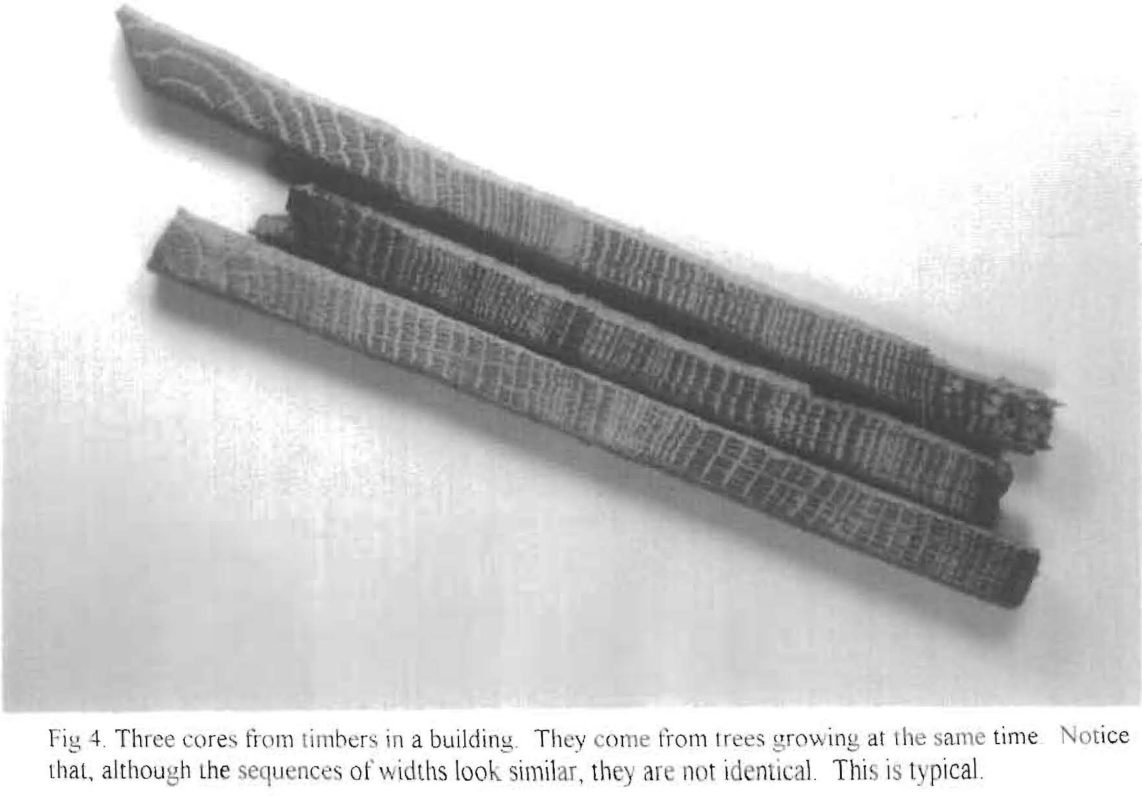


Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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

During the initial 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		+17	+27
C05	5.2	10.4		+10
C04	5.9	3.7	5.1	

Bar Diagram

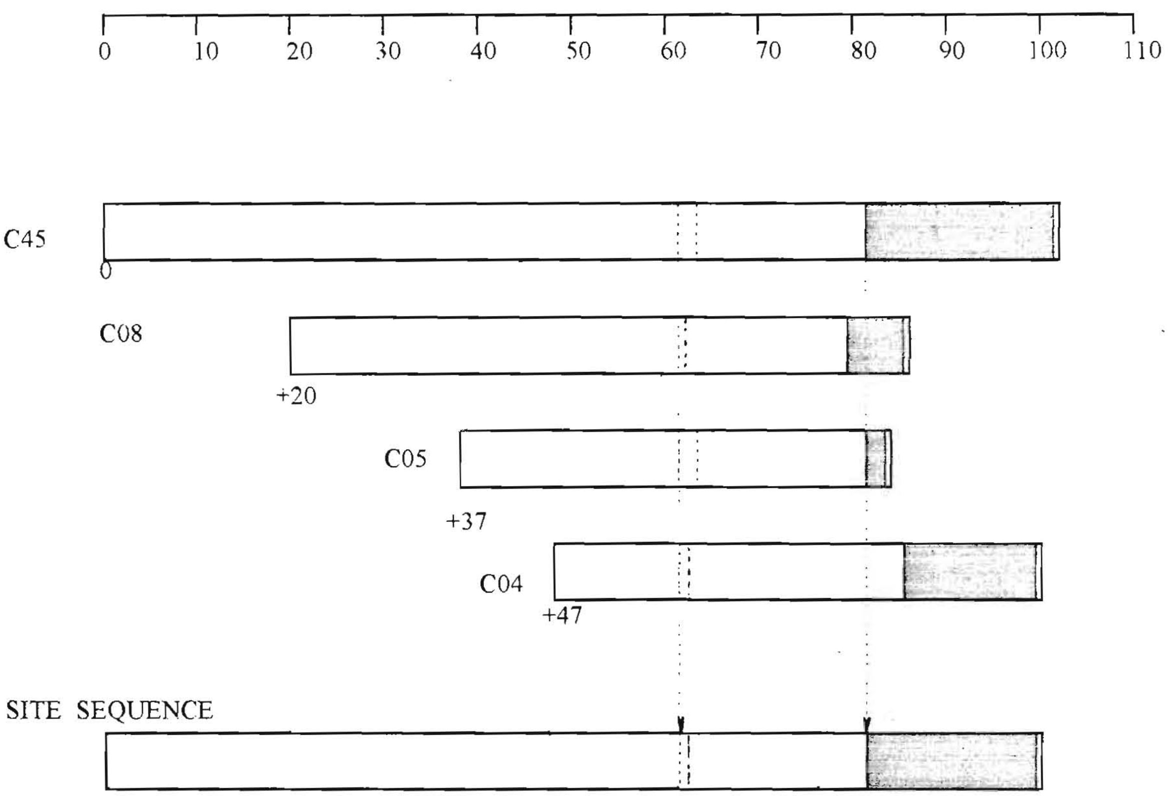


Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.
The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set at relative positions *(offsets)* to each other at which they have maximum correlation as measured by the *t-values*.
The *t-value offset* matrix contains the maximum t-values below the diagonal and the offsets above it.
Thus, the maximum t-value between C08 and C45 occurs at the offset of +20 rings and the t-value is then 5.6.
The *site sequence* is composed of the average of the corresponding widths, as illustrated with one width.

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

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

5. ***Estimating the Date of Construction.*** There is a considerable body of evidence in the data collected by the Laboratory that the oak timbers used in vernacular buildings, at least, were used 'green' (see also Rackham (1976)). Hence provided the samples are taken *in situ,* and several dated with the same estimated common felling date, then this felling date will give an estimated date for the construction of the building, or for the phase of construction. If for some reason or other we are rather restricted in what samples we can take, then an estimated common felling date may not be such a precise estimate of the date of construction. More sampling may be needed for this.

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

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

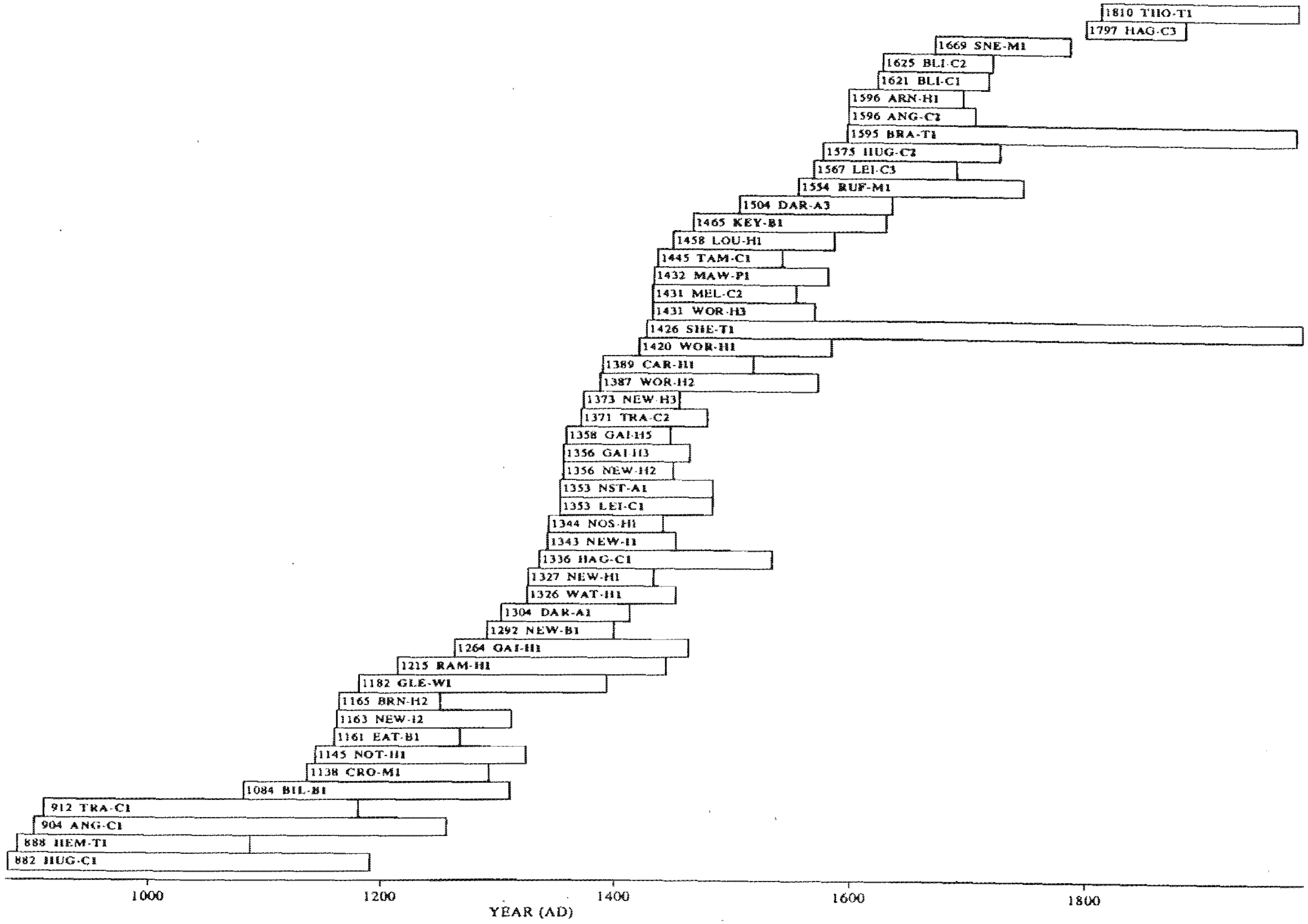
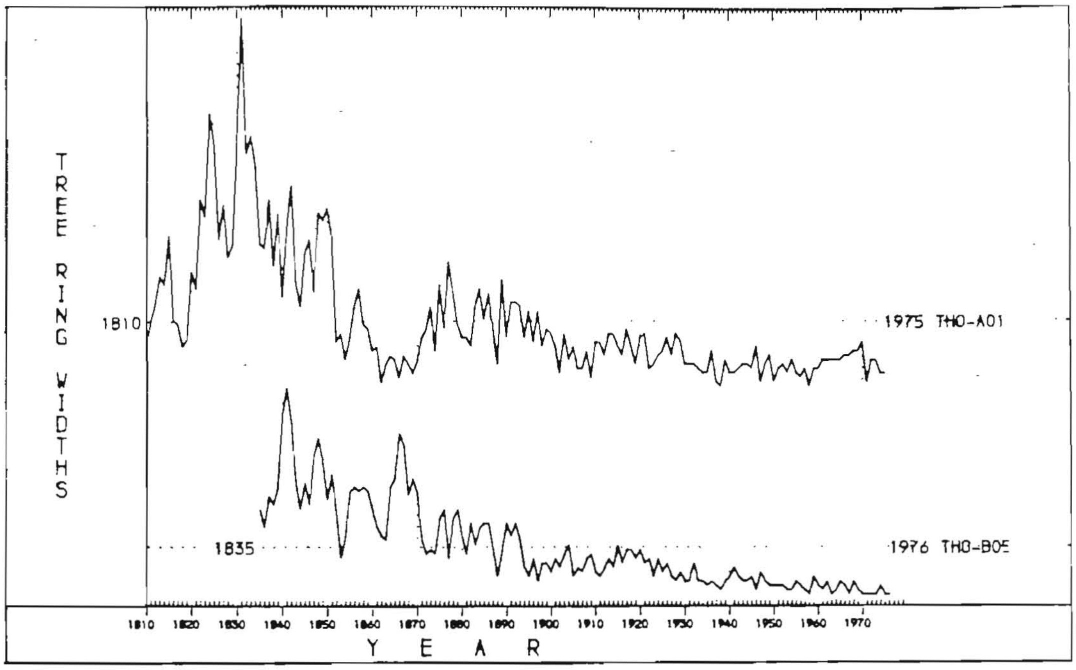


Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

(a)



(b)

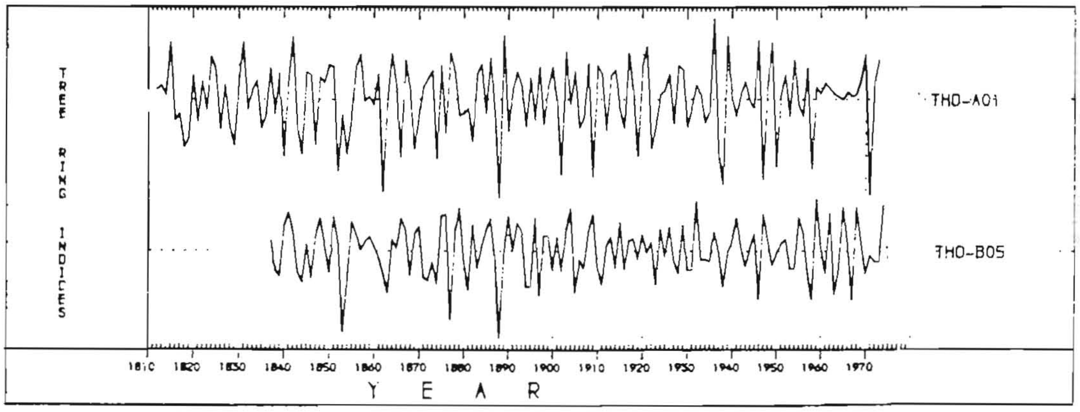


Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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