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ST ANTHONY'S HALL, PEASHOLME GREEN, YORK
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

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SUMMARY

Analysis of 74 measured samples from different locations at this site produced nine site chronologies, only the first of which, comprising 28 samples, can be dated, its 229 rings spanning AD 1215–1443.

Interpretation of the sapwood on the dated samples indicates the likelihood that the timbers were cut as part of a phased programme, with the felling of individual timbers probably occurring *c* AD 1435–59. The dated samples are predominantly from the western and eastern trusses of the hall roof and the chapel, the aisles providing a paltry three dated samples. The majority of samples from the western trusses and the chapel date to the early/mid fifteenth century but only a relatively small number of timbers have dated, also to the early/mid fifteenth century, from the eastern trusses, and even fewer in the aisles. This suggests that both the western roof and the chapel are likely to contain predominantly original timber associated with the primary construction of St Anthony's Hall, but the eastern trusses and aisles remain more enigmatic.

Eight other site chronologies cannot be dated, although interpretation suggests that the timbers of each respective group are possibly coeval with each other. Eleven samples remain ungrouped and undated.

CONTRIBUTORS

Alison Arnold, Robert Howard

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ARCHIVE LOCATION

City of York HER
Design Conservation and Sustainable Development
City of York Council
9 St Leonard's Place
York YO1 7ET

DATE OF INVESTIGATION

2008–9

CONTACT DETAILS

Nottingham Tree-ring Dating Laboratory
20 Hillcrest Grove
Sherwood
Nottingham NG5 1FT
alisonarnold@tree-ringdating.co.uk
roberthoward@tree-ringdating.co.uk

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INTRODUCTION

Following Ramm and Gee (1952), the RCHME report of 1981, and Pevsner and Neave (1995), from which much of this introduction is taken, it is known that St Anthony's Hall is so-named after a chapel which had previously stood on this site. The hall was the home of the Guild of St Martin, whose founding charter was granted by Henry VI in AD 1446. The building stands on the corner of Aldwark, facing Peasholme Green (SE 60734 51996, Figs 1 and 2) and is one of four surviving medieval guildhalls in the City, the others being the Merchant Taylors' Hall, the Guildhall, and the Merchant Adventurers' Hall.

In AD 1450 Archbishop Kempe issued a licence for mass to be said in the hospital chapel, with the 'newly-built' chapel being consecrated in AD 1453. It is known that building work continued to AD 1455 and there is some very tentative stylistic evidence, in the form of a moulded boss, that work was not finally completed till after AD 1485. In AD 1665 the whole of the north and east outside walls, and the upper parts of the south and west walls, were rebuilt in brick; new walls were also added inside. In AD 1828 further repairs and alterations were put in hand, with repairs to the roof of the hall, damaged by a storm in AD 1839, not being finished before AD 1850. In the interim the building has been used as a workhouse, an archery range, arsenal, prison, school, and hospital, each use requiring consequent adaptations.

The ground floor (Fig 3) is divided into two areas by a north–south through-passage, with a west wall of seventeenth-century date and an east wall of the eighteenth century. The area west of the passage may represent the medieval chapel, lit by the big arched window in the south end; it is divided into seven bays by moulded cross-beams, supported by wall-posts and braces, the ceiling of each bay subdivided by moulded beams into four compartments. The two north bays may have been screened off on the line of a present seventeenth-century wall, to form an antechapel entered by a large doorway in the west wall. The rest of the lower storey is presumed to have been the hospital, divided into four aisles by three east–west rows of timber posts supporting the arcades and the floor of the hall above.

On the first floor is the great hall of nine aisled bays (Fig 4). Three of the western roof trusses (T8–T10) are believed, on the basis of difference in form, carpentry, and architectural detail, to be of an earlier period of construction than six of the roof trusses to the east (T2–T7), the two truss types immediately abutting each other at trusses 7 and 8, there being no structural relationship between them. These three western roof trusses, thought likely to date to the original construction in the late AD 1440s or AD 1450s, have moulded tiebeams with crown posts and plates, and principal rafters carrying double purlins to each pitch. Only a single tiebeam, probably replaced relatively recently, remains of truss 11, to the west gable wall. Filling the bays between the trusses there are coupled common rafter frames with collars, the bays also being spanned by horizontal moulded beams between the ties to carry a ceiling.

The six eastern roof trusses, possibly of later fifteenth-century date, are carried on octagonal posts and are of arch-braced collar beam construction with moulded purlins; the braces spring from demi-angel corbels (Fig 5). The east-most roof truss (T1), in the gable wall, almost certainly a nineteenth-century replacement, is not arch-braced. The hall is separated from the aisles by seventeenth-century walls, the aisle roofs formed of principal rafter and tiebeam trusses, with arched braces at each end.

The multifarious uses to which the building has been put over its history have required much alteration and subsequent repair; a mid-seventeenth-century programme, for example, having denuded the structure of much of its original timberwork. It is believed, furthermore, that later repairs, particularly those of AD 1839–50, have resulted in both the reuse of original material in new locations and the insertion of carefully crafted copies of original beams in new wood. As a result it has become difficult to distinguish primary timbers from reused and later material, engendering considerable discussion and debate and a number of different and conflicting interpretations on its development.

SAMPLING

Sampling and analysis by dendrochronology of timbers within St Anthony's Hall were requested by Diane Green, Historic Buildings Inspector at English Heritage's York Office, the primary purpose of this programme being to inform statutory advice in the context of a programme of conservation and repair works. It was hoped that analysis would establish with greater certainty the dates of various elements of the building, helping to determine possible sequential phases of alteration and change. A further object of tree-ring analysis was to help determine how much primary material now remained in the building and, if possible, how much is later replacement.

Thus, from the timbers available, and allowing for uncertainty in respect of repairs and insertions, a total of 89 samples was obtained from six different parts of the building. Each sample was given the code YRK-I (for York, site 'I') and numbered 01–89. Fifteen of these samples, YRK-I01–I15, were taken from the potentially earlier three western roof trusses of the main hall, with a further 22 samples, YRK-I16–I37, being taken from the six, potentially later, eastern roof trusses. Twelve samples were obtained from each of the south and north aisles, YRK-I38–I50 and YRK-I51–62 respectively. Eleven samples, YRK-I63–I73, were taken from the timbers of the chapel walls and ceiling. Finally, 16 sliced samples, YRK-I74–I89, were obtained from a series of floorboards removed to allow for the insertion of a lift shaft in the east end of the south aisle at first floor level. These boards are approximately 0.20–0.25m wide and about 20–30mm thick. Although there is no particular reason to suspect that they might be original, their relatively unsophisticated form suggested that they might be of some antiquity, possibly late-medieval.

Where possible, the location of samples was noted at the time they were obtained and marked on plans and drawings, taken originally from Ramm and Gee's manuscript and the RCHME report, and provided by English Heritage. These are reproduced here as Figures

6a–i. In addition, in the absence of appropriate drawings, some of the timbers from the chapel were located on photographs (Figs 6j and 6k).The exception to these details are the floorboards, where, whilst their general location before lifting was known, the exact position of each individual board had not been recorded. Further details relating to the samples can be found in Table 1.

In this table, and in the plans, drawings, and photographs, the trusses, frames and other timbers have been located and numbered from either north to south or from east to west, as appropriate. To help distinguish and differentiate locations, the roof trusses of the hall and the aisles have been numbered 1–11, while the frames of the chapel have been identified as A–H.

ANALYSIS

Each of the 89 samples obtained was initially prepared by sanding and polishing. It was seen at this time that 15 samples had less than 54 rings, the minimum number required for reliable dating, and these were rejected from this programme of analysis. The annual ring widths of the remaining 74 samples were, however, measured, the data of these measurements being given at the end of this report.

The data of these 74 measured samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), allowing, at a minimum value of t=4.0, nine separate groups to be formed, accounting for a total of 63 measured samples, the samples of each group cross-matching as shown in the bar diagrams (Figs 7–15). The cross-matching samples of each group were combined at their indicated offset positions to form site chronologies YRKISQ01–SQ09.

Each of the nine site chronologies was then compared to an extensive corpus of reference material for oak, including not only that held by the Nottingham Tree-ring Dating Laboratory, but also that held, for example, by the Dendrochronology Laboratory at the Archaeology Graduate School at Sheffield University. This resulted in the satisfactory dating of only one site chronology, YRKISQ01, this comprising 28 samples with an overall length of 229 rings. This site chronology was seen to match repeatedly and consistently with a series of reference chronologies when the date of its first ring is AD 1215 and the date of its last measured ring is AD 1443. The evidence for this dating is given in Table 2. The remaining eight site chronologies remain undated.

The 11 remaining measured but ungrouped single samples were also compared to the reference chronologies but again there was no satisfactory cross-matching and these, therefore, must also remain undated.

This analysis may be summarised as follows:

Site chronology	Number of samples	Number of rings	Date span (where dated)
YRKISQ01	28	229	AD 1215–1443
YRKISQ02	13	107	undated
YRKISQ03	7	119	undated
YRKISQ04	5	101	undated
YRKISQ05	2	146	undated
YRKISQ06	2	132	undated
YRKISQ07	2	111	undated
YRKISQ08	2	110	undated
YRKISQ09	2	78	undated
singles	11	---	undated
unmeasured	15	---	undated

INTERPRETATION

Site chronology YRKISQ01 includes samples from five areas within St Anthony's Hall. None of these dated samples retains complete sapwood and it is thus not possible to indicate precise felling dates for any of the timbers represented. A number of samples from the five areas, however, do retain some sapwood or the heartwood/sapwood boundary and by taking each of the five areas represented by the dated samples in site chronology YRKISQ01 separately it is possible to demonstrate the likely felling date range of the timbers within.

The average heartwood/sapwood boundary date of the samples from the western trusses of the hall, for example, is AD 1422. Using the 95% confidence limit of 15–40 for the amount of sapwood these trees may have had, would give the timbers here an estimated felling date range of AD 1437–62.

The samples from the eastern trusses of the hall have an average heartwood/sapwood boundary date of AD 1417. Using the same 95% confidence limit of 15–40 sapwood rings would give these timbers an estimated felling date range of AD 1432–57. It is worth mentioning here, however, that there is a wide variation, some 30 years, in the position/date of the heartwood/sapwood boundary on these samples, suggesting a felling programme spanning several years, and that, whilst the rest of the dated samples from this area could have been felled at any point within this range, sample YRK-I32 was clearly felled towards the latter part of this range, as it has an outermost measured ring date of AD 1443.

Amongst those samples from the south aisle, only one, YRK-I47, retains the heartwood/sapwood boundary. Using the same sapwood estimate as above, 15–40 rings, would give the timber represented an estimated felling date in the range AD 1437–62.

Two samples from the north aisle retain the heartwood/sapwood boundary, the average of this being AD 1415. Using the usual sapwood estimate would give the timbers represented an estimated felling date range of AD 1430–55. Finally, the average date of the heartwood/sapwood boundary on the samples from the chapel is AD 1422. This would give the timbers represented an estimated felling date in the range AD 1437–62, this figure again based on a sapwood estimate of 15–40 rings.

It will be seen therefore, that there is a degree of similarity in the estimated felling date range of the timbers in each of these five areas. Taken overall, the average date of the heartwood/sapwood boundary on the 15 samples in site chronology YRKISQ01, where it exists, is AD 1419. Using a 95% confidence limit of 15–40 rings for the amount of sapwood these trees may have had, and allowing for the earliest and the latest heartwood/sapwood boundary dates, might give the individual timbers represented a felling occurring between, it is estimated, AD 1435 and AD 1459. It may be noted that such a range nicely encompasses the construction dates evidenced from the documentary and stylistic sources. There is good evidence, furthermore, by way of high degrees of cross-matching between some samples, that those timbers which do not retain at least the heartwood/sapwood boundary are likely to have been felled during this period as well.

That the timbers used here have been felled over a period of time, but are part of a single programme of work, is evidenced by the spread of the heartwood/sapwood boundary dates. As may be seen from Table 1 and the bar diagram, Fig 7, the heartwood/sapwood boundary varies, in fairly even progression, from as early as relative position 187 (AD 1401) on sample YRK-I28 to as late as relative position 221 (AD 1435) on sample YRK-I72, a variation of 34 years. Such an extensive and gradual variation is normally indicative of trees which have been felled over a number of years, rather than of those which have all been felled at exactly the same time. That the work undertaken here was part of a drawn-out process, rather than distinct well-separated episodes, is further evidenced by the fact that timbers found in different parts of the building were originally growing close to each other (*see* Discussion and Conclusion). This is less likely to be found in works of distinctly different periods.

Further samples from the six eastern roof trusses of the hall are found in the undated site chronology YRKISQ02 (Fig 8), along with some samples from the north and south aisle roofs. Although undated, it would appear that the timbers represented by these samples were felled at a very similar, if not identical, time as each other. As may be seen from the bar diagram, the relative position of the heartwood/sapwood boundary on these samples varies from relative position 80 on YRK-I35 to relative position 96 on YRK-I29, a variation of 16 years, this being more indicative of a single phase of felling.

The other, undated, site chronologies, YRKISQ03–SQ09 (Figs 9–15) represent the boards from the east end of the first floor of the south aisle, or mixed groups of two samples each from various other locations. Although not all these site chronologies include

multiple samples with heartwood/sapwood boundaries, it is probable that some of the respective samples represent timbers felled at the same time as each other.

DISCUSSION AND CONCLUSION

Tree-ring evidence suggests that all the timbers dated in this analysis, mostly those from the west roof of the hall and from the chapel, were cut as part of a single episode or phase of felling which took place in the mid-fifteenth century, the timbers most likely to have been felled in the period *c* AD 1435–59. These are, therefore, likely to be associated with the primary construction of St Anthony's Hall, whose founding charter, as noted in the introduction above, was granted by Henry VI in AD 1446 and upon which, it is known from documentary sources, building work continued to at least AD 1455.

Such an interpretation is, furthermore, supported not only by the small amount of stylistic evidence available, which intimates that the programme of works progressed over a period of time, but by the fact that timbers from different parts of the building may originally have been growing close to each other in the same woodland, a phenomenon less likely to be seen were parts of the building constructed at completely different times. While there is generally a high degree of cross-matching between samples from within a single area of the building, there are also examples of strong cross-matches between timbers found in different areas. There is, for example, a cross-match with a value of t=12.6 between samples YRK-I01 and I02, and t=12.2 between samples YRK-I06 and I09, samples from the western three roof trusses, and as high as t=19.0 between samples I71 and I72, samples from the chapel. Values of these levels would make it very likely that the relevant pairs of timbers are each derived from single trees. However, a cross-match with a value of t=10.6 is found between samples YRK-I01 and I59, a western truss and north aisle sample respectively, or t=10.7 between sample YRK-I01 and I71, a western truss and a chapel sample. Such values again suggest the possibility that, although timbers have been used in different locations, they have been derived from the same tree, or at least from trees probably originally growing close to each other in the same copse or stand of woodland, a possibility shared by many other timbers sampled here.

Several groups of timbers, although undated in absolute terms, appear to be coeval with each other. The fact that these timbers do not date, however, does not mean that each group is of a different date, either to each other, or to the main dated group of YRKISQ01; although the lack of dating could indicate that, as suspected from a structural interpretation, more than one phase of felling is represented, this cannot be proven at this time by dendrochronology.

The source woodland for the timbers dated here cannot be identified precisely by dendrochronology (eg Bridge 2000), but it is probable that they are relatively local to York. As may be seen from Table 2, which lists a short selection of the reference chronologies used to date site sequence YRKISQ01, the highest t-values, and thus the greatest degree of similarity, are with the reference chronologies made up of material

from other sites in York, York Minster, Bedern Hall, Merchant Taylors' Hall, and Coppergate. While the source woodland for each of these sites is itself unknown, it is likely that such timbers have not come very far, and that the timber used at St Anthony's Hall has come from a similar area.

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TABLES

Table 1: Details of tree-ring samples from St Anthony's Hall, Aldwark, York

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Hall roof – western 3 trusses						
YRK-I01	South principal rafter, truss 8	189	h/s	AD 1243	AD 1431	AD 1431
YRK-I02	North principal rafter, truss 8	140	no h/s	AD 1227	------	AD 1366
YRK-I03	West crown plate brace, truss 8	107	no h/s	AD 1299	------	AD 1405
YRK-I04	Collar frame 3, bay 7	118	no h/s	AD 1236	-----	AD 1353
YRK-I05	Collar, frame 4, bay 8	nm	---	------	------	------
YRK-I06	Collar, frame 3, bay 8	124	no h/s	AD 1275	------	AD 1398
YRK-I07	West crown plate brace, truss 9	118	no h/s	AD 1234	------	AD 1351
YRK-I08	South principal rafter, truss 9	171	no h/s	AD 1215	------	AD 1385
YRK-I09	Collar, frame 2, bay 9	124	14	AD 1306	AD 1415	AD 1429
YRK-I10	Collar, frame 3, bay 9	163	no h/s	AD 1230	------	AD 1392
YRK-I11	West crown plate brace, truss 10	86	4	AD 1341	AD 1422	AD 1426
YRK-I12	South principal rafter, truss 10	140	no h/s	AD 1217	------	AD 1356
YRK-I13	North principal rafter, truss 10	170	9	AD 1258	AD 1418	AD 1427
YRK-I14	Collar, truss 10	109	h/s	------	------	------
YRK-I15	Tiebeam, truss 10	nm	---	------	------	------
Hall roof – eastern 6 trusses						
YRK-I16	North lower archbrace, truss 2	54	no h/s	------	------	------
YRK-I17	Collar, truss 2	85	h/s	------	------	------
YRK-I18	South lower archbrace, truss 2	nm	---	------	------	------
YRK-I19	North principal rafter, truss 3	56	19c	------	------	------
YRK-I20	Collar, truss 3	104	h/s	AD 1318	AD 1421	AD 1421
YRK-I21	South stub tie, truss 3	nm	---			
YRK-I22	South wall post, truss 3	nm	---	------	------	------
YRK-I23	North upper archbrace, truss 4	nm	---	------	------	------
YRK-I24	South wall post, truss 4	nm	---	------	------	------
YRK-I25	South upper archbrace, truss 5	59	7	------	------	------
YRK-I26	North upper archbrace, truss 6	94	no h/s	AD 1282	------	AD 1375

Table 1: continued

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Hall roof – eastern 6 trusses						
YRK-I27	North stub tie, truss 6	63	h/s	------	------	------
YRK-I28	Collar, truss 6	147	h/s	AD 1255	AD 1401	AD 1401
YRK-I29	South principal rafter, truss 6	75	9	------	------	------
YRK-I30	South upper archbrace, truss 6	180	h/s	AD 1235	AD 1414	AD 1414
YRK-I31	South lower archbrace, truss 6	93	no h/s	AD 1297	------	AD 1389
YRK-I32	North wall post, truss 7	86	12	AD 1358	AD 1431	AD 1443
YRK-I33	North upper archbrace, truss 7	nm	---	------	------	------
YRK-I34	North lower archbrace, truss 7	132	h/s	------	------	------
YRK-I35	North principal rafter, truss 7	80	h/s	------	------	------
YRK-I36	South upper archbrace, truss 7	66	no h/s	------	------	------
YRK-I37	South lower archbrace, truss 7	113	no h/s	------	------	------
South aisle roof						
YRK-I38	North principal rafter, truss 3	55	h/s	------	------	------
YRK-I39	South principal rafter, truss 2	89	17C	------	------	------
YRK-I40	Tiebeam, truss 3	67	h/s	------	------	------
YRK-I41	North principal rafter, truss 2	66	h/s	------	------	------
YRK-I42	South common rafter 4, bay 4	73	3	------	------	------
YRK-I43	North principal rafter, truss 4	69	h/s	------	------	------
YRK-I44	North common rafter 4, bay 4	75	10	------	------	------
YRK-I45	North purlin, bay 3	70	h/s	------	------	------
YRK-I46	South principal rafter, truss 7	72	h/s	------	------	------
YRK-I47	North principal rafter, truss 6	60	h/s	AD 1363	AD 1422	AD 1422
YRK-I48	North principal rafter, truss 7	nm	---	------	------	------
YRK-I49	South common rafter 2, bay 6	50	16C	------	------	------
YRK-I50	North principal rafter, truss 10	70	h/s	------	------	------

Table 1: continued

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
North aisle roof						
YRK-I51	North common rafter 2, bay 1	124	h/s	AD 1297	AD 1420	AD 1420
YRK-I52	North common rafter 5, bay 1	101	no h/s	------	------	------
YRK-I53	Tiebeam, truss 2	96	h/s	------	------	------
YRK-I54	South purlin, bay 2	66	h/s	------	------	------
YRK-I55	South common rafter 4 bay 2	nm	---	------	------	------
YRK-I56	North common rafter 3, bay 2	129	h/s	------	------	------
YRK-I57	Tiebeam, truss 4	54	h/s	------	------	------
YRK-I58	South principal rafter, truss 4	61	h/s	------	------	------
YRK-I59	South common rafter 2, bay 4	164	h/s	AD A247	AD 1410	AD 1410
YRK-I60	South common rafter 2, bay 5	nm	---	------	------	------
YRK-I61	North principal rafter, truss 6	nm	---	------	------	------
YRK-I62	North principal rafter, truss 7	64	h/s	------	------	------
Chapel						
YRK-I63	Post 1, east wall	193	h/s	AD 1233	AD 1425	AD 1425
YRK-I64	Post 3, east wall	183	no h/s	AD 1218	------	AD 1400
YRK-I65	Post 4, east wall	74	h/s	------	------	------
YRK-I66	Post 6, east wall	nm	---	------	------	------
YRK-I67	Top rail, east wall	73	h/s	------	------	------
YRK-I68	Central ceiling beam, frame A-B	nm	---	------	------	------
YRK-I69	Cross-beam frame E	68	no h/s	AD 1241	------	AD 1308
YRK-I70	Cross-beam, frame B	87	no h/s	AD 1259	------	AD 1354
YRK-I71	West archbrace, frame E	185	h/s	AD 1228	AD 1412	AD 1412
YRK-I72	East archbrace, frame E	212	h/s	AD 1224	AD 1435	AD 1435
YRK-I73	Cross-beam, frame F	195	h/s	AD 1221	AD 1415	AD 1415

Table 1: continued

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Floorboards						
YRK-I74	Floorboard 'A'	86	no h/s	------	------	------
YRK-I75	Floorboard 'B'	111	no h/s	------	------	------
YRK-I76	Floorboard 'C'	82	h/s	------	------	------
YRK-I77	Floorboard 'D'	86	no h/s	------	------	------
YRK-I78	Floorboard 'E'	91	no h/s	------	------	------
YRK-I79	Floorboard 'F'	nm	---	------	------	------
YRK-I80	Floorboard 'G'	95	no h/s	------	------	------
YRK-I81	Floorboard 'H'	66	no h/s	------	------	------
YRK-I82	Floorboard 'I'	90	no h/s	------	------	------
YRK-I83	Floorboard 'J'	90	no h/s	------	------	------
YRK-I84	Floorboard 'K'	87	h/s	------	------	------
YRK-I85	Floorboard 'L'	60	no h/s	------	------	------
YRK-I86	Floorboard 'M'	82	no h/s	------	------	------
YRK-I87	Floorboard 'N'	87	no h/s	------	------	------
YRK-I88	Floorboard 'O'	62	h/s	------	------	------
YRK-I89	Floorboard 'P'	58	no h/s	------	------	------

h/s = the heartwood/sapwood ring is the last ring on the sample
C = complete sapwood is retained on the sample
c = complete sapwood is found on the timber, all or part of it has been lost from the sample in coring.
nm = sample not measured

Table 2: Results of the cross-matching of site sequence YRKISQ01 and relevant reference chronologies when the first-ring date is AD 1215 and the last-ring date is AD 1443

Reference chronology	*t*-value	Span of chronology	Reference
York Minster central tower, York	10.8	AD 1214–1462	(Hillam pers comm.)
Bedern Hall, York	9.7	AD 1231–1369	(Hillam 1982)
Merchant Taylors' Hall, York	8.6	AD 1240–1413	(Howard *et al* 1992)
Coppergate, York	8.3	AD 950–1395	(Hillam 2002)
Ulverscroft Priory, Charnwood Forest, Leics	7.1	AD 1219–1463	(Arnold *et al* 2008)
Old Chapel, Sinnington, North Yorkshire	7.0	AD 1296–1516	(Tyers 1999; Tyers 2001)
Abbey Inn, Manor Green, Burton-upon-Trent, Staffs	6.4	AD 1268–1444	(Howard *et al* 1998 unpubl)
Merchant Adventurers' Hall, York	6.3	AD 1241–1357	(Howard *et al* 1992)

FIGURES

Figure 1: Map to show the location of St Anthony's Hall, York (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 At Anthony's Hall, York (based on the Ordnance Survey map with permission of the Controller of Her Majesty's Stationery Office, ©Crown Copyright)

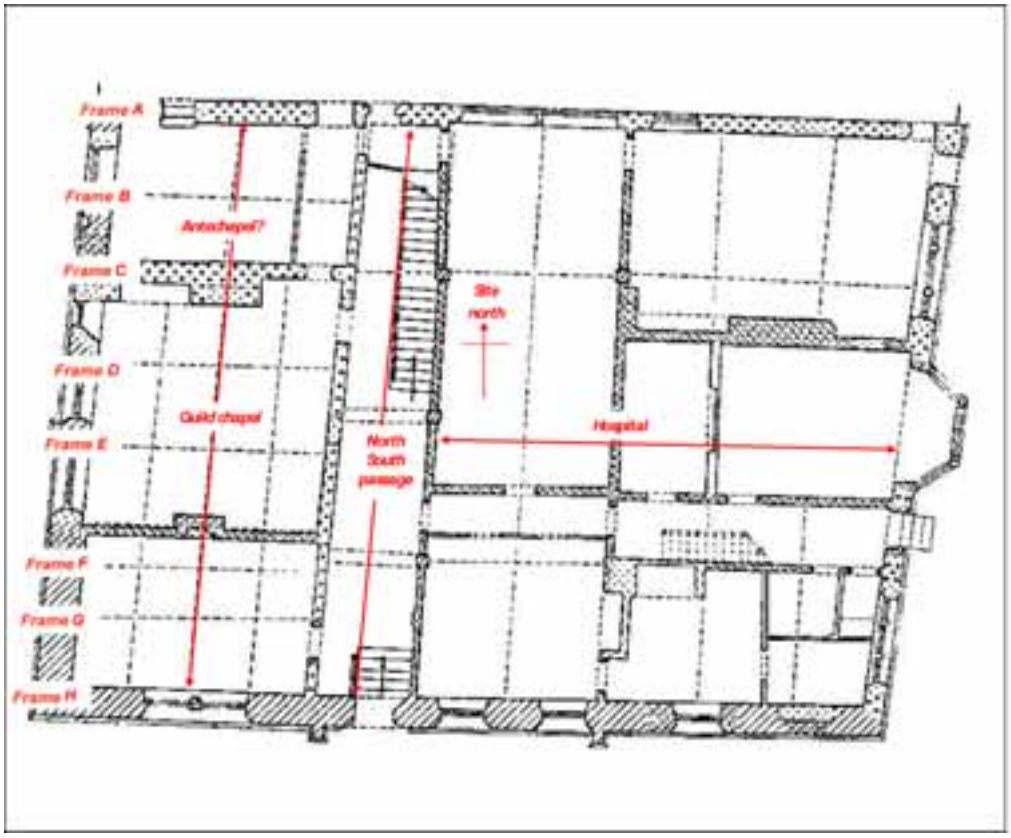


Figure 3: Plan at ground-floor level to show layout of building and position of the chapel trusses

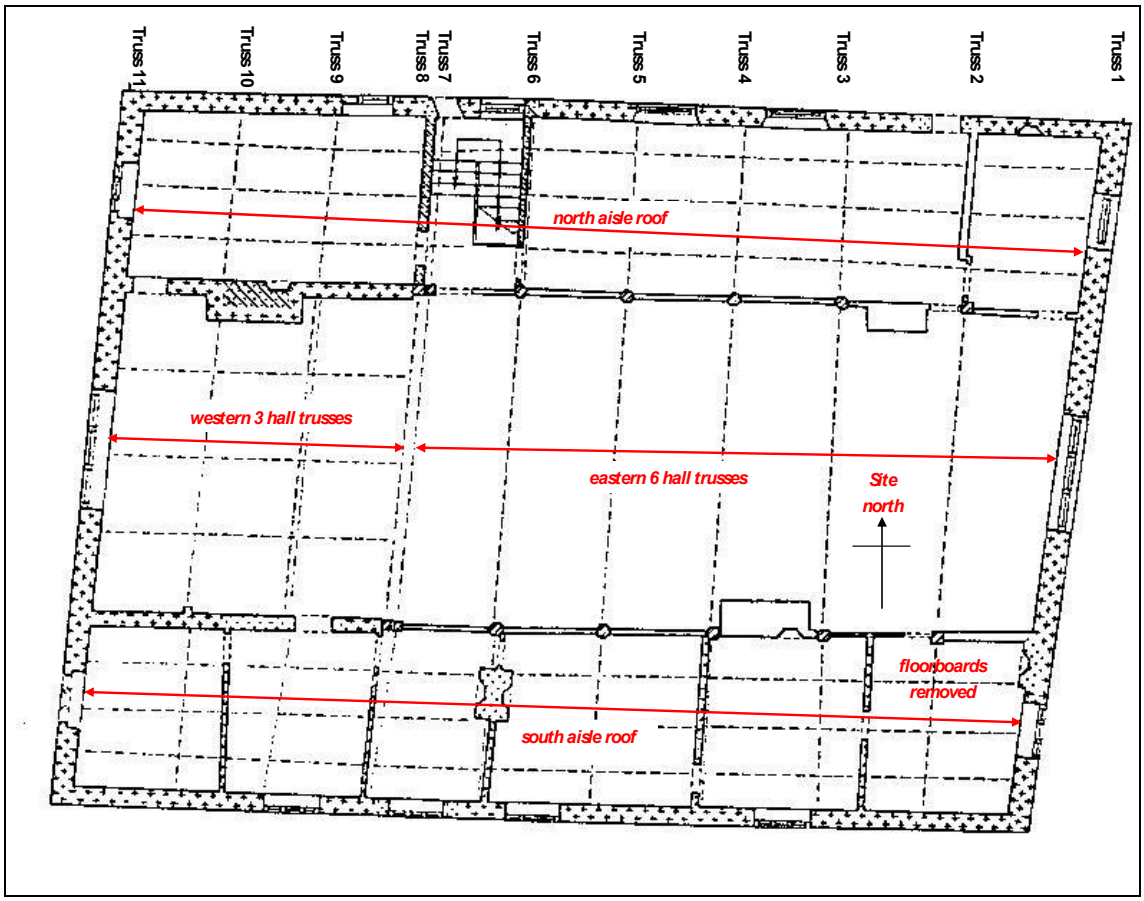


Figure 4: Plan at first-floor level to show layout of building, position of hall trusses, and area of removed floorboards

Figure 5: View of the first-floor hall (looking west to east)

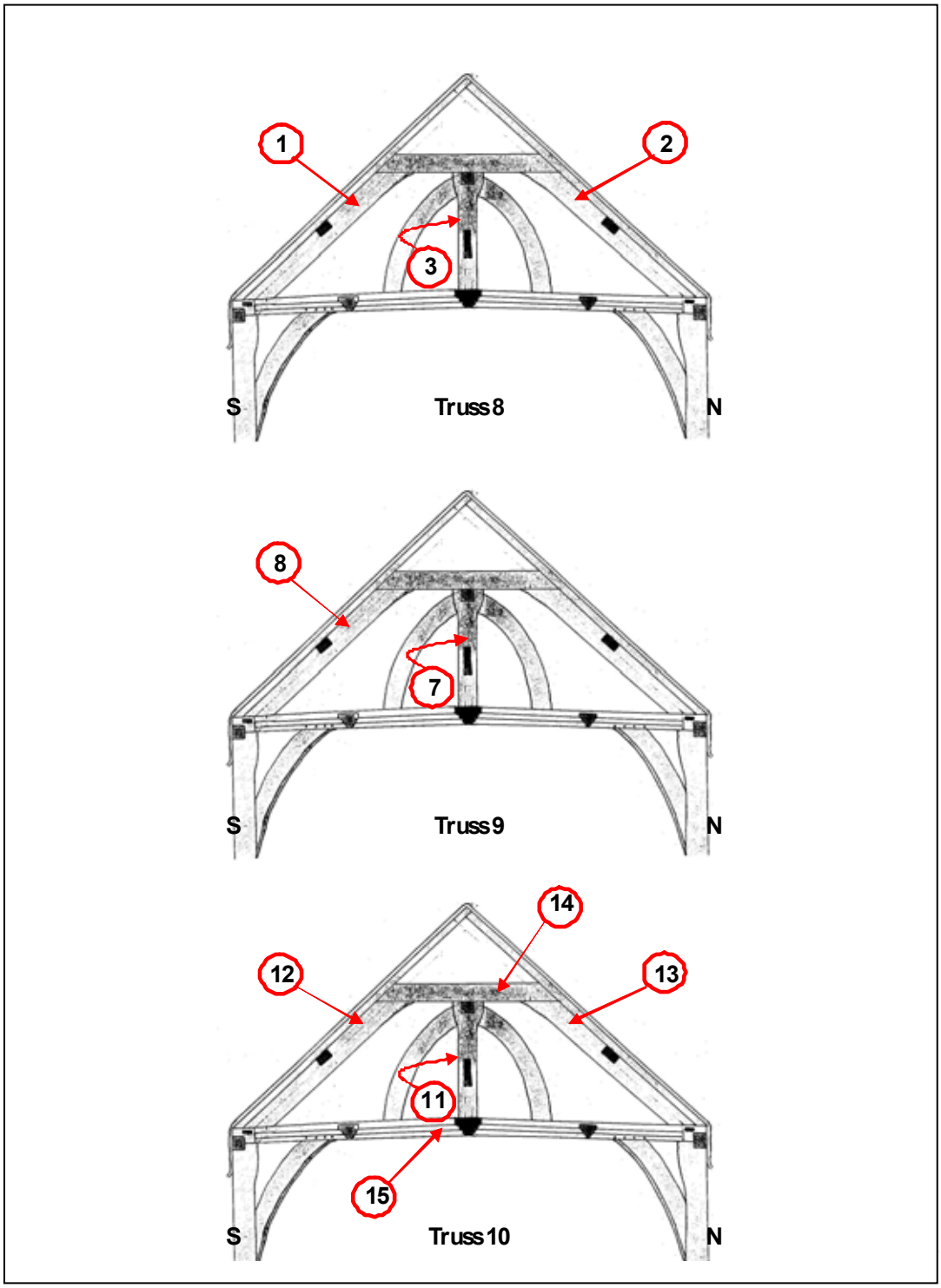


Figure 6a: Western three trusses of the hall roof to show sampled timbers

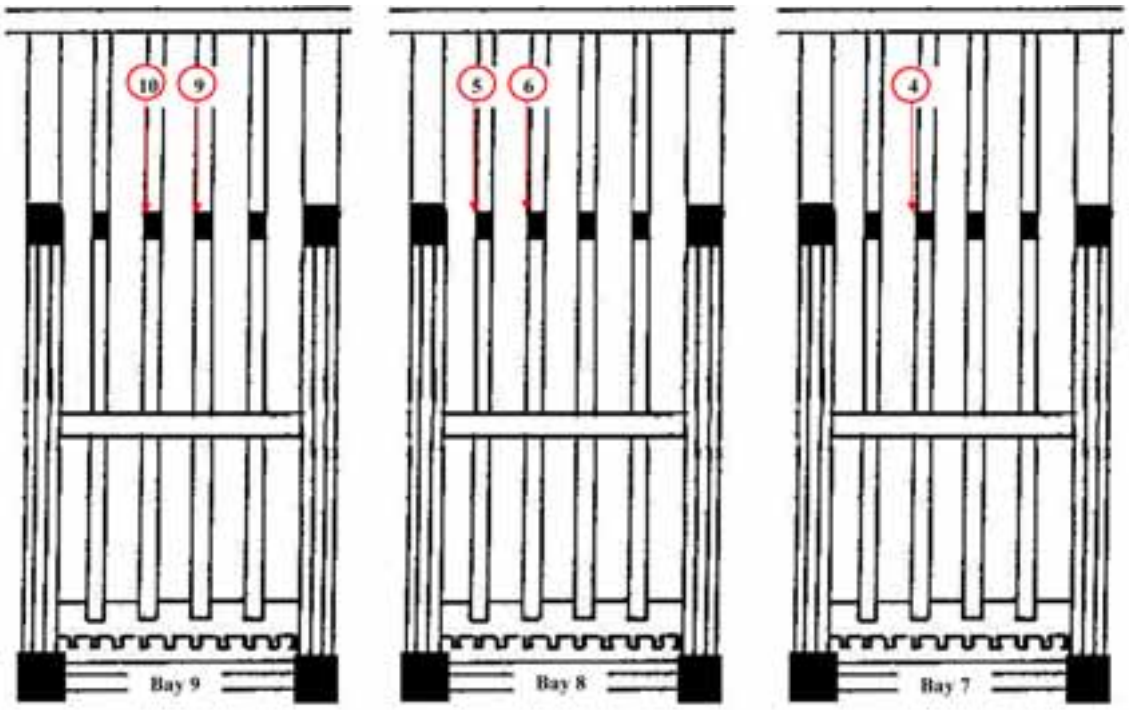


Figure 6b: Western three bays of the hall roof to show sampled timbers

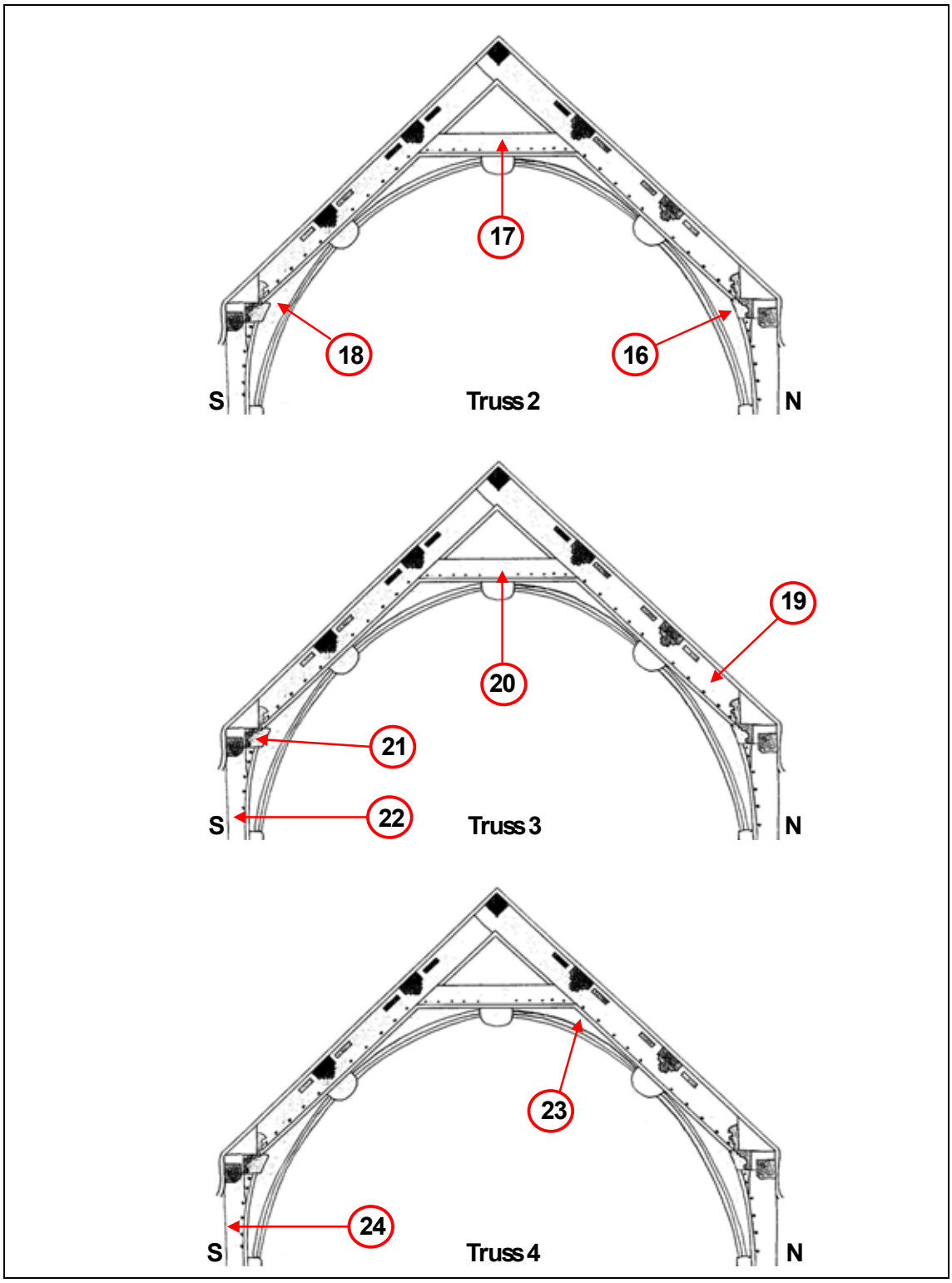


Figure 6c: Eastern trusses 2–4 of the hall roof to show sampled timbers

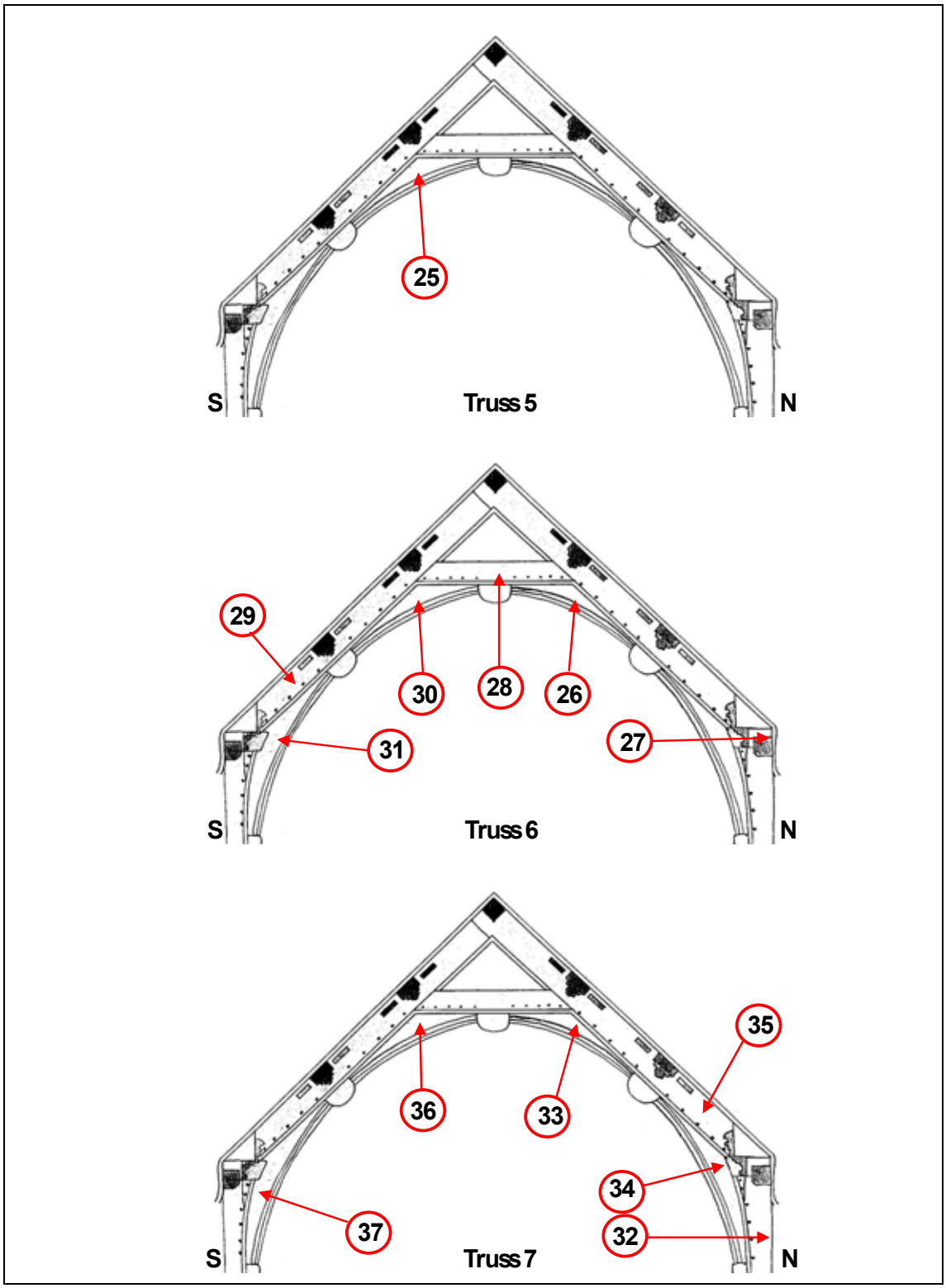


Figure 6d: Eastern trusses 5–7 of the hall roof to show sampled timbers

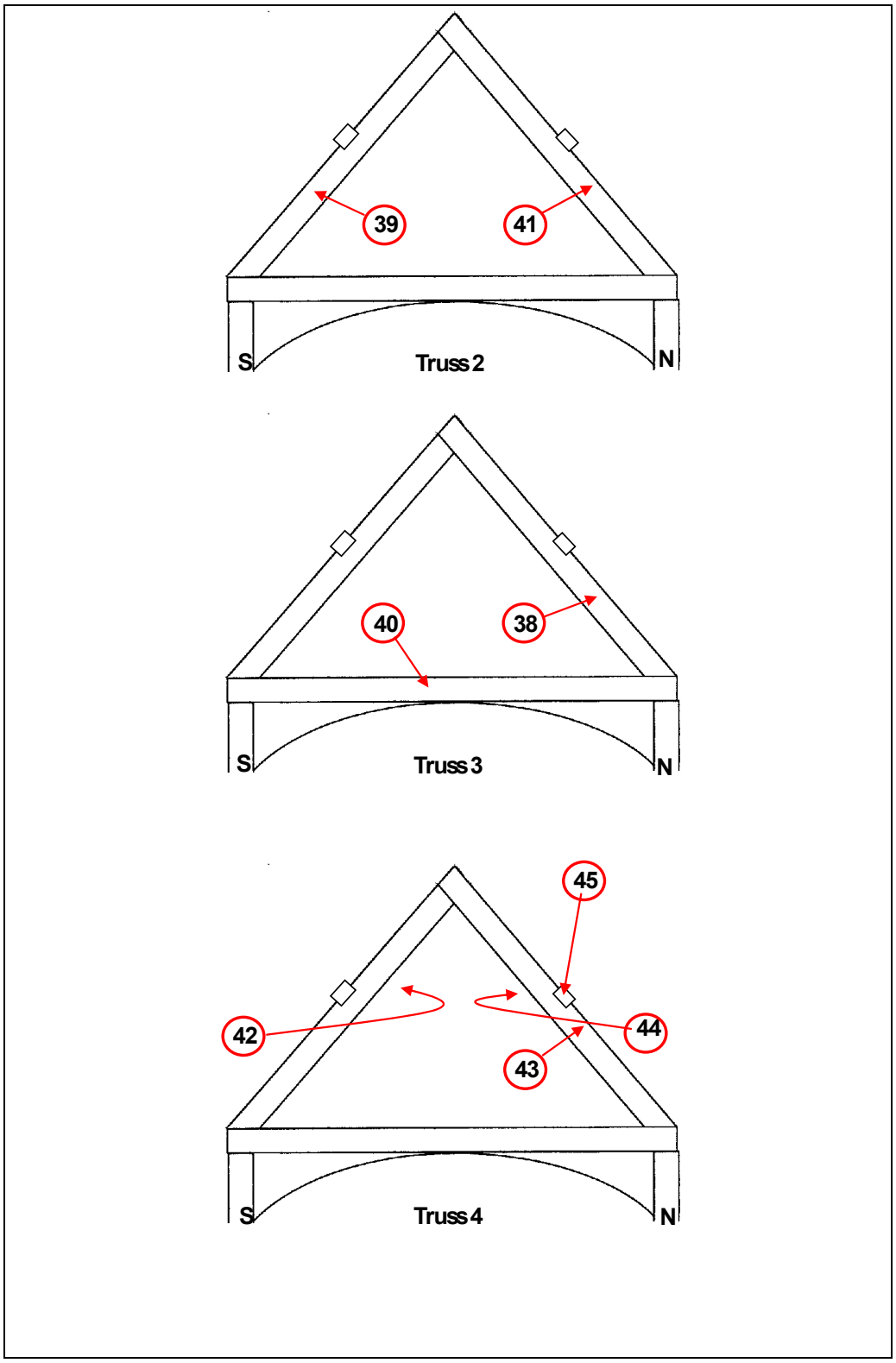


Figure 6e: Trusses 2–4 of the south aisle roof to show sampled timbers

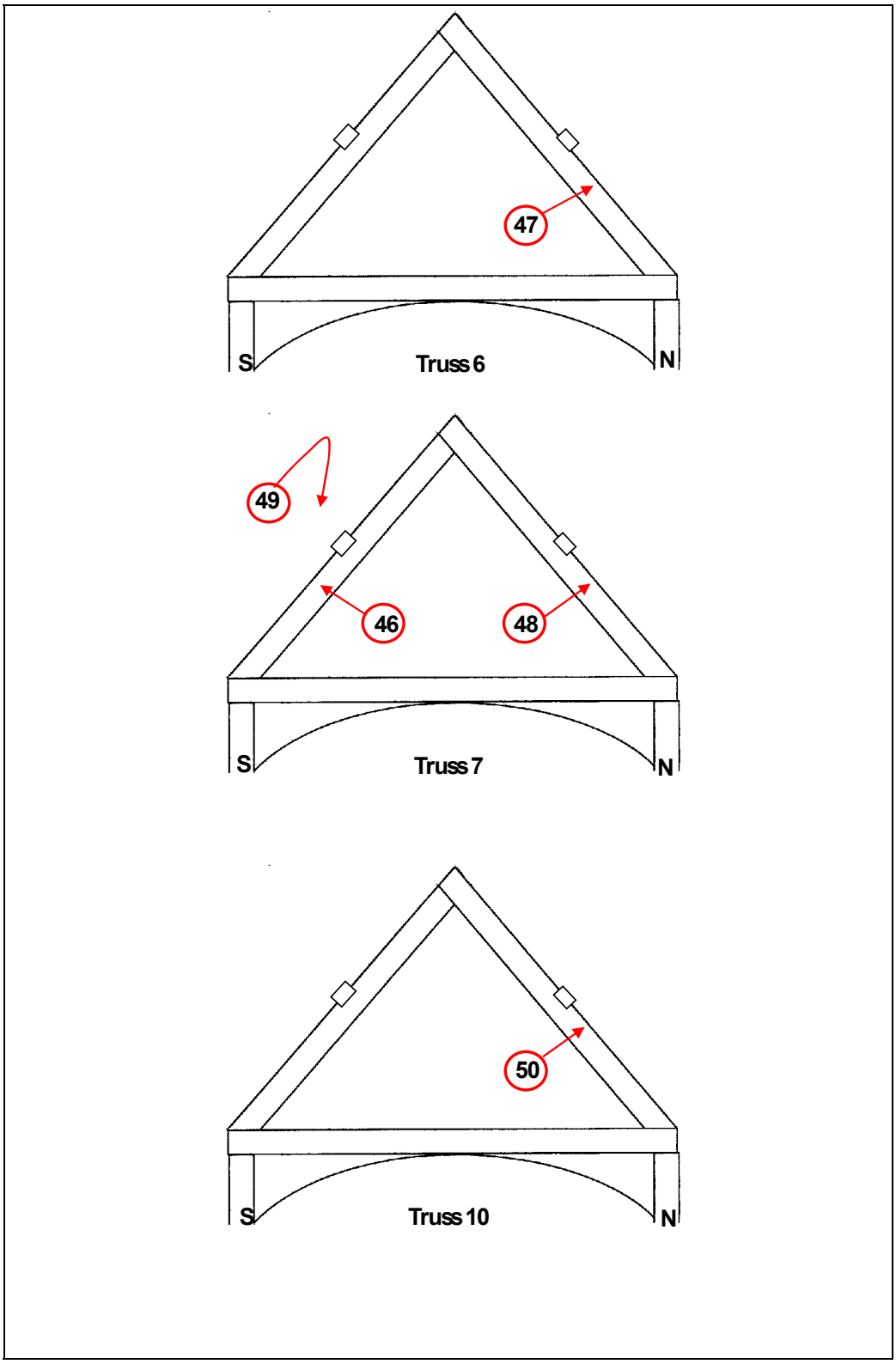


Figure 6f: Trusses 6–10 of the south aisle roof to show sampled timbers

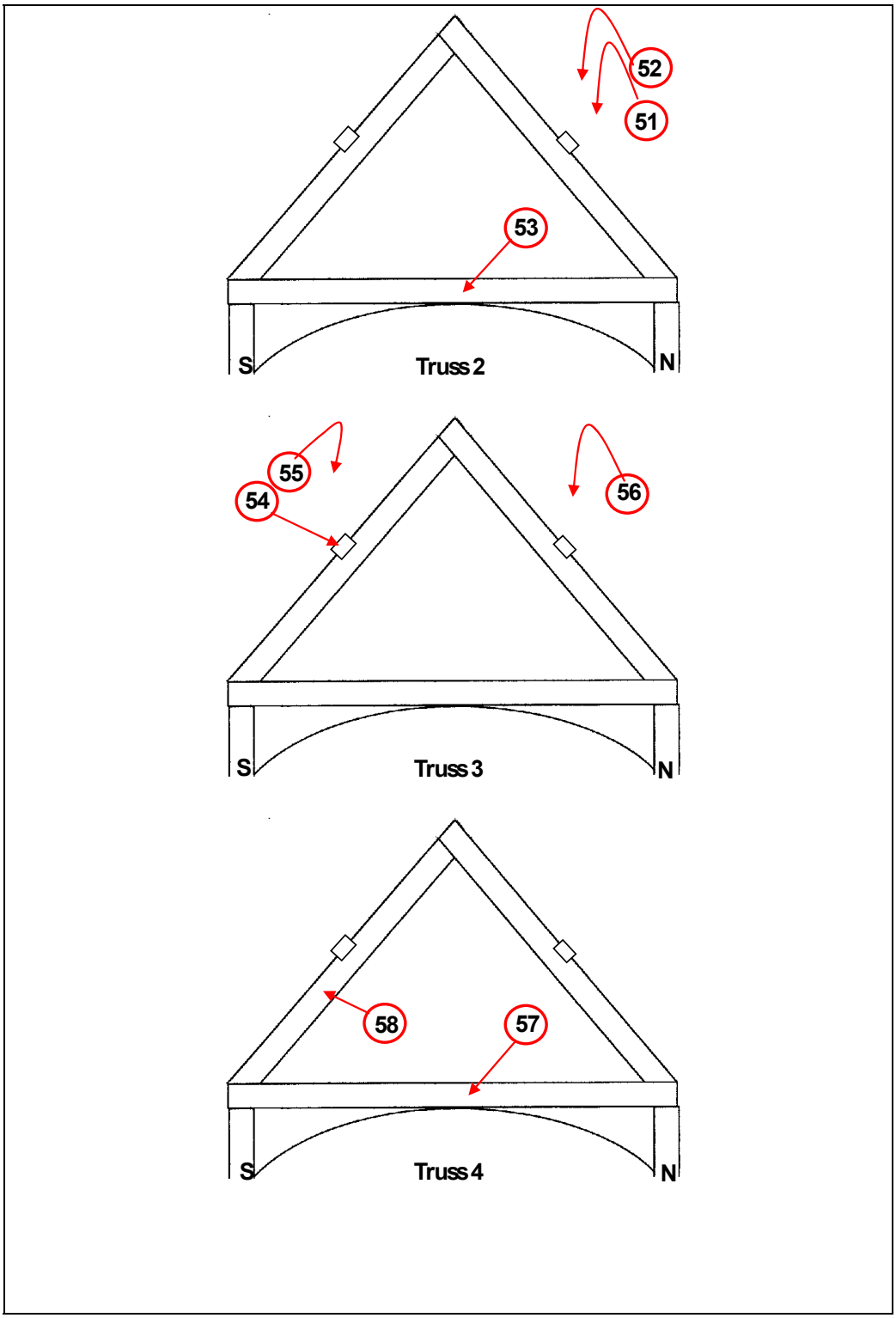


Figure 6g: Trusses 2–4 of the north aisle roof to show sampled timbers

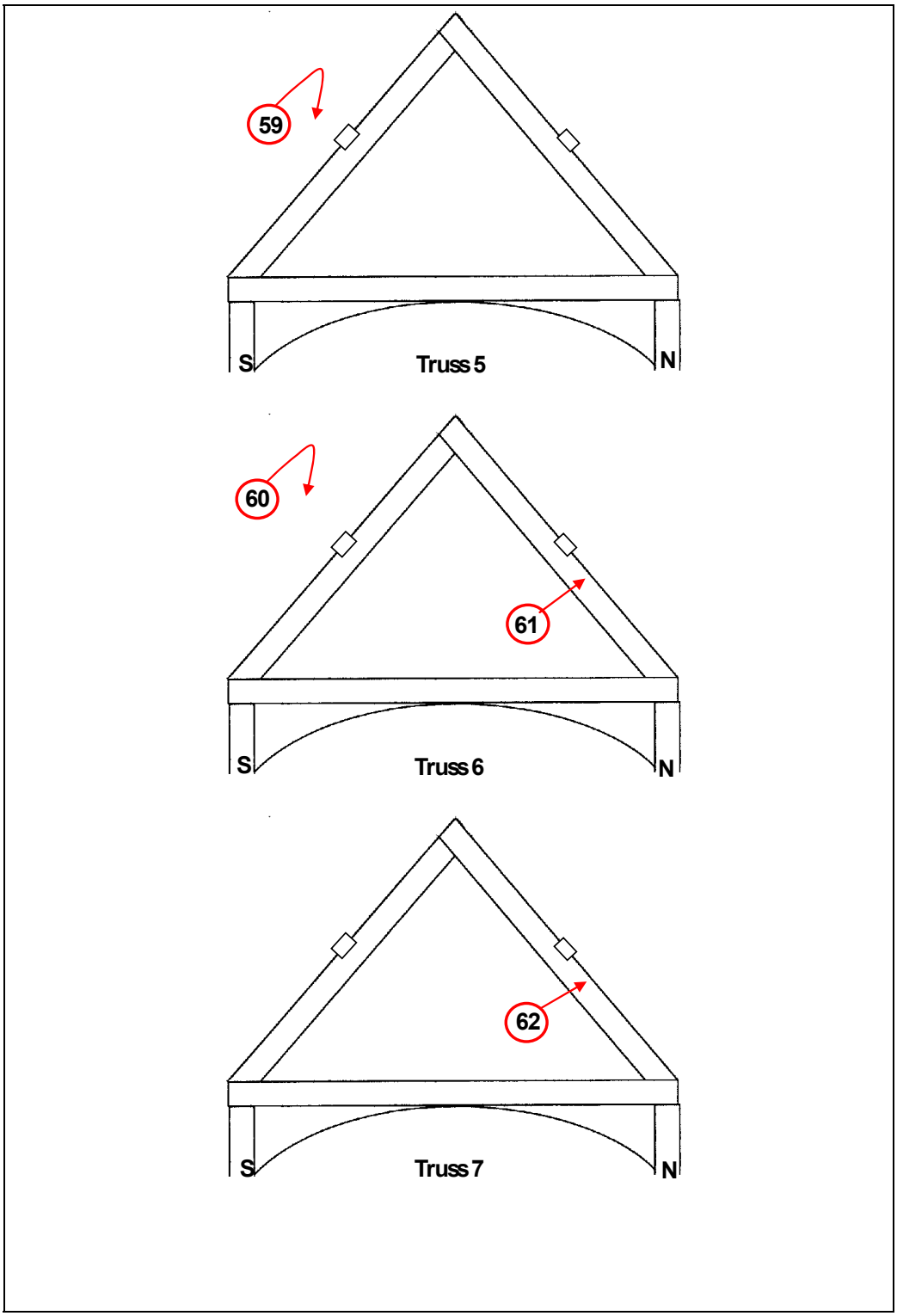


Figure 6h: Trusses 5–7 of the north aisle roof to show sampled timbers

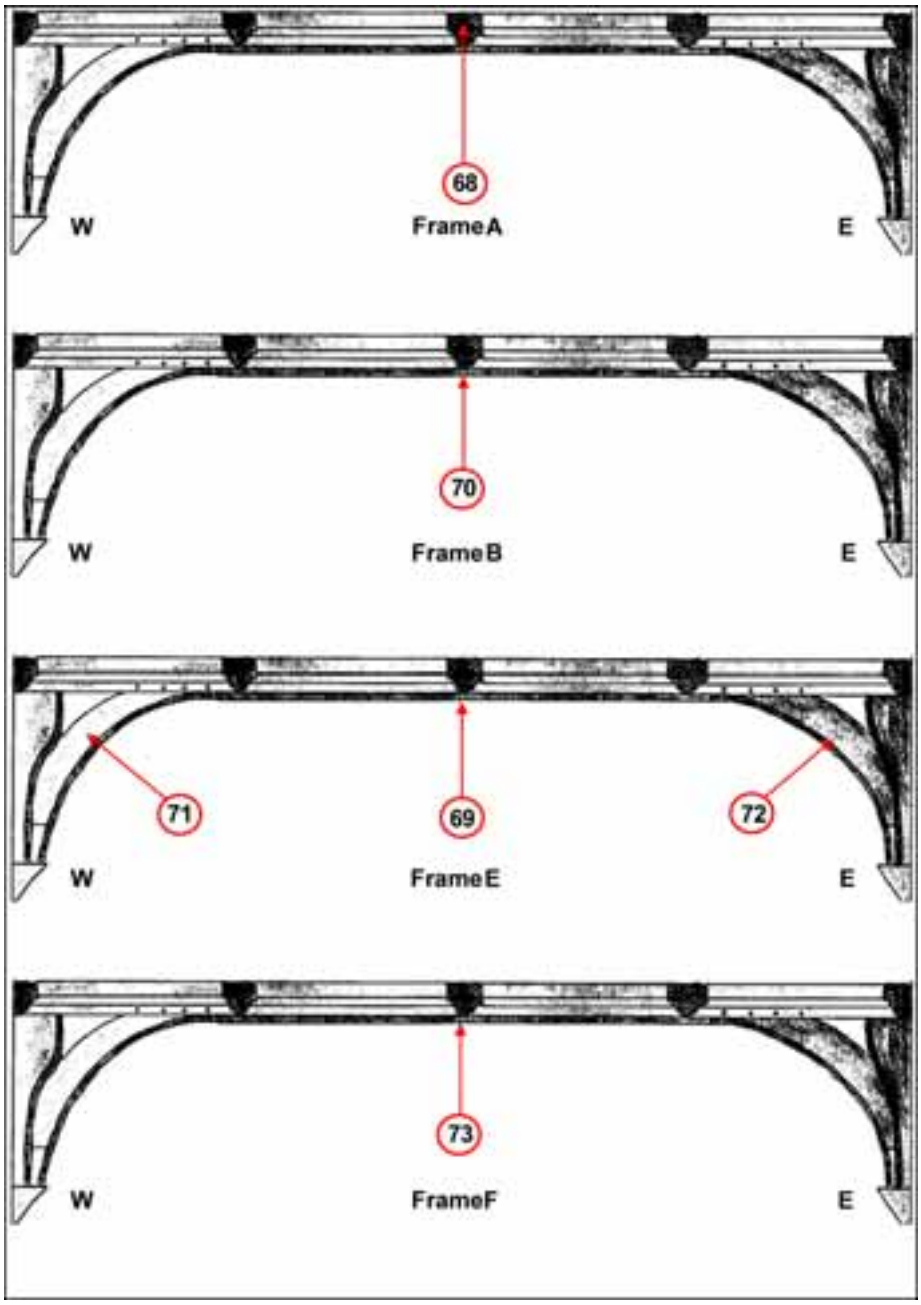


Figure 6i: Chapel frames to show sampled timbers

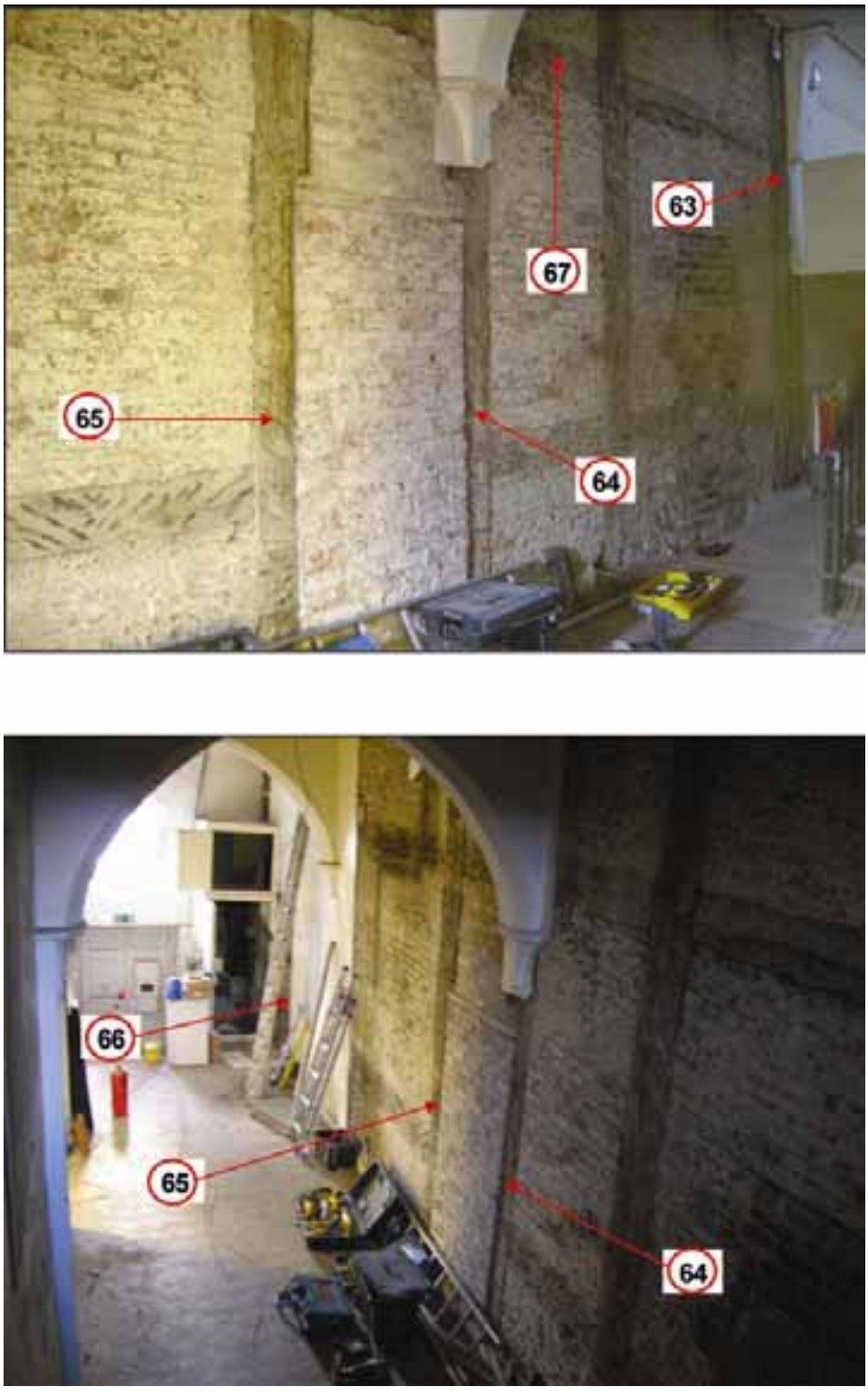
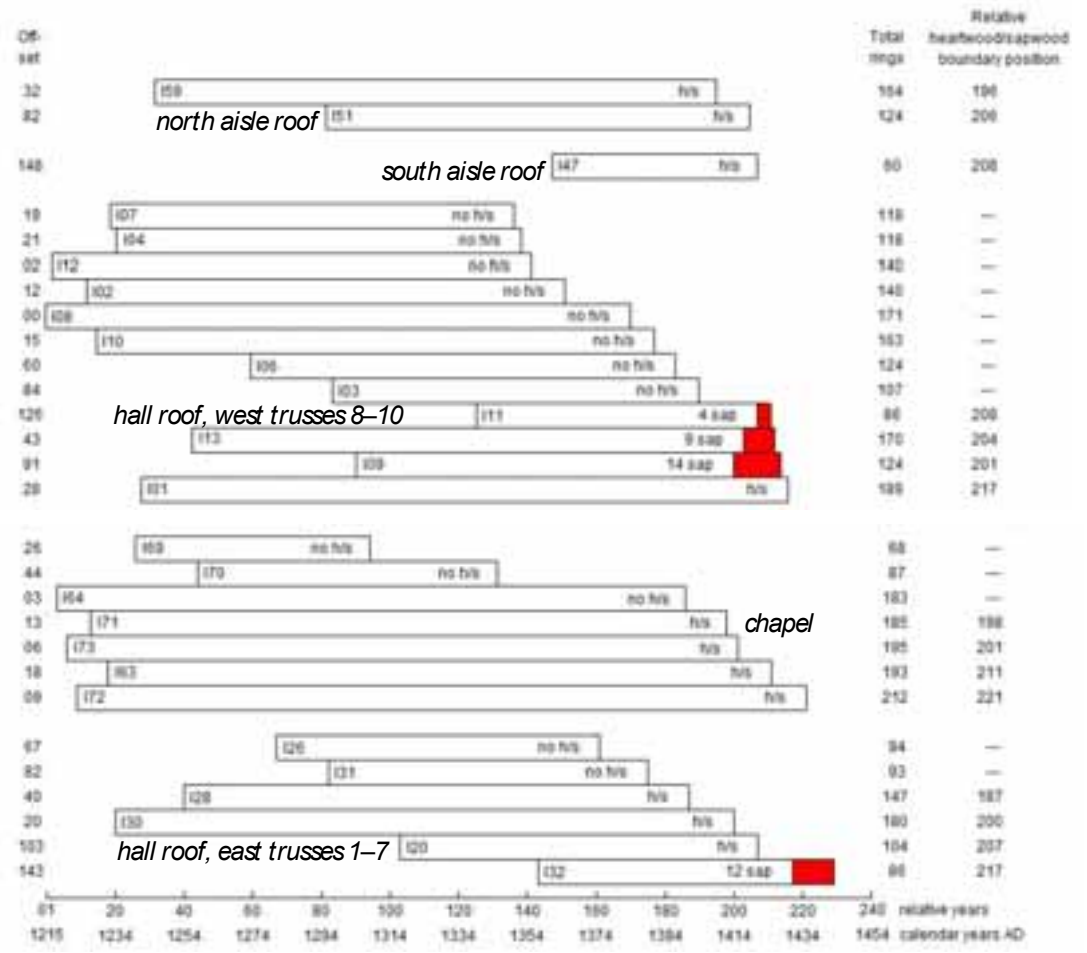


Figure 6j/k: East wall of the chapel to show sampled timbers



White bars = heartwood rings; shaded area = sapwood rings; h/s = heartwood/sapwood boundary

Figure 7: Bar diagram of the samples in site chronology YRKISQ01 sorted by location

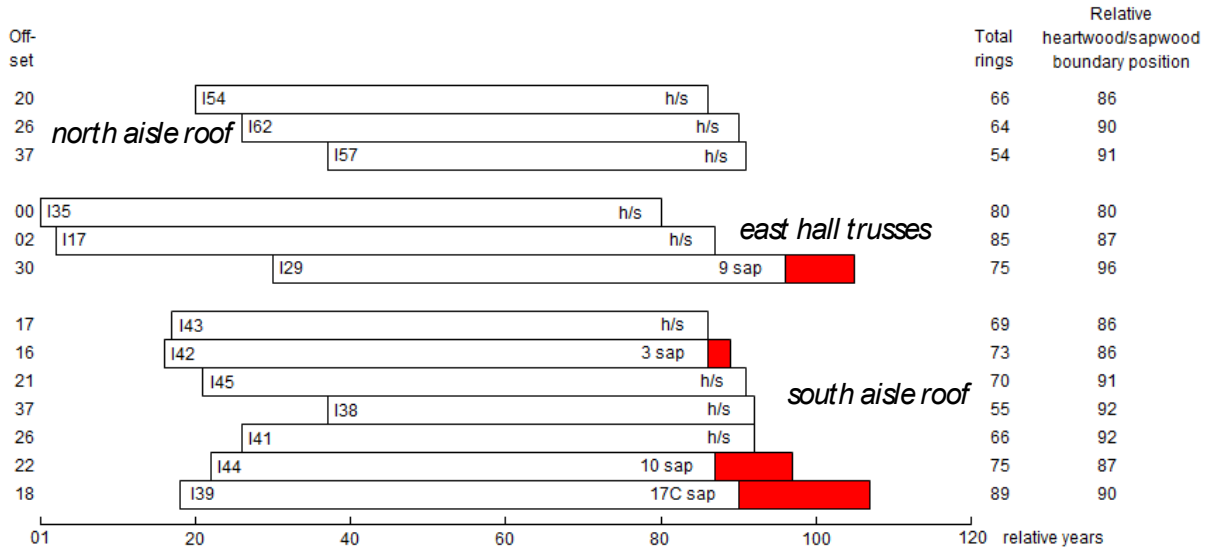


Figure 8: Bar diagram of the samples in site chronology YRKISQ02 sorted by location

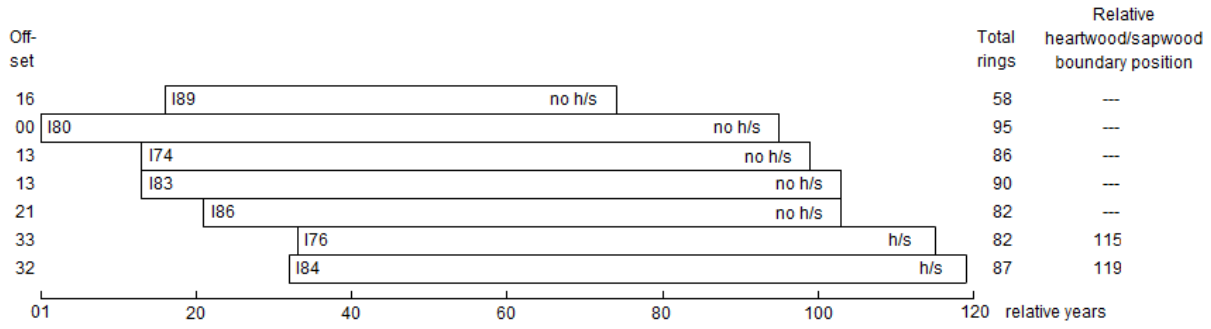


Figure 9: Bar diagram of the samples in site chronology YRKISQ03

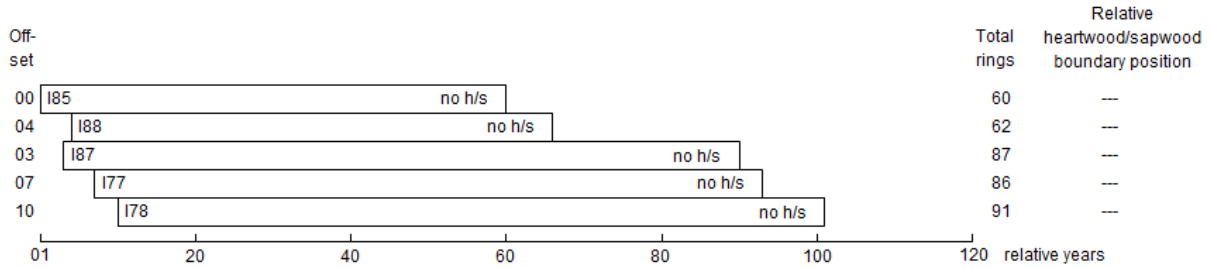


Figure 10: Bar diagram of the samples in site chronology YRKISQ04

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

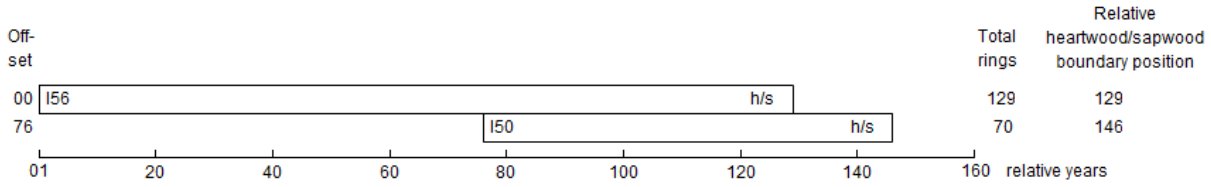


Figure 11: Bar diagram of the samples in site chronology YRKISQ05

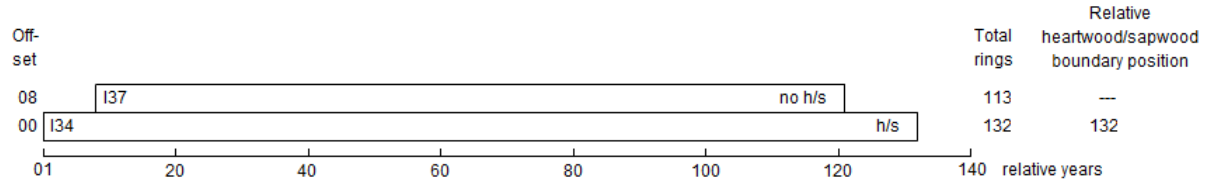


Figure 12: Bar diagram of the samples in site chronology YRKISQ06

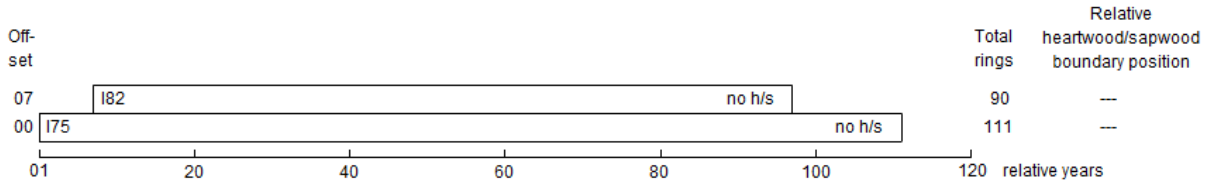


Figure 13: Bar diagram of the samples in site chronology YRKISQ07

White bars = heartwood rings; h/s = heartwood/sapwood boundary

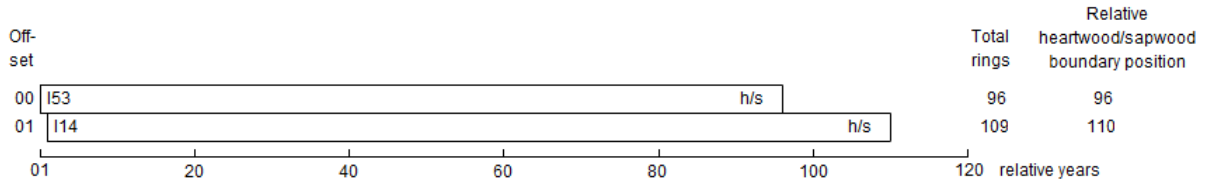


Figure 14: Bar diagram of the samples in site chronology YRKISQ08

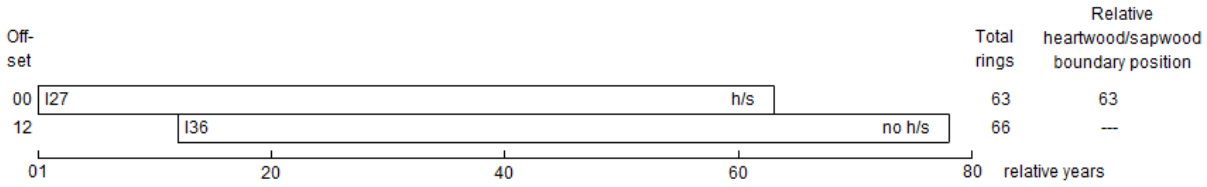


Figure 15: Bar diagram of the samples in site chronology YRKISQ09

White bars = heartwood rings; h/s = heartwood/sapwood boundary

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

YRK-I01A 189
214 227 172 68 101 141 166 177 209 100 105 147 172 123 140 69 103 153 87 59
56 51 56 49 43 50 32 33 41 31 36 33 52 72 84 56 52 51 55 38
26 42 47 61 31 76 87 84 88 81 74 44 44 47 65 83 73 77 55 53
46 35 93 87 57 60 103 54 65 52 43 49 57 52 57 65 132 121 82 58
40 44 49 57 66 85 62 53 38 40 47 56 70 48 46 37 75 62 65 129
155 168 196 107 74 62 53 40 37 45 71 91 127 170 123 52 60 41 58 44
64 70 74 101 58 46 71 103 86 71 55 71 83 52 41 41 66 41 51 72
66 68 95 149 189 103 86 67 83 103 100 89 84 153 173 171 83 69 52 104
124 121 113 147 121 85 110 180 197 189 118 71 78 91 155 95 63 70 110 92
103 91 64 96 147 192 232 140 243
YRK-I01B 189
176 232 164 59 105 126 156 176 207 112 135 150 155 97 168 57 102 152 96 52
55 50 59 51 39 53 32 38 37 35 35 25 58 70 62 70 42 50 56 37
27 48 43 44 42 83 92 82 83 78 78 44 45 51 70 72 64 74 59 45
39 51 78 76 64 50 113 66 68 58 41 50 54 45 56 86 113 111 70 53
47 36 53 62 64 84 62 52 34 38 44 61 69 51 46 45 71 58 78 123
153 165 196 109 75 63 44 46 42 46 64 85 127 161 134 59 55 44 59 44
62 82 67 102 54 41 80 102 83 79 46 74 82 54 42 45 58 43 55 66
60 81 89 142 188 102 98 59 90 92 109 91 90 156 192 174 83 76 49 94
127 122 114 153 121 87 110 179 203 203 118 61 81 86 132 115 64 79 92 89
109 89 67 92 189 159 212 131 235
YRK-I02A 140
182 88 103 135 99 131 237 258 257 175 286 230 230 86 153 137 158 157 158 74
135 132 161 155 188 123 161 185 222 152 137 76 118 122 83 60 53 46 62 46
32 46 37 32 31 34 22 32 44 32 34 48 33 32 52 45 36 52 50 48
32 88 92 74 108 113 116 66 47 59 75 96 92 110 81 66 46 51 116 118
76 86 117 80 91 86 64 107 94 84 112 192 190 133 59 66 49 47 48 62
63 76 80 69 73 75 64 79 85 59 47 69 93 73 130 227 200 228 249 136
116 93 109 62 56 72 113 152 164 162 153 99 80 83 92 54 122 105 108 159
YRK-I02B 140
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130 124 158 148 195 121 133 178 221 151 130 77 108 122 86 47 44 43 55 50
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62 83 116 78 101 76 71 95 102 79 119 194 189 131 64 61 53 45 46 61
59 79 80 82 59 78 64 76 84 68 51 69 96 78 127 219 224 241 240 139
118 95 100 57 66 73 105 152 155 185 153 101 72 68 109 51 110 96 125 159
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161 94 76 47 72 54 79 101 120 122 94 55 57 64 58 80 96 72 54 107
92 91 104 160 131 110 175 72 71 78 67 29 40 47 78 74 92 88 59 36
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70 53 45 72 67 98 108
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156 91 72 52 73 48 88 101 117 117 103 36 72 55 55 79 103 58 49 113

91 93 103 157 136 121 166 72 67 78 71 44 36 50 72 70 99 76 43 52
34 39 57 61 47 77 69 53 35 35 28 40 69 70 46 49 46 56 37 49
73 70 82 80 67 52 53 93 130 88 56 49 85 57 63 75 56 72 65 93
74 64 39 75 66 81 104

YRK-I04A 118

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138 154 145 145 144 138 78 91 78 77 74 59 74 90 102 122 158 173 105 105
128 161 152 168 158 138 84 55 56 85 61 60 50 68 81 83 60 91 75 92
62 64 64 84 95 80 74 97 101 128 127 150 184 165 170 135 153 157 129 140
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YRK-I04B 118

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122 162 164 164 151 103 59 50 64 69 64 61 66 64 69 79 56 81 65 102
52 66 61 89 92 80 70 97 108 122 126 158 178 172 170 142 149 155 126 147
83 60 69 87 88 89 148 147 148 212 174 134 103 67 53 81 62 117

YRK-I06A 124

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87 98 80 127

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254 188 178 139 84 122 122 157 188 185 159 121 184 105 131 62 40 77 78 75
92 107 100 65 91
YRK-I19A 56
338 291 345 333 350 326 398 334 354 323 401 440 338 386 328 234 155 227 208 300
251 186 203 225 217 244 189 126 171 155 142 210 173 131 126 139 192 148 131 158
100 127 247 165 113 92 134 127 103 70 65 90 104 107 106 123
YRK-I19B 56
356 308 327 327 353 307 408 334 344 334 400 445 330 390 324 238 159 216 213 309
248 176 201 223 211 237 199 136 166 151 143 215 168 138 123 126 201 152 130 168
111 106 267 166 99 89 152 132 102 50 73 83 96 98 115 142
YRK-I20A 104
172 154 222 166 165 147 124 145 140 174 147 146 223 177 279 300 290 278 202 181
205 337 372 387 577 467 344 444 137 79 50 59 138 207 412 426 390 367 393 219
191 180 152 332 252 351 412 317 240 171 186 240 174 141 152 117 108 114 96 91
67 132 152 146 143 158 132 161 214 243 230 182 133 174 139 151 140 175 201 242
156 98 134 120 96 184 203 143 148 137 156 200 234 202 121 101 105 154 120 114
119 111 134 162
YRK-I20B 104
176 146 224 171 165 173 110 136 113 153 151 153 219 169 275 305 326 254 196 175
198 335 378 383 596 453 416 438 127 75 49 67 125 221 427 427 374 296 416 210
206 168 147 331 279 381 408 307 208 177 188 241 174 134 165 126 106 106 107 81
74 131 147 142 146 165 124 159 225 230 228 176 126 176 143 145 145 181 202 246
154 104 135 108 101 178 213 127 153 120 149 211 243 188 132 104 100 155 123 102
124 111 133 147
YRK-I25A 59
336 330 253 381 247 245 288 404 484 486 444 383 636 547 561 713 581 533 656 445
464 609 601 500 502 458 468 491 447 460 916 488 560 428 424 434 280 243 178 236
284 313 253 297 344 342 432 461 402 562 486 352 450 410 394 374 273 307 400

YRK-I25B 59
297 338 260 378 252 236 275 400 503 507 430 383 609 537 559 708 575 541 681 443
417 642 583 536 479 423 472 473 446 481 844 498 549 419 383 419 269 250 185 243
288 292 256 305 339 347 406 466 424 538 438 395 435 400 389 381 282 322 408
YRK-I26A 94
493 424 401 270 270 234 317 403 336 304 313 286 218 149 172 247 266 195 190 234
134 124 121 201 349 381 285 338 206 351 294 249 299 407 293 319 275 340 342 206
254 145 80 91 84 135 130 416 292 200 195 283 171 183 179 152 158 211 269 223
348 383 400 550 396 337 285 257 155 130 168 184 338 375 418 347 206 215 178 219
157 304 284 262 261 169 116 161 182 155 107 102 137 161
YRK-I26B 94
518 438 405 260 267 239 303 407 347 287 335 265 211 146 184 244 261 194 193 259
125 120 118 192 336 415 301 323 237 332 296 258 275 423 305 319 284 319 339 208
232 133 85 83 91 116 142 447 279 208 188 269 168 207 167 166 159 196 280 230
337 403 394 542 396 339 282 268 162 117 168 173 355 379 403 368 196 206 182 210
154 298 296 282 232 177 112 164 191 146 106 107 134 157
YRK-I27A 63
370 486 566 358 392 425 461 390 445 390 283 405 353 364 342 256 270 313 353 313
302 185 137 136 193 203 219 227 212 251 256 213 187 235 217 180 120 144 149 176
203 174 170 156 170 166 148 134 152 183 206 200 143 147 132 85 129 152 204 181
131 158 145
YRK-I27B 63
374 482 529 359 381 417 469 400 440 388 285 399 358 405 328 257 255 302 359 319
311 184 134 135 184 210 219 233 207 249 239 228 182 251 218 166 128 132 131 184
203 146 145 183 178 169 144 131 165 172 213 198 144 154 142 91 129 149 211 172
127 157 199
YRK-I28A 147
278 422 384 294 240 355 350 259 248 210 147 173 177 274 223 228 242 153 112 98
191 198 280 193 148 256 237 150 127 132 76 102 57 80 158 170 159 166 126 117
81 96 166 150 109 140 180 133 120 149 235 136 96 102 173 136 112 114 120 154
135 148 220 237 232 189 140 144 101 72 84 120 126 176 114 80 46 56 89 121
165 97 83 66 160 259 235 294 280 260 248 206 188 181 165 111 85 93 100 155
192 222 204 117 122 126 229 178 288 267 222 163 111 123 182 225 197 125 102 146
167 175 126 135 179 163 195 168 127 129 101 96 71 123 111 84 66 94 75 133
104 72 100 170 159 144 137
YRK-I28B 147
328 409 379 292 233 381 367 235 253 198 148 180 173 273 208 226 248 148 121 97
176 200 290 199 157 226 269 160 132 124 81 93 69 91 149 167 167 163 166 99
90 98 161 147 111 121 190 127 120 141 249 144 78 104 166 133 114 107 125 131
163 149 210 250 220 181 153 142 105 79 87 108 128 185 127 71 64 53 78 105
176 94 75 65 163 275 235 273 290 260 247 207 173 191 158 112 89 88 94 167
199 202 208 129 133 148 214 171 287 280 216 176 99 143 174 190 215 137 97 144
175 180 137 122 168 159 189 171 133 136 140 101 61 137 103 74 75 97 77 137
103 70 92 180 161 139 136
YRK-I29A 75
281 201 286 370 387 243 362 370 296 449 291 318 310 69 36 40 70 122 145 120
153 143 70 77 180 126 110 152 144 114 92 122 159 164 158 222 106 129 106 89
99 113 67 60 53 72 144 67 67 90 89 165 133 162 159 87 62 84 69 85
112 77 133 76 52 126 68 105 89 75 64 56 94 95 102
YRK-I29B 75
237 197 281 363 396 260 360 377 310 422 303 306 297 61 26 36 82 109 137 120
144 143 84 66 192 140 113 166 121 108 97 118 159 173 139 223 118 115 104 89
96 110 82 70 74 76 125 69 70 99 77 159 139 157 154 92 53 90 61 89

113 82 127 72 55 107 83 111 86 77 61 65 91 97 107
YRK-I30A 180
435 278 406 324 336 207 326 310 245 243 212 170 217 163 117 143 192 146 113 160
194 151 194 94 150 244 184 193 143 104 135 65 80 78 69 119 100 96 95 131
138 151 128 66 50 120 159 83 90 86 70 96 71 41 89 112 176 147 129 75
67 65 96 109 92 115 87 62 49 56 96 96 67 84 101 114 72 68 81 113
106 151 194 195 74 52 55 56 54 52 83 85 53 88 51 33 27 50 42 65
53 40 36 52 115 101 103 112 101 105 43 39 39 52 41 38 51 84 88 95
78 89 58 55 42 61 80 51 101 127 94 70 78 72 88 81 57 89 69 158
78 55 53 57 91 78 77 59 50 60 61 83 72 77 54 48 64 60 59 56
37 82 95 87 75 94 92 88 97 88 74 71 150 107 73 89 83 69 87 98
YRK-I30B 180
445 272 382 341 361 192 315 304 235 253 203 200 214 164 126 128 187 139 115 161
216 152 197 87 152 239 183 189 148 99 125 68 85 77 74 109 113 90 97 138
135 143 115 74 49 124 163 88 75 90 71 80 70 48 87 115 177 145 125 77
56 74 95 110 82 116 85 62 44 50 97 97 65 87 111 104 82 63 73 116
115 155 213 185 77 43 58 53 45 60 82 90 56 78 46 34 25 35 50 48
66 44 31 54 108 94 102 107 113 81 53 38 37 53 33 41 59 84 75 94
86 91 58 48 48 65 73 49 99 133 100 65 76 69 96 81 71 73 75 145
95 57 53 64 91 77 77 76 55 45 71 82 75 79 51 49 61 66 60 53
38 78 97 87 90 75 70 107 86 89 86 69 64 83 127 130 91 66 77 102
YRK-I31A 93
102 176 112 155 144 95 59 89 136 192 95 90 145 132 121 94 120 145 159 170
213 226 149 119 111 99 125 122 212 181 150 204 157 117 136 114 108 143 148 97
71 79 142 186 190 252 201 187 189 133 80 123 118 68 85 111 144 149 145 142
105 83 78 107 144 93 188 211 185 137 120 72 132 148 126 101 83 181 136 86
72 91 185 185 182 187 112 115 161 181 224 177 138
YRK-I31B 93
116 172 115 152 141 75 68 94 130 188 77 84 149 122 118 97 119 169 141 176
215 223 138 110 114 94 127 119 214 166 147 195 158 117 126 94 127 130 147 103
61 85 127 173 203 242 210 184 203 131 87 112 121 73 62 114 156 158 137 145
108 78 72 108 159 89 186 199 190 142 137 84 103 146 136 99 79 179 142 80
84 177 184 182 204 180 120 114 173 181 202 152 152
YRK-I32A 86
460 486 554 664 530 348 480 434 550 319 332 284 270 265 269 222 265 209 226 170
132 242 273 353 332 228 171 238 328 386 284 195 154 221 145 123 110 64 95 128
151 105 139 168 145 213 233 168 178 194 286 295 333 292 187 147 109 184 186 177
149 160 196 225 245 230 183 207 150 135 225 268 224 201 402 222 257 184 172 163
172 146 229 190 170 140
YRK-I32B 86
525 496 557 672 529 344 467 423 515 304 342 269 284 261 249 224 262 200 222 174
144 235 273 362 328 211 171 229 321 403 293 191 143 234 115 131 99 62 100 130
150 85 142 175 138 215 231 164 190 189 296 284 334 288 181 140 110 177 189 173
171 163 190 217 223 228 191 200 134 162 214 278 207 195 377 221 254 175 170 139
163 163 202 199 160 145
YRK-I34A 132
283 189 340 319 250 466 375 390 307 464 360 359 346 367 356 330 277 223 256 302
276 317 227 314 344 327 242 238 341 297 255 211 219 264 313 272 273 220 232 228
218 197 189 227 205 259 256 243 313 240 295 277 309 460 449 277 301 370 407 329
378 375 344 222 171 183 235 329 253 185 165 203 196 170 157 155 113 154 124 146
200 160 154 120 96 81 80 111 95 82 103 83 121 91 68 87 96 101 110 73
89 99 85 96 86 80 90 88 69 57 46 58 48 40 74 61 64 70 51 70
48 89 80 88 62 51 68 44 71 59 49 84

YRK-I34B 132
224 208 333 345 264 489 325 389 303 484 359 326 353 389 343 339 289 212 262 276
256 296 231 352 324 313 244 241 342 265 242 214 202 275 301 297 261 213 227 226
205 203 179 223 197 254 248 288 320 222 284 304 304 439 441 274 302 369 388 354
388 373 335 236 167 185 243 337 235 224 143 204 199 168 171 149 116 157 134 132
196 171 154 116 100 76 88 88 101 73 108 71 133 96 61 80 98 95 109 84
83 114 69 104 81 72 88 86 65 64 44 54 42 44 67 72 68 66 56 68
52 85 85 81 58 55 72 50 72 55 54 86
YRK-I35A 80
305 366 408 394 411 514 438 373 287 328 300 240 334 256 385 339 340 373 336 300
203 202 297 181 359 381 248 254 269 324 266 174 130 217 161 238 174 264 208 233
249 174 198 120 82 78 100 148 146 139 93 120 89 61 77 110 80 155 116 135
141 95 144 135 127 126 79 114 84 116 133 107 92 74 112 99 88 65 74 142
YRK-I35B 80
328 358 406 397 380 513 443 322 303 326 312 237 323 242 408 355 347 356 344 278
190 224 302 179 364 382 233 262 266 314 260 164 137 200 166 242 165 252 216 244
242 182 196 119 80 90 94 147 142 163 86 115 82 59 82 105 94 135 134 141
134 88 146 147 126 123 89 110 96 118 114 118 78 85 103 92 96 57 79 130
YRK-I36A 66
347 364 282 341 258 289 308 272 222 120 157 244 371 277 323 281 161 192 167 198
148 278 307 93 64 41 49 73 92 80 57 50 82 77 95 69 82 130 103 91
119 131 245 197 223 411 310 150 75 145 199 205 213 220 317 199 235 173 303 307
232 362 320 266 293 383
YRK-I36B 66
355 354 270 406 236 327 316 294 234 118 157 237 353 287 294 275 168 192 171 176
134 279 325 97 57 45 46 75 82 83 62 50 66 89 84 78 84 122 113 93
121 131 271 211 236 379 298 168 83 137 168 205 267 218 302 260 225 141 287 310
234 361 303 271 284 370
YRK-I37A 113
306 401 347 358 293 324 366 420 320 252 320 317 283 314 244 361 356 382 287 277
372 316 345 221 233 289 286 236 289 274 208 274 259 206 236 217 173 217 259 211
263 240 279 273 302 428 390 238 339 369 347 231 256 223 219 236 112 106 130 192
167 147 146 207 225 188 227 232 172 184 135 177 183 207 181 170 121 105 89 122
108 86 106 100 153 126 102 81 108 129 138 116 113 131 104 135 141 126 131 99
64 61 63 62 63 62 91 74 104 72 76 90 108
YRK-I37B 113
312 411 349 320 322 303 369 434 332 250 308 312 284 320 246 359 363 341 262 292
373 336 327 218 242 321 289 237 292 271 225 269 259 205 226 211 151 240 236 220
249 242 283 281 289 365 394 263 324 352 343 252 235 228 236 250 115 91 134 188
154 150 153 201 233 180 234 224 174 184 136 172 188 200 189 173 124 103 91 114
109 104 105 80 150 113 94 92 108 133 137 121 99 144 109 138 137 124 135 102
82 57 61 65 66 66 88 68 108 71 77 88 120
YRK-I38A 55
379 341 374 530 365 292 265 263 213 180 247 444 382 347 335 228 225 348 368 355
501 451 386 285 388 364 440 395 341 234 252 234 266 320 312 333 265 329 248 270
167 166 196 221 345 287 256 300 198 202 188 236 216 236 228
YRK-I38B 55
372 350 361 549 374 287 264 242 222 178 260 422 394 372 322 246 239 349 368 366
502 450 403 276 354 393 447 426 308 244 222 253 260 319 289 321 260 307 242 280
167 155 187 223 337 302 278 296 192 207 179 227 225 238 227
YRK-I39A 89
457 442 426 334 468 427 405 426 354 273 246 306 414 374 371 360 340 232 208 252
313 328 263 215 147 123 77 68 78 125 184 219 197 163 109 98 110 154 153 192

159 169 143 154 207 255 300 250 155 142 118 130 139 129 144 152 149 108 109 90
120 180 182 164 256 208 200 147 136 175 200 162 120 108 146 122 84 125 148 120
134 114 75 61 66 82 78 85 94
YRK-I39B 89
489 448 452 339 461 425 407 433 345 265 267 297 425 367 366 339 344 238 209 261
331 315 266 229 148 116 97 65 83 117 186 229 176 161 101 110 100 161 167 181
170 164 137 156 197 256 294 261 162 139 128 131 137 118 155 158 157 104 118 93
114 182 188 147 235 207 211 139 145 192 191 163 122 105 144 126 77 130 136 121
127 117 66 65 59 82 83 106 89
YRK-I40A 67
223 393 400 543 550 566 507 468 451 386 442 442 562 511 474 442 388 331 183 125
169 152 365 277 290 366 215 188 183 243 173 208 343 353 355 326 392 230 418 370
236 231 219 140 152 99 222 376 287 223 193 220 152 204 95 116 190 168 237 222
249 190 211 177 268 281 299
YRK-I40B 67
214 382 428 451 571 590 486 457 440 396 428 412 556 543 482 446 384 330 181 127
169 151 370 228 277 358 205 187 191 259 186 220 336 362 363 304 410 214 434 399
242 234 202 158 148 117 227 371 293 235 189 210 162 227 93 114 185 187 219 231
231 171 197 182 291 279 296
YRK-I41A 66
217 286 303 446 511 280 376 340 323 213 253 202 392 448 469 239 240 277 312 214
315 468 485 394 228 169 182 252 334 411 241 276 144 125 82 204 298 416 350 288
212 262 223 256 293 281 158 204 199 111 230 235 227 325 253 169 121 219 170 119
123 197 299 261 283 154
YRK-I41B 66
313 261 297 472 515 250 409 344 349 206 255 262 352 459 463 288 245 284 290 204
343 466 475 428 214 178 203 251 310 407 259 256 149 118 99 196 311 433 320 292
237 273 194 275 318 244 179 206 230 93 230 233 251 323 255 172 110 206 145 110
134 194 287 245 278 149
YRK-I42A 73
486 508 530 425 422 468 431 342 428 448 288 276 361 389 396 336 304 217 189 153
190 248 188 177 276 193 133 165 90 97 105 90 120 96 93 58 56 78 83 143
91 152 101 70 58 117 182 161 131 127 90 83 67 66 145 83 74 56 71 40
46 26 30 37 48 35 54 56 42 39 32 43 69
YRK-I42B 73
488 502 512 416 393 457 439 321 427 470 286 284 346 374 399 328 289 210 174 172
185 243 194 182 265 194 135 155 95 102 115 92 126 87 83 63 54 77 79 144
92 160 99 70 58 114 177 163 135 129 75 87 69 69 146 87 77 56 70 36
45 29 29 41 49 36 55 50 52 47 36 40 66
YRK-I43A 69
157 227 198 164 180 199 326 366 332 324 303 284 319 438 429 345 496 437 493 328
354 282 296 419 373 381 140 111 184 256 314 396 314 311 250 215 215 270 364 307
421 250 293 190 319 422 306 280 196 152 187 178 202 278 208 233 162 172 90 104
66 59 88 88 119 164 219 179 184
YRK-I43B 69
192 224 215 175 168 202 304 371 354 319 327 275 294 429 434 351 496 451 521 306
359 271 278 414 367 390 163 111 148 272 321 377 332 295 263 228 211 249 376 298
392 252 295 204 312 431 287 281 200 149 177 184 215 261 240 212 170 188 81 112
66 51 96 94 123 163 224 193 197
YRK-I44A 75
242 337 498 461 323 320 256 271 296 225 166 195 189 156 192 221 231 165 256 249
283 261 203 151 183 307 314 229 207 132 109 112 131 162 181 272 181 125 101 157
332 217 253 226 142 137 112 170 237 190 118 134 120 79 97 55 65 89 59 104

87 86 130 72 79 84 70 130 118 68 136 119 86 102 112
YRK-I44B 75
216 340 509 468 329 325 268 260 301 234 170 189 194 154 178 232 241 168 252 258
270 269 202 153 178 306 286 227 198 138 108 127 121 152 198 273 173 135 79 164
316 229 247 229 128 131 118 162 220 217 126 136 113 67 94 70 61 95 62 111
90 91 130 73 81 89 90 131 88 67 152 111 73 113 137
YRK-I45A 70
178 177 136 421 246 235 348 286 303 425 422 350 426 373 328 182 301 309 336 426
296 306 237 249 173 232 341 376 246 206 169 103 87 114 154 144 197 227 229 150
188 280 222 267 211 190 133 114 213 233 220 176 116 136 94 155 120 99 193 184
163 131 172 201 116 120 176 119 150 231
YRK-I45B 70
119 172 173 332 213 201 333 267 309 445 390 361 449 353 324 204 317 302 326 437
277 328 238 242 178 246 335 386 253 199 176 105 84 115 145 122 181 229 215 144
205 268 235 267 221 184 129 116 211 230 211 154 121 138 88 164 111 110 176 175
158 127 165 220 109 130 176 118 151 219
YRK-I46A 72
98 66 79 221 309 290 300 410 260 198 200 184 187 207 347 407 427 435 370 443
288 186 199 265 396 380 309 186 91 64 106 154 200 190 183 201 209 175 179 251
229 347 256 199 232 365 335 304 318 296 222 207 167 212 296 271 243 218 229 155
221 152 119 218 159 174 218 207 253 240 165 202
YRK-I46B 72
97 64 73 221 329 314 292 381 250 186 210 193 193 203 349 434 416 408 363 490
243 166 189 294 400 384 302 194 78 67 90 160 201 160 179 198 187 181 175 249
233 345 249 220 219 382 343 287 310 297 216 208 172 219 289 281 226 218 223 165
216 159 110 218 181 172 195 228 250 238 164 201
YRK-I47A 60
341 408 385 332 292 313 422 437 291 276 189 216 193 220 202 290 373 327 306 339
335 366 333 326 395 310 305 207 252 184 219 163 137 240 218 279 166 304 357 265
329 316 168 218 167 279 303 234 255 193 113 95 199 132 103 133 152 193 265 251
YRK-I47B 60
338 411 385 316 232 317 428 440 283 290 190 188 190 208 207 290 356 345 308 344
323 332 343 327 389 298 295 225 238 191 234 169 143 247 217 275 181 301 317 262
323 319 174 203 167 287 278 235 257 176 116 108 200 119 120 126 156 192 272 255
YRK-I49A 50
197 251 217 495 303 248 162 182 209 223 291 261 258 202 263 237 227 202 311 698
478 307 357 320 249 187 324 366 426 383 353 349 253 367 321 98 83 71 87 110
97 98 135 156 127 94 120 134 117 157
YRK-I49B 50
219 241 241 499 310 241 162 185 199 245 292 252 260 220 246 225 233 192 355 645
481 319 354 315 250 184 339 360 434 358 348 368 250 387 315 113 75 74 89 94
88 119 133 153 127 89 127 133 113 144
YRK-I50A 70
376 298 225 425 312 207 337 378 272 203 219 166 158 226 179 223 195 162 156 201
171 188 176 200 132 129 118 150 143 128 150 151 193 228 185 200 220 132 129 172
150 134 111 136 149 123 147 149 162 193 150 157 189 185 123 105 84 77 67 91
99 118 85 92 140 122 172 112 105 117
YRK-I50B 70
376 303 227 438 306 208 327 361 285 193 226 164 155 230 175 211 192 182 150 207
169 185 200 194 124 141 149 135 145 130 143 139 248 227 177 181 212 108 114 168
157 138 110 128 152 122 151 141 145 188 156 152 211 182 149 83 82 70 81 90
99 115 87 77 155 142 161 111 106 107
YRK-I51A 124

116 69 73 76 65 55 71 88 129 105 95 83 89 81 104 96 86 85 92 73
74 85 87 106 88 66 85 56 66 90 80 91 113 89 92 102 100 84 91 60
66 60 81 65 72 67 85 70 85 83 66 96 82 70 56 79 77 80 66 91
76 42 58 53 50 46 57 65 56 53 42 25 41 37 37 36 33 44 29 39
35 28 33 32 37 31 30 34 41 34 38 49 48 28 38 35 45 34 25 32
36 37 41 35 36 35 56 71 70 68 32 64 64 93 129 81 87 91 89 114 126 205 169 214

YRK-I51B 124

117 63 71 75 73 51 84 73 134 108 92 87 88 95 100 92 107 90 103 67
83 79 95 107 101 69 79 51 86 83 76 94 109 94 87 105 100 78 101 56
69 72 75 61 70 66 83 74 80 89 68 98 92 61 61 75 80 72 70 101
78 34 65 50 44 57 49 57 46 60 41 26 40 35 37 43 32 38 29 41
35 31 27 38 37 33 32 32 43 35 37 44 45 33 32 43 36 36 28 31
38 44 35 38 35 29 57 82 61 74 28 61 64 92 130 92 81 89 85 112
130 210 167 219

YRK-I52A 101

202 328 309 273 233 210 146 133 122 136 84 96 124 78 62 119 91 62 92 67
78 65 74 80 72 74 82 111 118 122 117 105 115 113 76 130 138 110 63 91
61 47 86 53 78 70 77 66 67 61 49 42 63 84 62 60 67 60 60 69
46 59 54 39 60 41 42 58 44 52 42 52 47 60 64 69 60 58 77 67
63 67 69 49 59 51 64 78 64 82 95 68 64 77 109 90 88 59 63 94
84

YRK-I52B 101

199 336 301 268 241 208 144 118 130 149 100 85 128 88 49 112 83 68 91 69
72 76 76 102 83 93 99 111 111 130 112 116 108 120 89 111 125 113 67 83
53 48 86 51 67 81 75 70 65 55 52 41 61 86 61 64 65 63 57 71
60 55 51 47 53 47 32 53 57 60 41 49 46 55 68 68 60 63 72 75
60 62 70 55 57 41 77 75 72 78 95 68 70 79 98 102 71 69 57 83
98

YRK-I53A 96

367 272 234 251 281 180 222 176 289 337 261 218 227 222 369 303 301 344 192 242
197 231 332 480 277 656 513 339 403 246 439 370 379 291 373 322 320 320 333 288
184 318 309 284 167 274 274 246 294 260 244 243 250 278 346 374 289 329 334 306
183 255 191 279 408 422 311 390 242 362 278 324 249 266 257 331 152 197 163 129
121 109 110 119 118 116 141 143 127 147 129 134 150 163 145 189

YRK-I53B 96

373 265 243 219 302 205 202 187 299 340 256 220 228 223 371 328 308 331 217 229
162 229 344 494 257 637 455 366 388 258 416 369 366 305 369 338 318 328 337 288
190 326 307 283 185 257 295 250 310 280 262 228 210 268 330 357 294 329 308 294
202 239 186 238 332 412 301 347 254 311 240 319 218 277 259 308 159 217 151 140
135 120 114 131 126 116 138 132 127 157 125 141 150 158 149 170

YRK-I54A 66

304 260 322 247 444 502 331 216 286 342 410 249 278 313 249 249 206 285 263 323
296 231 259 261 201 194 220 282 319 359 305 215 125 135 145 233 217 252 155 199
132 271 241 275 296 166 97 200 215 169 212 143 194 244 197 128 106 89 71 136
117 131 97 112 113 93

YRK-I54B 66

307 257 320 252 436 478 332 204 290 366 404 263 292 307 249 266 214 285 235 318
281 238 265 261 208 199 193 288 346 359 319 222 127 123 158 230 206 273 169 202
122 269 239 288 282 178 84 180 242 177 175 163 202 231 191 125 125 84 80 141
109 117 97 107 113 65

YRK-I56A 129

102 88 128 131 139 153 94 143 85 73 109 122 170 163 104 96 110 93 96 103
106 132 98 75 65 99 98 128 91 81 74 70 103 100 94 115 87 84 102 102

97 94 95 68 61 67 101 77 54 89 53 57 76 63 91 104 77 59 33 48
64 56 62 43 42 40 34 34 45 39 57 52 39 50 32 29 34 42 27 40
33 34 31 35 29 29 29 24 34 32 32 40 36 32 37 53 34 40 34 43
30 43 51 53 43 50 44 50 53 68 68 74 72 42 37 57 65 86 66 88
79 102 89 102 92 135 101 97 114

YRK-I56B 129

92 92 131 129 137 154 109 161 64 90 105 116 163 174 80 100 112 89 102 106
102 137 100 75 63 104 89 128 95 70 81 72 111 102 92 117 80 85 106 84
80 100 98 65 69 67 94 69 65 88 70 48 80 48 100 105 80 55 38 52
54 57 58 49 41 46 36 29 46 45 63 38 45 39 39 27 33 38 35 38
31 21 37 38 23 23 33 31 31 34 32 32 36 35 39 51 31 44 35 40
33 46 43 58 47 53 50 52 61 60 61 70 66 44 45 65 52 88 66 91
90 91 82 107 94 134 97 120 138

YRK-I57A 54

383 377 630 525 384 359 148 172 287 297 485 354 399 300 438 243 299 482 352 312
431 297 380 273 444 344 405 333 200 135 127 158 172 242 208 136 89 115 78 122
90 100 157 141 180 156 214 156 113 115 159 178 207 321

YRK-I57B 54

408 370 580 487 385 339 154 199 269 329 473 353 405 308 442 238 300 519 356 289
421 338 356 288 425 354 415 347 216 145 128 168 163 245 202 133 91 109 87 119
85 110 158 146 172 159 219 154 120 102 172 187 216 331

YRK-I58A 61

186 208 127 68 181 234 270 413 361 404 425 577 477 332 212 347 318 393 349 461
411 283 226 201 325 398 278 329 353 331 349 275 321 327 408 356 291 151 57 49
75 88 116 184 172 109 126 88 111 120 201 175 260 153 153 130 149 312 294 265
189

YRK-I58B 61

179 196 134 61 195 243 289 437 317 389 428 573 465 318 229 354 316 399 346 466
402 298 222 191 346 409 310 332 344 355 324 273 307 345 412 344 298 149 49 52
78 99 95 200 163 117 123 104 101 117 193 182 265 148 165 141 138 313 295 255
178

YRK-I59A 164

88 97 114 113 157 181 144 164 175 145 122 101 127 155 98 62 50 49 59 52
32 54 35 35 30 30 19 23 21 38 50 52 55 65 93 47 43 35 34 41
33 33 72 67 65 83 71 47 35 41 63 75 71 55 62 57 56 59 66 70
44 75 130 91 67 47 58 62 68 68 82 94 140 117 93 55 85 80 101 139
123 115 91 94 64 62 83 90 126 85 69 66 121 132 153 181 176 163 193 172
121 131 108 102 61 88 100 151 171 227 160 99 70 57 86 62 89 88 113 109
76 49 62 84 100 90 65 84 101 110 61 60 78 69 68 82 82 59 71 72
119 98 65 54 45 57 77 67 79 98 80 125 86 68 49 49 65 73 62 104
59 74 118 79

YRK-I59B 164

100 98 113 103 152 137 150 174 183 152 106 94 117 168 96 65 48 49 57 52
35 49 40 31 35 22 24 20 22 46 37 70 41 69 94 59 37 33 41 28
40 38 61 81 63 74 65 53 40 46 47 79 69 65 57 70 50 58 69 73
47 82 113 100 69 60 52 62 63 66 85 93 138 133 96 60 90 74 96 140
122 113 96 89 56 74 78 89 123 93 71 63 121 156 158 179 189 158 190 165
129 123 109 100 66 81 97 150 175 234 169 90 82 65 83 62 95 97 119 111
64 49 64 91 95 92 60 98 101 103 68 55 82 69 89 73 78 73 64 74
111 98 69 51 41 58 68 61 90 97 89 127 88 59 54 45 73 71 71 94
68 68 104 76

YRK-I62A 64

338 322 343 336 426 437 387 464 531 423 364 350 382 373 400 311 352 292 326 220

202 282 309 318 229 241 172 151 113 202 195 304 280 216 140 241 226 301 406 349
287 223 202 192 231 271 196 190 225 170 203 187 153 251 280 403 280 319 402 232
221 223 320 383
YRK-I62B 64
345 299 321 301 457 429 397 443 487 449 387 347 381 369 396 315 345 299 318 232
204 283 315 314 218 235 178 150 130 187 179 320 278 222 125 233 237 299 404 354
282 212 205 188 236 280 200 180 216 165 201 190 141 255 289 394 277 318 419 244
224 219 319 325
YRK-I63A 193
87 87 104 107 107 105 99 51 93 77 102 126 97 35 103 46 53 77 63 53
57 93 106 100 53 47 98 95 67 34 31 49 58 58 58 80 43 44 43 55
106 64 95 90 90 103 86 142 113 72 126 94 83 81 48 85 128 151 127 128
153 121 90 83 102 109 80 121 75 39 36 27 54 55 34 56 81 52 47 42
42 71 115 103 74 51 57 70 46 59 88 79 106 107 88 97 58 66 49 96
80 60 84 70 60 44 75 80 96 126 134 85 115 100 84 90 67 43 66 85
84 106 78 97 45 44 48 46 57 48 108 93 121 77 46 56 62 82 67 61
52 97 84 95 86 90 94 79 51 57 56 52 55 66 94 69 53 39 40 91
92 75 39 78 71 73 79 64 67 59 77 67 54 79 70 46 79 61 57 77
79 59 70 57 80 74 59 69 103 75 73 143 112
YRK-I63B 193
79 93 96 108 108 122 146 59 123 99 106 89 81 44 91 45 64 70 88 62
73 92 130 103 53 43 88 103 59 25 30 43 57 64 47 69 40 46 39 61
70 60 88 84 85 96 80 148 105 102 119 88 73 76 41 87 121 129 158 108
180 119 95 78 91 112 95 115 80 40 38 28 57 50 34 58 82 51 48 41
45 65 112 104 70 49 68 63 63 55 87 75 108 101 90 95 60 69 48 86
87 63 71 66 47 55 83 77 107 141 151 103 108 98 82 91 62 46 61 90
84 106 78 95 41 49 50 44 64 45 106 81 123 88 44 54 59 84 72 56
56 104 71 74 76 87 97 79 51 54 52 50 58 67 90 73 54 41 41 84
85 74 47 71 77 70 77 67 61 69 70 64 61 78 69 52 81 53 57 70
72 69 70 56 94 65 56 72 92 77 89 116 106
YRK-I64A 183
129 171 226 225 219 136 245 208 185 200 156 178 181 141 106 126 138 134 127 154
177 191 106 110 126 132 137 107 86 100 75 91 106 114 105 138 168 161 162 134
84 133 201 166 88 81 69 80 76 65 105 83 77 99 78 96 78 146 214 230
193 147 137 182 163 127 136 126 110 138 249 411 414 334 266 248 127 79 87 147
164 138 146 132 142 83 78 69 63 87 83 105 103 132 96 107 111 142 128 115
113 108 74 67 59 55 38 66 78 105 90 76 58 42 47 73 69 111 89 79
79 134 122 129 183 144 116 126 94 90 58 74 48 53 64 81 118 118 163 147
116 89 78 101 112 129 111 117 138 102 58 64 87 82 80 87 73 98 72 87
66 92 75 75 78 77 85 87 129 152 126 83 88 62 78 102 116 84 129 119
177 113 132
YRK-I64B 183
127 167 228 222 228 134 249 207 182 196 155 158 186 139 109 126 138 134 125 149
185 193 105 109 122 161 114 111 84 115 66 89 97 118 88 143 177 173 166 138
87 146 215 127 88 80 68 84 81 69 95 87 83 102 82 92 73 143 216 219
220 145 138 184 176 140 157 130 124 136 235 403 421 365 233 248 110 91 86 140
168 133 141 128 146 86 86 75 61 70 104 116 117 125 104 96 118 140 130 116
118 114 102 72 65 60 55 73 84 93 97 69 60 29 49 78 64 114 92 80
75 141 114 131 169 142 115 131 99 86 66 70 46 58 61 77 111 123 165 150
110 93 76 107 106 130 103 114 132 99 68 67 89 80 84 65 87 104 79 57
64 98 68 79 71 87 71 90 131 154 111 76 93 69 78 85 110 106 98 138
137 142 131
YRK-I65A 74

382 395 280 313 300 380 460 352 297 452 585 639 485 392 346 397 440 354 295 335
314 264 237 324 238 300 417 300 84 61 61 68 93 137 190 170 166 127 130 128
174 192 227 337 283 271 169 298 321 332 370 299 223 200 138 219 210 216 205 163
135 136 119 133 120 150 125 192 171 143 89 151 163 236
YRK-I65B 74
369 399 270 312 285 401 448 355 290 385 608 628 478 367 348 429 420 373 273 331
318 266 224 285 248 297 414 305 81 59 47 50 81 100 191 151 149 146 139 146
195 193 242 333 271 291 196 306 304 318 372 295 223 185 136 212 221 217 197 170
144 134 122 126 122 153 133 183 174 139 90 150 17 226
YRK-I67A 73
384 409 459 520 491 459 327 392 408 406 467 450 395 441 355 415 243 363 356 353
292 259 117 214 120 158 190 195 218 246 140 177 114 211 203 260 165 286 180 209
239 278 299 244 297 281 152 209 165 166 223 191 184 204 167 154 139 103 104 156
96 122 147 126 131 99 51 91 94 79 138 63 141
YRK-I67B 73
382 396 400 474 456 448 327 382 424 370 476 431 398 403 324 439 264 349 360 341
328 249 113 214 118 163 197 186 223 241 133 176 121 211 212 244 172 289 190 200
236 278 305 232 296 278 172 207 168 158 215 183 177 224 154 147 138 121 106 150
119 115 133 136 118 84 63 93 104 83 156 61 137
YRK-I69A 68
140 142 131 125 122 73 94 81 91 121 137 118 139 109 145 186 180 34 76 120
69 58 80 110 132 103 111 129 111 87 69 89 94 53 63 96 153 117 112 116
70 53 59 42 37 73 30 107 142 110 133 77 56 39 47 52 127 157 107 106
151 98 52 43 84 35 42 86
YRK-I69B 68
125 141 126 124 127 76 136 77 90 112 124 118 124 135 162 184 161 55 84 104
76 49 63 112 107 120 127 128 105 92 65 83 99 51 65 108 141 141 124 126
70 51 46 55 45 57 50 91 135 114 102 87 52 44 51 66 107 164 105 110
162 109 47 44 77 26 47 92
YRK-I70A 87
215 211 196 104 83 166 148 151 84 107 85 108 104 113 82 88 113 158 109 118
88 111 116 75 80 100 80 87 53 82 135 125 134 160 151 85 82 87 121 122
96 143 87 53 71 93 119 95 98 117 137 100 98 86 99 178 170 127 77 58
85 78 77 66 70 77 84 88 64 94 71 71 53 87 143 122 127 93 83 156
164 175 148 156 159 154 185
YRK-I70B 87
220 213 186 86 95 150 139 142 87 100 85 109 71 105 94 96 135 142 118 127
100 90 122 84 76 100 94 85 64 74 121 134 139 151 160 92 80 87 138 147
69 126 86 69 56 103 120 96 103 104 148 88 105 86 96 165 167 117 96 59
92 76 71 61 78 75 90 88 74 96 58 71 64 78 162 118 125 94 84 170
169 179 148 147 157 159 188
YRK-I71A 185
202 142 143 88 90 111 110 143 154 263 251 443 282 179 143 204 177 160 92 156
81 132 157 170 147 143 215 181 114 111 87 105 138 80 60 47 45 40 63 38
60 46 40 51 42 47 34 46 71 74 79 64 98 88 52 65 62 52 62 45
80 117 125 149 180 152 59 52 61 70 89 84 82 76 57 44 30 66 74 75
76 100 60 82 63 73 85 88 57 97 67 110 77 63 44 53 34 45 50 58
71 77 66 23 28 49 57 67 48 41 34 56 54 67 91 86 77 161 89 100
92 71 37 41 43 60 77 128 147 128 89 87 48 61 50 79 80 80 63 47
45 50 77 64 62 43 58 48 54 58 43 62 44 73 61 53 66 97 106 200
120 81 87 81 76 76 67 66 72 61 124 75 67 55 42 109 100 71 125 86
99 76 130 104 170
YRK-I71B 185

172 166 144 84 89 103 104 129 127 208 301 433 269 176 153 196 178 164 65 154
99 126 173 161 148 141 213 204 120 110 81 115 128 82 56 48 43 39 64 41
61 56 42 54 39 42 42 48 77 76 72 64 98 77 58 58 62 58 50 55
86 113 133 148 183 139 59 52 58 77 92 77 82 83 48 50 34 66 74 72
80 94 67 78 76 66 82 95 55 97 65 117 74 61 50 49 36 40 47 62
68 75 67 28 28 42 50 60 53 41 37 57 51 66 91 91 75 156 94 100
90 62 32 48 46 52 78 132 160 135 87 85 45 67 52 78 74 80 62 52
33 56 77 63 57 51 53 51 53 52 48 58 51 62 76 60 56 106 103 199
108 85 79 91 70 79 67 51 63 73 132 76 67 53 52 101 98 77 124 88
94 82 135 106 152

YRK-I72A 212

416 425 414 267 207 203 153 89 92 136 190 223 191 378 296 327 221 215 150 234
228 195 85 240 117 175 321 282 206 179 220 255 141 123 114 185 226 131 68 72
48 69 76 61 84 68 61 58 55 50 49 63 88 94 70 61 118 78 60 75
82 67 71 51 73 142 144 115 166 162 83 60 61 70 101 77 81 78 49 45
29 66 65 72 80 113 84 72 56 86 83 97 82 133 127 172 132 95 87 77
55 71 91 138 127 137 124 46 52 66 69 73 59 41 35 39 47 62 74 80
81 123 97 115 71 62 37 40 39 45 67 89 126 100 68 78 45 48 42 63
80 89 79 102 24 41 73 62 41 30 60 47 48 54 38 59 67 65 82 72
62 92 121 220 119 95 88 101 91 92 74 77 83 70 129 74 69 55 54 97
82 63 135 63 80 71 128 123 155 104 66 66 59 98 78 65 123 169 128 110
173 97 113 171 161 198 176 125 133 159 136 213

YRK-I72B 212

450 432 416 249 218 190 164 81 91 141 183 223 180 391 302 315 234 201 160 234
227 195 82 241 113 182 333 277 208 167 232 256 136 137 127 192 221 112 74 72
53 60 85 60 89 69 60 58 45 51 52 61 95 87 76 54 117 85 44 76
84 68 68 54 73 133 138 115 179 153 86 58 61 75 87 82 75 72 57 45
38 58 66 74 76 110 69 73 60 86 89 95 86 162 147 195 137 92 75 91
56 77 89 138 135 135 119 46 51 62 72 73 62 44 31 48 44 53 79 85
70 127 102 113 68 62 45 41 44 40 70 93 123 109 69 71 46 49 53 59
72 94 83 111 32 46 65 55 40 34 55 54 43 38 44 57 64 70 83 58
64 100 105 214 132 98 87 93 95 94 73 75 76 71 123 83 82 52 65 97
90 71 131 72 72 87 119 122 147 112 66 66 65 82 62 78 133 160 96 110
169 111 111 99 162 195 177 115 135 141 127 209

YRK-I73A 195

425 349 321 255 247 383 382 333 358 350 170 161 101 168 211 204 267 209 176 89
112 111 153 101 156 91 63 66 89 111 96 90 151 74 122 118 140 102 74 108
88 70 87 60 85 98 79 82 93 118 113 124 130 171 114 158 166 102 190 191
228 136 97 148 161 112 85 129 154 180 159 194 135 109 106 120 151 90 61 93
118 99 71 96 109 122 125 79 132 106 70 71 85 70 78 101 86 111 99 106
94 88 114 126 137 112 132 146 97 79 86 126 134 91 116 86 59 51 126 126
137 164 126 127 141 85 102 122 109 94 62 104 120 108 107 145 113 70 73 76
102 78 136 91 131 116 113 108 99 94 94 46 84 96 95 75 72 97 89 94
63 68 76 89 77 105 92 110 86 54 67 82 108 111 85 125 95 122 109 129
105 82 77 79 61 49 57 92 77 106 86 81 67 65 72

YRK-I73B 195

421 510 323 252 237 384 391 355 384 376 170 140 97 168 205 178 269 214 188 98
113 131 139 119 130 97 65 69 72 100 96 79 140 100 116 130 160 82 69 102
94 85 60 71 89 103 63 83 101 110 165 134 128 166 121 160 148 110 181 186
233 137 106 144 162 112 86 125 160 180 151 209 124 110 108 131 148 83 59 96
109 93 73 102 116 128 115 78 130 105 75 79 77 68 80 104 85 115 97 99
104 93 117 120 127 126 131 149 91 79 95 110 144 97 116 78 63 51 133 142
132 178 141 140 132 94 111 111 109 97 62 109 121 111 91 157 97 77 68 86

99 86 144 108 142 109 117 99 101 90 83 43 81 92 107 75 80 89 97 84
61 57 72 88 77 90 97 108 87 56 50 89 107 116 107 129 108 127 112 116
104 88 79 73 66 53 70 78 83 95 94 71 101 45 73
YRK-I74A 86
649 502 554 530 408 430 414 365 404 373 335 343 353 351 400 409 350 390 279 296
463 427 238 207 256 407 400 231 340 389 406 454 378 360 294 223 324 367 341 259
242 272 256 245 175 256 302 312 228 233 233 180 132 148 162 181 217 291 378 259
210 239 204 228 239 246 238 373 300 271 183 203 270 231 236 192 235 164 153 172
207 203 262 199 172 224
YRK-I74B 86
642 578 582 491 430 433 416 347 388 353 317 369 411 365 429 412 330 419 264 306
497 337 226 215 331 384 331 274 345 365 365 450 409 347 298 226 293 402 344 245
238 280 250 246 170 246 300 298 251 228 222 178 148 142 148 180 228 288 374 266
214 243 209 225 230 257 244 358 306 260 167 216 262 217 234 199 230 172 143 173
199 189 275 191 180 221
YRK-I75A 111
338 429 371 368 395 264 304 466 562 524 503 268 305 276 457 369 383 281 328 315
256 223 190 169 162 249 219 284 323 319 182 241 200 200 126 199 255 213 199 203
203 194 271 166 239 219 165 144 134 155 196 208 214 185 205 213 191 289 171 182
153 150 218 187 154 145 180 157 150 191 140 110 116 124 128 139 168 199 179 220
197 125 86 135 156 168 142 167 98 108 128 160 155 167 143 122 149 219 124 128
134 152 105 70 115 107 74 186 176 193 267
YRK-I75B 111
345 443 337 378 378 287 255 451 537 437 518 280 294 278 466 370 374 307 306 324
244 227 202 174 166 244 226 298 311 306 187 250 210 195 145 169 214 220 218 186
209 206 229 210 227 193 189 133 155 148 172 224 212 179 213 196 170 310 167 170
127 167 189 175 169 154 157 173 164 173 124 110 110 119 132 146 161 192 183 199
156 122 99 110 168 168 140 181 79 102 139 152 149 179 141 129 141 213 133 122
120 172 91 66 121 97 85 188 158 210 266
YRK-I76A 82
520 589 567 416 411 409 371 260 219 432 515 636 539 653 442 345 299 612 449 225
160 240 229 156 215 318 563 488 201 354 160 208 128 73 120 218 253 224 292 166
227 236 256 239 265 300 217 235 193 148 101 153 210 216 115 108 192 100 113 166
174 240 322 243 163 128 82 161 177 243 130 175 124 114 111 156 184 163 138 107
93 141
YRK-I76B 82
554 631 608 428 393 405 355 268 228 417 525 641 516 626 443 292 279 617 422 243
144 242 212 157 223 341 546 517 212 362 145 218 114 92 106 235 246 211 290 138
219 231 284 219 264 296 213 227 218 131 91 147 215 205 123 93 168 104 112 167
149 243 330 206 169 132 85 150 192 242 156 181 124 99 100 164 170 193 146 109
95 146
YRK-I77A 86
296 257 281 225 220 135 232 192 203 191 106 181 208 139 163 147 212 216 254 369
347 319 286 318 232 332 360 223 317 340 307 347 370 391 396 375 352 235 242 189
186 197 184 232 270 279 166 194 224 156 166 140 132 183 164 191 171 146 212 200
133 125 205 148 165 163 151 129 107 96 75 59 111 92 100 96 146 121 120 150
159 139 149 178 229 229
YRK-I77B 86
306 273 290 219 201 156 215 201 252 159 133 191 228 172 148 148 219 214 208 364
359 332 278 306 256 318 354 229 330 349 301 348 364 390 424 384 349 248 255 186
179 209 176 232 278 280 166 205 205 155 174 151 129 180 168 191 167 148 230 172
128 114 207 162 153 157 146 122 114 92 80 70 97 88 110 88 151 133 113 153
157 134 149 159 245 246

YRK-I78A 91
417 580 208 256 205 248 170 177 259 215 134 153 131 148 199 145 319 400 225 186
169 111 191 229 201 219 241 165 370 493 406 540 323 354 227 237 157 244 222 216
256 187 246 229 232 237 265 158 214 164 171 189 219 137 136 231 178 146 136 192
182 190 160 201 135 156 81 79 58 94 68 96 95 117 120 126 130 142 128 180
119 203 155 196 149 121 104 143 114 146 153
YRK-I78B 91
416 593 218 285 211 250 158 188 252 211 136 163 125 144 181 150 335 411 212 223
157 132 214 236 170 207 232 175 361 499 405 537 325 344 240 233 170 211 234 211
248 196 230 228 247 243 265 149 228 169 172 177 206 103 130 229 179 155 124 205
188 189 158 194 137 159 79 70 63 89 75 104 87 117 121 129 124 149 130 181
108 217 142 193 132 138 97 135 122 141 165
YRK-I80A 95
413 261 393 388 458 302 363 395 581 476 406 403 449 439 454 405 430 423 396 361
316 391 391 250 328 453 362 371 513 384 427 327 309 374 341 227 245 289 353 275
272 328 350 399 454 472 337 394 344 233 329 388 305 218 445 409 254 183 343 424
414 277 343 233 212 160 137 189 269 267 337 357 165 178 253 189 256 204 306 246
245 240 246 170 260 215 235 190 169 232 113 166 183 201 209
YRK-I80B 95
377 286 349 415 461 297 349 410 562 458 393 433 420 449 425 400 458 413 418 389
324 360 421 246 341 428 372 361 484 355 443 308 307 383 324 227 234 268 354 248
305 302 338 382 503 438 331 415 351 254 340 338 255 215 429 395 283 172 342 419
405 279 331 245 208 157 155 178 277 279 318 357 173 187 238 207 250 203 304 238
254 247 271 156 229 243 235 175 180 253 126 152 150 236 250
YRK-I81A 66
251 275 221 230 296 308 260 282 273 219 210 264 325 291 270 290 298 320 269 306
317 314 298 273 229 204 246 187 330 280 389 274 232 197 249 385 288 266 223 184
203 151 175 177 202 166 160 202 141 133 137 136 131 147 152 171 153 214 160 178
230 208 148 197 147 192
YRK-I81B 66
284 260 242 212 313 323 223 301 249 248 217 263 344 246 250 277 326 315 340 326
315 303 332 289 228 181 240 189 341 257 393 281 212 188 251 369 305 228 199 167
157 182 199 201 217 189 155 203 146 117 132 125 137 133 147 172 162 196 162 164
243 194 173 174 149 185
YRK-I82A 90
392 359 380 482 244 336 247 345 406 315 256 348 284 274 242 191 156 170 286 270
255 314 296 186 271 211 229 151 207 256 213 197 176 198 243 258 252 262 246 161
147 145 107 161 167 229 189 236 207 171 278 168 162 185 121 240 177 170 152 145
166 153 145 149 131 131 120 162 166 156 160 127 102 183 121 93 140 153 153 191
267 172 153 176 194 169 156 250 173 171
YRK-I82B 90
362 359 381 446 232 265 250 413 360 302 275 362 307 292 266 197 163 162 222 225
229 288 281 190 271 220 208 143 198 259 191 189 163 188 254 263 245 268 225 163
161 141 111 173 176 236 165 245 201 163 286 168 158 208 114 236 189 166 143 163
159 146 151 158 127 115 111 144 164 160 164 154 117 151 142 89 129 148 166 184
259 145 141 162 194 179 201 216 161 141
YRK-I83A 90
593 595 562 487 453 415 392 412 413 410 322 337 322 317 420 412 320 403 250 303
430 384 206 239 236 279 325 269 315 365 415 441 413 352 309 261 320 419 309 287
211 275 249 239 189 305 305 320 191 281 241 183 152 148 161 194 260 296 370 280
209 247 194 254 212 256 232 372 302 277 200 221 225 250 229 186 249 175 165 184
213 212 263 185 195 184 114 128 197 244
YRK-I83B 90

558 589 533 532 440 412 360 438 420 407 320 355 324 302 430 423 334 409 264 299
477 369 261 210 296 289 327 239 317 384 382 442 423 354 307 252 301 423 325 279
220 282 241 245 184 304 303 339 209 214 224 195 159 152 164 180 258 258 374 289
213 249 212 224 230 257 243 353 329 278 210 218 256 227 229 191 246 170 197 152
202 192 285 173 196 178 98 135 192 240

YRK-I84A 87

559 578 595 567 423 456 378 318 193 218 448 423 578 484 613 345 317 300 619 521
229 148 216 238 145 196 319 518 390 192 295 124 191 96 79 107 247 240 210 327
177 252 268 302 254 252 372 208 215 233 102 120 144 213 203 119 116 173 116 105
160 166 242 307 215 171 126 89 126 188 245 176 186 128 99 122 167 180 188 144
90 82 152 166 283 221 259

YRK-I84B 87

578 577 592 571 428 453 375 310 230 215 413 455 590 448 576 370 306 297 626 506
227 122 206 239 138 173 344 492 382 194 290 133 183 111 88 107 216 255 206 342
155 255 279 304 258 254 370 203 222 220 116 72 146 212 202 105 98 207 111 107
158 168 254 315 210 176 118 97 131 188 230 177 180 123 106 101 167 172 192 156
91 76 158 165 278 212 246

YRK-I85A 60

318 423 419 493 430 395 312 500 434 362 376 356 260 264 311 487 350 440 387 464
241 260 235 322 287 307 529 489 415 446 427 303 642 600 463 498 477 300 453 579
591 737 439 460 458 324 343 336 425 332 436 404 415 388 466 486 521 324 411 393

YRK-I85B 60

277 415 456 467 434 417 322 505 467 335 413 346 254 238 302 436 315 433 436 457
243 240 261 306 300 305 536 464 430 439 375 307 641 628 445 510 473 294 449 591
580 744 414 452 475 326 346 324 435 357 405 391 428 386 509 451 514 451 379 367

YRK-I86A 82

267 277 288 291 393 341 317 353 309 352 281 275 425 343 254 221 307 346 369 241
288 346 387 405 289 274 241 284 275 434 301 221 196 254 229 193 121 301 221 272
171 164 195 152 111 101 114 132 173 250 335 204 183 218 165 262 234 254 261 326
261 274 146 269 217 193 191 184 231 167 113 174 178 174 309 182 171 196 89 137
195 173

YRK-I86B 82

246 290 297 298 396 336 343 358 298 351 276 289 413 324 252 224 290 362 326 267
260 322 382 398 325 293 279 298 256 437 342 209 166 256 232 175 116 242 222 288
164 168 181 165 131 90 104 127 161 258 349 206 182 226 206 209 251 252 231 318
220 244 153 252 226 227 196 167 238 144 127 158 195 207 287 162 191 149 115 127
194 171

YRK-I87A 87

186 124 182 189 265 258 228 223 196 106 210 158 182 167 143 201 190 123 145 182
225 279 240 372 339 320 247 239 246 326 405 222 362 326 292 332 369 368 419 331
354 286 269 205 183 194 153 236 259 278 155 196 191 190 165 142 136 168 196 182
166 153 147 139 99 100 142 142 156 164 191 125 133 112 82 57 100 93 113 132
131 123 132 141 184 145 165

YRK-I87B 87

166 139 168 180 277 276 236 202 191 129 160 151 177 152 135 147 224 135 171 154
211 280 258 349 354 320 246 231 233 360 401 241 337 388 274 340 376 347 442 307
379 322 252 211 165 183 158 245 257 279 152 166 207 179 177 127 139 166 184 180
142 101 163 148 133 124 183 146 157 154 192 132 115 121 104 56 104 94 97 128
128 140 128 165 185 123 170

YRK-I88A 62

280 206 222 326 221 272 271 297 336 307 284 377 201 261 297 280 134 152 124 153
169 138 262 249 189 173 142 86 175 164 127 118 196 155 233 324 360 545 221 354
208 185 160 194 236 218 228 203 324 206 278 239 268 186 257 178 223 212 201 166

163 249
YRK-I88B 62
273 224 211 307 244 240 273 318 338 290 276 401 190 252 289 251 124 140 111 139
171 144 261 238 196 176 141 79 187 149 127 135 185 152 225 316 368 414 256 413
235 212 187 183 224 221 231 228 301 239 237 232 260 174 225 157 228 206 197 167
158 225
YRK-I89A 58
311 350 492 369 419 530 697 378 477 556 444 397 490 286 387 310 409 387 403 441
302 334 383 272 223 182 305 325 468 372 581 273 294 227 493 473 254 130 113 201
162 118 189 514 440 303 346 201 228 181 118 117 217 228 286 368 192 335
YRK-I89B 58
303 327 498 333 419 588 697 395 470 544 498 425 466 270 331 280 398 365 370 390
283 316 350 246 205 183 291 338 453 349 553 262 278 233 474 494 234 146 110 223
152 94 203 483 441 300 350 195 225 167 135 131 206 235 302 321 229 333

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.

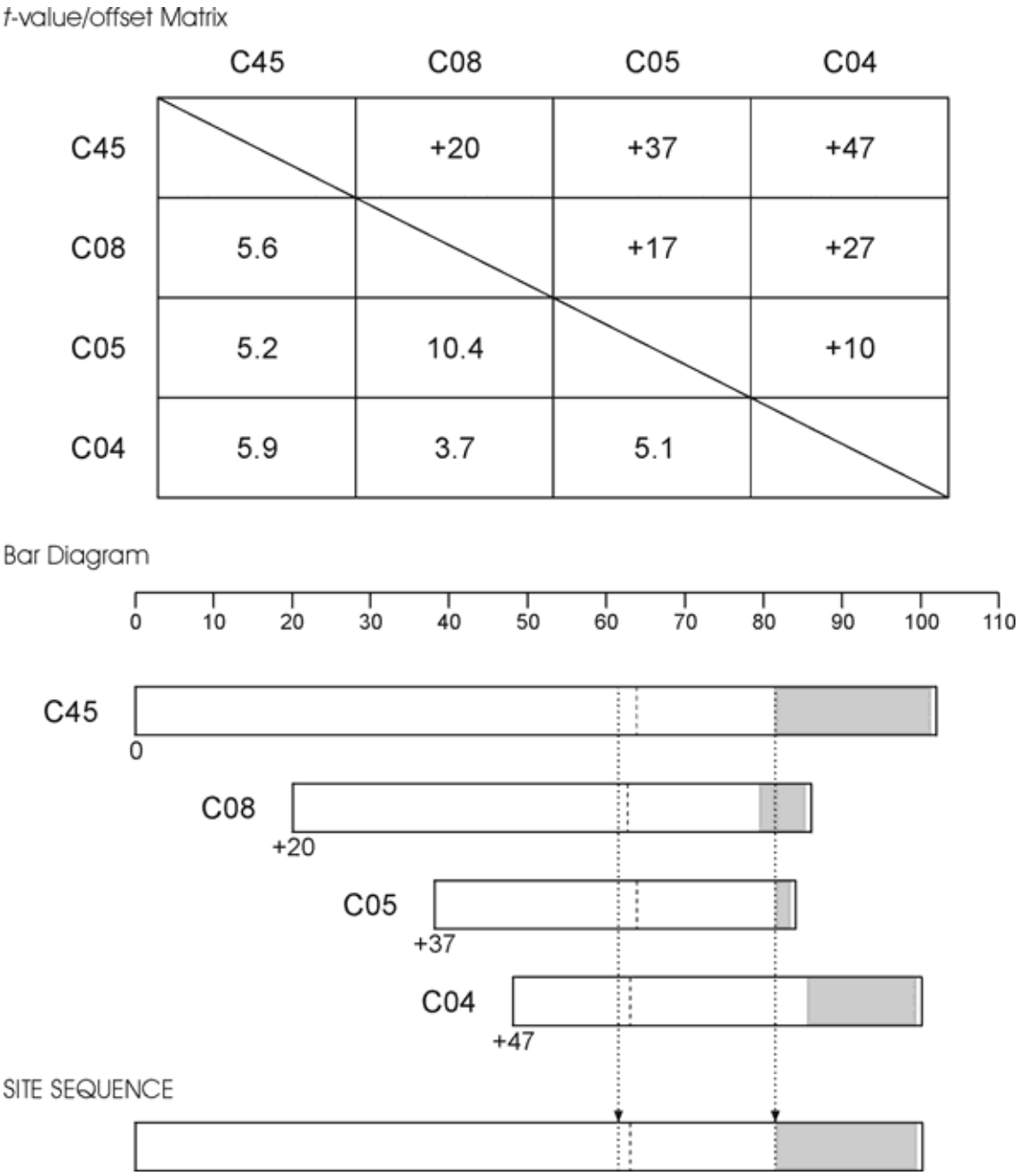

Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

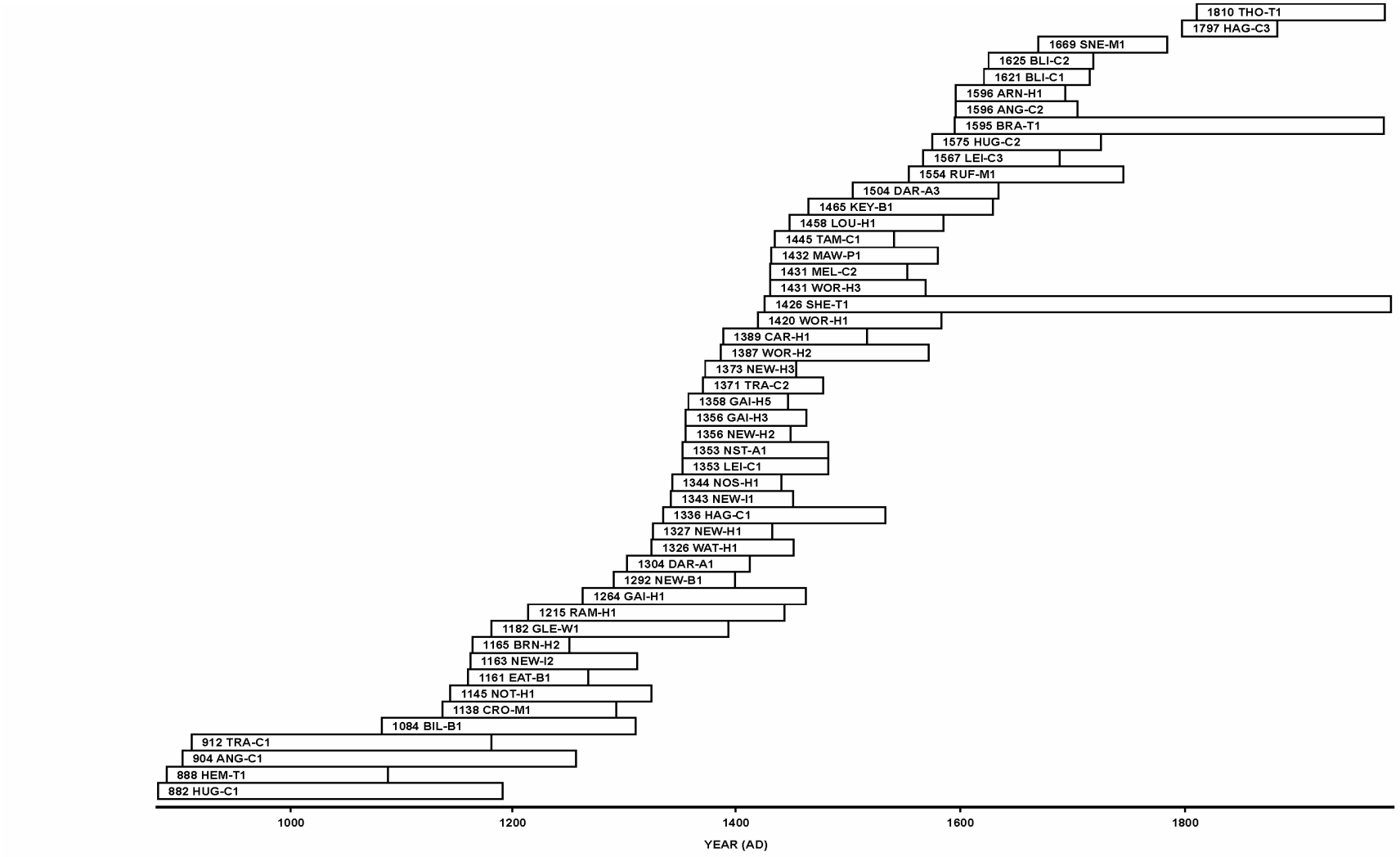

Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence. EM08/87

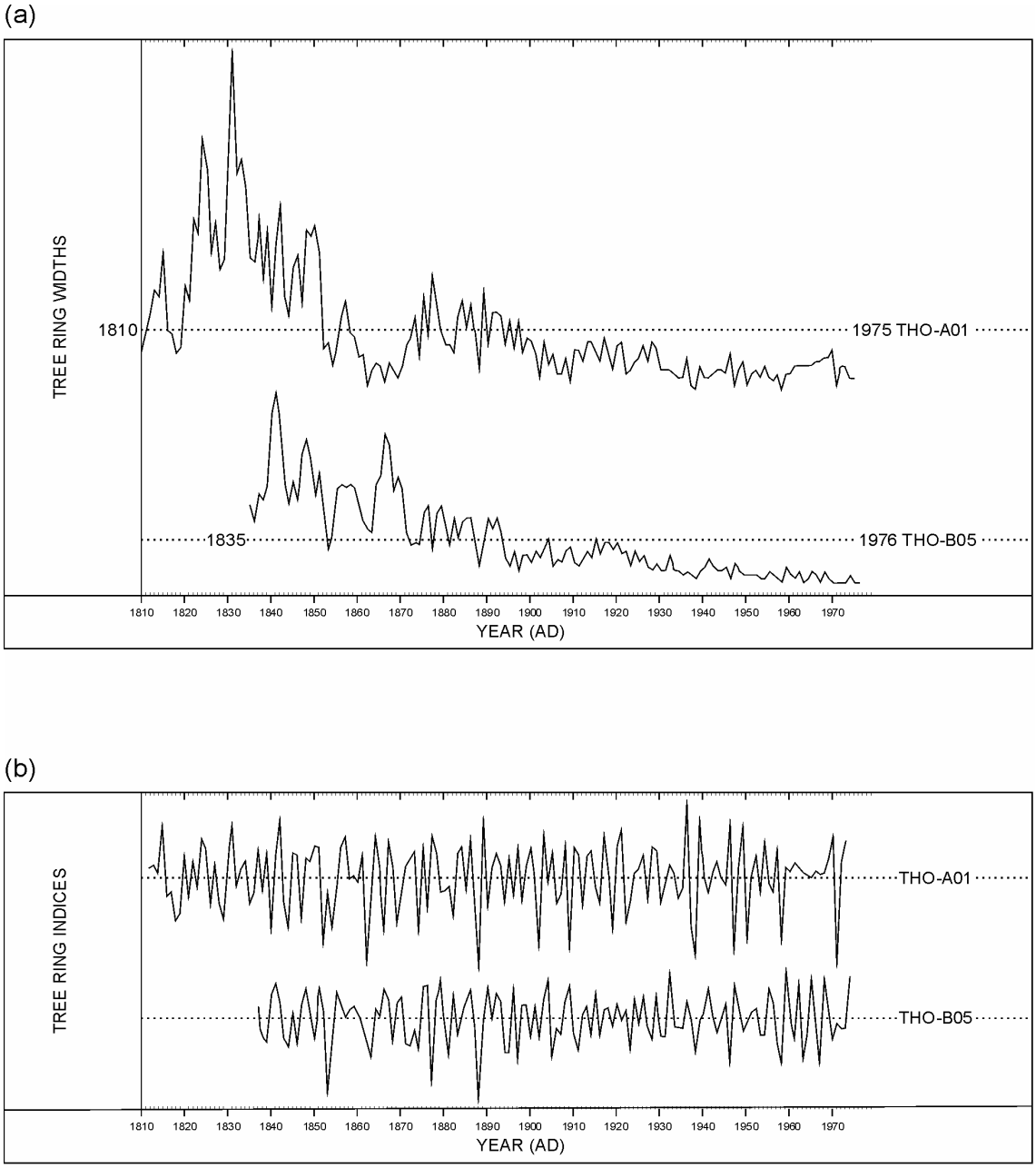

Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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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