RESEARCH DEPARTMENT REPORT SERIES no. 49-2009 ISSN 1749-8775

THE MANOR HOUSE, HALL GREEN ROAD, WEST BROMWICH, WEST MIDLANDS
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

ARCHAEOLOGICAL SCIENCE

ENGLISH HERITAGE

Research Department Report Series 49-2009

THE MANOR HOUSE, HALL GREEN ROAD, WEST BROMWICH, WEST MIDLANDS

TREE-RING ANALYSIS OF TIMBERS

A J Arnold, R E Howard

NGR: SP 00551 94316

ISSN 1749-8775

The Research Department Report Series incorporates reports from all the specialist teams within the English Heritage Research Department: Archaeological Science; Archaeological Archives; Historic Interiors Research and Conservation; Archaeological Projects; Aerial Survey and Investigation; Archaeological Survey and Investigation; Architectural Investigation; Imaging, Graphics and Survey, and the Survey of London. It replaces the former Centre for Archaeology Reports Series, the Archaeological Investigation Report Series and the Architectural Investigation Report Series.

Many of these are interim reports which make available the results of specialist investigations in advance of full publication. They are not usually subject to external refereeing, and their conclusions may sometimes have to be modified in the light of information not available at the time of the investigation. Where no final project report is available, readers must consult the author before citing these reports in any publication. Opinions expressed in Research Department reports are those of the author(s) and are not necessarily those of English Heritage.

Requests for further hard copies, after the initial print run, can be made by emailing:
Res.reports@english-heritage.org.uk
or by writing to:
English Heritage, Fort Cumberland, Fort Cumberland Road, Eastney, Portsmouth PO4 9LD
Please note that a charge will be made to cover printing and postage.

SUMMARY
Analysis of 66 measured samples from various areas in the Manor House has produced ten site chronologies, two of which, comprising 21 and 10 samples, can be dated, their 273 and 163 rings spanning the years AD 1318–1590 and AD 1107–1269 respectively. Interpretation of the sapwood on these samples indicates the Great Hall as the earliest component, its timbers having an estimated felling date of AD 1270–88, placing it slightly earlier than originally anticipated. Two timbers from the solar in the north cross-wing have an estimated felling date of AD 1412–37 with a further, slightly later, timber from the solar having an estimated felling of AD 1429–54. The projecting west bay off the Great Hall utilises timber felled in the AD1530s. The latest felling of AD 1590 is represented by a group of timbers in the gatehouse. Eight other site chronologies, accounting for 17 samples, cannot be dated, although interpretation of the sapwood would suggest that some groups represent coeval timbers. 16 measured samples remain ungrouped and undated.

CONTRIBUTORS
Alison Arnold, Robert Howard

ACKNOWLEDGEMENTS
The Laboratory would like to take this opportunity to thank Mr Frank Caldwell of Sandwell Metropolitan Borough Council, owners of the Manor House, for his enthusiasm and help with this programme of tree-ring analysis, and for assisting in gaining access to the site for sampling. Mr Caldwell and his staff have at all times been most cooperative. The Laboratory would also like to thank Mr Graham Eyre-Morgan, also of Sandwell Metropolitan Borough Council, for his thoughts on the structure and his help in understanding the possible phasing of this complex building. Finally, the Laboratory would like to thank Stanley Jones for the wholesale use of his notes, plans, and other drawings taking from his extensive and thorough survey.

ARCHIVE LOCATION
Sandwell Sites & Monuments Record
Sandwell Metropolitan Borough Council
PO Box 42, Lombard Street
West Bromwich B70 8RU

DATE OF INVESTIGATION
2008-09

CONTACT DETAILS
Alison Arnold and Robert Howard
Nottingham Tree-ring Dating Laboratory
20 Hillcrest Grove
Sherwood
Nottingham NG5 1FT

CONTENTS

INTRODUCTION

The Manor House at West Bromwich now stands in an open space surrounded by a modern-day housing estate, (SP 00551 94316, Figs 1 and 2). Of the original complex of living quarters, agricultural buildings, sheds, and ponds possibly built by the de Marnham family at the centre of their agricultural estate in West Bromwich in the late-thirteenth or early-fourteenth century, only the central, north–south, hall range now survives. Successive occupants so altered and extended the site that it was described in AD 1790 as 'a large pile of irregular half-timbered buildings, black and white, and surrounded with numerous out-houses and lofty walls' (Shaw 1801).

According to Stanley Jones (Jones 1975–76), from which this introductory description is taken, the original hall range comprises a two-bay Great Hall, formed by a single base-cruck truss, with an entrance bay to the south separated from it by a spere truss. Between the base-cruck truss and the spere truss, and the base-cruck and the north end of the Great Hall, the roof above the wall plates includes an 'intermediate' or end truss, comprising a tiebeam and crown post with braces to the collar purlin. These elements are all believed to be original and are dated stylistically to *c* AD 1300.

It can be inferred from structural evidence that there was probably a cross-wing at the northern end of the hall range (Fig 3a). It is also likely, again on the basis of structural evidence, that there was a structure to the south of the hall range, beyond the entrance bay. It is not certain, however, if this structure was also a cross-wing, or simply an in-line continuation bay of the hall range (Fig 3a).

It is believed, on the basis of stylistic evidence such as the moulding and cusping to decorated timbers, that in the mid-fifteenth century this original, or earlier, north cross-wing was demolished and a new, two-storey, solar, cross-wing was built in its place; a similar cross-wing being added across the south end of the hall range, also replacing an earlier structure (Fig 3b). At this time the roof of the hall range was modified at either end to accommodate these changes. To the west end of both north and south cross-wings, similar small annexe were also built, each possibly having a projection off, which has been interpreted as a garderobe (Fig 3b).

The next major development is the building of the two-bay 'chapel block', with a full-height chapel in its east bay and a western bay of two storeys, the 'chapel chamber', attached to the east end of the north cross-wing (Fig 3c). Structural and stylistic evidence suggests that this work was undertaken in the late-fifteenth century, or possibly in the early sixteenth century.

Some time after this, probably in the mid-sixteenth century, the north end of the west wall of the Great Hall was demolished, and a new two-storey structure was built, projecting westwards from the hall by a single bay (Fig 3d). This was lit by a large mullioned and transom window in the west gable. Further work of indeterminate date, though probably of the late-sixteenth century, included the construction of a two storey,

semi-detached, kitchen and lodging block to the south-west corner of the building complex (Fig 3d); this area was altered again in the mid-seventeenth century.

The final major development to the site was the building of the jettied 'gatehouse', to the east side of the site, there being a short connecting bay between the southern end of the gatehouse and the east end of the southern cross-wing (Fig 3e). These elements are close-studded, with lozenge panels to the upper part of the first floor. A large brick-built chimney stack projects from its south gable wall. This new development enclosed a small courtyard and finally produced the general plan seen today (Fig 4).

The Manor House fell into gradual decay from the eighteenth century onwards, this being particularly rapid in the early years of the twentieth century. Such was its state of neglect that it was scheduled for demolition in the early 1950s and was only saved by the intervention of West Bromwich Corporation which carried out an extensive and sympathetic restoration, with results as now seen (Fig 5a/b). It was during preparatory survey for this work that the national importance of West Bromwich Manor was finally realised. The importance of this building was emphasised by the survey and interpretation undertaken by Jones (1975-76).

The Manor House at West Bromwich has been the subject of a previous, though limited, programme of tree-ring analysis. A relatively small number of samples was taken in 1987 from the Great Hall, the solar end of the northern cross-wing, and the gatehouse (Esling *et al* 1989). This analysis resulted in the dating of only two timbers from the Great Hall, producing an estimated felling date in the range AD 1269–95, and the dating of three timbers from the gatehouse, producing an estimated felling date in the early AD 1590s (this felling date being based on a sample from which the outermost few rings had been lost). None of the samples taken from the solar portion of the north cross-wing were dated, but many of these samples in any case were not actually suitable for analysis.

SAMPLING

In view of the limited nature of the 1988 dendrochronological programme, a further programme of sampling and analysis by dendrochronology of timbers within the Manor House were requested by Alan Taylor, Historic Buildings Inspector at English Heritage's Birmingham office, in order to inform statutory advice. It was hoped that this more extensive programme would augment the earlier programme of tree-ring dating and hence further elucidate the development of this complex. A further objective of tree-ring analysis was to give some indication as to how much primary material now remained in the building. The extensive alterations and repairs have resulted in it being difficult to distinguish between primary timbers in their original locations, primary timbers reused in new positions, and those modern replacements made in an 'original' style during 1950s restoration.

Thus, from the timbers available, and allowing for uncertainty in respect of repairs and insertions, a total of 79 samples was obtained from five different parts of the building.

This includes 12 samples taken in 1987 and a further 67 taken in 2008. Each sample was given the code WBR-A (for West Bromwich, site 'A') and numbered 01–79. Twelve of these samples, WBR-A01–A12, were taken from the chapel and chapel chamber, with a further 25 samples, WBR-A13–37, being taken from the roof and lower wall timbers of the solar in the north cross-wing. Eighteen samples, WBR-A38–55 were obtained from the gatehouse, these samples being distributed between the roof and the lower wall timbers. Eight samples, WBR-A56–63 were obtained from the small number of what appeared to be primary timbers available in the projecting west bay off the hall range (mostly from the east truss, the west truss appearing to be composed of either modern replacements or possibly salvaged and spliced-in timbers) . Finally, 16 samples, WBR-A64–79, were obtained from the timbers of the hall range, in order to obtain a range of samples from both the roof and the lower-level timbers to confirm that both elements were of the same date, there being some doubt about this. In three instances, timbers sampled in 1987 were re-cored in an attempt to increase ring numbers or to obtain sapwood. Such timbers thus have two sample numbers: WBR-A14/A27, WBR-A15/A29, and WBR-A26/A36, in each case, the lower number sample being that obtained in 1987.

Although further timbers were accessible for sampling, it was seen that many of these, a few in the west truss of the west bay off the Great Hall, or those from the roof and lower wall frames of the south cross-wing and its west annexe for example, although of a substantial size were derived from fast-grown trees. It was felt that as such these timbers were unlikely to provide samples with the minimum number of rings for reliable dating, set here, given the number of samples obtained, at 48 rings. The timbers of the semi-detached kitchen and lodging wing were similarly unsuitable, though here the problem was compounded by the use of later, probably nineteenth-century, oak timbers, small amounts of pine, and replacement by modern softwood, probably as part of the 1950s restoration.

The location of the cores was noted at the time of sampling and they have been marked on plans and drawings from Jones (1975-76), and provided by English Heritage. These are reproduced here as Figures 6a–9b. In some instances, individual timbers of a particular frame or bay may not be shown. In such cases an attempt is still made to show the general location of the timber sampled. Further details relating to the samples can be found in Table 1. In this table, and in the plans and drawings, the trusses, frames, and other timbers have been identified and located following, where given, the schema on the plans and drawings originally made by Jones (1975-76), with the timbers being further located on a north–south or east–west basis as appropriate.

ANALYSIS AND RESULTS

Each of the 79 samples obtained in the two programmes of sampling was initially prepared by sanding and polishing. It was seen at this time that 12 samples had less than 48 rings, the minimum it was felt necessary in this case for reliable dating, and these were rejected from this programme of analysis. The annual ring widths of the remaining 66

samples were, however, measured, the data of these measurements being given at the end of this report.

The data of these 66 measured samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), allowing eleven separate groups, accounting for 50 measured samples, to be formed at a minimum value of t=4.0. The samples of each group cross-match as shown in Figures 10–20. The cross-matching samples of each group were combined at their indicated offsets positions to form site chronologies WBRASQ01–SQ11.

Each of the eleven 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 at the Sheffield University Dendrochronology Laboratory, this process resulting in the satisfactory dating of two site chronologies.

Site chronology WBRASQ01, comprising 21 samples with an overall length of 273 rings, was found 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 1590. The evidence for this dating is given in Table 2.

Site chronology WBRASQ02, comprising 10 samples with an overall length of 163 rings, was also found to match repeatedly and consistently with a series of reference chronologies, when the date of its first ring is AD 1107 and the date of its last measured ring is AD 1269. The evidence for this dating is given in Table 3.

All other site chronologies remain undated. The 17 remaining measured but ungrouped single samples were also compared to the reference chronologies, but again there was no satisfactory cross-matching and these timbers, therefore, must also remain undated.

This analysis may be summarised as follows:

Site chronology	Number of samples	Number of rings	Date span AD (where dated)
WBRASQ01	21	273	1318–1590
WBRASQ02	10	163	1107–1269
WBRASQ03	2	131	undated
WBRASQ04	2	73	undated
WBRASQ05	2	85	undated
WBRASQ06	2	115	undated
WBRASQ07	2	83	undated
WBRASQ08	2	58	undated
WBRASQ09	3	69	undated
WBRASQ10	2	64	undated
WBRASQ11	2	56	undated
singles	17	---	undated
unmeasured	12	---	undated

INTERPRETATION

The hall range

Of the 16 samples taken from this area (WBR-A64–79), ten, including both those from timbers above wall plate level as well as those below it, have combined to form site chronology WBRASQ02 (Fig 11), its 163 rings dated as spanning the years AD 1107–1269. None of these ten samples retains complete sapwood and it is thus not possible to give a precise felling date for any of the timbers represented. Eight of them, however, do retain some sapwood or at least the heartwood/sapwood boundary, this enabling an estimated felling date range to be calculated. The average date of the boundary on the eight samples where it exists is AD 1248 which, using a 95% confidence limit of 15–40 for the number of sapwood rings these trees may have had, and allowing that the latest ring on any individual sample (WBR-A75) dates to AD 1269, would give the timbers represented an estimated felling date in the range AD 1270–88.

As may be seen from Table 1 and the bar diagram, the heartwood/sapwood boundary on the eight samples, on both those from timbers above and below wall plate level, varies from relative position 134 (AD 1240) on sample WBR-A64, to relative position 149 (AD 1255) on sample WBR-A66, a difference of 15 years. This limited variation, and the fact that all ten samples cross-match well with each other, would suggest that all the timbers, both those with the heartwood/sapwood boundary as well as those without, were cut as part of a single programme of felling and that the timbers above and below wall plate level are of the same date.

The solar

Only three of the 25 samples obtained from this area were dated and included in site chronology WBRASQ01 (Fig 10) and it would appear that these three represent two different phases of felling. The earliest phase is represented by samples WBR-A22 and A31, both roof timbers from the principal rafters of truss 'F'. These samples again have only the heartwood/sapwood boundary, the average date on them being AD 1397. Using the same 95% confidence limit of 15–40 rings for the amount of sapwood these trees may have had would give these timbers an estimated felling date in the range AD 1412–37.

The later phase of felling from this area is represented by sample WBR-A37, from a door jamb, with an estimated felling date in the range AD 1429–54 (based on the usual sapwood estimate of 15–40 rings). This timber therefore has potentially been felled slightly later than the dated roof timbers.

West bay projecting off Great Hall

The bay projecting westwards off the Great Hall provides a further seven samples, out of the eight obtained here, that are included in site chronology WBRASQ01. Three of these samples, WBR-A57, A59, and A61, each retain complete sapwood, the last ring, and thus the felling date of each timber represented, being AD 1538, AD 1539, and AD 1531, respectively. It is thus clear that samples with different felling dates have been used in the construction of this part of the building.

The remaining four samples, all with heartwood/sapwood boundary, have an average boundary date of AD 1510, which produces an estimated felling date range of AD 1525–1550 (using a 95% confidence limit of 15–40 rings for the amount of sapwood the trees are likely to have had). It will be seen that this estimated date encompasses the known precise felling dates of the three other timbers from this area, suggesting that the seven timbers represented were felled in the AD 1530s, although, given the overall variation in the heartwood/sapwood boundary, 24 years, it is not unexpected to obtain a number of precise felling dates that vary by some years. Such an interpretation is further supported by the fact that the majority of the seven dated samples cross-match sufficiently well with each other to suggest that they represent trees growing close to each other, probably within the same patch of woodland, though not immediately adjacent to each other. Such a phenomenon would be less likely were the trees felled at very different times. It thus appears likely that all of these timbers were felled, probably in the AD 1530s, and subsequently used as part of a single programme of works towards the middle of the sixteenth century.

The gatehouse

Eleven of the 18 samples from the gatehouse are included in site chronology WBRASQ01. Three of these samples, WBR-A39, A41, and A44, retain complete sapwood, the last measured ring of which, and thus the felling of each timber represented, is dated to AD 1590.

A further six samples retain at least the heartwood/sapwood boundary, this varying by 16 years from AD 1556 on sample WBR-A47 to AD 1572 on sample WBR-A53, the average date of the heartwood/sapwood boundary on these six being AD 1566. Using the same sapwood estimate as above, 15–40 rings, would give these timbers an estimated felling date in the range AD 1581–1606. It will be seen again that this estimated felling date brackets the known precise felling date of three other timbers from the gatehouse. This would suggest that all these timbers were probably felled at a very similar, if not identical, time.

Such an interpretation is in part supported by the degree of cross-matching between these samples, which suggests that the trees used were growing in the same woodland, some trees being closely adjacent to each other. Were the trees used here felled at

different times, it is unlikely that they would cross-match with each other to the same degree. Such an interpretation extends to the two dated samples from the gatehouse which do not retain the heartwood/sapwood boundary. Although the felling date of the timbers represented cannot be determined, except to say that it is unlikely to be earlier than 15 years after the last measured ring date, there is no reason to suspect that they were not felled at the same time as all the other dated timbers from the gatehouse. The timbers represented are integral to the structure, show no evidence of any earlier use, and cross-match with all the other samples.

DISCUSSION AND CONCLUSION

The tree-ring analysis has successfully dated timbers from four areas within the Manor House. The earliest group of timbers, all from the Great Hall, have an estimated felling date range of AD 1270–88, making this part of the manorial complex possibly very slightly earlier than the late-thirteenth or early-fourteenth century date previously expected. Interpretation of the individual samples, furthermore, demonstrates that there is no difference in the date of the timbers above the wall plates here, and those below it, as was originally tenuously believed possible. All such timbers are of the same date and represent a single programme of felling. The dated timbers of the Great Hall, however, are all associated with the base cruck and south end, intermediate, trusses. There is, therefore, no dating evidence produced for the spere truss and hence the hall range entrance bay.

The next felling phase identified is represented by three timbers, two principal rafters and a door jamb, from the solar in the north cross-wing. The principal rafters have an estimated felling date range AD 1412–37, while the door jamb has an estimated felling date in the range AD 1429–54. These timbers may relate to the replacement of an earlier north cross-wing in the mid-fifteenth century, as suggested by Jones (1975-76). However, a large number of timbers in this area remain undated, and it is known that this part of the building has been heavily renovated. The small number of dated timbers may therefore simply represent reused material and hence not provide any evidence for the dating of the initial construction of this extant north cross-wing.

The west bay projecting off the Great Hall utilises timbers which were all probably felled in the AD 1530s. The dating of the majority of the sampled timbers from this area suggests that the felling date evidence obtained is likely to be representative of the construction date. This supports the mid-sixteenth century date suggested in Jones (1975-76), despite the fact that most of the dated timbers are from the east truss (the west truss showing some evidence for reconstruction using modern and possibly reclaimed timbers). Indeed, it is perhaps noteworthy that whilst the east truss and door jamb samples all match together quite well, the west truss sample groups best with those from the gatehouse (although it clearly matches well overall and dates well individually).

The latest felling phase detected is for timbers from the gatehouse. These were all probably felled as part of a single programme of felling in AD 1590. The dating of the majority of sampled timbers from this area again suggests that the felling date evidence obtained is likely to be representative of the construction date of the gatehouse. Jones (1975-76) had suggested that the kitchen and lodging area to the south-west corner of the building complex may be of late-sixteenth century date and hence the gatehouse may form part of these works. It is unfortunate however that no dendrochronological dating evidence could be obtained for this kitchen/lodging block, nor indeed the chapel block.

Judging by the level of cross-matching, it is likely that some samples represent timbers that have been derived from the same tree, or from trees that were growing close to each other in the same copse or stand of woodland. The highest value, for example, is t=15.9 between samples WBR-A56 and A62, both from timbers in the west projecting bay off the Great Hall. Other groups of samples with cross-matching values in excess of t=10.0 include WBR-A11/A12, WBR-A39/A44, WBR-A65/A68, and WBR-A50/A51/A53.

There appears to be a tendency for the best cross-matching to occur between samples from the same context or area, rather than between samples from different parts of the building. Most of the samples from the west projecting bay cross-match well with each other, as, particularly, do most of the samples from the timbers of the Great Hall. This would suggest that the timbers used for these parts of the building, perhaps not unexpectedly, each came from single woodland sources, and possibly, in some instances, from a relatively small stand or copse. More importantly perhaps, it indicates that there has been less movement and reuse of salvaged timber than perhaps had been anticipated.

Other groups of timbers, commonly pairs, although undated in absolute terms, appear to be generally coeval with each other (where the heartwood/sapwood boundary allows for such an interpretation), although it is possible that some such timbers may have been felled a few years apart. The exception to this rule may be represented by samples WBR-A38 and A54 from the gatehouse. While it is just possible that the two timbers were felled at the same or similar time, this is unlikely. In all cases each pair of timbers is from the same part of the building.

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 two main dated groups, although this is a possibility. The lack of dating of these groups, and of the 16 remaining single samples, could be indicative of the use of multi-phase timbers, a phenomenon suspected from the structural interpretation as a distinct possibility, given the extensive repairs and renovations undertaken here. Dendrochronology has not proven the case either way.

The precise location of the source woodland for the dated timbers used at the Manor House cannot be identified by dendrochronology (eg Bridge 2000). However, it is probable that they did not come from any great distance. As may be seen from Table 2, which lists a short selection of the reference chronologies used to date both site sequence WBRASQ01 and WBRASQ02, there is a clear tendency towards the highest t-

value, and thus the greatest degree of similarity, being with reference chronologies from other sites in the West Midlands region and surrounding counties.

BIBLIOGRAPHY

Alcock, N W, Warwick University, Howard, R E, Laxton, R R, and Litton, C D, Nottingham University Tree-ring Dating Laboratory, and Miles, D H, 1990 unpubl site chronology for 26 Warwick Rd, Southam, Warwicks – Leverhulme Cruck Project: unpubl computer file *SOUASQ01,* Nottingham Univ Tree-Ring Dating Laboratory

Arnold, A J, Howard, R E, and Litton, C D, 2006 *Tree-ring analysis of timbers from Middleton Hall, Middleton, Warwickshire*, EH Res Dep Rep Ser, 13/2006

Arnold, A J, and Howard, R E, 2007 *Tree-ring analysis of timbers from Polesworth Abbey Gatehouse*, Centre for Archaeol Rep, 6/2007

Arnold, A J, and Howard, R E, 2007 *Leicester's Gatehouse, Kenilworth Castle, Kenilworth, Warwickshire: tree-ring analysis of timbers*, Centre for Archaeol Rep, 8/2007

Arnold, A J, and Howard, R E, *Primrose Hill Farm House and Barn, Meadowsweet Avenue, Kings Norton, Birmingham: tree-ring analysis of timbers*, EH Res Dep Rep Ser, 41/2008

Bridge, M, 2000 Can dendrochronology be used to indicate the source of oak within Britain? *Vernacular Architect*, 31, 67–72

Esling, J, Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1989 List 29 no 13a/b - Nottingham University Tree-Ring Dating Laboratory: Results, *Vernacular Architect,* 20, 39–41

Groves, C, 1997 Dendrochronological analysis of Ightfield Hall Farm Barn, Ightfield, Whitchurch, Shropshire, 1997, Anc Mon Lab Rep, 91/97

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1992 List 44 no 16 - Nottingham University Tree-Ring Dating Laboratory: results, *Vernacular Architect,* 23, 51–6

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1995 List 60 no 2a - Nottingham University Tree-ring Dating Laboratory Results: general list, *Vernacular Architect*, 26, 47–53

Howard, R E, Laxton, R R, and Litton, C D, 1996 List 68 no 4 - Nottingham University Tree-Ring Dating Laboratory: Sherwood Forest Oak; a dendrochronological Survey, *Vernacular Architect*, 27, 87–90

Howard, R E, Laxton, R R, and Litton, C D, 1999 *Tree-ring analysis of timbers from The Manor House, Medbourne, Leicestershire,* Anc Mon Lab Rep, 63/1999

Howard, R E, Laxton, R R, and Litton, C D, 1998 *Tree-ring analysis of timbers from Brockworth Court Barn, Brockworth, Gloucestershire,* Anc Mon Lab Rep 66/2000

Jones, S R, 1975-76 West Bromwich (Staffs) Manor House, *South Staffs Archaeol Hist Soc Trans*, XVII, 1

Laxton, R R, and Litton, C D, 1988 An East Midlands master tree-ring chronology and its use for dating vernacular buildings, University of Nottingham, Dept of Classical and Archaeol Studies, Monograph Series, III

Shaw, S, 1801 *History and Antiquities of Staffordshire*, ii, p128

Tyers, I, 1996 *Tree-ring analysis of six secular buildings from the City of Hereford*, Anc Mon Lab Rep, 17/96

Tyers, I, 2002 *Tree-ring analysis of oak timbers from the Abbot's Hall and Parlour at Wigmore Abbey, near Adforton, Herefordshire*, Centre for Archaeol Rep, 112/2002

Tyers, I, 2003 *Tree-ring analysis of oak timbers from a building on the Lea Road Foundry site, Church Street, Dronfield, Derbyshire*, Centre for Archaeol Rep, 75/2003

TABLES

Table 1: Details of tree-ring samples from the Manor House, West Bromwich

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
Chapel and chapel chamber						
WBR-A01	North principal rafter, truss B	74	h/s	------	------	------
WBR-A02	South principal rafter, truss B	96	h/s	------	------	------
WBR-A03	Tiebeam, truss B	100	h/s	------	------	------
WBR-A04	Upper collar, truss B	112	21C	------	------	------
WBR-A05	North purlin, truss B–C	56	no h/s	------	------	------
WBR-A06	North principal rafter, truss C	96	no h/s	------	------	------
WBR-A07	North queen strut, truss C	99	h/s	------	------	------
WBR-A08	Joist 1 (from north) to passageway	nm	---	------	------	------
WBR-A09	Joist 7 (from north) to passageway ®	56	25	------	------	------
WBR-A10	Joist 8 (from north) to passageway ®	73	24C	------	------	------
WBR-A11	Rail over passageway, north wall	85	h/s	------	------	------
WBR-A12	Rail, truss A to passageway, north wall	83	h/s	------	------	------
Solar						
WBR-A13	Tiebeam, truss D	78	8	------	------	------
WBR-A14†	North main wall post, truss D	nm	---	------	------	------
WBR-A15†	South principal rafter, truss D	52	18	------	------	------
WBR-A16	Middle rail, truss D	58	h/s	------	------	------
WBR-A17	Lower stud post 1, truss D	79	h/s	------	------	------
WBR-A18	Lower stud post 4, truss D	66	h/s	------	------	------
WBR-A19	North principal rafter, truss E	49	h/s	------	------	------
WBR-A20	North archbrace, truss E	50	h/s	------	------	------
WBR-A21	South principal rafter truss E	56	h/s	------	------	------
WBR-A22	North principal rafter, truss F	67	10	AD 1339	AD 1395	AD 1405
WBR-A23	North main wall post, truss H	57	h/s	------	------	------
WBR-A24	Stud post, truss H	nm	---	------	------	------
WBR-A25	South main wall post, truss H	54	h/s	------	------	------

Table 1: continued

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
Solar continued						
WBR-A26†	South main wall post ,truss F	nm	---	------	------	------
WBR-A27	North main wall post, truss D	nm	---	------	------	------
WBR-A28	South main wall post, truss D	nm	---	------	------	------
WBR-A29	South principal rafter, truss D	69	8	------	------	------
WBR-A30	North principal rafter, truss D	nm	---	------	------	------
WBR-A31	South principal rafter, truss F	62	8	AD 1346	AD 1399	AD 1407
WBR-A32	North moulded queen strut, truss F	55	h/s	------	------	------
WBR-A33	South moulded queen strut, truss F	50	h/s	------	------	------
WBR-A34	Stud post 2, south wall, bay 4	nm	---	------	------	------
WBR-A35	Brace from south wall post, truss F	nm	---	------	------	------
WBR-A36	South main wall post, truss F	nm	---	------	------	------
WBR-A37	North door jamb, truss D	69	h/s	AD 1346	AD 1414	AD 1414
Gatehouse						
WBR-A38	East upper main wall post, truss 1 (north)	108	h/s	------	------	------
WBR-A39	West upper main wall post, truss 1	222	26C	AD 1369	AD 1564	AD 1590
WBR-A40	West upper main wall post, truss 2 (middle)	95	17	------	------	------
WBR-A41	East mid-rail truss 2 (first floor)	168	38C	AD 1423	AD 1552	AD 1590
WBR-A42	West main stud post, truss 2 (first floor)	107	h/s	AD 1462	AD 1568	AD 1568
WBR-A43	South upper rail, west side, bay 2 (first floor)	112	12	AD 1469	AD 1568	AD 1580
WBR-A44	West upper main wall post, truss 3	218	26C	AD 1373	AD 1564	AD 1590
WBR-A45	Ceiling beam, bay 2 ®	94	h/s	------	------	------
WBR-A46	East purlin, bay 1 ®	69	8	------	------	------
WBR-A47	West purlin, bay 1	142	h/s	AD 1415	AD 1556	AD 1556
WBR-A48	East queen strut, truss 2	96	no h/s	AD 1426	------	AD 1521
WBR-A49	West principal rafter, truss 2	133	23C	------	------	------
WBR-A50	West queen strut, truss 2	91	19	AD 1493	AD 1564	AD 1583
WBR-A51	East principal rafter, truss 3	92	h/s	AD 1479	AD 1570	AD 1570
WBR-A52	West principal rafter, truss 3	nm	---	------	------	------

Table 1: continued

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
Gatehouse continued						
WBR-A53	Lower stud 5, truss 3 (first floor)	100	h/s	AD 1473	AD 1572	AD 1572
WBR-A54	East upper main wall post, truss 3	131	h/s	------	------	------
WBR-A55	East upper main wall post, truss 2	122	no h/s	AD 1392	------	AD 1513
Projecting west bay off the Great Hall						
WBR-A56	North upper main wall post, east truss	201	h/s	AD 1318	AD 1518	AD 1518
WBR-A57	Tiebeam, east truss	171	30C	AD 1368	AD 1508	AD 1538
WBR-A58	West main stud post, south wall	93	no h/s	------	------	------
WBR-A59	Brace, south post of east truss to tiebeam	109	39C	AD 1431	AD 1500	AD 1539
WBR-A60	South upper main wall post, east truss	181	h/s	AD 1327	AD 1507	AD 1507
WBR-A61	Mid-rail, south side, east truss	179	37C	AD 1353	AD 1494	AD 1531
WBR-A62	East door jamb, north wall	185	h/s	AD 1327	AD 1511	AD 1511
WBR-A63	South upper main wall post, west truss	146	h/s	AD 1359	AD 1504	AD 1504
Hall range above wall plates						
WBR-A64	Crown post, base cruck	97	h/s	AD 1144	AD 1240	AD 1240
WBR-A65	East strut, tiebeam–rafter, base cruck	113	no h/s	AD 1107	------	AD 1219
WBR-A66	East strut, tiebeam–crown post, base cruck	91	h/s	AD 1165	AD 1255	AD 1255
WBR-A67	South brace crown post–collar purlin, base cruck	63	h/s	AD 1184	AD 1246	AD 1246
WBR-A68	West strut, tiebeam–rafter, base cruck	112	no h/s	AD 1127	------	AD 1238
WBR-A69	West strut, tiebeam–crown post, base cruck	92	h/s	AD 1162	AD 1253	AD 1253
WBR-A70	Crown post, south end truss	89	h/s	AD 1157	AD 1245	AD 1245
Hall range below wall plates						
WBR-A71	Tiebeam, south end truss	104	h/s	AD 1151	AD 1254	AD 1254
WBR-A72	East blade, base cruck	74	no h/s	------	------	------
WBR-A73	West blade, base cruck	112	no h/s	------	------	------
WBR-A74	Lower tiebeam, base cruck	108	14	AD 1150	AD 1243	AD 1257
WBR-A75	Upper tiebeam, base cruck	124	22	AD 1146	AD 1247	AD 1269
WBR-A76	East aisle post, spere truss	66	5	------	------	------
WBR-A77	West aisle post, spere truss	68	5	------	------	------

Table 1: continued

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
Hall range below wall plates continued						
WBR-A78	Tiebeam, spere truss	nm	---	------	------	------
WBR-A79	East brace to spere truss	54	no h/s	------	------	------

*NM = not measured
**h/s = the heartwood/sapwood ring is the last ring on the sample
C = complete sapwood retained on sample, last measured ring is the felling date
® = timbers possibly reused
† = timber sampled as part of 1987 analysis and re-sampled in 2008

Table 2: Results of the cross-matching of site sequence WBRASQ01 and relevant reference chronologies when the first-ring date is AD 1318 and the last-ring date is AD 1590

Reference chronology	*t*-value	Span of chronology	Reference
Primrose Hill, Kings Norton, Birmingham	11.0	AD 1354–1593	(Arnold and Howard 2008)
Ightfield Hall barn, Shropshire	11.0	AD 1341–1566	(Groves 1997)
Church Street, Dronfield, Derbyshire	10.1	AD 1344–1526	(Tyers 2003)
East Midlands Master Chronology	9.9	AD 882–1981	(Laxton and Litton 1988)
Tusmoore Park, Oxfordshire	9.3	AD 1359–1545	(Howard *et al* 1992)
Middleton Hall, Warwickshire	9.1	AD 1390–1646	(Arnold *et al* 2006)
Lodge Park, Aldsworth, Gloucestershire	9.1	AD 1324–1587	(Howard *et al* 1995)
26 Warwick Road, Southam, Warwickshire	8.5	AD 1304–1418	(Alcock *et al* 1990 unpubl)

Table 3: Results of the cross-matching of site sequence WBRASQ02 and relevant reference chronologies when the first-ring date is AD 1107 and the last-ring date is AD 1269

Reference chronology	*t*-value	Span of chronology	Reference
'Severns', Castle Road, Nottingham	8.9	AD 1030–1334	(Howard *et al* 1996)
Cathedral barn, Hereford, Herefordshire	8.8	AD 1111–1253	(Tyers 1996)
East Midlands Master Chronology	8.6	AD 882–1981	(Laxton and Litton 1988)
Kenilworth Castle Gatehouse, Kenilworth, Warwickshire	8.6	AD 1092–1332	(Arnold and Howard 2007)
Medbourne Manor, Medbourne, Leicestershire	8.1	AD 1068–1287	(Howard *et al* 1999)
Polesworth Abbey Gatehouse, Polesworth, Warwickshire	8.0	AD 1095–1342	(Arnold and Howard 2007)
Wigmore Abbey, Herefordshire	7.9	AD 1055–1729	(Tyers 2002)
Brockworth Court Barn, Brockworth, Gloucestershire	7.7	AD 1122–1289	(Howard *et al* 1998)

FIGURES

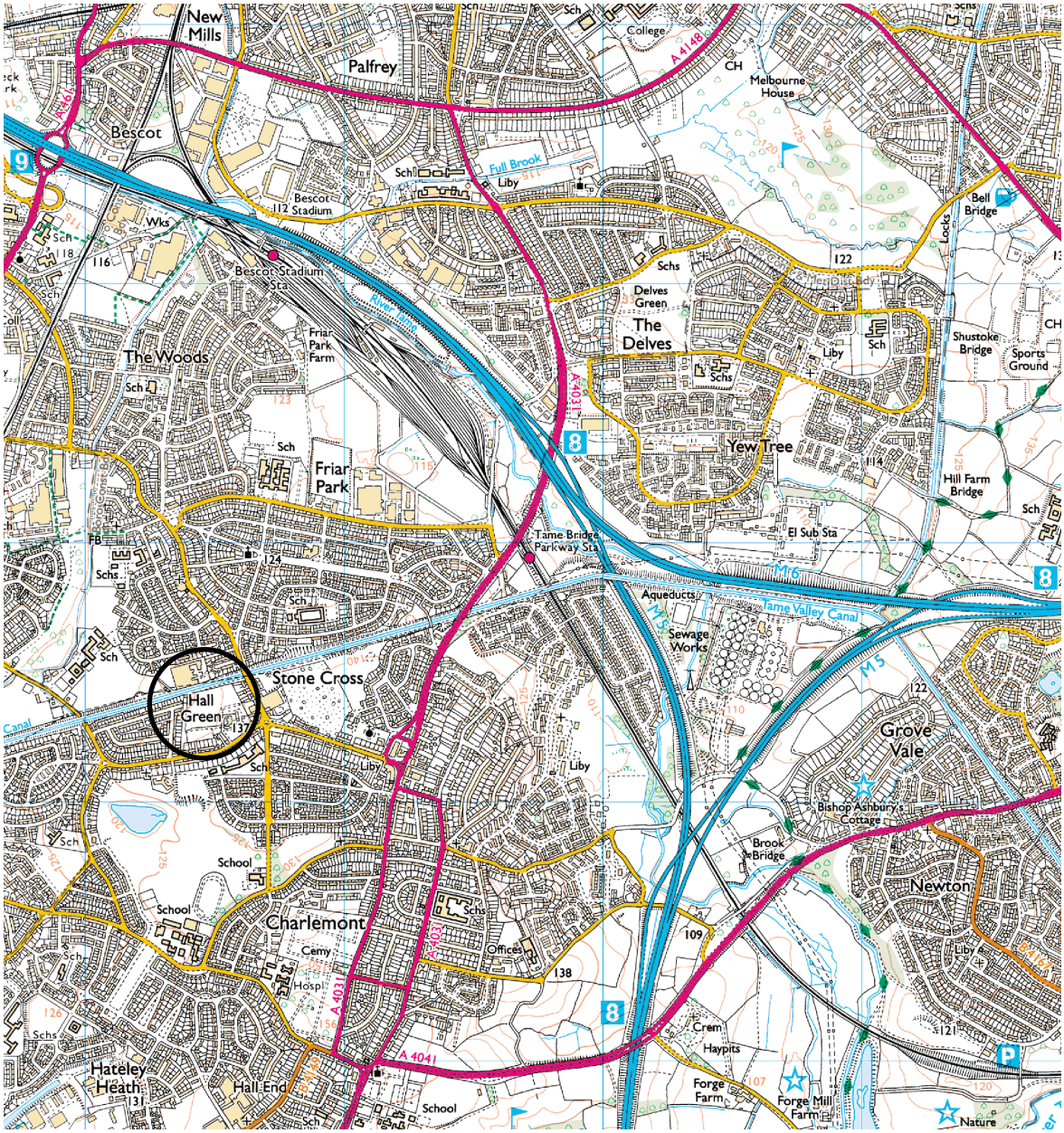


Figure 1: Map to show the location of The Manor House, West Bromwich (based on the Ordnance Survey map with permission of the Controller of Her Majesty's Stationery Office, © Crown Copyright)

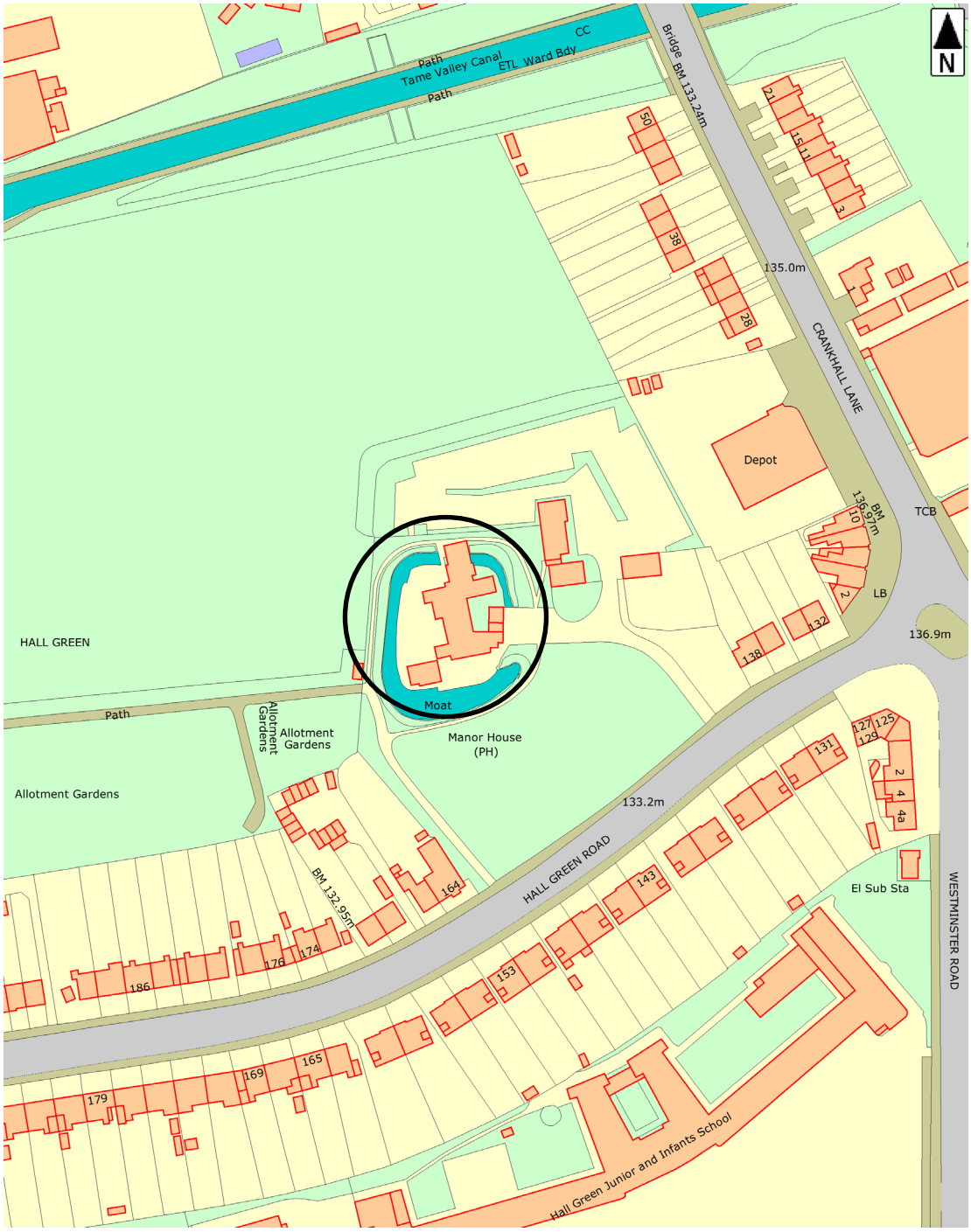


Figure 2: Map to show the location of the Manor House, West Bromwich, (based on the Ordnance Survey map with permission of the Controller of Her Majesty's Stationery Office, ©Crown Copyright)

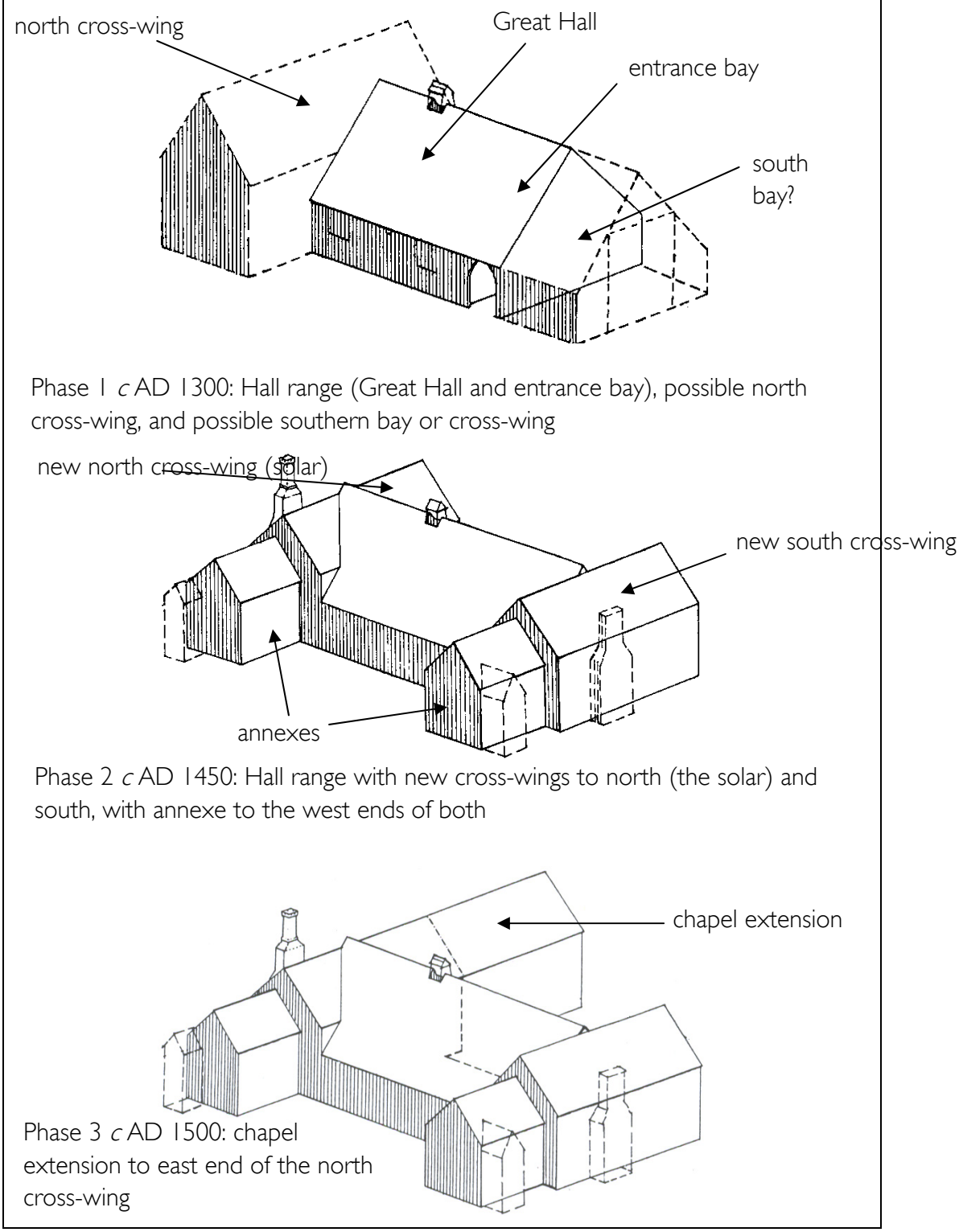


Figure 3a-c: Proposed phase of development (after Jones 1975–76)

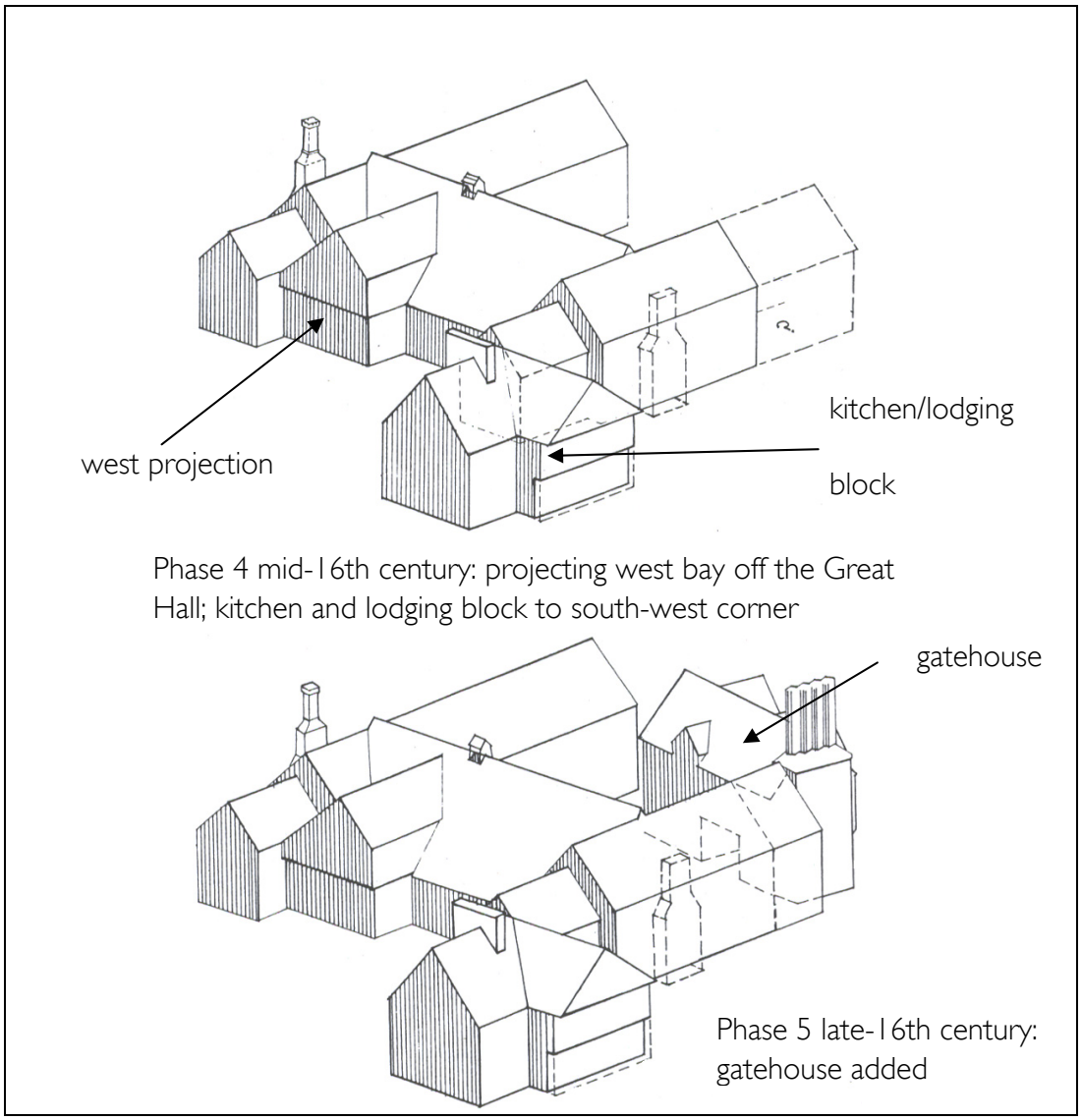


Figure 3d-e: Proposed phase of development (after Jones 1975–76)

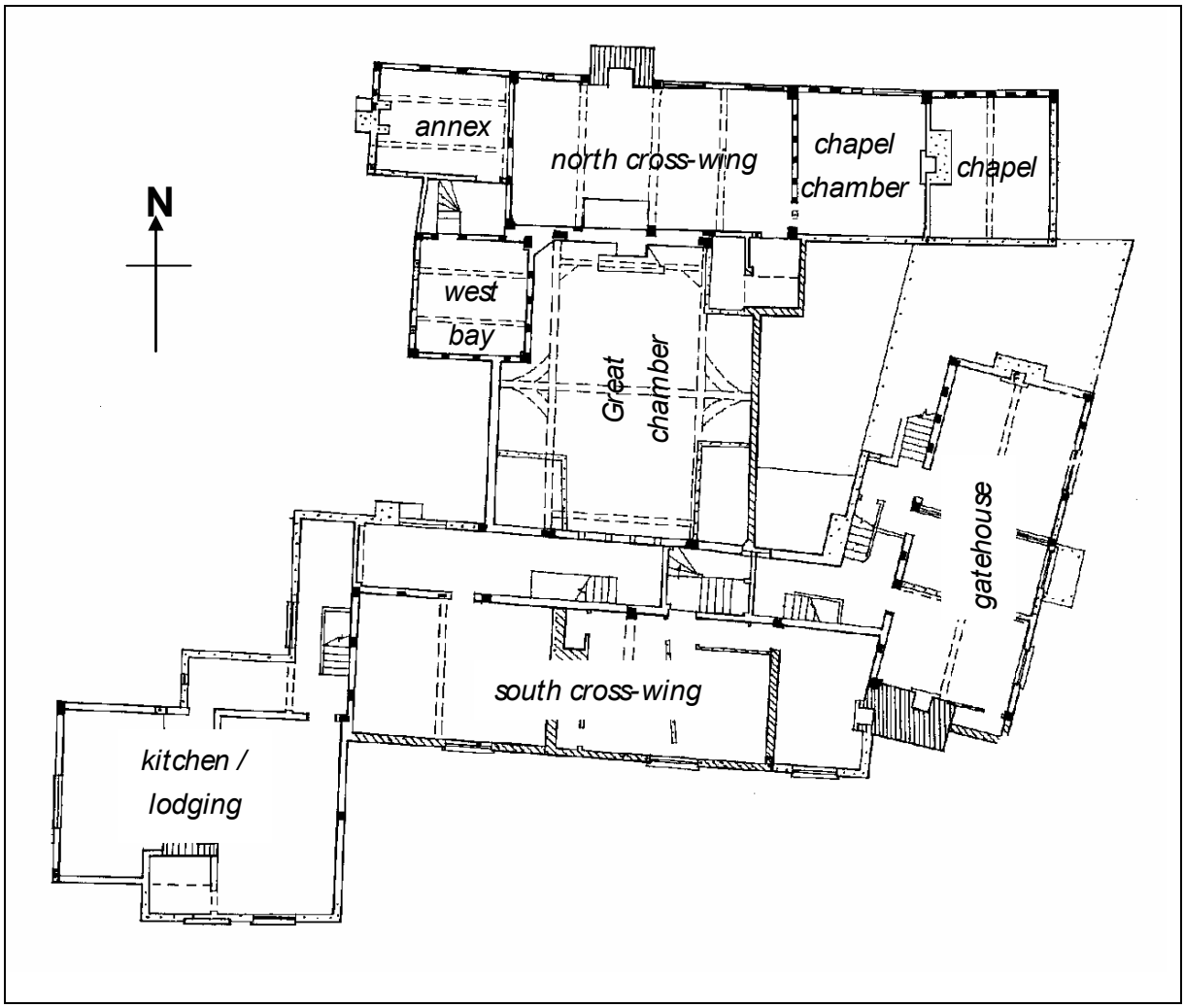


Figure 4: Plan at first-floor level to show layout of building (after Jones 1975–76)

Figure 5a (top): Annexe at west end of the north cross-wing, and projecting west bay off Great Hall

Figure 5b (bottom): Chapel and north cross-wing with jettied gatehouse beyond

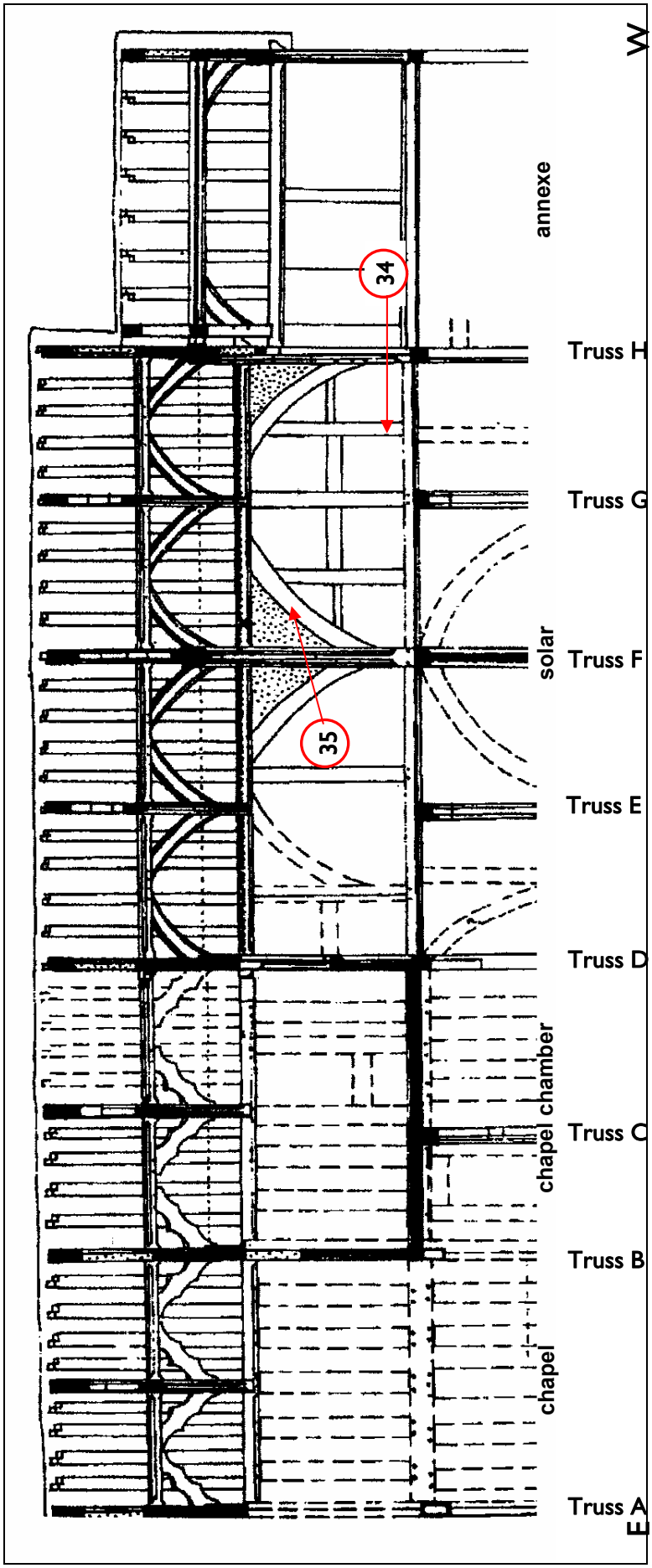


Figure 6a: Long section through the north cross-wing (chapel, chapel chamber, solar, and west annexe) to show position of trusses and timbers sampled (after Jones 1975–76)

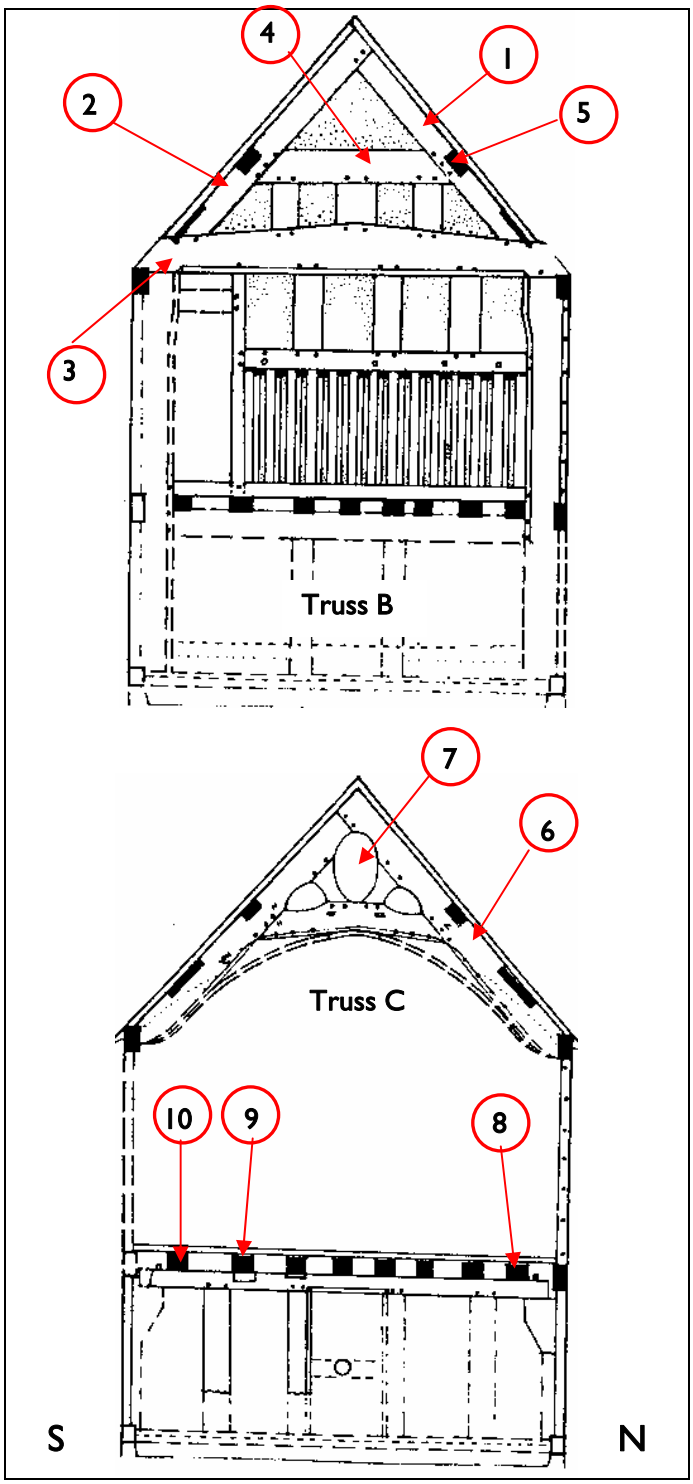


Figure 6b: North cross-wing trusses (chapel and chapel chamber) to show timbers sampled (after Jones 1975–76)

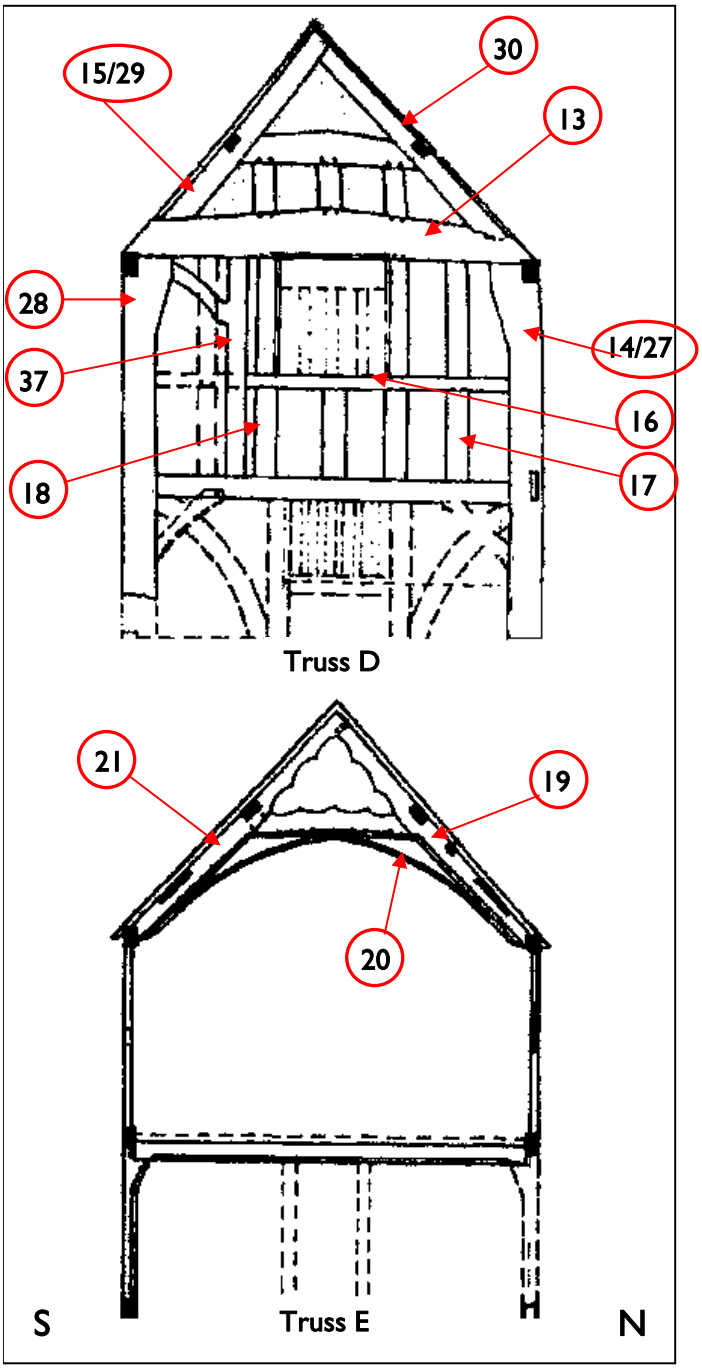


Figure 6c: North cross-wing trusses (solar) to show timbers sampled (after Jones 1975–76)

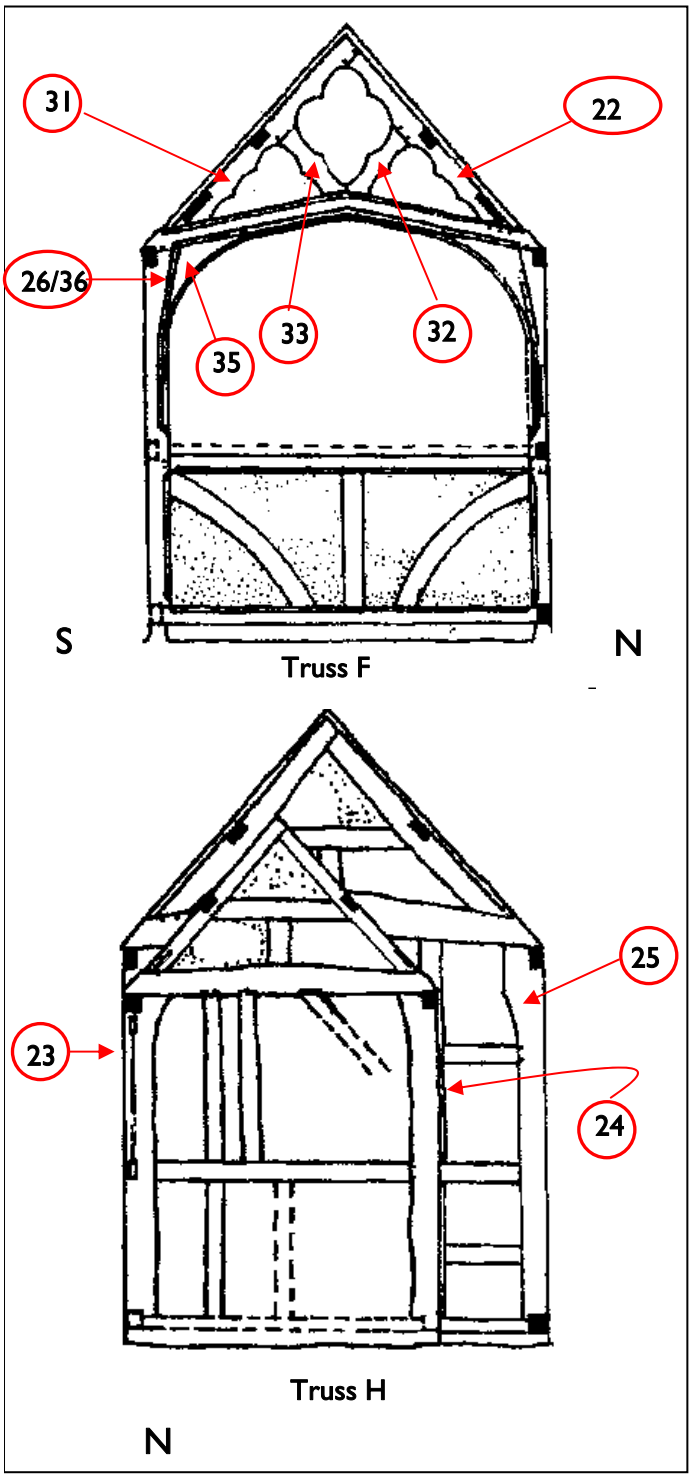


Figure 6d: North cross-wing trusses (solar) to show timbers sampled (after Jones 1975–76)

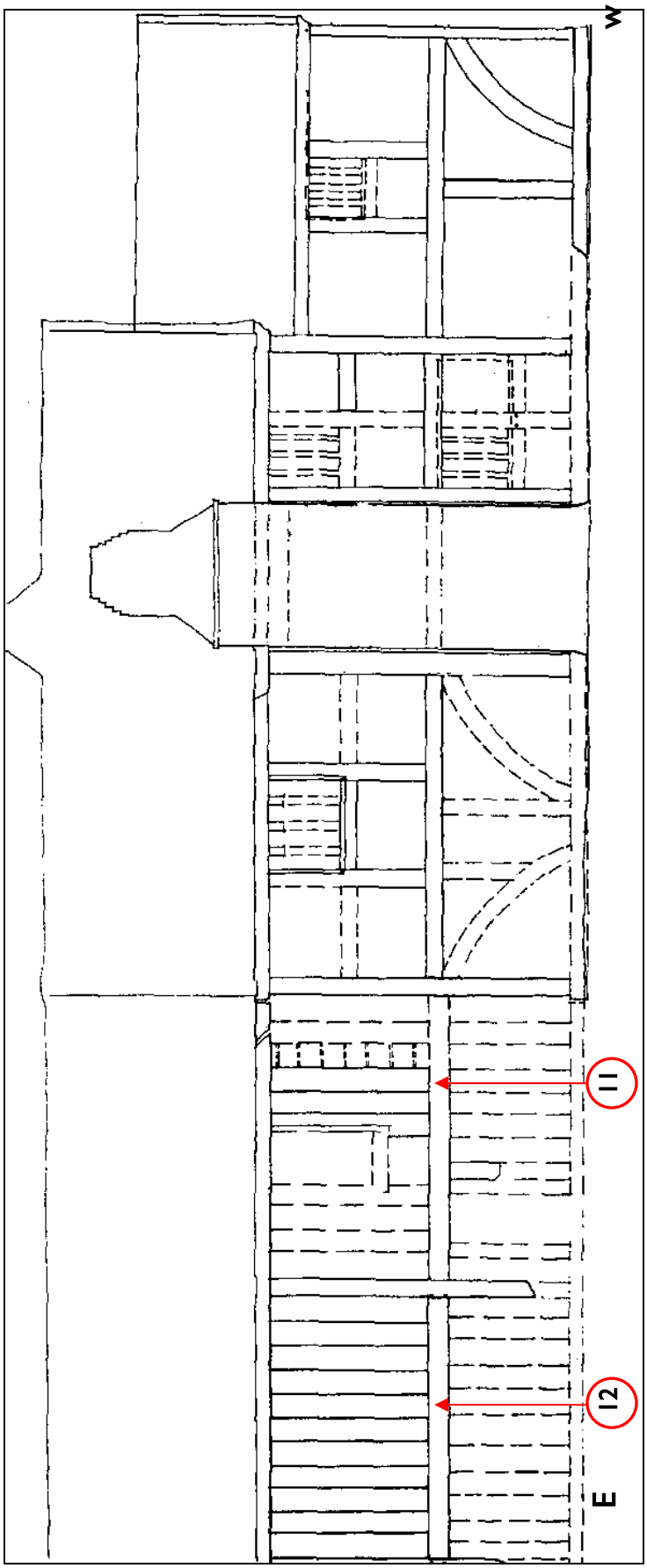


Figure 6e: North elevation of the north cross-wing to show timbers sampled (after Jones 1975–76)

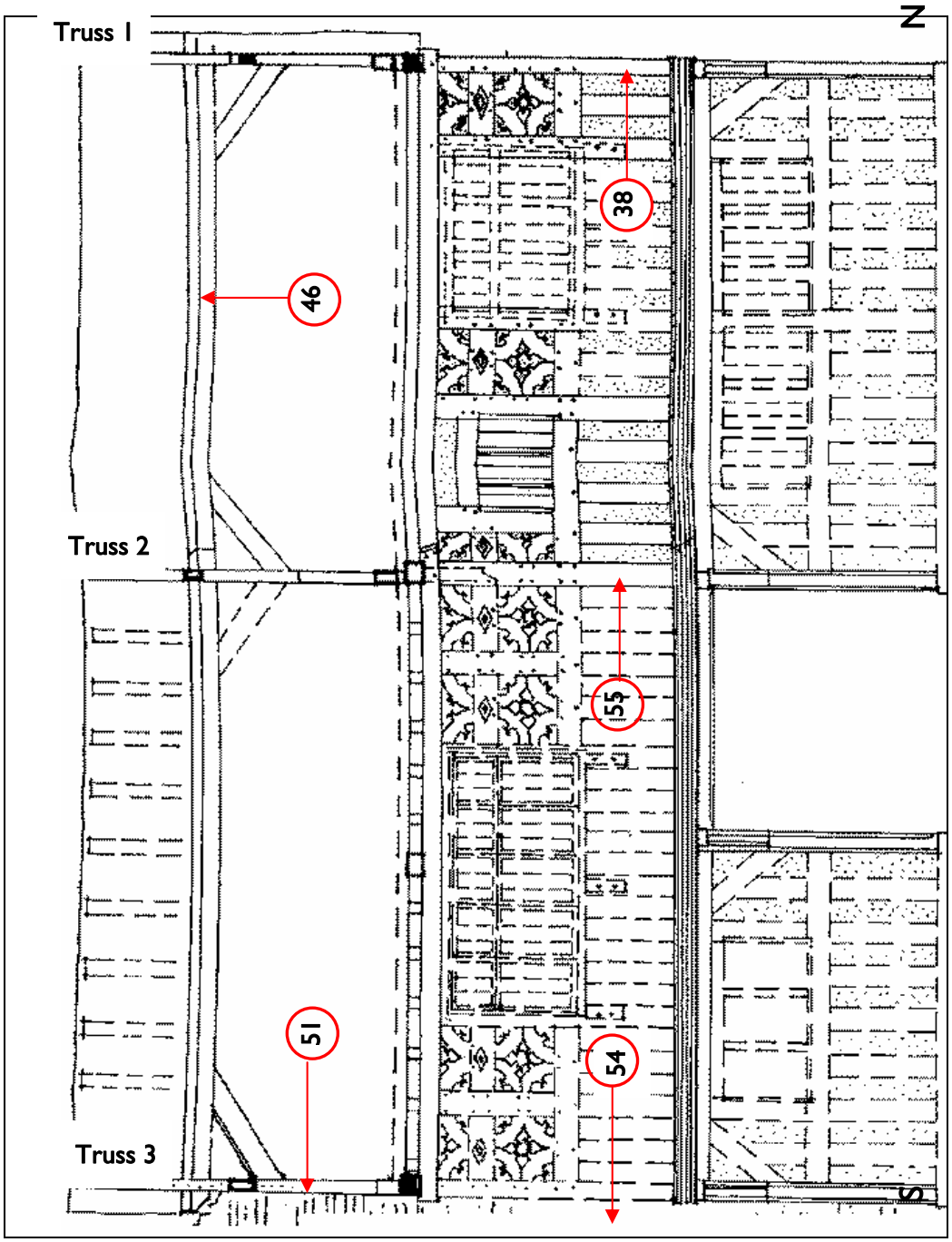


Figure 7a: East elevation and section through roof of the gatehouse to show timbers sampled (after Jones 1975–76)

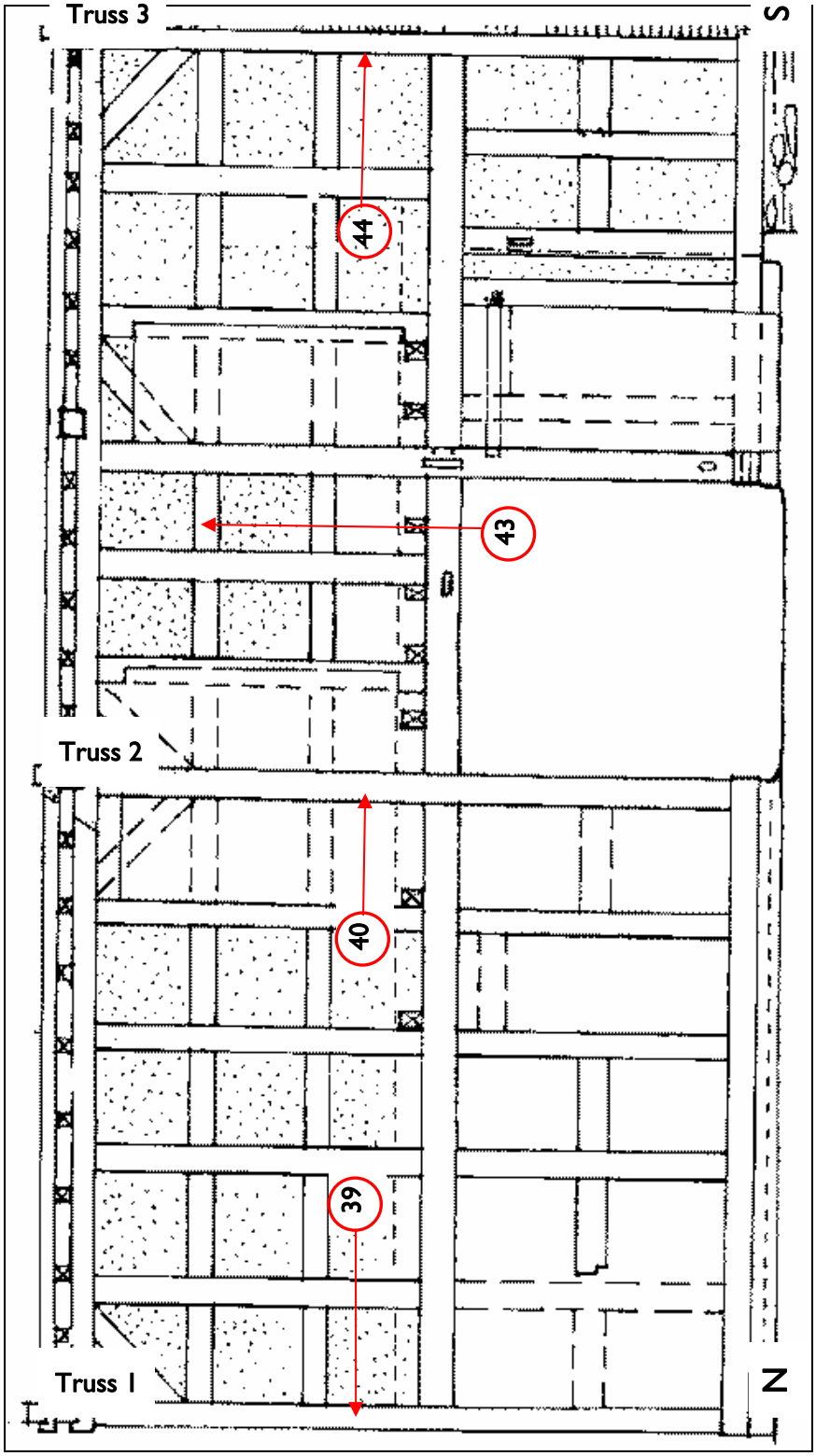


Figure 7b: West elevation of the gatehouse to show timbers sampled (after Jones 1975–76)

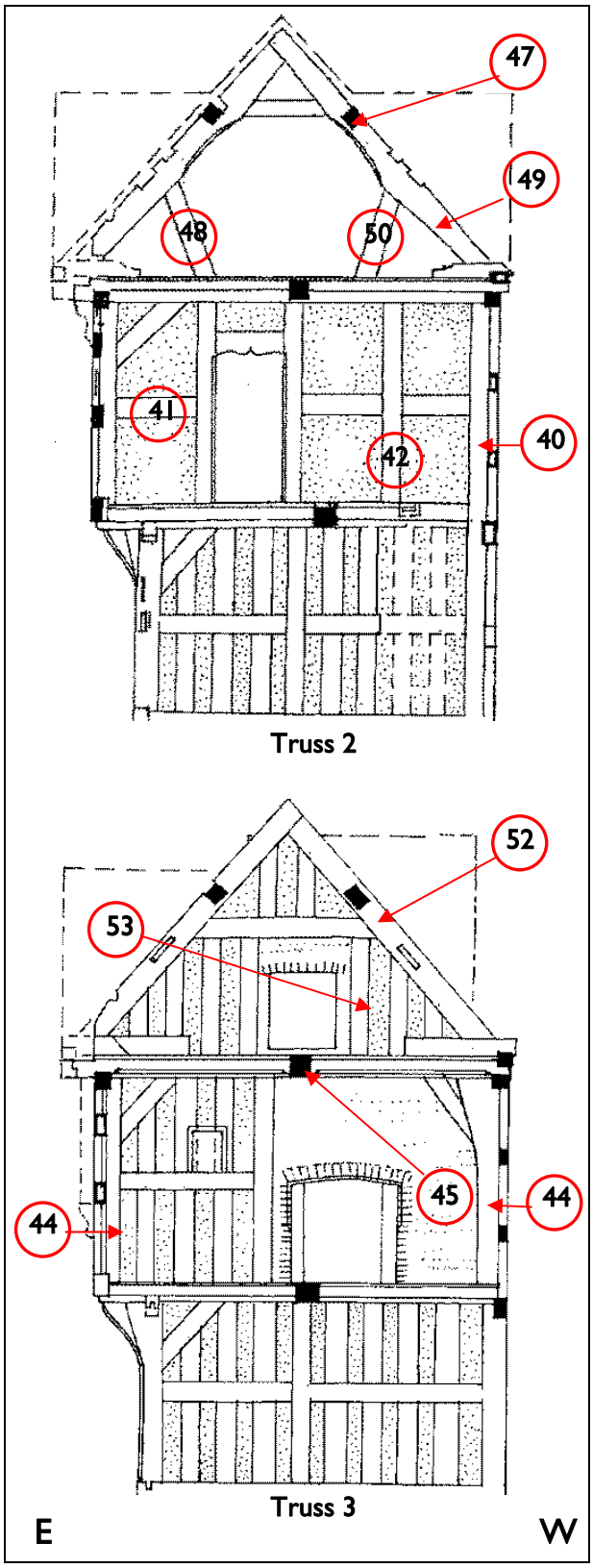


Figure 7c: Gatehouse trusses to show timbers sampled (after Jones 1975–76)

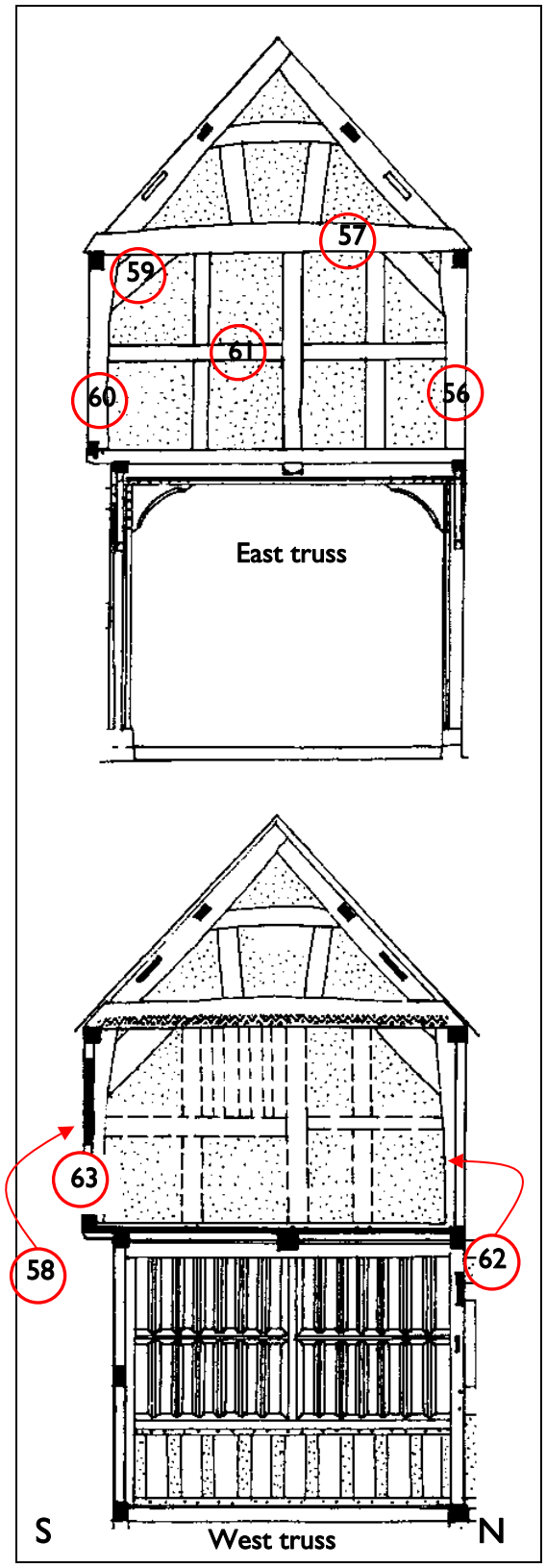


Figure 8: Hall range west projection to show timbers sampled (after Jones 1975–76)

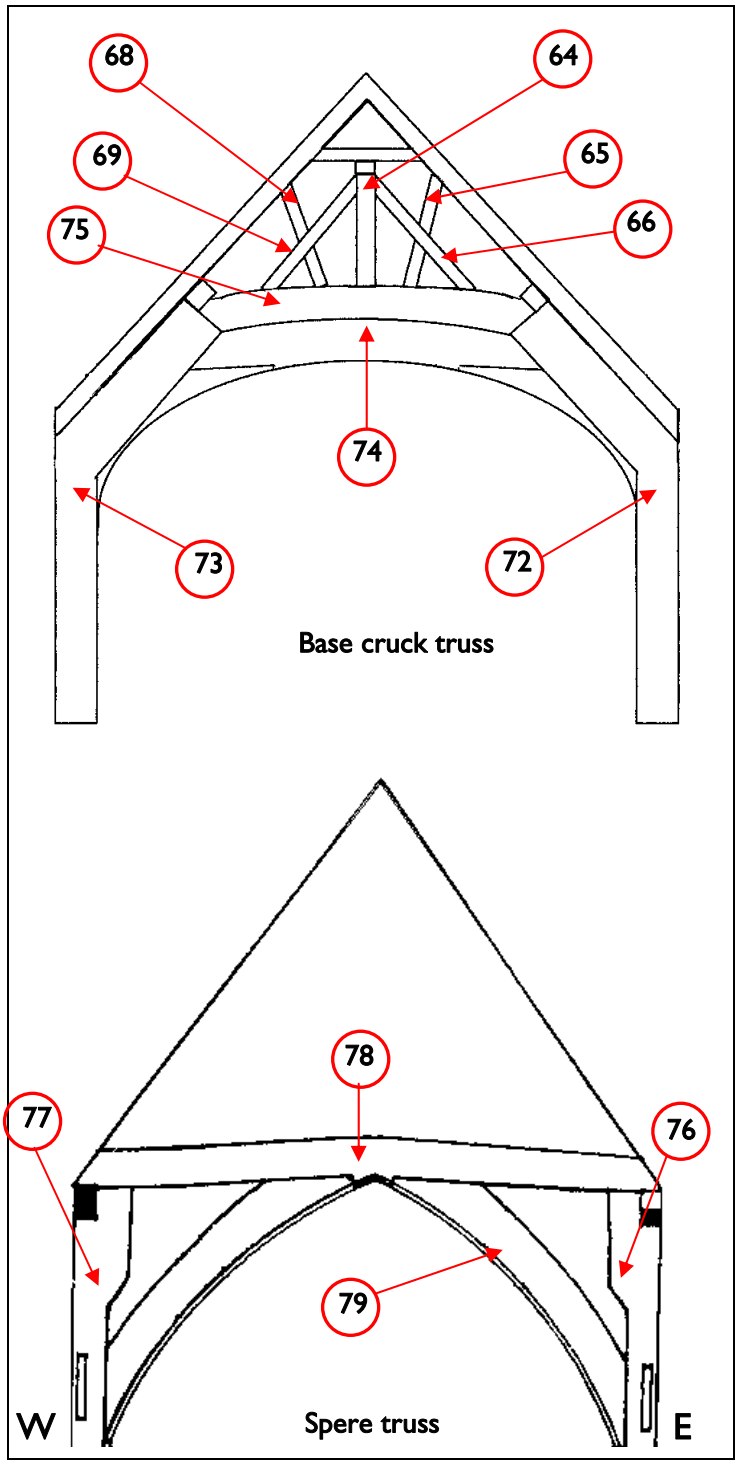


Figure 9a: Great Hall trusses to show timbers sampled (after Jones 1975–76)

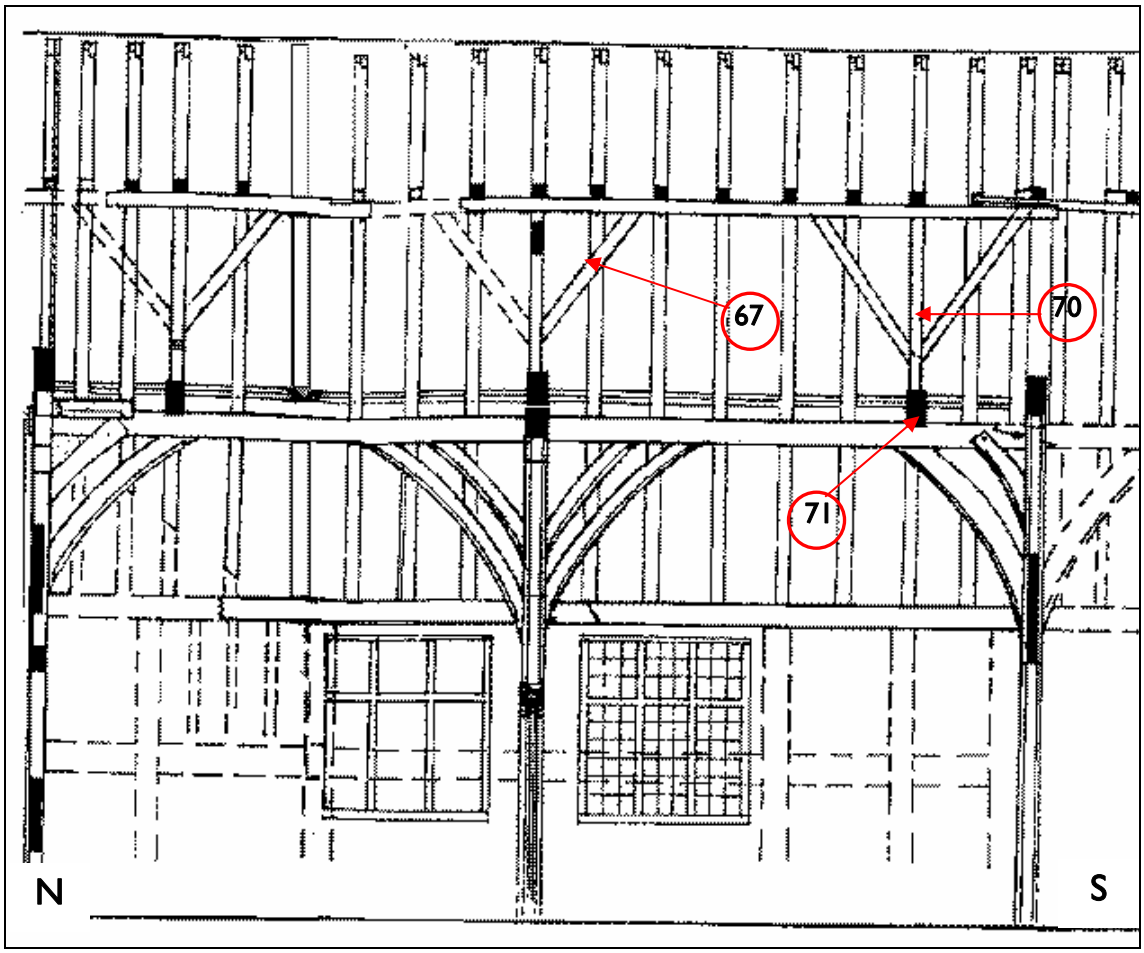
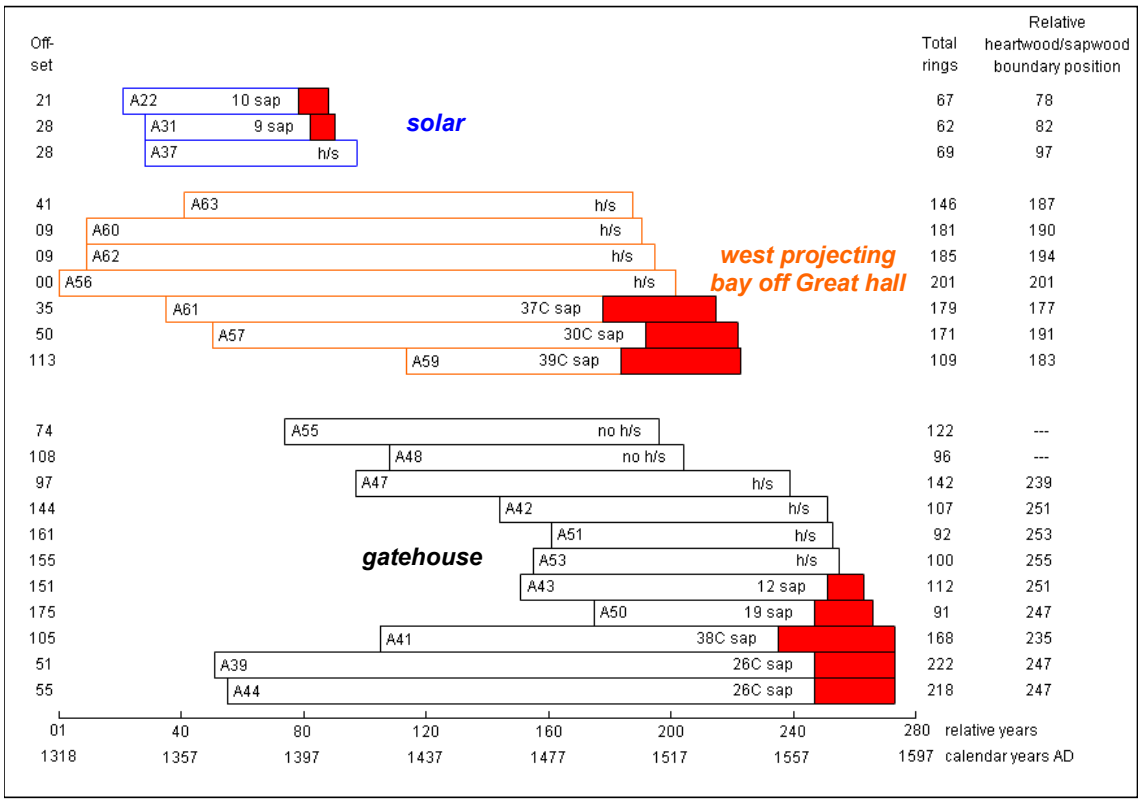


Figure 9b: Long section through the Great Hall looking west to east to show timbers sampled (after Jones 1975–76)



White bars = heartwood rings; shaded area = sapwood rings; h/s = heartwood/sapwood boundary; C = complete sapwood is retained on the sample, where dated the last measured ring date is the felling date of the tree represented

Figure 10: Bar diagram of the samples in site chronology WBRASQ01 sorted by sample location

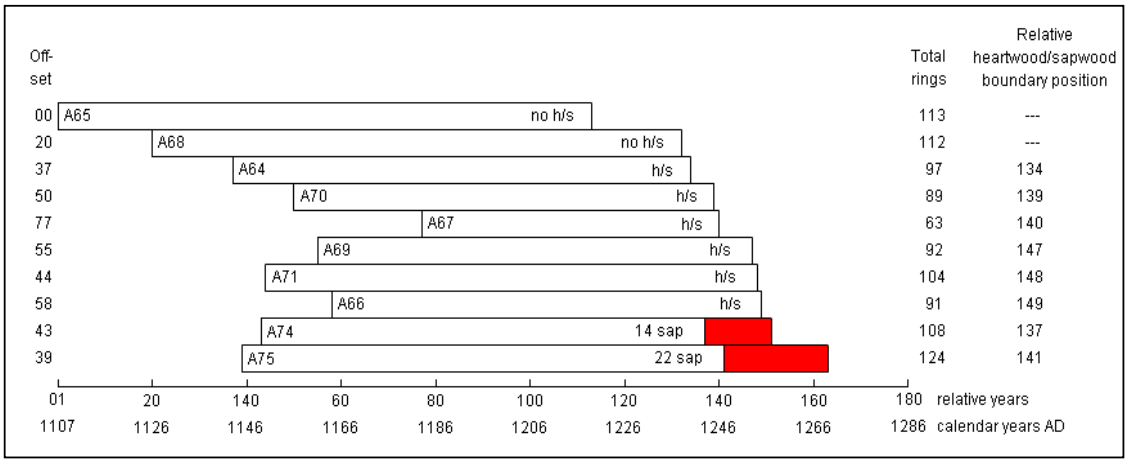


Figure 11: Bar diagram of the samples in site chronology WBRASQ02 sorted by sample location

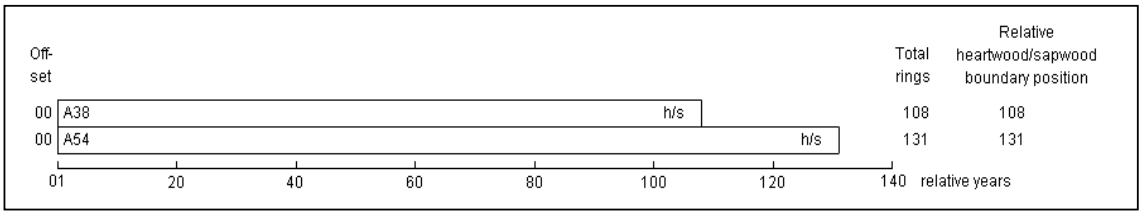


Figure 12: Bar diagram of the samples in site chronology WBRASQ03

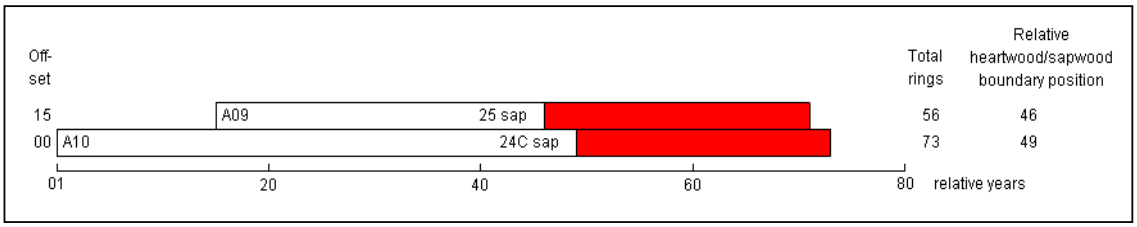


Figure 13: Bar diagram of the samples in site chronology WBRASQ04

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

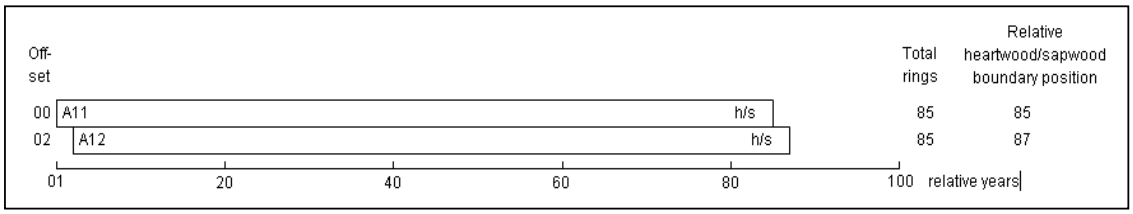


Figure 14: Bar diagram of the samples in site chronology WBRASQ05

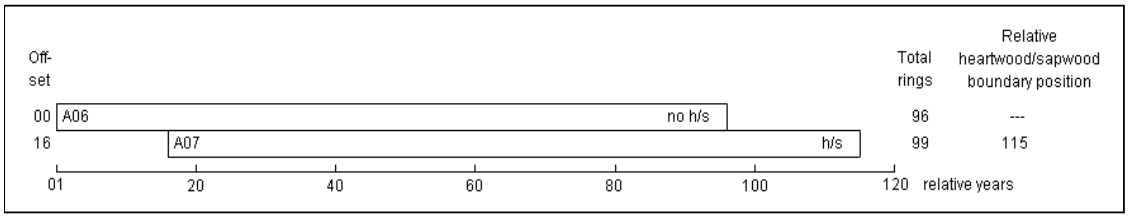


Figure 15: Bar diagram of the samples in site chronology WBRASQ06

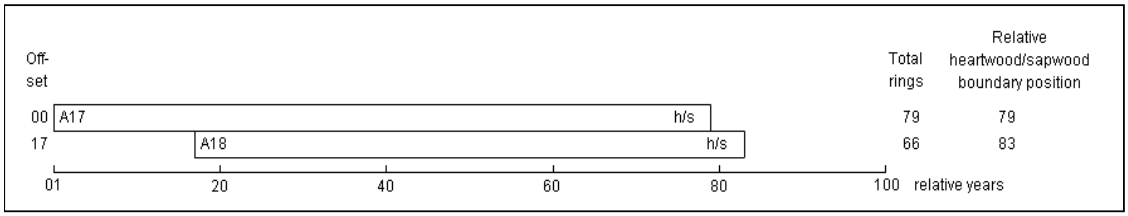


Figure 16: Bar diagram of the samples in site chronology WBRASQ07

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

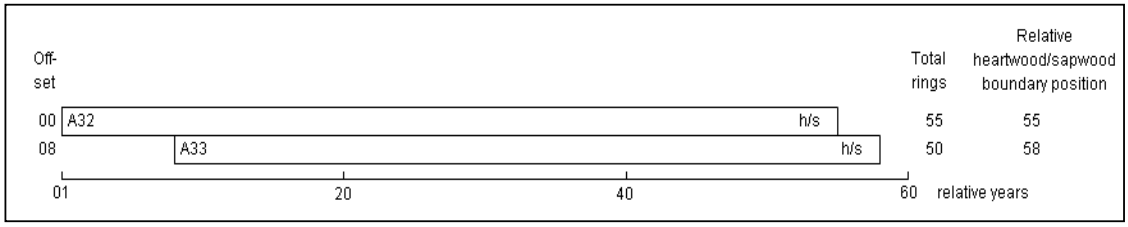


Figure 17: Bar diagram of the samples in site chronology WBRASQ08

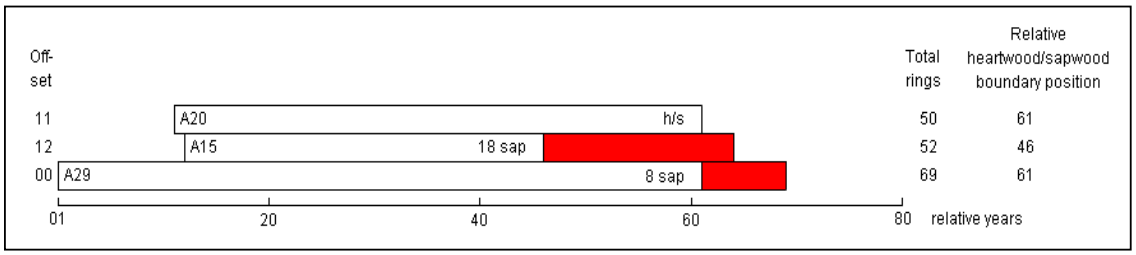


Figure 18: Bar diagram of the samples in site chronology WBRASQ09

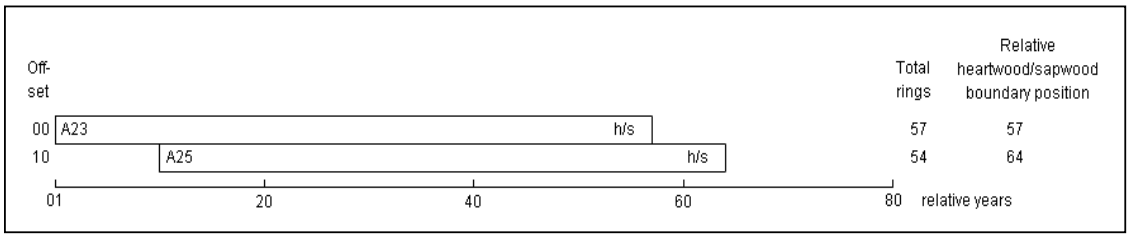


Figure 19: Bar diagram of the samples in site chronology WBRASQ10

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

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

WBR-A01A 74
362 358 311 269 243 236 231 242 252 271 193 170 170 283 258 231 224 202 224 220
319 330 401 291 312 253 221 186 230 231 185 230 158 139 122 122 88 88 81 85
101 72 65 74 72 63 44 51 59 40 62 44 37 40 37 40 34 32 30 33
33 42 41 22 29 34 49 44 43 30 43 36 34 39
WBR-A01B 74
361 350 314 281 234 245 239 229 244 269 191 170 172 296 258 221 233 199 214 240
323 350 400 303 309 258 231 189 220 221 189 227 165 136 132 111 92 90 75 91
91 68 62 71 76 60 48 54 56 52 70 41 39 34 38 41 43 29 28 36
33 42 30 41 33 31 44 42 39 36 35 33 36 43
WBR-A02A 96
216 271 342 592 667 598 499 360 604 658 569 526 506 436 467 449 581 574 459 439
349 333 434 317 398 282 300 229 349 206 252 227 228 210 194 175 186 139 139 221
149 166 147 147 189 161 210 169 147 149 140 82 90 100 96 108 92 108 99 73
66 57 58 68 65 61 63 55 48 44 59 46 45 37 48 43 53 32 32 43
49 44 55 61 64 57 46 43 46 29 26 28 28 38 39 55
WBR-A02B 96
266 251 359 598 664 546 459 368 582 650 581 510 517 450 463 458 574 576 460 452
339 341 432 311 388 290 314 241 344 203 235 231 218 217 188 169 179 162 135 203
153 167 149 154 170 168 196 169 147 151 137 73 84 102 99 114 92 114 102 68
74 52 60 69 67 65 60 59 55 30 57 55 55 31 42 40 56 34 34 44
49 43 54 59 60 48 49 45 42 31 24 27 24 33 39 54
WBR-A03A 100
888 806 670 635 540 400 315 371 335 336 273 250 191 245 189 306 309 414 261 288
110 112 114 133 265 270 308 247 220 170 253 269 357 377 328 354 280 282 270 277
185 282 199 259 334 365 360 338 305 267 238 175 238 269 281 318 283 231 205 185
154 168 157 174 155 176 134 99 99 118 85 98 123 157 148 163 212 208 195 136
138 150 145 111 94 108 130 158 159 172 163 151 150 152 155 158 218 152 169 181
WBR-A03B 100
888 815 677 652 556 411 303 371 341 332 275 248 202 234 197 289 312 425 275 270
135 113 131 133 262 274 319 222 224 182 266 279 343 375 312 346 294 254 280 225
213 262 203 247 339 365 359 311 320 273 229 176 234 268 276 323 270 242 198 164
166 166 158 158 148 203 129 98 106 120 92 96 116 163 148 165 204 218 190 133
135 158 139 117 98 102 133 170 153 163 174 153 136 158 150 169 202 144 181 196
WBR-A04A 112
391 383 260 266 186 150 180 236 257 252 249 255 243 232 282 278 216 230 288 228
193 211 184 170 209 231 216 214 244 177 124 157 158 191 177 196 168 165 171 182
167 148 143 173 229 178 207 135 131 154 160 115 96 107 90 105 80 113 76 75
66 71 71 86 110 115 131 117 118 111 114 92 90 86 98 90 105 107 101 123
124 88 72 116 98 99 97 92 85 78 74 73 77 79 79 78 63 66 63 88
57 107 80 84 90 85 82 89 68 76 72 88
WBR-A04B 112
407 375 274 270 182 159 173 238 243 255 247 267 236 221 287 286 216 217 293 238
178 209 182 167 208 248 218 201 233 178 141 154 163 186 167 184 191 161 169 199
157 149 142 181 220 189 205 154 136 156 137 128 103 95 95 96 95 87 84 88
67 75 72 95 111 100 130 120 116 118 120 88 79 90 101 91 104 113 92 122
123 96 58 112 102 106 97 92 83 102 76 77 73 77 74 80 66 76 56 90
62 95 91 81 93 67 92 77 79 70 79 96

WBR-A05A 56
307 254 341 311 253 261 273 314 322 347 228 188 207 287 265 178 174 152 237 157
245 207 279 250 286 379 252 256 209 221 183 206 190 237 259 191 199 190 190 167
263 213 256 196 233 215 188 160 164 139 120 162 154 129 149 154
WBR-A05B 56
286 257 313 307 261 258 270 314 266 326 226 183 199 239 264 186 175 146 228 170
219 217 263 259 313 384 237 248 197 228 187 196 195 227 251 201 193 209 180 166
257 216 259 197 248 207 184 173 176 131 131 153 152 131 157 153
WBR-A06A 96
491 462 425 323 165 136 106 177 221 192 163 175 195 187 136 264 365 408 364 296
323 255 305 308 276 157 214 240 228 254 333 312 323 421 366 336 273 246 199 221
236 268 252 228 214 196 235 228 185 142 209 292 256 190 195 207 147 141 159 157
152 140 104 118 85 112 126 154 106 95 122 99 159 169 206 194 179 179 184 210
140 92 61 99 119 86 75 85 84 76 43 46 36 33 38 37
WBR-A06B 96
483 456 402 325 173 128 156 161 215 204 174 168 194 188 139 265 378 383 355 295
319 239 297 311 272 150 235 225 226 253 314 321 337 412 363 335 276 245 191 222
240 266 257 222 213 204 228 226 185 143 205 284 273 195 184 207 142 142 154 161
151 144 106 109 97 104 122 158 99 99 103 116 167 164 213 195 178 179 179 209
150 81 78 99 118 93 77 87 82 78 47 45 33 43 35 35
WBR-A07A 99
199 407 469 455 371 407 450 348 327 239 271 218 137 120 146 97 131 102 83 129
65 90 81 101 124 153 131 189 109 93 76 80 75 74 122 124 127 114 104 103
73 88 130 110 113 84 95 78 61 53 69 109 98 86 71 71 63 59 56 53
53 62 58 56 54 53 63 105 128 74 87 93 111 92 81 112 82 85 88 94
175 123 133 117 144 207 218 279 274 257 258 169 164 151 151 176 126 107 133
WBR-A07B 99
196 418 489 460 384 420 407 355 338 216 210 201 149 122 134 87 145 112 92 128
65 101 77 106 109 117 92 157 100 92 55 84 68 76 139 132 127 113 99 104
72 97 115 112 108 89 97 70 66 50 70 126 102 82 74 70 67 60 57 59
48 62 55 55 63 50 64 99 127 83 79 91 110 94 88 103 85 77 86 94
208 126 126 120 143 208 224 269 284 254 270 180 155 155 158 167 132 121 134
WBR-A09A 56
306 262 202 338 400 299 473 465 329 508 451 448 504 308 390 446 455 271 331 311
268 170 171 233 279 426 408 542 494 512 494 190 154 178 223 148 167 146 123 115
101 114 142 108 104 67 58 53 47 64 59 85 88 81 118 110
WBR-A09B 56
290 260 203 356 395 310 461 460 333 493 415 453 468 307 373 433 431 283 322 309
276 172 182 250 291 433 391 541 489 511 495 187 163 177 211 155 169 146 127 119
111 161 108 92 68 64 37 65 49 59 84 92 80 84 114 117
WBR-A10A 73
189 384 265 216 274 219 277 287 231 302 219 322 260 267 360 281 162 102 85 105
97 219 189 122 174 182 177 203 120 128 150 141 93 167 137 146 117 125 175 258
153 144 152 195 165 187 129 132 198 235 230 270 266 140 123 111 190 222 69 49
42 44 72 86 162 104 135 134 167 115 77 73 107
WBR-A10B 73
184 386 267 241 266 227 273 275 230 310 224 296 277 273 327 288 151 97 82 114
90 234 191 127 156 182 194 200 113 125 141 140 98 157 137 152 114 138 165 261
151 147 163 177 170 192 113 138 190 243 261 278 260 159 123 112 205 207 69 47
41 52 77 94 156 113 123 164 157 108 87 81 111
WBR-A11A 85
269 344 283 342 288 257 354 379 368 405 328 326 299 339 313 299 385 199 215 168
188 228 340 364 274 220 288 245 261 225 271 179 223 279 194 193 157 180 112 178

192 202 201 137 161 207 214 146 129 140 191 218 266 161 122 97 125 124 137 109
148 99 117 147 82 104 91 138 96 128 99 109 102 143 136 113 142 106 89 100
94 71 74 78 90
WBR-A11B 85
204 311 273 324 276 273 353 395 352 423 328 342 290 330 296 308 328 211 214 189
206 226 351 344 270 244 295 260 263 210 276 155 205 288 212 159 164 169 107 212
180 222 186 137 163 207 214 148 127 135 188 206 264 167 121 94 114 133 141 98
160 90 115 150 76 100 103 139 88 110 103 120 102 161 129 107 131 118 91 88
107 68 76 79 91
WBR-A12A 83
341 451 378 250 398 501 429 426 339 227 292 278 317 346 416 264 300 196 169 182
421 430 423 317 348 335 356 297 379 256 229 329 247 216 207 209 140 192 165 189
185 142 139 149 176 138 115 126 145 159 200 151 96 118 98 123 105 76 113 98
116 143 71 107 127 158 93 134 93 135 107 170 131 134 165 116 89 106 100 64
57 62 95
WBR-A12B 83
348 448 375 250 405 507 440 403 343 265 278 290 300 349 395 238 317 203 190 172
408 396 451 295 361 344 338 297 388 245 240 320 251 230 197 211 134 201 165 186
196 145 134 155 172 137 124 130 135 162 199 150 93 115 105 122 102 87 111 95
111 137 99 108 105 171 106 129 97 131 99 167 147 137 178 110 89 111 107 59
65 71 98
WBR-A13A 78
697 640 681 652 452 236 256 366 373 420 534 427 324 461 643 415 600 395 386 407
293 335 420 361 268 236 313 223 315 345 253 207 213 170 217 189 190 182 180 198
196 211 198 201 261 313 288 146 116 99 156 219 245 237 245 218 234 221 166 191
140 196 250 299 375 317 180 311 302 317 288 307 238 315 264 215 234 287
WBR-A13B 78
641 651 703 662 454 249 249 369 384 445 537 439 339 485 612 426 580 388 380 395
294 373 442 346 254 237 296 199 302 345 252 202 216 192 215 200 189 183 176 200
201 198 197 197 269 323 276 157 114 105 163 207 243 241 239 213 237 223 149 205
142 185 273 305 357 307 187 305 316 315 292 315 236 299 257 219 232 283
WBR-A15A 52
371 292 180 216 293 228 207 273 299 263 235 201 152 122 170 127 146 124 208 273
134 188 172 190 213 150 127 190 80 47 50 81 129 131 143 134 178 149 113 143
82 121 134 217 188 231 146 176 213 223 188 187
WBR-A15B 52
355 273 187 227 286 232 195 276 296 276 232 213 163 111 164 126 149 143 182 258
128 189 172 197 194 140 130 193 81 47 54 80 129 130 144 141 162 144 116 114
91 122 139 213 213 223 134 186 188 221 197 197
WBR-A16A 58
309 220 342 277 400 244 233 326 341 177 364 225 323 264 131 110 126 149 111 57
72 52 53 58 39 50 36 28 27 40 44 38 32 54 49 62 94 96 103 110
85 136 107 146 144 379 453 307 204 262 290 209 150 152 110 260 240 245
WBR-A16B 58
324 209 351 249 417 239 250 324 344 184 356 235 309 269 164 111 121 152 115 53
69 49 58 54 46 44 37 28 32 37 37 42 32 59 46 67 93 97 111 108
91 131 119 142 156 360 432 321 224 257 295 215 167 148 124 269 240 258
WBR-A17A 79
151 183 173 194 313 298 257 173 144 197 217 181 183 191 250 213 234 247 158 263
504 324 251 332 216 144 126 134 152 142 129 126 130 160 218 242 224 201 336 251
214 271 234 183 287 214 312 271 177 233 350 327 298 191 220 156 95 99 94 86
65 49 105 79 84 47 51 56 43 60 70 107 104 102 122 116 148 171 89
WBR-A17B 79

160 189 166 205 296 308 241 187 135 214 202 186 183 195 262 214 216 245 165 269
512 328 238 336 211 143 120 123 143 127 142 122 139 154 208 244 238 212 330 236
208 281 237 180 276 214 317 269 171 226 368 315 295 220 217 156 117 99 85 76
61 57 99 85 84 49 49 46 50 59 67 109 113 88 120 129 141 173 84
WBR-A18A 66
261 206 269 299 273 209 260 114 55 55 67 139 153 151 230 260 201 301 240 247
243 274 233 181 241 204 186 282 227 358 281 237 218 305 220 288 205 200 175 226
289 147 88 76 71 145 143 144 122 142 113 127 102 219 235 148 102 136 167 162
157 163 216 265 248 244
WBR-A18B 66
277 213 227 336 265 218 252 114 62 54 65 131 154 155 251 276 223 314 217 216
242 289 247 209 239 221 198 293 225 357 267 247 224 312 234 284 211 212 176 249
280 140 94 76 73 140 142 141 121 149 103 134 109 210 232 154 111 131 155 167
160 166 212 262 271 273
WBR-A19A 49
391 461 386 219 299 452 500 470 500 984 866 747 501 432 376 297 328 411 330 292
248 287 271 320 378 559 493 465 348 310 354 383 474 476 473 485 344 325 389 340
239 303 185 236 211 193 271 337 273
WBR-A19B 49
380 428 414 244 290 430 493 462 528 988 877 734 504 437 383 306 363 410 334 283
274 289 289 327 387 532 478 448 360 316 338 373 470 475 478 453 347 339 364 362
263 291 173 224 200 196 282 330 258
WBR-A20A 50
200 194 219 206 238 221 138 121 129 209 261 201 265 180 184 288 262 229 282 115
221 155 215 193 238 341 252 205 278 87 90 89 168 230 204 189 151 143 175 270
241 161 292 225 302 345 316 179 224 321
WBR-A20B 50
168 210 194 216 185 241 140 126 137 213 262 188 240 184 199 299 275 186 273 115
246 154 210 226 223 304 269 239 264 125 88 69 172 231 198 199 162 126 234 262
190 163 287 249 326 340 301 193 227 324
WBR-A21A 56
71 61 60 48 45 198 280 365 207 244 433 494 342 431 728 479 458 330 367 279
224 302 329 297 235 279 321 286 373 355 372 350 321 242 257 229 305 363 400 473
408 323 270 322 336 230 278 211 288 248 333 439 453 328 321 284
WBR-A21B 56
93 64 44 41 50 172 325 387 235 243 303 485 382 427 689 472 467 336 354 287
225 302 308 297 250 294 299 298 353 349 414 346 300 223 257 246 286 369 387 477
416 312 257 318 324 221 282 194 300 237 341 435 441 326 290 277
WBR-A22A 67
240 114 158 179 241 156 264 251 217 357 386 358 234 110 243 211 183 287 255 261
293 164 236 350 377 378 216 329 283 161 213 182 151 158 168 280 257 236 341 402
402 235 245 264 320 329 296 550 425 338 196 134 149 147 186 204 144 156 166 191
174 293 249 202 266 210 250
WBR-A22B 67
183 110 164 189 241 166 240 268 216 362 445 314 254 107 248 198 187 257 245 282
290 162 230 358 378 361 236 328 269 180 212 186 164 151 180 266 264 251 349 421
383 239 261 271 305 322 285 536 414 333 184 125 151 144 168 199 165 147 172 188
169 292 261 198 242 261 242
WBR-A23A 57
110 101 139 101 101 212 141 131 645 785 487 705 449 462 327 244 463 524 276 340
218 250 201 204 271 276 243 311 219 232 240 297 386 260 396 270 198 304 267 263
233 255 221 283 275 273 269 338 341 170 92 88 94 152 219 302 235
WBR-A23B 57

140 104 139 92 115 216 140 131 685 769 487 549 444 475 344 248 458 526 304 333
213 268 170 194 260 269 243 307 203 230 239 285 385 299 334 254 207 317 287 265
196 232 254 217 270 314 253 365 315 191 99 97 105 145 204 308 246
WBR-A25A 54
345 445 328 422 349 290 459 468 317 306 202 280 236 262 266 295 318 303 216 234
305 299 320 259 302 238 288 369 220 184 272 262 296 306 288 362 341 405 366 117
84 108 85 115 108 194 241 269 192 236 197 173 216 200
WBR-A25B 54
275 450 346 418 342 285 472 456 326 277 221 275 244 248 280 289 321 296 240 210
323 312 285 279 297 244 232 347 222 183 270 261 300 321 298 355 367 403 384 118
77 93 102 118 117 185 231 270 200 239 196 187 228 208
WBR-A29A 69
594 389 459 125 49 118 121 175 212 213 331 267 433 352 249 370 338 221 206 309
312 327 245 186 177 115 200 130 171 135 180 218 135 151 165 221 204 161 166 186
88 53 28 79 110 118 129 142 180 169 122 124 87 119 139 240 224 249 143 187
179 231 195 230 163 162 165 144 124
WBR-A29B 69
622 400 495 100 66 110 167 166 223 228 334 281 458 363 245 348 317 220 222 302
319 336 248 187 174 119 195 133 174 146 167 221 129 159 158 203 191 166 159 190
92 49 39 65 119 116 140 140 176 168 132 121 84 115 151 228 231 235 150 200
184 218 179 231 189 146 130 167 153
WBR-A31A 62
163 163 178 232 149 208 117 230 264 223 277 235 328 340 183 210 318 261 305 230
267 254 198 322 180 167 223 222 316 232 220 273 187 229 211 191 171 175 214 134
278 282 307 201 184 231 176 157 167 178 138 160 194 254 436 283 208 378 345 399
305 386
WBR-A31B 62
146 154 177 235 154 210 127 278 273 218 265 216 318 331 176 195 323 255 325 210
269 273 195 319 181 166 202 216 323 240 220 266 185 238 201 186 179 163 241 132
274 276 321 209 185 232 185 165 171 153 138 168 196 251 438 279 218 361 353 371
379 386
WBR-A32A 55
961 479 696 776 555 597 612 552 512 498 495 359 437 391 477 389 364 382 589 395
218 204 248 174 195 286 254 306 225 211 164 227 262 269 287 332 262 212 211 233
129 66 51 84 107 86 183 315 266 197 106 74 80 44 93
WBR-A32B 55
936 438 742 771 586 632 624 575 509 506 492 371 431 414 488 374 390 372 600 373
200 211 260 176 209 285 244 304 237 209 161 240 247 270 297 336 262 201 217 234
120 61 48 88 111 83 186 317 263 201 102 79 73 53 98
WBR-A33A 50
534 656 508 426 502 526 546 566 352 432 442 452 332 253 300 197 224 303 223 320
248 275 271 232 297 325 391 418 234 207 282 316 125 72 42 69 117 141 217 320
282 257 161 78 100 88 107 257 286 367
WBR-A33B 50
523 660 526 414 491 551 533 551 357 429 450 463 350 231 318 178 213 315 226 311
234 264 278 239 320 308 378 415 231 219 312 286 133 74 43 70 120 140 189 407
315 277 147 123 106 79 106 225 282 366
WBR-A37A 69
115 80 83 125 76 46 43 49 39 51 62 57 60 57 34 32 41 57 45 39
39 26 40 50 25 23 36 41 37 34 40 53 63 74 61 55 100 54 106 139
188 264 167 133 109 148 149 121 128 192 283 299 254 233 440 273 276 388 380 468
367 232 274 300 158 93 134 140 160
WBR-A37B 69

112 81 89 119 62 39 39 34 34 40 42 48 55 46 32 28 41 69 41 38
44 25 41 44 36 24 29 24 37 34 45 57 68 69 75 48 92 62 117 139
186 259 185 150 140 142 157 104 143 182 270 294 254 233 441 288 279 382 357 429
361 208 248 285 141 104 117 144 162
WBR-A38A 108
139 232 243 269 246 260 271 78 69 77 67 76 92 72 83 105 135 108 110 108
130 108 180 201 251 204 248 156 163 121 139 149 141 134 142 135 134 180 168 151
180 137 84 84 61 70 62 86 91 62 77 83 98 78 103 106 88 82 86 127
148 85 84 108 122 148 145 153 84 46 34 25 23 36 31 34 41 72 69 57
52 65 55 84 57 71 61 91 66 80 89 96 97 127 119 133 66 64 43 28
26 45 45 46 51 49 42 53
WBR-A38B 108
148 222 252 274 234 252 281 78 68 57 76 85 81 86 81 114 139 112 126 117
151 125 200 224 267 202 244 156 156 111 118 147 157 132 139 156 145 180 151 177
182 113 89 84 54 69 77 70 84 62 81 70 97 83 98 112 101 89 80 100
161 100 68 109 123 141 160 158 80 42 31 29 24 35 31 35 46 61 75 51
56 68 49 91 57 64 64 93 65 84 79 99 97 120 134 127 73 56 44 30
30 45 40 40 65 46 40 49
WBR-A39A 222
191 223 197 278 253 271 182 219 193 189 204 196 166 238 238 287 329 292 226 195
106 144 165 183 128 104 89 179 149 149 201 302 129 179 240 191 158 173 153 204
171 133 123 148 137 142 169 151 127 134 111 119 137 160 201 291 184 140 104 160
185 156 139 292 178 183 163 87 64 76 67 77 130 110 128 74 69 54 55 54
72 71 71 100 106 108 89 106 100 98 89 86 108 92 104 98 128 201 118 159
297 234 211 157 171 145 212 251 182 147 152 164 211 146 113 87 80 114 163 153
85 50 50 31 26 39 39 43 33 51 61 49 43 45 68 71 59 66 60 66
65 51 76 71 90 78 60 82 104 137 95 72 82 104 93 87 87 115 113 107
89 67 104 66 89 113 104 103 109 110 100 129 114 73 92 87 80 102 94 125
167 133 105 101 96 92 93 95 94 157 134 111 131 117 104 108 107 81 62 91
89 106 124 112 87 80 59 55 56 41 34 43 37 27 31 43 38 29 21 27
31 50
WBR-A39B 222
171 241 144 239 225 251 200 211 198 179 188 198 170 226 240 294 321 275 225 197
100 144 164 179 121 101 99 170 157 131 197 292 126 178 225 186 148 147 163 200
177 119 133 145 130 143 167 133 128 145 94 120 137 157 204 310 185 155 107 178
190 160 148 276 184 185 170 96 59 72 72 89 131 117 124 79 67 54 50 58
71 61 81 99 108 110 83 104 108 89 88 92 104 95 105 102 129 204 116 164
290 235 209 158 186 145 196 246 172 152 145 162 216 148 114 84 80 116 165 149
71 53 46 35 31 39 35 44 37 49 55 57 44 38 74 65 70 61 61 65
60 52 75 75 80 85 59 89 96 131 108 62 86 107 85 95 83 119 116 104
83 75 95 77 83 109 106 108 107 113 105 120 118 76 85 85 87 86 105 132
155 137 103 95 99 96 100 115 82 164 147 96 139 120 107 110 113 93 69 81
93 104 122 97 101 65 63 47 51 44 38 39 33 19 28 39 27 35 22 46
34 48
WBR-A40A 95
282 300 243 359 260 300 200 234 241 203 135 117 121 106 165 192 118 150 143 169
150 173 136 144 172 169 180 184 106 175 162 257 234 165 210 170 259 204 353 272
194 285 158 207 178 163 267 272 259 193 246 203 154 174 213 188 113 136 127 180
156 126 167 140 136 119 137 123 115 105 119 140 180 140 101 123 99 139 138 127
78 65 98 97 70 98 78 127 130 148 119 108 110 86 81
WBR-A40B 95
308 301 243 364 270 294 201 222 245 188 129 117 122 112 168 206 122 141 144 163
141 159 138 151 173 163 181 194 95 162 178 235 213 173 212 183 251 207 352 252

191 292 169 210 187 165 276 284 261 200 245 206 145 176 217 188 121 133 125 188
158 128 159 154 118 122 132 125 108 115 126 131 185 134 116 116 111 135 144 117
81 71 97 96 77 100 78 122 133 150 111 119 111 87 76
WBR-A41A 168
252 301 218 126 184 188 171 195 174 256 178 223 193 150 95 68 71 114 151 103
155 185 151 93 88 120 127 121 193 125 117 136 143 145 149 143 144 133 104 105
103 93 109 147 117 152 148 95 105 140 92 107 151 126 99 97 115 89 128 156
102 60 59 79 133 161 137 135 198 94 68 120 116 140 121 113 116 146 89 95
105 129 151 104 164 127 142 102 81 53 48 50 49 68 83 125 106 89 113 133
126 134 132 133 135 150 141 91 134 114 95 120 128 118 88 108 115 142 137 96
103 75 63 71 71 104 116 113 113 67 95 101 105 86 57 65 75 109 96 124
70 100 112 94 90 99 90 108 87 89 69 83 69 52 57 60 71 92 55 71
68 73 77 63 49 43 57 55
WBR-A41B 168
252 305 206 135 187 167 168 214 182 273 182 211 199 125 96 68 78 111 156 86
168 191 148 102 80 138 134 125 196 118 127 148 128 144 147 141 151 140 100 98
101 95 104 123 120 155 152 98 98 138 102 107 145 135 104 93 112 99 132 144
99 64 58 80 127 163 137 134 138 103 72 113 121 150 118 109 128 144 82 99
115 114 159 97 155 128 138 113 68 64 42 55 54 57 95 124 108 88 133 135
133 128 139 142 133 139 144 84 154 91 108 119 120 113 92 109 122 158 150 102
99 78 63 63 69 92 130 91 98 82 91 93 100 82 59 66 81 93 91 121
59 98 110 90 87 95 82 107 83 83 67 82 69 54 56 58 66 90 51 67
63 81 74 67 49 47 55 53
WBR-A42A 107
184 134 115 145 144 157 164 162 157 198 148 190 172 210 157 168 150 172 187 126
105 117 81 75 84 104 102 109 117 107 83 99 130 140 146 150 152 131 97 89
72 111 115 102 83 91 104 121 102 114 121 130 112 84 82 107 100 94 94 98
120 115 130 119 130 130 135 132 115 150 132 118 118 142 131 120 150 164 165 154
119 124 104 98 127 125 156 142 143 140 141 146 139 144 101 102 76 56 54 67
61 69 76 65 67 69 88
WBR-A42B 107
171 135 121 137 138 149 174 153 169 206 141 182 157 212 171 182 156 172 164 163
107 118 89 72 79 102 81 100 119 92 101 97 128 140 153 144 140 129 109 83
73 112 113 99 80 98 110 109 106 119 139 144 100 93 86 96 99 102 95 98
121 112 137 116 127 132 146 140 113 154 126 116 128 136 129 112 145 178 158 152
148 112 103 101 120 106 164 142 131 155 144 154 141 136 108 97 77 49 50 73
49 73 75 71 54 74 103
WBR-A43A 112
146 139 202 175 184 156 159 151 163 147 161 163 134 109 117 84 76 84 105 124
99 130 124 103 106 115 122 156 159 130 139 123 93 70 88 102 95 98 95 125
115 132 116 136 87 91 48 63 78 87 62 71 77 73 63 84 86 96 78 105
89 95 108 100 101 101 107 97 131 140 165 177 156 102 139 109 102 128 131 194
200 174 188 143 150 134 115 111 109 82 51 60 55 60 49 71 57 72 80 96
96 98 108 131 123 112 100 77 98 87 117 165
WBR-A43B 112
166 143 230 138 150 143 174 164 178 147 165 134 125 123 100 89 75 87 112 117
104 135 122 103 103 117 129 144 150 150 137 138 95 74 105 105 94 99 101 126
118 134 131 127 92 81 59 66 72 86 62 67 81 97 84 90 90 93 81 85
94 83 111 113 93 102 112 110 111 148 150 176 158 108 143 127 106 119 135 185
211 164 192 150 161 142 119 108 105 76 66 69 58 55 55 65 61 78 82 111
119 89 112 127 126 113 91 73 94 89 117 165
WBR-A44A 218
210 251 169 193 204 220 232 226 196 243 265 213 282 299 305 275 157 190 274 245

134 131 110 177 139 160 237 229 130 144 190 206 167 185 139 169 196 168 141 181
168 188 230 176 170 188 146 180 175 185 179 175 139 130 93 168 196 141 167 142
119 99 98 75 87 91 70 79 95 71 110 72 59 46 58 68 71 61 76 85
81 72 47 63 80 66 71 88 107 117 83 93 117 131 103 122 121 159 141 132
148 120 170 157 149 152 151 178 201 197 147 124 95 145 193 168 69 102 78 55
48 73 65 89 70 104 116 108 68 85 91 123 93 103 83 102 110 103 103 127
113 115 82 99 107 128 105 75 71 115 111 99 109 132 97 92 97 75 100 96
76 86 88 91 91 102 104 95 93 61 70 70 58 68 64 68 83 74 87 79
94 82 86 70 65 84 61 75 74 102 87 118 111 91 71 98 78 120 104 111
100 122 79 62 55 59 74 96 53 69 29 45 41 30 23 29 34 53

WBR-A44B 218

214 258 179 195 193 212 228 212 175 244 278 228 318 275 325 273 153 192 277 238
136 113 108 195 133 177 226 226 144 142 189 236 164 176 141 175 199 155 149 178
173 183 229 181 167 184 153 183 174 184 183 175 140 130 80 174 224 137 168 138
110 107 101 72 88 88 72 78 100 89 103 77 58 47 66 62 70 63 67 84
83 69 51 65 69 64 74 73 117 119 88 100 127 135 108 134 128 165 127 123
137 125 165 167 149 162 159 167 198 206 139 113 118 151 183 149 75 93 72 54
49 56 77 85 68 108 122 95 74 86 106 128 87 99 88 105 111 99 101 131
102 102 82 102 112 129 98 80 73 104 101 100 106 122 100 89 93 76 96 100
77 92 84 88 91 98 104 92 86 68 72 67 53 76 55 71 80 81 88 78
102 72 93 73 64 73 74 65 82 93 99 117 117 84 68 95 76 135 104 96
103 120 79 64 56 58 76 93 53 66 27 42 37 31 24 26 35 49

WBR-A45A 94

350 328 194 118 164 138 209 128 168 182 155 277 182 415 347 330 332 366 222 94
93 97 88 103 68 139 124 128 125 148 178 142 249 227 73 36 28 50 65 90
127 154 214 130 199 173 226 259 348 477 463 275 293 237 209 253 332 308 312 306
264 266 287 240 213 232 251 236 278 318 235 307 260 234 391 234 326 347 360 234
209 246 189 301 268 308 287 192 243 214 276 228 214 106

WBR-A45B 94

350 326 186 125 158 141 211 114 178 178 151 291 178 396 343 362 327 367 209 112
75 108 93 116 64 131 121 134 131 142 176 151 253 222 67 31 30 50 80 89
115 152 219 142 184 197 204 250 364 466 465 277 297 233 210 247 345 297 315 291
264 273 285 254 203 243 247 233 260 348 222 323 262 243 380 246 354 337 381 230
224 254 172 309 239 313 294 200 242 207 258 236 205 101

WBR-A46A 69

172 248 126 96 47 60 65 138 163 319 256 232 385 410 441 452 411 384 349 438
370 285 269 369 413 244 292 312 350 305 241 322 283 328 275 272 379 356 256 419
207 209 259 326 335 393 339 219 314 327 318 332 295 381 350 362 355 414 286 426
316 469 322 271 230 311 245 280 308

WBR-A46B 69

176 261 141 114 48 54 95 185 166 334 254 218 368 406 478 465 412 359 340 440
383 285 285 380 394 248 298 324 356 308 232 322 288 318 274 277 376 371 248 385
202 233 257 346 314 404 343 224 307 323 303 341 295 378 352 365 368 391 304 416
319 466 309 279 230 289 255 299 329

WBR-A47A 142

381 289 321 180 295 269 314 285 260 183 243 180 130 148 155 174 171 149 114 137
96 81 70 78 56 57 78 64 95 107 60 74 84 97 105 108 170 162 134 168
162 172 136 136 123 184 137 135 140 104 151 187 159 147 133 143 141 150 158 144
222 152 149 164 160 138 143 138 122 129 89 130 153 166 136 142 98 104 101 132
146 197 157 138 152 130 100 116 139 166 177 118 100 129 191 145 94 96 138 150
134 133 115 97 93 82 107 120 101 95 68 91 103 110 84 76 112 104 99 107
124 79 133 130 125 185 149 113 119 129 120 111 83 130 113 110 113 115 106 111
92 124

WBR-A47B 142
392 303 322 196 297 274 309 281 277 179 253 178 125 153 155 181 161 157 118 123
88 88 58 81 55 69 74 72 74 99 70 70 77 104 98 119 179 176 131 165
172 158 138 130 133 171 137 146 133 126 152 181 168 150 136 140 141 154 152 141
204 162 147 168 154 141 141 141 126 132 90 120 153 160 138 141 103 101 100 141
134 176 163 141 152 140 95 104 145 152 192 126 109 139 205 158 99 94 135 139
136 138 118 98 83 89 110 130 90 112 71 84 98 118 98 73 106 111 97 104
125 71 141 120 134 192 145 105 117 131 115 101 88 121 120 108 113 119 98 106
113 124
WBR-A48A 96
157 142 202 214 181 204 206 148 163 146 102 76 76 68 72 85 68 97 84 86
45 64 63 86 79 94 103 109 93 87 92 111 101 103 102 114 135 103 92 127
129 147 146 147 139 127 145 169 138 156 138 146 132 114 116 123 125 122 131 104
130 151 97 43 42 38 33 37 32 46 36 74 72 57 61 61 74 86 78 72
66 86 80 80 75 99 92 81 63 81 73 94 78 77 94 98
WBR-A48B 96
159 132 195 230 175 196 188 151 171 134 101 86 78 63 77 82 71 89 80 64
57 71 70 94 78 92 106 106 95 102 88 104 110 100 107 101 132 99 127 117
142 124 144 143 149 117 151 132 138 161 131 145 136 119 110 120 115 114 136 120
115 158 101 43 41 36 42 39 43 50 41 67 78 57 59 51 69 90 75 68
64 79 83 68 75 91 79 82 64 77 86 87 77 74 84 97
WBR-A49A 133
458 508 408 241 243 380 252 457 554 456 322 377 342 435 536 468 712 500 296 332
318 372 408 303 242 312 137 212 111 55 36 37 42 43 50 59 88 124 130 177
151 79 74 58 37 45 43 55 59 70 87 54 131 98 88 83 66 87 67 110
137 106 137 152 135 110 143 103 122 96 95 91 96 64 112 131 90 179 162 284
235 221 113 72 119 80 69 74 78 99 77 106 114 136 136 66 82 34 40 33
35 29 50 66 72 79 61 63 83 149 87 156 133 124 136 69 55 64 71 100
204 76 36 28 28 45 39 52 42 54 49 50 57
WBR-A49B 133
412 512 373 272 258 366 259 433 521 457 345 370 326 442 538 491 687 494 285 306
309 379 412 294 234 297 121 207 105 54 42 44 45 39 50 49 87 124 127 185
137 85 73 73 45 43 42 39 63 80 88 50 126 81 88 87 62 75 71 120
125 115 135 150 122 122 123 99 133 93 83 84 97 70 107 130 92 187 165 287
228 219 115 72 108 83 64 71 80 96 83 99 120 134 141 74 79 36 39 32
37 26 46 65 65 92 49 71 87 177 79 166 135 110 149 69 55 60 76 106
205 63 33 29 31 55 45 47 38 49 50 50 57
WBR-A50A 91
293 470 581 670 376 361 322 261 131 135 216 308 192 144 187 207 231 287 307 299
258 243 194 283 225 372 292 303 318 168 74 50 83 90 77 77 63 39 100 90
96 188 145 110 191 190 189 225 119 87 95 82 58 120 113 133 120 125 128 120
145 102 91 64 101 114 114 110 130 141 161 175 87 116 72 186 112 152 106 95
136 59 70 66 53 72 118 118 60 56 75
WBR-A50B 91
281 415 585 684 363 375 313 283 114 139 204 313 197 143 189 178 235 297 300 299
226 249 199 271 220 383 302 292 313 166 84 59 65 99 91 81 76 43 104 70
102 187 144 114 190 183 202 220 124 72 99 74 72 119 108 142 127 129 139 126
142 100 94 57 97 128 113 101 128 132 171 172 99 119 78 172 105 149 110 103
125 65 74 59 61 65 117 128 77 52 72
WBR-A51A 92
73 105 105 100 132 141 124 158 316 246 213 236 188 235 175 203 344 321 234 249
255 196 118 114 145 169 130 134 136 185 172 190 155 160 132 161 131 181 127 218
195 233 237 185 100 120 98 129 122 166 176 105 182 182 182 195 170 195 376 436

347 440 248 200 191 148 168 147 153 263 190 237 190 227 194 159 140 93 132 174
196 166 162 189 246 220 155 209 137 252 178 193
WBR-A51B 92
92 106 109 102 125 142 113 157 330 247 206 224 171 260 175 209 336 345 229 249
245 202 124 111 154 165 142 119 139 198 170 189 143 159 127 166 143 180 135 204
209 229 254 182 100 110 104 128 133 168 135 134 193 190 179 180 166 208 376 446
353 435 249 205 189 141 175 154 178 253 200 246 191 227 192 161 124 95 136 186
192 168 180 184 243 207 146 206 133 243 177 177
WBR-A53A 100
262 139 181 296 231 221 265 240 300 247 273 232 183 224 370 266 244 282 186 217
166 272 368 405 291 303 311 289 163 150 195 269 179 149 164 173 190 193 183 253
218 229 192 219 178 267 221 220 282 182 64 85 75 113 90 105 98 92 144 132
157 132 160 145 194 241 223 271 178 120 147 126 138 152 180 224 208 231 177 166
232 176 168 143 172 197 165 145 158 171 211 244 182 194 147 222 172 295 197 181
WBR-A53B 100
257 146 164 292 254 208 284 239 289 250 282 235 180 236 363 269 271 282 194 214
166 254 373 412 295 303 306 297 166 149 201 260 184 135 172 175 200 188 176 244
214 221 211 205 187 263 218 212 278 166 79 94 75 110 87 101 95 89 133 146
145 152 175 147 196 246 217 255 169 114 142 135 141 158 174 228 220 221 187 166
209 196 163 144 155 203 161 150 154 172 210 247 189 188 137 208 177 300 198 175
WBR-A54A 131
294 296 232 255 329 348 307 305 84 81 69 76 69 87 84 111 169 131 126 144
187 148 204 250 246 202 233 135 156 141 135 157 159 144 134 122 146 176 161 190
184 127 99 97 58 72 86 83 91 74 86 110 102 96 95 117 113 99 98 122
174 118 87 101 139 159 158 175 89 39 47 34 33 44 45 38 41 54 74 66
69 67 63 95 75 76 65 82 84 80 86 104 101 111 125 124 66 62 30 26
28 32 48 34 54 55 52 57 50 60 56 70 61 65 69 43 46 31 29 27
33 42 38 35 34 71 62 74 79 77 83
WBR-A54B 131
294 313 245 258 331 355 321 298 103 73 85 84 88 86 96 106 161 132 119 143
184 139 256 230 261 192 225 136 166 121 156 180 136 131 142 112 169 179 147 174
179 142 98 94 69 80 67 90 94 66 81 107 91 97 104 113 115 92 92 121
173 107 87 103 123 163 165 165 87 40 48 36 31 49 45 33 38 59 73 61
69 72 62 89 70 73 67 82 86 82 90 110 99 116 120 124 67 63 30 29
27 30 47 38 51 60 44 59 41 71 54 76 59 63 67 37 41 28 28 29
31 39 35 36 35 69 59 71 74 75 81
WBR-A55A 122
170 230 177 187 242 208 188 213 258 224 174 197 172 132 140 149 177 182 173 172
176 167 165 213 139 167 185 171 181 186 212 193 169 131 101 93 118 180 164 140
161 113 161 186 102 117 93 75 78 100 56 97 59 44 30 37 36 42 52 49
67 70 46 50 56 57 63 67 65 68 70 71 64 87 107 107 110 162 227 164
134 176 139 203 198 147 97 82 108 187 183 193 188 141 171 194 184 61 40 60
42 48 54 67 77 106 120 88 75 74 83 87 77 86 84 114 104 99 90 122
93 95
WBR-A55B 122
156 223 174 180 238 207 192 207 244 232 193 181 167 133 150 145 206 211 176 178
173 164 163 218 148 171 179 171 177 183 214 188 168 128 102 92 120 171 168 130
150 116 159 190 103 114 91 83 72 92 76 83 43 52 36 33 37 43 56 53
66 71 46 53 54 71 63 73 64 66 74 77 69 90 107 94 129 163 232 172
126 176 140 199 193 139 106 94 118 177 181 199 189 143 170 194 184 59 39 71
45 48 51 76 74 115 123 88 73 73 68 86 84 72 95 106 104 94 103 116
94 93
WBR-A56A 201

370 220 173 222 104 162 243 200 154 290 209 264 275 227 165 139 141 192 120 127
115 126 102 147 168 212 113 133 149 135 136 163 135 171 127 170 201 130 154 128
98 160 90 103 129 134 124 87 112 80 67 136 108 94 98 91 134 81 87 113
99 91 89 82 104 100 136 136 137 107 111 83 51 65 62 80 57 75 84 92
101 81 74 107 54 94 83 129 88 69 81 119 63 59 56 69 72 87 74 48
45 35 55 84 77 63 69 59 67 76 95 104 79 68 50 62 51 47 50 38
31 30 36 50 38 61 65 48 42 49 53 53 63 64 50 61 81 76 91 81
74 108 116 95 89 82 74 113 103 111 89 85 107 114 130 144 135 181 113 79
83 81 106 131 125 129 119 74 98 134 126 105 125 112 96 113 107 112 120 119
103 137 101 81 60 75 110 127 68 98 104 115 128 107 129 131 111 134 119 145
145

WBR-A56B 201

372 218 181 228 110 163 241 211 138 302 229 274 274 225 165 139 147 173 124 122
121 109 118 152 174 218 119 138 146 124 151 167 128 162 134 161 201 136 158 124
115 160 94 86 141 128 134 87 111 88 67 129 114 76 104 105 122 98 69 105
104 99 77 93 97 94 136 134 134 127 104 83 42 80 58 78 54 69 91 102
92 91 84 105 67 98 82 135 90 79 73 120 56 69 59 61 70 98 71 55
47 31 64 74 87 67 64 61 65 79 88 99 90 67 50 62 47 57 47 36
32 35 41 41 33 65 64 45 44 41 58 55 63 69 41 69 78 78 95 73
85 103 116 94 86 81 85 100 103 115 86 86 115 114 133 140 142 172 112 83
85 68 108 136 128 125 119 81 98 134 122 120 125 114 89 106 123 97 123 114
95 137 102 78 56 69 106 118 73 93 95 108 122 112 128 141 108 123 115 129
128

WBR-A57A 171

116 203 146 137 143 155 174 135 106 119 149 136 128 149 160 186 212 237 288 271
192 273 179 211 142 120 102 98 101 122 158 118 136 95 151 168 160 140 127 123
127 125 125 113 96 116 97 140 64 58 63 52 76 141 118 121 131 105 86 92
115 117 120 93 126 84 92 78 91 64 66 55 51 55 58 78 120 96 49 58
64 65 79 91 79 88 74 75 77 78 64 63 60 51 56 44 45 68 68 73
62 33 33 50 28 35 53 53 42 48 30 36 34 48 35 35 40 33 30 40
33 32 41 34 36 34 41 47 33 57 46 53 42 39 33 39 49 60 44 39
58 47 49 58 55 60 66 68 45 57 63 54 43 54 60 52 48 50 60 48
41 45 47 48 40 65 60 48 47 57 66

WBR-A57B 171

106 191 156 137 133 160 168 130 105 131 149 144 118 143 158 188 221 205 255 272
196 258 187 203 145 109 106 93 107 120 160 114 136 95 142 161 123 135 126 134
118 117 121 114 96 115 93 133 78 61 65 52 81 147 110 127 131 107 93 94
124 115 115 94 114 85 83 80 96 64 69 62 41 73 65 70 116 81 45 59
65 63 73 92 83 87 79 65 77 76 60 61 72 46 59 42 39 57 73 69
74 31 40 37 36 32 48 50 42 47 36 42 32 49 30 38 41 36 30 36
37 37 40 29 26 36 33 46 53 48 38 52 53 34 39 43 45 61 32 44
50 51 51 56 52 62 61 65 53 56 66 60 36 57 60 53 49 51 60 59
51 45 58 59 56 55 48 59 43 59 79

WBR-A58A 93

384 315 265 248 227 211 231 233 194 211 310 174 114 107 101 81 105 159 199 190
164 147 227 222 251 213 208 239 201 199 178 138 87 98 105 152 163 234 221 258
169 86 125 156 178 143 140 100 113 115 86 44 47 44 78 73 92 90 115 119
91 88 76 87 119 101 109 82 112 93 99 72 58 65 93 70 89 68 80 67
84 75 97 44 35 42 62 66 65 50 57 52 101

WBR-A58B 93

340 318 237 257 233 256 224 227 217 202 324 162 112 96 138 84 90 173 182 200
171 173 235 230 251 203 214 226 169 163 172 105 88 99 137 129 131 237 218 246
137 82 129 135 148 152 183 111 127 124 82 44 49 49 79 80 92 115 113 107

66 99 82 82 110 110 120 70 117 84 91 74 61 59 91 76 87 68 78 74
71 81 95 33 43 47 51 59 61 63 48 66 72
WBR-A59A 109
383 369 261 278 207 143 110 109 97 140 160 130 173 180 163 119 153 169 170 172
269 238 241 245 201 222 227 172 160 160 161 136 161 103 105 103 149 104 85 100
137 128 113 131 160 172 125 117 112 104 117 94 86 71 43 96 87 82 64 89
69 55 50 42 46 50 69 71 78 81 63 49 54 93 89 68 44 65 71 91
73 97 86 76 83 92 62 124 94 58 67 91 79 95 62 87 75 96 89 64
96 77 80 81 109 78 93 93 98
WBR-A59B 109
325 371 298 249 203 141 125 98 90 142 156 117 199 176 158 119 168 148 171 164
256 234 222 271 229 207 217 199 167 182 164 133 158 107 90 112 136 105 82 102
128 123 115 131 157 172 128 109 125 93 119 97 77 78 49 84 91 81 62 87
60 49 50 43 53 52 66 68 72 79 49 49 61 88 92 68 47 62 78 80
75 99 87 72 80 103 52 129 93 61 82 94 84 83 73 78 91 90 78 76
95 81 64 91 86 90 104 83 90
WBR-A60A 181
500 328 333 377 294 297 315 317 376 332 370 421 289 190 239 251 446 269 318 272
303 536 475 327 312 178 309 280 205 279 243 170 212 58 97 268 170 160 151 238
122 129 145 57 60 76 100 121 69 59 65 83 143 129 121 133 122 140 146 140
166 161 127 80 95 84 84 69 73 71 55 71 65 60 44 52 43 47 25 44
38 45 49 49 46 43 47 41 56 29 22 28 27 37 38 43 53 46 39 31
39 36 25 34 31 49 39 43 40 36 30 18 24 30 42 26 43 51 35 28
27 22 24 72 88 63 42 74 75 93 53 63 53 44 74 65 37 57 68 75
93 135 74 133 81 77 54 77 44 68 92 86 65 121 88 84 108 67 64 64
64 66 60 62 72 49 51 38 39 89 52 47 116 87 60 63 84 108 151 112
144
WBR-A60B 181
511 325 318 392 286 305 322 325 386 327 389 414 286 195 222 262 423 261 317 262
322 530 496 343 315 187 303 281 201 291 259 200 200 68 96 289 163 163 172 244
122 120 142 56 51 77 91 121 79 62 66 80 152 125 122 131 117 143 147 147
159 166 126 85 102 84 78 76 67 75 51 81 51 62 47 52 50 48 25 56
27 50 45 54 45 43 49 35 57 29 31 27 25 48 43 37 64 47 43 37
34 42 33 31 42 53 39 48 43 36 33 29 25 33 36 23 44 55 33 27
20 33 23 60 93 59 46 74 71 91 57 59 52 45 74 62 43 48 70 75
90 128 68 143 91 65 57 85 46 76 88 85 61 108 87 90 109 64 52 52
75 58 67 69 64 46 50 45 51 101 63 60 118 80 65 62 74 103 147 122
134
WBR-A61A 179
170 173 143 136 128 118 109 71 84 111 145 169 130 114 101 97 131 119 91 77
104 109 96 76 91 96 112 96 89 104 98 93 106 108 134 117 84 70 101 96
72 61 86 86 86 85 77 105 70 73 89 81 76 81 87 92 90 61 67 68
57 54 65 41 72 60 56 61 67 62 56 71 50 50 52 47 58 60 45 60
52 43 57 48 55 44 34 30 43 39 42 38 35 47 37 45 44 41 48 60
57 55 58 57 61 64 43 80 53 78 47 40 61 58 47 53 42 48 40 46
56 60 60 65 61 49 49 60 69 72 67 57 37 33 60 67 69 66 61 64
53 57 66 69 57 48 77 57 45 61 49 64 54 60 51 51 58 65 83 61
56 60 69 48 67 81 41 64 73 93 71 58 46 68 73 68 58 51 77
WBR-A61B 179
178 175 155 126 129 117 101 73 72 116 155 134 118 103 99 116 115 116 96 108
98 110 104 72 84 96 101 107 110 102 109 90 117 92 120 118 86 71 98 93
69 73 87 83 82 92 80 85 87 68 88 85 75 88 77 100 86 62 58 72
61 53 65 50 70 62 54 57 74 90 62 67 50 56 50 64 51 56 50 67

40 54 58 41 53 51 33 31 42 33 42 50 38 37 31 54 36 39 56 58
55 62 52 62 57 58 59 76 60 65 48 46 56 53 51 45 44 44 46 47
53 56 58 72 51 57 54 55 67 73 57 48 39 46 58 62 71 65 62 58
54 65 67 62 68 51 78 61 47 53 47 59 62 48 59 54 64 64 75 64
57 62 69 53 61 73 61 57 76 94 70 55 45 70 77 70 62 67 100
WBR-A62A 185
158 141 210 240 168 147 127 142 139 77 89 118 120 86 141 142 128 68 96 94
70 116 87 66 83 80 102 103 71 127 82 74 93 58 73 110 74 99 53 86
68 48 96 82 54 86 57 95 60 48 64 66 69 59 64 71 66 82 86 70
86 59 74 38 72 60 72 51 50 65 69 80 70 54 71 52 80 62 124 68
46 56 74 49 51 69 58 63 79 58 49 43 36 52 77 81 66 55 62 51
60 67 70 61 50 55 59 55 71 48 47 39 38 33 49 54 59 69 45 41
45 62 53 58 97 88 75 91 82 98 73 65 91 92 84 81 64 46 85 81
81 64 84 80 88 104 91 97 109 84 52 55 92 93 110 78 82 69 60 83
110 101 78 97 101 73 98 98 77 97 87 85 103 81 54 48 57 75 84 59
75 66 84 74 78
WBR-A62B 185
163 150 222 215 172 160 130 134 149 69 106 108 133 78 141 137 125 75 98 92
67 105 99 64 82 77 97 108 67 113 82 76 96 58 66 96 69 86 65 82
59 55 100 74 65 67 66 91 62 55 71 65 77 58 51 77 51 91 72 81
63 76 65 40 59 54 66 54 49 67 75 68 73 60 65 61 73 71 117 75
47 60 67 42 55 66 56 69 79 58 50 43 42 52 77 77 64 57 66 44
59 67 73 65 50 61 56 56 62 63 50 41 34 43 52 44 69 62 57 34
41 60 60 59 91 87 74 90 83 98 78 73 83 103 80 78 74 41 88 76
76 69 81 83 88 105 95 97 104 85 65 57 88 88 97 81 88 61 55 81
110 107 72 91 100 86 95 101 83 98 88 79 107 86 49 47 57 69 95 57
72 69 87 66 77
WBR-A63A 146
230 74 102 144 249 173 165 152 120 111 153 113 105 96 89 142 64 59 78 61
99 83 81 80 90 97 130 137 136 97 117 79 128 70 46 51 48 59 56 89
69 84 50 68 70 65 40 68 54 75 79 79 68 58 63 60 84 53 43 39
37 52 57 36 47 51 50 34 40 46 42 33 31 50 33 24 26 32 28 22
26 27 46 28 32 35 21 33 18 25 57 63 53 36 59 44 63 61 45 52
52 37 50 37 34 51 40 41 29 36 40 31 31 32 32 38 56 57 42 58
47 68 63 53 55 36 52 59 69 61 51 52 42 42 45 78 153 74 62 111
72 56 56 51 77 104
WBR-A63B 146
209 73 106 143 257 189 167 155 117 101 154 113 95 110 106 131 75 70 73 68
86 86 86 91 79 94 136 157 143 94 113 69 122 79 51 62 38 89 53 91
70 82 50 69 70 69 42 68 50 79 76 80 70 62 65 59 85 45 48 41
39 52 55 36 50 53 47 38 40 44 33 42 36 44 27 35 34 28 29 29
33 28 42 27 33 33 25 33 15 30 52 64 48 39 52 50 67 59 46 51
41 49 51 31 34 46 54 41 40 34 46 32 31 33 36 42 60 47 41 55
60 68 62 57 45 45 51 61 63 65 65 55 40 49 47 90 140 89 64 106
67 64 50 59 75 101
WBR-A64A 97
259 217 149 197 199 229 167 239 168 196 177 228 319 318 294 339 412 279 403 228
325 453 353 300 248 373 233 406 269 372 455 451 528 334 220 248 141 141 189 239
175 181 214 318 151 206 220 169 225 234 182 248 178 159 132 185 188 235 225 180
145 194 173 110 150 123 155 201 129 158 142 152 140 145 106 91 162 151 138 154
213 185 249 224 252 258 266 144 127 128 122 164 174 147 96 120 106
WBR-A64B 97
249 226 150 189 190 238 171 243 162 210 166 230 307 318 294 331 433 278 400 243

346 459 342 293 254 376 220 395 281 344 450 451 540 332 228 217 134 165 215 217
157 196 218 307 153 208 206 167 236 238 187 252 201 137 135 189 176 242 219 182
129 197 180 116 132 114 174 196 132 156 144 150 141 149 103 108 140 165 139 145
192 174 253 226 260 268 242 170 106 141 138 159 172 138 90 116 112
WBR-A65A 113
263 342 312 293 175 102 242 207 215 161 188 246 119 146 209 161 242 182 143 128
124 165 75 103 144 151 121 132 107 146 88 91 109 149 259 250 191 226 202 230
192 203 278 130 93 119 143 125 158 181 143 186 195 191 193 127 136 194 205 188
169 201 192 127 174 166 134 151 160 189 94 114 154 110 122 137 120 99 147 119
157 91 97 85 92 67 107 119 133 137 116 114 115 114 98 85 94 76 104 115
68 131 129 129 133 109 102 98 120 130 193 171 140
WBR-A65B 113
285 343 315 290 175 96 237 210 227 163 174 254 111 149 211 161 217 191 144 125
115 168 77 101 142 158 108 127 110 147 85 95 102 153 269 246 195 241 195 231
189 198 291 127 86 119 140 139 157 185 166 172 203 192 188 130 132 193 209 180
182 186 194 129 173 168 133 163 145 168 101 109 152 112 122 132 129 96 139 121
159 90 84 88 104 65 118 125 123 139 121 117 104 127 91 85 94 70 102 120
74 121 137 131 135 114 98 110 116 125 185 136 135
WBR-A66A 91
276 212 136 179 176 134 145 144 105 152 140 136 95 100 121 99 122 115 131 83
114 116 157 86 87 86 84 77 100 113 136 149 131 140 127 131 93 90 119 77
98 129 109 120 119 154 143 129 145 142 169 145 146 117 122 119 119 112 119 146
171 194 185 208 175 223 190 154 185 155 189 146 194 181 166 189 175 141 241 167
166 196 189 185 138 91 110 107 146 168 179
WBR-A66B 91
267 207 140 179 180 138 156 134 111 133 149 131 103 106 123 100 131 117 135 99
99 124 137 100 83 87 91 67 103 122 138 170 144 125 117 129 107 90 99 85
94 134 107 128 119 138 152 138 136 143 163 142 156 114 129 116 117 103 126 149
171 198 178 181 183 230 189 150 192 151 198 139 202 178 170 203 171 150 248 163
159 202 203 190 124 91 117 116 146 145 163
WBR-A67A 63
393 642 390 501 142 226 339 221 147 207 206 210 176 121 196 168 127 206 224 251
216 201 129 95 90 94 111 159 150 144 136 129 150 140 148 171 159 138 97 95
146 156 209 166 150 177 190 140 132 139 160 170 116 197 139 157 189 136 113 178
163 171 187
WBR-A67B 63
411 623 401 490 146 241 273 228 144 204 214 201 190 127 195 166 148 204 235 241
186 211 160 75 94 96 104 157 149 139 134 128 146 153 152 175 152 128 100 83
131 150 198 140 157 173 175 149 146 139 153 165 117 191 142 165 181 128 114 168
166 176 190
WBR-A68A 112
185 240 93 147 226 144 147 147 153 166 110 123 135 160 244 186 196 185 195 198
201 198 267 146 133 168 205 170 174 229 194 236 232 185 206 209 171 267 217 223
157 167 183 147 154 151 155 173 156 173 130 132 141 137 163 189 179 132 154 158
215 113 112 115 106 85 142 170 173 179 162 151 145 123 115 109 140 116 108 125
107 153 124 139 130 114 114 121 130 131 145 102 120 105 113 110 104 150 192 241
200 202 205 205 154 128 160 159 147 150 202 170
WBR-A68B 112
239 224 126 148 204 160 141 154 144 166 101 119 114 152 215 219 187 190 192 195
215 204 264 144 120 151 188 177 156 242 204 270 198 193 197 200 180 247 246 202
168 177 179 182 195 155 149 162 141 193 140 135 137 142 159 201 184 139 155 151
208 128 105 104 109 98 127 180 185 178 172 151 138 119 111 114 143 104 114 116
93 149 127 148 141 111 112 121 139 126 144 103 116 108 121 103 92 147 176 214

212 191 198 199 159 126 156 161 152 143 192 145
WBR-A69A 92
205 161 189 284 208 189 214 248 202 170 206 218 223 187 200 133 122 156 147 245
161 196 121 168 180 182 102 109 124 116 89 137 130 156 170 147 160 126 132 133
101 107 101 123 138 123 137 128 141 146 149 163 135 164 156 150 120 140 111 123
98 104 160 222 219 198 197 204 238 171 154 166 196 160 138 179 150 163 174 161
116 189 140 138 182 159 146 133 126 132 123 145
WBR-A69B 92
226 154 199 273 204 181 231 264 173 173 225 198 231 173 195 127 119 177 135 251
180 174 125 169 183 176 108 106 115 121 98 124 158 143 169 144 153 127 137 123
105 124 99 119 133 118 144 119 139 153 144 161 135 168 151 152 123 141 109 119
108 103 164 206 231 192 196 219 219 189 154 166 189 146 139 181 158 153 175 161
128 182 143 148 180 151 141 141 116 128 131 151
WBR-A70A 89
265 241 276 327 234 239 156 221 255 265 242 210 213 189 228 259 222 227 215 274
161 176 163 151 163 240 328 116 163 134 200 114 141 231 194 133 171 160 176 180
174 174 164 161 177 161 185 175 126 163 100 136 124 137 168 142 166 156 171 164
178 230 217 202 245 144 144 192 228 241 182 159 215 212 173 163 169 131 169 109
219 162 230 221 156 142 196 132 111
WBR-A70B 89
260 236 282 323 224 214 170 221 256 254 253 217 205 189 224 256 238 222 224 262
172 174 162 136 150 227 318 131 165 143 208 99 141 220 198 133 165 171 167 184
168 173 170 144 188 158 191 176 130 174 104 129 132 148 198 167 158 159 176 153
190 227 214 206 233 145 149 195 216 239 184 151 223 219 166 163 162 138 160 129
186 155 217 213 150 141 203 153 113
WBR-A71A 104
150 143 193 182 157 179 229 195 144 187 164 158 149 195 150 123 132 162 137 151
159 179 146 154 156 210 135 153 176 145 127 141 128 78 111 126 151 97 115 159
125 153 193 187 193 169 157 163 169 164 165 133 134 155 145 149 68 118 128 161
166 143 153 127 141 188 227 227 212 189 130 120 103 126 112 144 125 148 155 159
158 125 162 141 196 122 200 201 238 210 117 158 193 138 113 121 142 140 114 135
131 93 132 189
WBR-A71B 104
177 133 203 175 158 177 218 190 163 235 183 156 139 194 164 120 138 159 147 121
188 161 148 168 159 211 144 143 181 144 136 131 147 78 123 124 150 77 110 140
118 154 193 196 187 182 143 171 167 172 167 113 155 132 135 151 78 105 129 168
152 145 160 140 137 181 220 211 197 183 140 105 120 124 133 135 126 156 142 150
149 132 173 127 195 120 197 193 211 199 128 143 184 152 109 134 138 136 110 130
131 107 132 165
WBR-A72A 74
231 356 483 335 338 522 413 534 451 218 151 137 114 110 106 229 330 468 333 151
228 139 173 232 184 171 141 147 202 239 201 95 107 105 134 184 148 135 109 111
96 109 160 130 138 127 144 97 201 139 240 183 122 134 155 132 179 218 371 535
406 530 283 366 301 367 386 455 373 477 499 404 393 265
WBR-A72B 74
235 349 474 326 324 553 407 534 453 216 148 137 122 113 105 237 330 457 316 170
223 131 173 204 184 168 152 159 212 235 218 79 107 101 135 177 147 133 104 114
99 107 161 132 140 132 137 101 199 138 240 183 124 131 155 141 171 220 370 554
407 493 282 368 316 361 382 456 374 479 500 384 405 234
WBR-A73A 112
500 208 375 360 649 615 557 132 185 411 305 202 149 323 204 165 240 433 620 307
116 156 231 157 49 40 74 138 192 271 140 122 107 270 351 209 222 114 161 91
93 152 69 86 156 190 324 364 233 136 137 181 213 271 271 355 321 441 222 554

296 309 235 181 194 209 217 239 198 125 99 254 250 236 219 329 212 192 151 157
168 158 197 153 194 177 228 156 318 215 298 322 243 318 373 223 233 205 348 204
283 184 262 215 348 430 540 363 406 484 375 369
WBR-A73B 112
455 234 360 399 635 574 583 175 176 411 272 205 141 317 204 160 256 451 559 299
131 145 224 160 44 41 77 130 195 255 143 118 118 278 345 215 221 111 136 99
96 151 76 73 163 203 324 348 232 133 139 179 216 260 276 325 319 445 234 604
291 298 221 183 191 209 214 256 169 120 102 251 252 222 216 304 201 204 143 150
165 169 210 155 190 193 220 160 318 214 293 325 246 313 355 236 235 208 347 204
292 165 273 206 367 410 547 363 425 447 387 362
WBR-A74A 108
242 168 203 283 200 155 174 242 286 209 223 148 171 155 164 234 169 178 195 184
140 160 170 155 143 189 161 83 105 160 108 162 176 164 88 136 104 122 76 80
108 97 80 102 106 122 101 103 87 82 97 89 78 92 72 82 82 76 109 119
100 96 115 108 140 123 166 175 142 178 127 110 97 102 125 130 175 112 159 184
145 152 117 115 145 137 91 157 131 136 137 114 116 146 128 102 130 142 132 144
106 110 93 92 114 117 111 106
WBR-A74B 108
234 172 209 274 197 153 174 248 296 213 224 157 169 159 170 250 171 174 181 167
145 171 166 138 142 190 153 85 118 150 108 166 199 154 94 124 104 118 80 89
121 92 79 105 113 114 104 107 87 83 93 90 83 93 75 81 87 68 120 115
100 101 117 111 134 129 163 166 146 166 136 131 113 98 121 129 169 112 167 170
155 148 116 115 144 138 92 155 133 131 148 109 118 149 126 100 127 147 133 148
103 112 91 93 106 118 110 105
WBR-A75A 124
120 188 256 178 136 118 161 174 189 163 145 211 201 198 190 176 167 191 189 250
171 190 269 210 183 183 235 210 204 223 248 165 138 175 125 177 177 207 129 175
133 166 105 108 107 103 81 134 189 194 182 150 167 166 121 135 118 145 96 100
106 99 147 134 157 143 124 123 137 159 184 161 185 181 150 147 149 91 199 212
197 206 237 228 204 196 155 151 158 159 101 151 144 136 172 135 152 152 139 101
143 166 156 183 127 160 101 95 105 125 118 95 115 108 85 85 119 102 81 101
88 95 90 134
WBR-A75B 124
116 154 270 196 126 122 153 180 193 186 125 206 214 193 185 178 193 158 168 269
184 193 246 201 161 192 225 207 196 230 252 177 157 178 129 187 189 207 150 163
112 180 93 100 119 107 95 132 200 205 190 156 152 170 116 133 119 144 108 98
116 89 156 123 157 148 114 128 145 159 183 167 179 172 151 146 147 97 191 213
197 214 225 209 206 188 167 158 164 168 100 153 132 148 162 132 153 157 139 100
146 169 161 180 125 161 101 93 107 122 122 94 113 114 84 84 119 98 83 105
81 100 93 121
WBR-A76A 66
153 131 194 185 161 146 135 116 123 112 111 81 73 120 181 141 115 115 124 154
184 128 113 134 135 167 142 110 112 132 123 143 109 135 225 190 124 90 165 113
119 149 150 156 146 116 172 152 197 176 211 167 146 166 207 133 128 141 189 193
200 185 203 224 148 182
WBR-A76B 66
139 133 209 179 159 164 124 106 124 104 109 80 82 115 186 143 113 113 132 151
171 121 108 130 118 163 131 111 110 137 163 141 112 126 226 180 118 90 137 108
124 138 137 156 137 119 143 139 188 178 218 174 144 168 212 166 111 144 181 195
213 178 215 231 148 178
WBR-A77A 68
555 267 320 362 382 317 205 211 170 197 255 278 312 254 221 179 236 182 229 182
261 261 264 279 402 354 248 207 216 306 270 233 315 319 341 240 206 250 263 464

547 413 592 516 422 565 411 367 574 593 583 423 468 501 386 282 299 370 391 399
299 455 500 363 385 390 412 306
WBR-A77B 68
552 269 324 368 373 322 201 213 166 162 269 265 295 301 243 159 235 192 231 183
265 259 284 264 378 340 253 213 184 334 285 251 313 313 362 234 208 245 266 466
529 401 566 518 413 561 417 370 538 542 595 452 499 525 381 298 333 381 400 441
310 497 501 378 371 378 401 302
WBR-A79A 54
366 239 300 228 192 123 117 108 84 103 105 116 107 123 116 98 71 45 42 62
47 125 94 104 100 88 100 66 61 43 47 95 183 212 129 152 98 136 158 131
184 195 130 305 221 104 200 156 219 203 161 159 66 120
WBR-A79B 54
371 243 253 239 230 116 112 97 92 95 116 110 113 126 114 95 76 42 48 58
59 127 83 97 115 94 98 77 57 42 40 103 184 213 134 145 95 129 163 122
199 183 133 310 198 107 197 161 226 203 157 160 69 118

APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

sequence is the average of these, 0.55mm. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

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

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

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

Various estimates have been made and used for the average number of sapwood rings in mature oak trees (English Heritage 1998). A fairly conservative range is between 15 and 50 and that this holds for 95% of mature oaks. This means, of course, that in a small number of cases there could be fewer than 15 and more than 50 sapwood rings. For example, the core CRO-A06 has only 9 sapwood rings and some have obviously been lost over time – either they were removed originally by the carpenter and/or they rotted away in the building and/or they were lost in the coring. It is not known exactly how many sapwood rings are missing, but using the above range the Laboratory would estimate between a minimum of 6 (=15-9) and a maximum of 41 (=50-9). If the last ring of CRO-A06 has been dated to 1500, say, then the estimated felling-date range for the tree from which it came originally would be between 1506 and 1541. The Laboratory uses this estimate for sapwood in areas of England where it has no prior information. It

also uses it when dealing with samples with very many rings, about 120 to the last heartwood ring. But in other areas of England where the Laboratory has accumulated a number of samples with complete sapwood, that is, no sapwood lost since felling, other estimates in place of the conservative range of 15 to 50 are used. In the East Midlands (Laxton *et al* 2001) and the east to the south down to Kent (Pearson 1995) where it has sampled extensively in the past, the Laboratory uses the shorter estimate of 15 to 35 sapwood rings in 95% of mature oaks growing in these parts. Since the sample CRO-A06 comes from a house in Cropwell Bishop in the East Midlands, a better estimate of sapwood rings lost since felling is between a minimum of 6 (=15-9) and 26 (=35-9) and the felling would be estimated to have taken place between 1506 and 1526, a shorter period than before. Oak boards quite often come from the Baltic region and in these cases the 95% confidence limits for sapwood are 9 to 36 (Howard *et al* 1992, 56).

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

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

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

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

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

t-value/offset Matrix

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

Bar Diagram

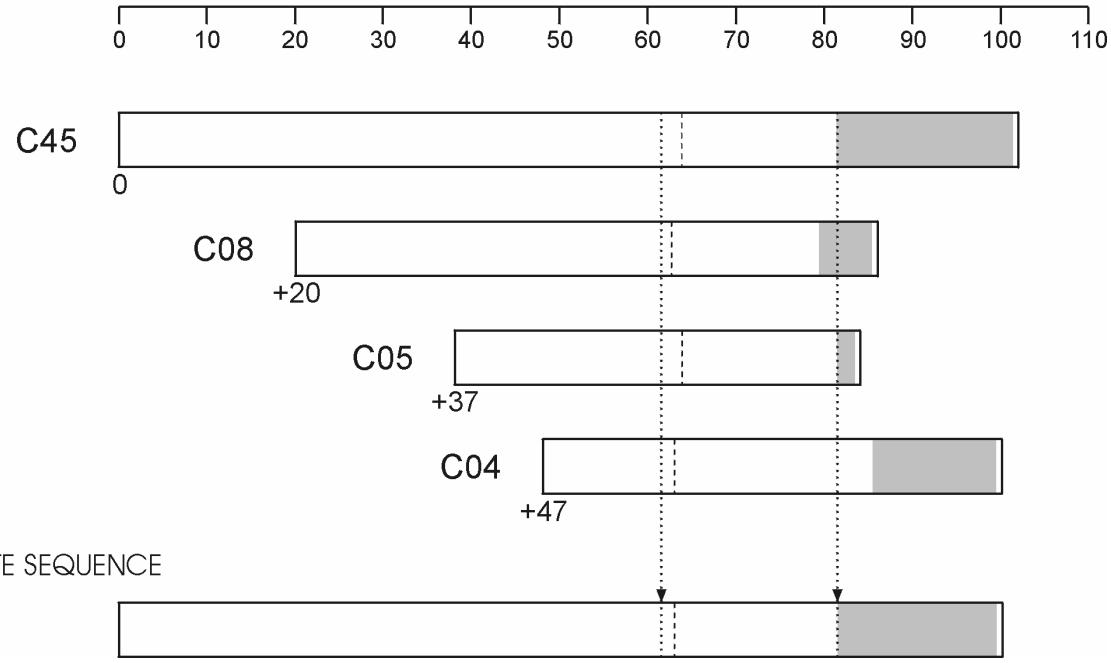


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

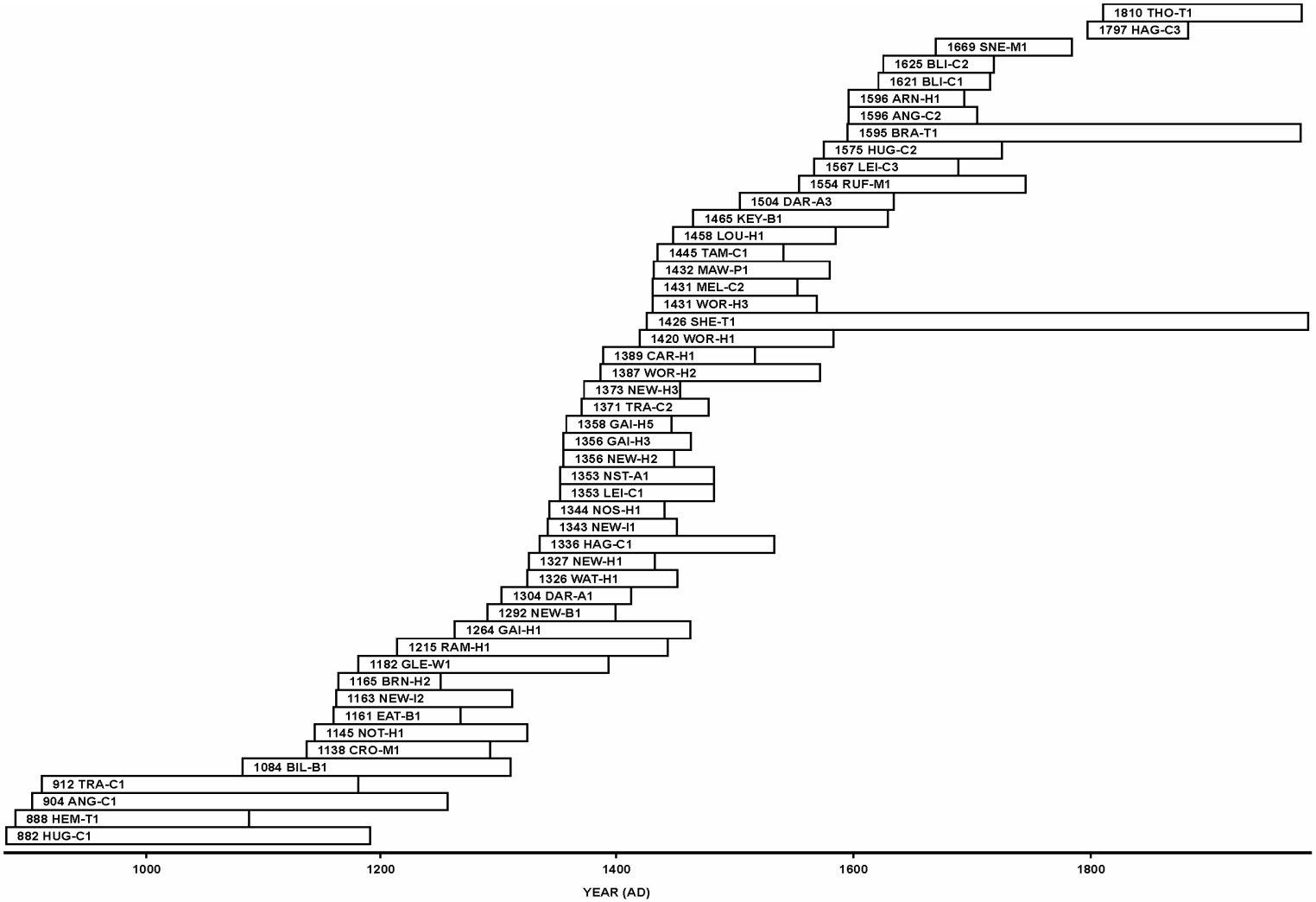
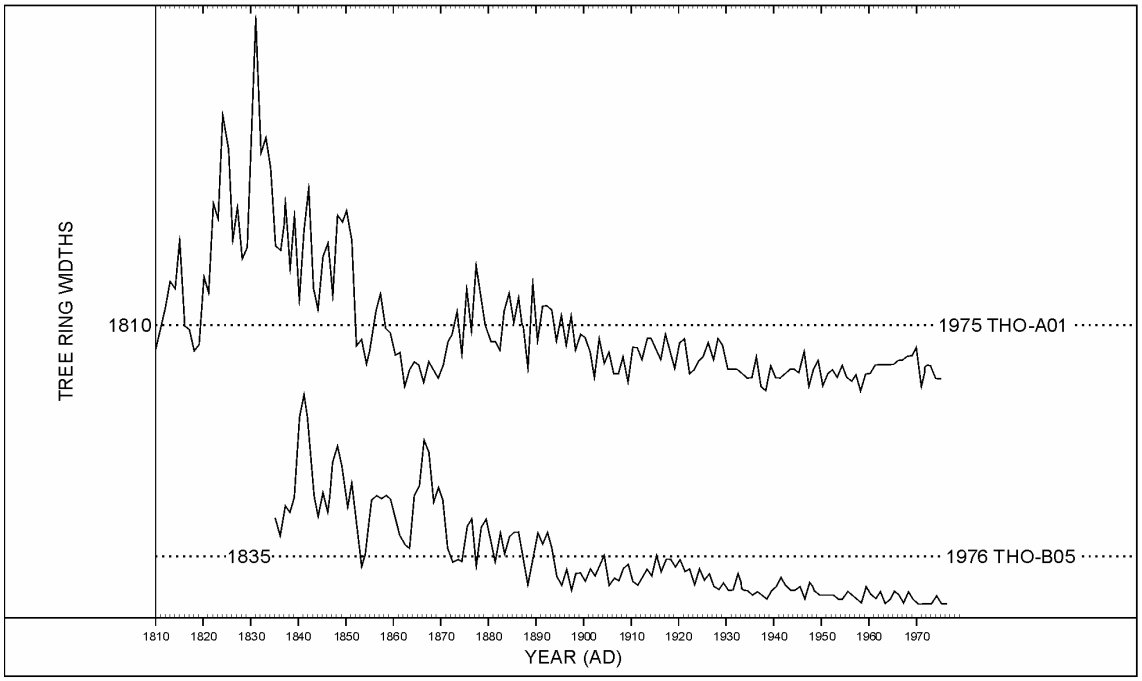


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

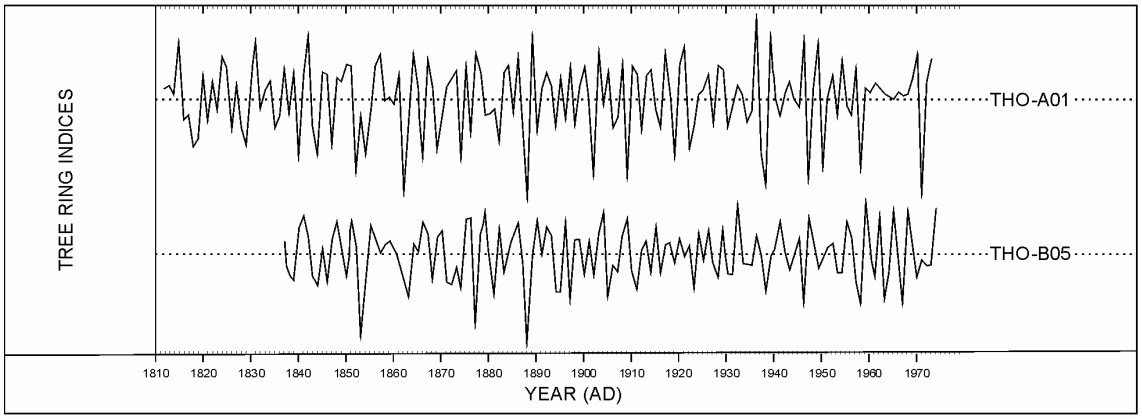


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

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

The growth trends have been removed completely

References

Baillie, M G L, and Pilcher, J R, 1973 A simple cross-dating program for tree-ring research, *Tree-Ring Bull*, **33**, 7–14

English Heritage, 1998 *Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates*, London

Hillam, J, Morgan, R A, and Tyers, I, 1987 Sapwood estimates and the dating of short ring sequences, *Applications of tree-ring studies*, BAR Int Ser, **3**, 165–85

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1984–95 Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect*, **15–26**

Hughes, M K, Milson, S J, and Legett, P A, 1981 Sapwood estimates in the interpretation of tree-ring dates, *J Archaeol Sci*, **8**, 381–90

Laxon, R R, Litton, C D, and Zainodin, H J, 1988 An objective method for forming a master ring-width sequence, *P A C T*, **22**, 25–35

Laxton, R R, and Litton, C D, 1988 *An East Midlands Master Chronology and its use for dating vernacular buildings*, University of Nottingham, Department of Archaeology Publication, Monograph Series III

Laxton, R R, and Litton, C D, 1989 Construction of a Kent master dendrochronological sequence for oak, AD 1158 to 1540, *Medieval Archaeol*, **33**, 90–8

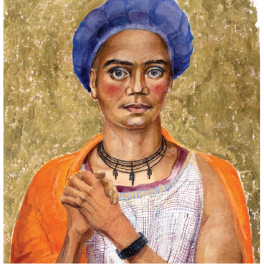
Laxton, R R, Litton, C D, and Howard, R E, 2001 *Timber: Dendrochronology of Roof Timbers at Lincoln Cathedral*, Engl Heritage Res Trans, 7

Litton, C D, and Zainodin, H J, 1991 Statistical models of dendrochronology, *J Archaeol Sci*, **18**, 29–40

Miles, D W H, 1997 The interpretation, presentation and use of tree-ring dates, *Vernacular Architect*, **28**, 40–56

Pearson, S, 1995 *The Medieval Houses of Kent, an Historical Analysis*, London

Rackham, O, 1976 *Trees and Woodland in the British Landscape*, London



ENGLISH HERITAGE RESEARCH DEPARTMENT

English Heritage undertakes and commissions research into the historic environment, and the issues that affect its condition and survival, in order to provide the understanding necessary for informed policy and decision making, for sustainable management, and to promote the widest access, appreciation and enjoyment of our heritage.

The Research Department provides English Heritage with this capacity in the fields of buildings history, archaeology, and landscape history. It brings together seven teams with complementary investigative and analytical skills to provide integrated research expertise across the range of the historic environment. These are:

* *Aerial Survey and Investigation*
* *Archaeological Projects (excavation)*
* *Archaeological Science*
* *Archaeological Survey and Investigation (landscape analysis)*
* *Architectural Investigation*
* *Imaging, Graphics and Survey (including measured and metric survey, and photography)*
* *Survey of London*

The Research Department undertakes a wide range of investigative and analytical projects, and provides quality assurance and management support for externally-commissioned research. We aim for innovative work of the highest quality which will set agendas and standards for the historic environment sector. In support of this, and to build capacity and promote best practice in the sector, we also publish guidance and provide advice and training. We support outreach and education activities and build these in to our projects and programmes wherever possible.

We make the results of our work available through the Research Department Report Series, and through journal publications and monographs. Our publication Research News, which appears three times a year, aims to keep our partners within and outside English Heritage up-to-date with our projects and activities. A full list of Research Department Reports, with abstracts and information on how to obtain copies, may be found on www.english-heritage.org.uk/researchreports

For further information visit www.english-heritage.org.uk

ENGLISH HERITAGE