Historic England

Scientific Dating

Lancaster Castle, Castle Park, Lancaster

Tree-ring Analysis of Oak and Pine Timbers in the Keep and Gatehouse

Alison Arnold, Robert Howard and Cathy Tyers

Discovery, Innovation and Science in the Historic Environment

Research Report Series no. 35-2016

Research Report Series 35-2016

LANCASTER CASTLE, CASTLE PARK, LANCASTER

TREE-RING ANALYSIS OF OAK AND PINE TIMBERS IN THE KEEP AND GATEHOUSE

Alison Arnold, Robert Howard and Cathy Tyers

NGR: SD 473 618

ISSN 2059-4453 (Online)

For more information write to Res.reports@HistoricEngland.org.uk
or mail: Historic England, Fort Cumberland, Fort Cumberland Road, Eastney, Portsmouth PO4 9LD

SUMMARY
Dendrochronological analysis was undertaken on 37 of the 38 structural oak timbers sampled in the Keep and Gatehouse, as well as the 10 ring series measured *in-situ* on oak boards from doors in the Keep. Forty-four of the ring series cross-matched to produce an oak site chronology, its 455 rings dated as spanning AD 950–1404. The 44 dated ring series, 36 from structural timbers and 8 from door boards, are clearly broadly coeval and represent trees felled in the late-fourteenth and early-fifteenth centuries. Interpretation indicates that the dated structural oak timbers in the undercroft in the Keep were felled in the AD 1380s, whilst those from the Great Hall in the Keep were felled potentially slightly later, towards the end of the fourteenth century or just possibly the very early-fifteenth century. The dated structural oak timbers in the Gatehouse were all probably felled in, or around, AD 1404. The dated horizontal oak boards associated with two cell doors in the Keep appear to be coeval and interpretation indicates that they were all probably felled after AD 1371 and could thus be associated with the late-fourteenth or very early-fifteenth century felling date ranges identified from the structural timbers.

Dendrochronological analysis was also undertaken on 22 of the 23 structural pine timbers sampled in the Keep. However this analysis was unsuccessful with none of the ring series being successfully dated.

CONTRIBUTORS
Alison Arnold, Robert Howard and Cathy Tyers

ACKNOWLEDGEMENTS
Mr Graeme Chalk, Head of Project Management for the Duchy of Lancaster, and other members of his team, are thanked for their constant help and cooperation, along with Chris Selkirk, Events Manager at Lancaster Castle, who managed to accommodate several episodes of sampling during a particularly busy schedule. Thanks are due to Alan Davies, Architect Director of Building Design Projects, for his constant help in facilitating access and sampling, along with the staff of Castlegate Security who were also very helpful. Our thanks must also go to Stephen Gardner, Senior Conservation Officer with Lancaster City Council, and Nigel Neil, Consulting Archaeologist, for their help not only with providing plans, drawings, copies of reports, and much background information besides, but they also very kindly assisted with the moving of tools and equipment during the various site visits. Finally Andrew Davison, Historic England Principal Inspector of Ancient Monuments, and Shahina Farid, of the Historic England Scientific Dating Team, are thanked for, respectively, requesting and facilitating this programme of tree-ring analysis.

ARCHIVE LOCATION
Lancashire Historic Environment Record
Lancashire County Council Planning and Environment
PO Box 100,
County Hall, Pitt Street
Preston PR1 8RD

DATE OF INVESTIGATION
2015–16

CONTACT DETAILS
Alison Arnold and Robert Howard
Nottingham Tree-ring Dating Laboratory
20 Hillcrest Grove
Sherwood
Nottingham NG5 1FT
0115 960 3833
roberthoward@tree-ringdating.co.uk
alisonarnold@tree-ringdating.co.uk

Cathy Tyers
Historic England
1 Waterhouse Square
138–142 Holborn
London EC1N 2ST
0207 973 3000
cathy.tyers@historicengland.org.uk

CONTENTS

INTRODUCTION

Lancaster Castle occupies a city-centre hilltop location on the site of three successive Roman forts (Figs 1a–c) and overlooking a crossing of the River Lune. The early history of the Castle is unclear but it may have been founded in the eleventh century. In AD 1164, the Honour of Lancaster, including the castle, came under royal control and in AD 1322 and AD 1389 the Scots invaded England, progressing as far as Lancaster and damaging the Castle. It did not see military action again until the English Civil War, after which time its use as a prison, which had begun in AD 1196, became increasingly important.

The site now comprises of an extensive group of historic structures, including the twelfth century Keep, the fourteenth century Witches' Tower, the fifteenth century Gatehouse, and the Female Penitentiary, which dates from the early years of the nineteenth century. The castle buildings are owned by the Duchy of Lancaster, which leases part of the structure to Lancashire County Council who operates a Crown Court in part of the building. Until 2011 the majority of the buildings were leased to the Ministry of Justice as Her Majesty's Prison Lancaster at which time they were returned to the Duchy's ownership. The Castle is a grade I listed building, with the area to the north of it designated as a Scheduled Monument. Of primary interest to this programme of analysis are the Keep and the Gatehouse (Figs 2–3), both of these buildings having been the subject of archaeological survey and reports (Guy 2015). The following information is based on Guy (2015) and Neil (*pers comm*).

The Keep

The original Keep appears to have been a rather squat building, 24m by 24m by 17m high. Outwardly it appeared three-storeys high, as marked by string-courses and offsets, but contained only two floors including the undercroft. There remain traces of the original lower height battlements in the discolouration of the stone work, particularly on the east façade, and a photogrammetric survey of the façades seems to indicate three or four building seasons or breaks, marked by the use of different sized or different quarried stones. The building was subsequently heightened by one storey sometime after AD 1400. The Keep is double-piled with a central east-west spine wall dividing the spaces north and south equally. These spaces are presently covered by two parallel east–west hipped slate roofs.

The south side of the undercroft has been divided into rooms by more recent walls, including those associated with modern brick-built cells. Running east–west through these rooms is an oak-timbered support that took the weight of the floor of the Great Hall above, supporting the north–south joists of the Hall's floor that rested on it. The support comprises a line of three stout posts running

down the centre of southern half of the undercroft, these supporting a horizontal bridging beam made of a number of large timbers scarfed together. There are slightly curved braces rising from the east and west sides of the posts to the bridging beam (Fig 4a). This support has been thought to be of Tudor origin, re-using timbers and replacing a similar structure. There may have been a comparable arrangement in the northern half of the undercroft, but here the Keep was roofless for 150 years after the Civil War and the timber work is no longer extant.

The undercroft retains three small solitary confinement cells, each one closed by a single heavy wooden door. The doors are constructed of five thick vertical oak boards to their front or outer faces, these being backed by seven or sometimes eight horizontal boards of similar thickness forming the rear or inner faces. The boards are held together by studs, bolts, and large nails set in a semi-random pattern (Fig 4b–c). The date of these doors is uncertain. It is believed that they may be of some antiquity, though there seems to be no record of when the cells were first formed.

The Great Hall within the Keep immediately above the undercroft, was originally a large 'double-height' first-floor room running up through two storeys, typical of Norman hall-keeps as originally configured. A third floor then appears to have been inserted within the Great Hall, possibly between *c* AD 1360–1430, with inserted stone corbels and full-width timber cross-beams with arched bracing (Fig 4d). This created a three-floor/three-storey building and effectively lowered the height of the hall. This lowering was later followed by the insertion of a replacement roof structure, believed to date to *c* AD 1800 (Fig 4e). An additional fourth floor was inserted into the new roof space in a later period, probably the twentieth century.

The Gatehouse

The Gatehouse is believed to have been built as late as AD 1405, the arms of Henry V, as Prince of Wales, appearing on a shield above the gateway. It is therefore one of the latest military works in the castles of the Duchy and the last of a series of gatehouses which owed their origin to the lords of the House of Lancaster.

Internally each of the two upper floors contains three rooms, one in the central block of the gatehouse above the gate-passage, the others in the towers at the sides. The rooms run parallel with each other from front to rear. These rooms are all similarly large and lofty and their wooden ceilings still retain traces of colour. All have flat timbered-ceilings, the common east–west joists supported by original north–south main beams on short posts rising from stone corbels with arched braces between post and main beam (Figs 4f–g).

SAMPLING

Dendrochronological analysis was requested by Andrew Davison in relation to listed building consent for proposed works. It was hoped to obtain, if possible, independent dating evidence and hence inform advice and enhance understanding of the Keep and the Gatehouse. The assessment of dendrochronological potential was focussed on the oak timber support structure to the undercroft, a series of oak cell doors within the undercroft, and the oak timbers of the Great Hall above but also on the pine timbers of the double-pile roof of the Keep. In the Gatehouse the assessment focussed on timbers accessible from the first and second floor rooms.

Following the assessment a programme of sampling was agreed and undertaken. Core samples were obtained from a total of 61 structural timbers, each sample being given the code LAN-C (for Lancaster Castle) and numbered 01–61 (Table 1). From the Keep 11 oak samples (LAN-C01–LAN-C11) were obtained from the support timbers of the undercroft (Fig 5), 12 oak samples (LAN-C12–LAN-C23) were obtained from the timbers of the Great Hall (Figs 6a–d), and a further 23 pine samples (LAN-C24–LAN-C46) were obtained from the north and south roofs (Figs 7a–i). From the Gatehouse a further 15 core samples were obtained; seven (LAN-C47–LAN-C53) from the first floor rooms (Figs 8a–f) and eight (LAN-C54–LAN-C61) from the second floor rooms (Fig 9a–f).

In addition to the samples obtained from the structural timbers, the exposed cross-sectional surface on 10 boards from two of the three doors (the middle and southern ones) to the cells in the undercroft of the Keep was measured *in-situ* (Figs 10a–d). These ring series were given the code LAN-D (for Lancaster 'Doors') and numbered 01–10 (Table 1). Although some of the other boards to the doors were assessed as having sufficient numbers of rings for dendrochronological analysis, the exposed cross-sectional surface was either too severely decayed or split for reliable, but minimal, preparation (particularly the lower horizontal boards and the outer vertical boards to the closing sides of the doors) or was obscured by the deep stone lintels of the doorways (the vertical boards to the hinged sides of the doors). Such boards were therefore excluded from this programme of analysis.

ANALYSIS AND RESULTS

Each of the core samples obtained was prepared by sanding and polishing. It was seen at this point that one pine sample, LAN-C39, and one oak sample, LAN-C52, had less than the minimum number of rings here deemed necessary for reliable dating, respectively 70 rings and 50 rings, and they were rejected from this programme of analysis. The annual growth ring widths of the

remaining 59 cores samples were measured and the data for each ring width series is given at the end of this report.

The ring width series from the 37 measured oak core samples and the ring width series from the oak door boards were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix). This comparative process resulted in the production of two oak site chronologies. The first oak site chronology, LANCSQ01 (Fig 11a), comprises 44 samples from both structural timbers and door boards, and is 455 rings long. The second oak site chronology, LANCSQ02 (Fig 11b), comprises two samples, each of them from the boards of a different cell door. This site chronology is 120 rings long.

The data of the 22 measured pine core samples were also compared with each other, this analysis producing four pine site chronologies, LANCSQ03–06, these comprising from two to five samples (Fig 12a–d).

Each of the two oak chronologies and the four pine site chronologies was then compared respectively to an extensive corpus of either oak or pine reference material. This process indicated a consistent and repeated cross-match only for oak site chronology LANCSQ01 when its 455 rings span the years AD 950–1404. The evidence for this dating is given in Table 2. The second oak site chronology, LANCSQ02, and all four pine site chronologies, remain undated.

The two oak site chronologies and each of the four pine site chronologies was then respectively compared to the remaining measured but ungrouped oak or pine samples, but there was no further cross-matching. Each of the measured but ungrouped oak and pine samples was then compared individually with the full corpus of its respective reference material, but again there was no conclusive cross-matching and all these samples must remain undated for the moment.

This sampling and analysis may be summarised as follows:

	Number of samples	Number of rings	Date span AD (where dated)
LANCSQ01 (oak)	44	455	950–1404
LANCSQ02 (oak)	2	120	---
LANCSQ03 (pine)	5	171	---
LANCSQ04 (pine)	2	161	---
LANCSQ05 (pine)	2	97	---
LANCSQ06 (pine)	2	184	---
Ungrouped/undated	1 oak 11 pine	---	---
Unmeasured	1 oak 1 pine	---	---

INTERPRETATION

The 44 dated oak timbers (structural and door boards) are clearly broadly coeval but the variation in the date of the heartwood/sapwood boundary ring (where it exists), from relative position 392 (AD 1341) on samples LAN-C04 and LAN-C16 to relative position 441 (AD 1390) on samples LAN-C51 and LAN-C60 (Fig 11a), indicates that the timbers come from trees felled at different times rather than representing a single episode of felling. The trees utilised have either been felled over an extended period of time or, as seems more likely, represent a series of discrete periods of felling that occurred at slightly different dates.

Felling date ranges have been calculated, where appropriate, using the estimate that 95% of mature oak trees in this region have 15–40 sapwood rings.

The Keep

Undercroft cell door boards (LAN-D01–LAN-D10)

None of the eight dated samples from the boards of the doors retain complete sapwood (the last growth ring produced by the tree before it was felled), and it is thus not possible to provide a precise felling date for any of these timbers. In the absence of any trace of sapwood it is also not possible to indicate a likely felling date range for the timbers. However, the overall level of similarity between the ring series from these eight dated boards is such as to suggest that they are likely to be coeval and hence, given that the latest measured ring on any of these samples is dated AD 1356 (LAN-D08), and allowing for a minimum of 15 sapwood rings, that they were all probably felled after AD 1371.

Undercroft structural timbers (LAN-C01–LAN-C11)

Nine of the 11 dated structural timbers appear to be broadly coeval, the heartwood/sapwood boundary on them varying by 27 years from relative position 392 (AD 1341) on sample LAN-C04, to relative position 419 (AD 1368) on sample LAN-C11. Such a variation suggests that although they are likely to represent a single episode of felling, this episode possibly spanned more than a single year. The average date of the heartwood/sapwood boundary of these samples is AD 1354 and thus, allowing for a last measured ring of AD 1370 on sample LAN-C03, these timbers have an estimated felling date in the range AD 1371–94. However one of these samples, LAN-C03, does have complete sapwood but unfortunately, due to compaction of the outer portion, only the first 19 sapwood rings could be measured. It is estimated that the unmeasured 10mm section of the core contains a further *c* 10–15 sapwood rings. Given that the last extant sapwood ring on this sample is dated AD 1370, such an estimate

would suggest that the source tree was felled in the AD 1380s. It is therefore likely that all nine of these timbers were felled at, or about, the same time.

The remaining two timbers (LAN-C06 and LAN-C07) have significantly earlier outermost measured heartwood rings, AD 1165 and AD 1162 respectively. They therefore could represent an earlier felling episode but, bearing in mind the longevity of some of the other trees, it seems more likely that they simply represent the inner sections of very heavily trimmed trees.

Great Hall (LAN-C12–LAN-C23)

The 12 dated Great Hall timbers also appear to be broadly coeval. Taken overall, the average date of the heartwood/sapwood boundary is AD 1364, which would give these timbers an estimated felling date in the range AD 1379–1404. However, the date of the heartwood/sapwood boundary on these samples ranges from relative position 392 (AD 1341) on sample LAN-C16 to relative position 429 (AD 1378) on sample LAN-C21, a variation of 37 years. Such a wide variation suggests that the felling episode represented by these 12 samples may span a number of years, or may be the product of a number of discrete different felling phases undertaken over a longer period of time. Thus the actual felling date of individual timbers may vary somewhat within the range AD 1379–1404.

The Gatehouse

First floor timbers (LAN-C47–LAN-C53)

All six of the dated timbers appear to be coeval. The date of the heartwood/sapwood boundary varies from relative year 429 (AD 1378) on samples LAN-C47 and LAN-C50 to relative year 441 (AD 1390) on sample LAN-C51, with the average heartwood/sapwood boundary date being AD 1383. This variation in date is more in keeping with timbers being felled as part of a single short episode of felling. However one sample (LAN-C50) retains complete sapwood. This means that it retains the last ring produced by the tree represented before it was felled. The last sapwood ring, and thus the felling of the tree, is dated to AD 1404. The remaining five timbers were also likely to have been felled in, or around, AD 1404.

Second floor timbers (LAN-C54–LAN-C61)

All seven of the dated timbers appear to be coeval. The date of the heartwood/sapwood boundary also varies from relative year 429 (AD 1378) on sample LAN-C54 to relative year 441 (AD 1390) on sample LAN-C60, with the average heartwood/sapwood boundary date also being AD 1383. This variation

in date is again more in keeping with timbers being felled as part of a single short episode of felling. However two samples (LAN-C60 and LAN-C61) retain complete sapwood. The last sapwood ring, and thus the felling of the trees represented, is dated to AD 1404. The remaining five timbers were also likely to have been felled in, or around, AD 1404.

DISCUSSION AND CONCLUSION

Dendrochronological analysis has demonstrated that the 44 dated oak timbers, both structural and boards, are likely to represent a number of different episodes of felling in the late-fourteenth and early-fifteenth centuries. Some of these episodes of felling may potentially span a number of years with others episodes being carried out over a shorter period of time, each episode potentially being separated by only a few years. The only exception to this late-fourteenth and early-fifteenth felling are the boards from the doors but, as will be seen below, this is thought unlikely.

It appears likely that the earliest phase of felling is represented by the structural timbers of the undercroft of the Keep which appear to have been felled in the AD 1380s, with construction following on shortly thereafter. The timbers from the Great Hall of the Keep were felled in the late-fourteenth or possibly the very early-fifteenth century, and could thus potentially be coeval with the structural timbers from the undercroft or, more probably, slightly later. The average heartwood/sapwood boundary date of the Great Hall timbers is 10 years later than that of the undercroft structural timbers, this suggesting that they may well post-date the undercroft timbers by a few years. In addition it is worth noting that the average heartwood/sapwood boundary date of the Great Hall timbers is 19 years earlier than the dated timbers in the Gatehouse, this suggesting that they may well pre-date the Gatehouse timbers by some time. Thus the felling of the timbers for, and the construction of, the Great Hall appears most likely to have taken place in the late-fourteenth century. Such an interpretation might be further supported by structural evidence, the slightly earlier undercroft timbers presumably being put in place to support the floor of the slightly later Great Hall. The latest phase of felling identified is represented by the timbers of the Gatehouse, those to both first and second floor being felled for of a single programme of work in, or around, AD 1404.

The timbers for the boards of the cell doors of the undercroft were probably all felled after AD 1371, and it is thus possible that they were cut in the AD 1380s at the same, or similar, time as the structural timbers used here. Based on the overall levels of similarity between the dated timbers from the undercroft, the Great Hall, and the Gatehouse, it appears likely that the trees used for them were growing in the same general area, and indeed, with a series of *t*-values of 6, 7 and 8 between the individual samples from the structural timbers in the undercroft and the cell door boards, it is likely that the trees used for these were

growing close to each other. As such, had the timbers for the doors been felled at a very different time it might be considered something of a coincidence that they too should come to be used in the undercroft. Thus, although it is of course possible that they were felled later, it is perhaps more likely that the timbers for the cell doors were felled at approximately the same time as the others used here.

The analysis has not identified any timbers in the Keep relating to the original twelfth century construction but it has identified a major programme of building works in the Keep in the latter part of the fourteenth century and hence broadly coeval with works identified through a previous dendrochronological analysis in the Witches Tower (Groves 1994). The analysis also appears to confirm the very early-fifteenth century date of construction for the Gatehouse.

As intimated above, the overall level of cross-matching between the 44 dated oak samples of site chronology LANCSQ01 suggests that it is probable that the trees utilised were originally growing in the same general area of woodland, albeit potentially an expansive area. The timbers in different areas of the castle do, however, in general appear to show slightly higher levels of similarity with each other suggesting that each group was sourced from more concentrated areas within the general woodland extent. Of particular note in this respect is the high level of similarity between the eight dated boards from the cell doors which suggests that the boards may well have been derived from no more than two or three trees which were originally growing very close to each other in the same area of woodland. There are a series of *t*-values in excess of 9, including LAN-D03 and LAN-D08 from different doors, while LAN-D07 and LAN-D09, both from the same door, cross-match with a value of t=12.3. It is also possible, given the relative date spans of some individual samples (Table 1, Fig 13) that some boards have been derived from the inner section of a long-lived tree, with other boards being derived from the outer section of, potentially, the same long-lived tree. Given the relatively small sizes of the boards this would make efficient use of such trees. These observations therefore suggest that the timbers are likely to be of the same date as each other.

In respect of the location of the source woodland, it may be noted that although oak site chronology LANCSQ01 shows a good level of similarity with reference chronologies from across the British Isles, due to its length and replication, the highest levels of similarity are found with sites in surrounding counties, particularly Cumbria.

Despite having sufficient rings for reliable dating, one oak sample, LAN-C58, remains ungrouped and undated, though it does not show any distortion or disturbance to its growth which might make cross-matching and dating difficult. The presence of undated samples is, however, normal and in this respect this

analysis is most unusual in having only one of the 37 measured oak samples being undated.

The pine timbers sampled from the north and south roofs of the Keep show no obvious anomalies which would hamper successful analysis but despite being compared to available reference chronologies from Europe and North America they all remain undated. Whilst there has been some cross-matching between individual timbers identified within each roof overall cross-matching, for what is thought to be a coeval group of timbers, is poor. However this is an issue that arises more commonly with imported conifer timbers. It should however be noted that this lack of cross-matching does not demonstrate that the sampled timbers are of different dates but does raise the possibility that the timbers are derived from different woodland sources.

BIBLIOGRAPHY

Arnold, A J, Howard, R E, and Litton, C D, 2004 *Tree-ring Analysis of Timbers from Carlisle Castle, Carlisle, Cumbria,* Centre for Archaeol Rep, **25/2004**

Arnold, A J, and Howard, R E, 2011 *Church of St Mary, Stockport, Greater Manchester: Tree-ring Analysis of Timbers of the Chancel Roof*, English Heritage Res Dep Rep Ser, **24/2011**

Arnold, A J, and Howard, R E, 2009 unpubl Tree-ring Analysis of Timbers from the Tithe Barn, West Walls, Carlisle, Cumbria – Nottingham Tree-ring Dating Laboratory unpubl computer file *CRLESQ01*

Groves, C, 1994 *Tree-ring analysis of the Witches Tower, Lancaster Castle, Lancaster, Lancashire*, ARCUS Rep **177**

Guy, N, 2015 Lancaster Castle Revealed; Part 1 - The Keep, *The Castle Studies Group Journal*, **28**, 2014–15

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1994 List 59 no 1a - Nottingham University Tree-Ring Dating Laboratory: north list, *Vernacular Architect*, **25,** 43–4

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**

Tyers, I, 2005 *Dendrochronological spot-dates of samples from Second Wood Street (site E696), Nantwich, Cheshire,* ARCUS Rep, **573w**

TABLES

Table 1: Details of tree-ring samples from Lancaster Castle, Lancaster

Sample number	Sample location	Total rings	Sapwood rings*	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	Keep - undercroft					
LAN-C01	West brace, post 3	268	16	1097	1348	1364
LAN-C02	Plate, post 1 – 2	336	7	1022	1350	1357
LAN-C03	Post 3	285+	19+c10-15nmc	1086	1351	1370
LAN-C04	East brace, post 2	226	h/s	1116	1341	1341
LAN-C05	East brace, post 3	372	14	985	1342	1356
LAN-C06	Post 2	216	no h/s	950	------	1165
LAN-C07	Post 1	201	no h/s	962	------	1162
LAN-C08	Plate, post 3 – west wall	154	h/s	1214	1367	1367
LAN-C09	West brace, post 2	162	h/s	1192	1353	1353
LAN-C10	West brace, post 1	92	h/s	1276	1367	1367
LAN-C11	East brace, post 1	122	h/s	1247	1368	1368
	Keep - Great Hall					
LAN-C12	Tiebeam, truss 1 (from east)	230+	no/h/s+c25nm to h/s	1099	------	1338
LAN-C13	South wall post, truss 1	187	h/s	1169	1355	1355
LAN-C14	South brace, truss 1	234	h/s	1142	1375	1375
LAN-C15	Tiebeam, truss 2	213	no h/s	1126	------	1328
LAN-C16	North wall post, truss 2	225	h/s	1117	1341	1341
LAN-C17	North brace, truss 2	98	h/s	1256	1353	1353
LAN-C18	South wall post, truss 2	168	h/s	1197	1364	1364
LAN-C19	South brace, truss 2	209	h/s	1163	1371	1371
LAN-C20	Tiebeam, truss 3	114	no h/s	1193	------	1306
LAN-C21	North wall post, truss 3	129	h/s	1250	1378	1378
LAN-C22	North brace, truss 3	179	h/s	1194	1372	1372
LAN-C23	Tiebeam, truss 4	112	no h/s	1158	------	1269

Table 1: continued

Sample number	Sample location	Total rings	Sapwood rings*	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	Keep – north roof (pine timbers)					
LAN-C24	Tiebeam, truss 1 (from east)	118	no h/s	------	------	------
LAN-C25	Common joist 4 (from north), bay 2	123	no h/s	------	------	------
LAN-C26	Common joist 2, bay 2	90	no h/s	------	------	------
LAN-C27	South sub-principal rafter, truss 1	109	no h/s	------	------	------
LAN-C28	Tiebeam, truss 3	190	no h/s	------	------	------
LAN-C29	North sub-principal rafter, truss 3	75	no h/s	------	------	------
LAN-C30	North queen strut, truss 3	61	no h/s	------	------	------
LAN-C31	North queen strut, truss 4	141	no h/s	------	------	------
LAN-C32	North principal rafter, truss 4	135	no h/s	------	------	------
LAN-C33	North lower purlin, bay 5	96	no h/s	------	------	------
LAN-C34	South sub-principal rafter, truss 4	95	no h/s	------	------	------
LAN-C35	South queen strut, truss 4	117	no h/s	------	------	------
	Keep – south roof (pine timbers)					
LAN-C36	South lower purlin, bay 3	85	no h/s	------	------	------
LAN-C37	Common joist 4, bay 3	59	no h/s	------	------	------
LAN-C38	Tiebeam, truss 2	154	no h/s	------	------	------
LAN-C39	South queen strut, truss 2	nm	---	------	------	------
LAN-C40	North lower purlin, bay 1	110	no h/s	------	------	------
LAN-C41	North lower purlin, bay 2	161	no h/s	------	------	------
LAN-C42	Tiebeam, truss 1	112	no h/s	------	------	------
LAN-C43	Common joist 1, bay 3	95	no h/s	------	------	------
LAN-C44	Common joist 2, bay 3	93	no h/s	------	------	------
LAN-C45	North sub-principal rafter, truss 3	178	no h/s	------	------	------
LAN-C46	Tiebeam, truss 4	146	no h/s	------	------	------

Table 1: continued

Sample number	Sample location	Total rings	Sapwood rings*	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	Gatehouse 1st floor					
LAN-C47	Tiebeam truss 3, room 1	177	16	1218	1378	1394
LAN-C48	North brace, truss 2, room 1	157	no h/s	1130	------	1286
LAN-C49	North wall post, truss 1, room 1	186	h/s	1199	1384	1384
LAN-C50	North wall post truss 2, room 2	263	26C	1142	1378	1404
LAN-C51	North brace truss 1, room 2	148	h/s	1243	1390	1390
LAN-C52	Tiebeam truss 2, room 2	nm	---	------	------	------
LAN-C53	North brace truss 3, room 3	95	no h/s	1264	------	1358
	Gatehouse 2nd floor					
LAN-C54	South brace truss 2, room 2	168	h/s	1211	1378	1378
LAN-C55	North wall post truss 4, room 2	95	no h/s	1228	------	1322
LAN-C56	North wall post truss 5, room 2	137	no h/s	1160	------	1296
LAN-C57	South brace truss 6, room 2	189	no h/s	1168		1356
LAN-C58	Tiebeam truss 2, room 3	97	h/s	------	------	------
LAN-C59	South wall post truss 2, room 3	69	no h/s	1286		1354
LAN-C60	South brace truss 2, room 3	203	14C	1202	1390	1404
LAN-C61	Tiebeam truss 3, room 3	185	23C	1220	1381	1404

Table 1: continued

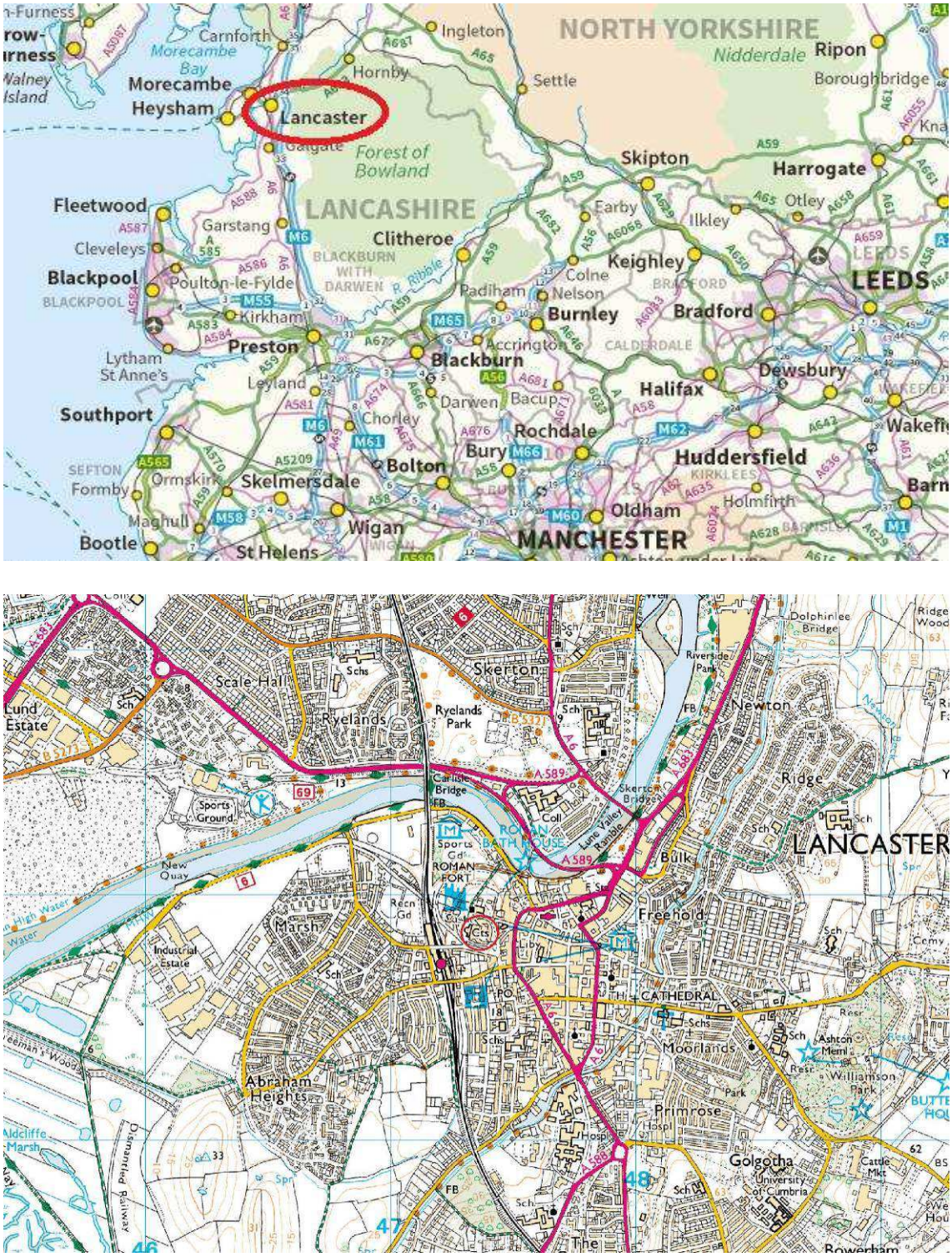
Sample number	Sample location	Total rings	Sapwood rings*	First measured ring date AD	Last heartwood ring date AD	Last measured ring date AD
	Middle cell door					
LAN-D01	Inner face, horizontal board 1 (from top)	140	no h/s	1160	------	1299
LAN-D02	Inner face, horizontal board 2	140	no h/s	1191	------	1330
LAN-D03	Inner face, horizontal board 3	122	no h/s	1189	------	1310
LAN-D04	Inner face, horizontal board 4	84	no h/s	1211	------	1294
LAN-D05	Outer face, middle vertical board	92	no h/s	------	------	------
	South cell door					
LAN-D06	Inner face, horizontal board 1 (from top)	79	no h/s	1190	------	1268
LAN-D07	Inner face, horizontal board 2	125	no h/s	1107	------	1231
LAN-D08	Inner face, horizontal board 3	141	no h/s	1216	------	1356
LAN-D09	Inner face, horizontal board 4	102	no h/s	1117	------	1218
LAN-D10	Outer face, middle vertical board	82	7	------	------	------

Key:
h/s = the heartwood/sapwood ring is the last ring on the sample
C = complete sapwood is retained on the sample
c = complete sapwood on timber, but all or part lost from sample in coring
nm = rings not measured

Table 2: Results of the cross-matching of site sequence LANCSQ01 and relevant reference chronologies when the first-ring date is AD 950 and the last-ring date is AD 1404

Reference chronology	Span of chronology	*t*-value	Reference
St Mary's Church, Stockport, Greater Manchester	AD 1099–1293	14.0	(Arnold and Howard 2011)
Second Wood Street, Nantwich, Cheshire	AD 932–1509	11.9	(Tyers 2005)
Carlisle Castle, Carlisle, Cumbria	AD 966–1446	10.7	(Arnold *et al* 2004)
Guildhall (east range), Carlisle, Cumbria	AD 976–1382	10.7	(Howard *et al* 1994)
Angel Choir, Lincoln Cathedral	AD 904–1257	10.0	(Laxton and Litton 1988)
Tithe Barn, West Walls, Carlisle, Cumbria	AD 1112–1476	9.8	(Arnold and Howard 2009 unpubl)
Witches Tower, Lancaster Castle, Lancashire	AD 1154–1368	9.5	(Groves 1994)
The Lanes buildings, Carlisle, Cumbria	AD 1062–1600	9.3	(C Tyers unpubl)

FIGURES



Figures 1a and 1b: Maps to show the location of Lancaster (top) and the location of the Castle within the town (bottom) © Crown Copyright and database right 2016. All rights reserved. Ordnance Survey Licence number 100024900

Figure 1c: Map showing the detailed location of the Castle © Crown Copyright and database right 2016. All rights reserved. Ordnance Survey Licence number 100024900

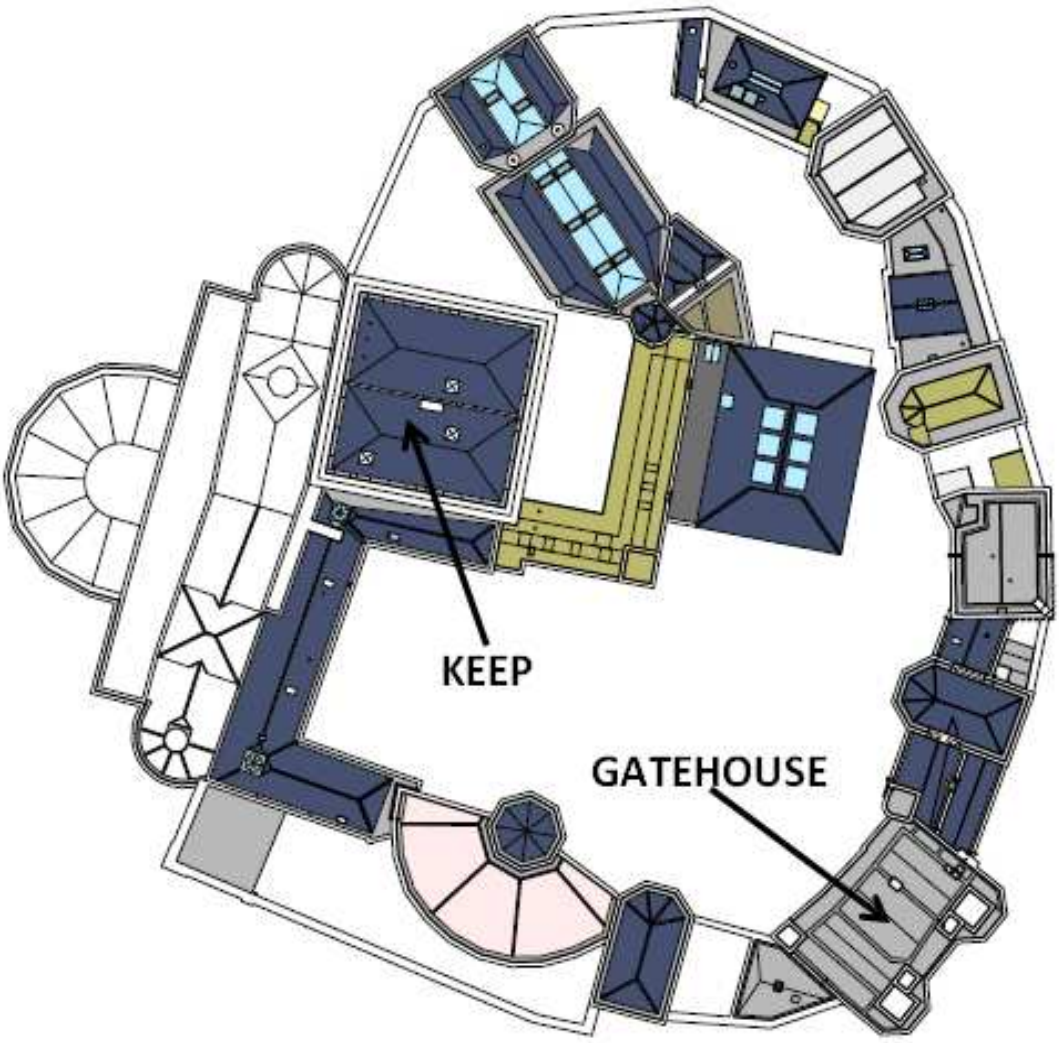
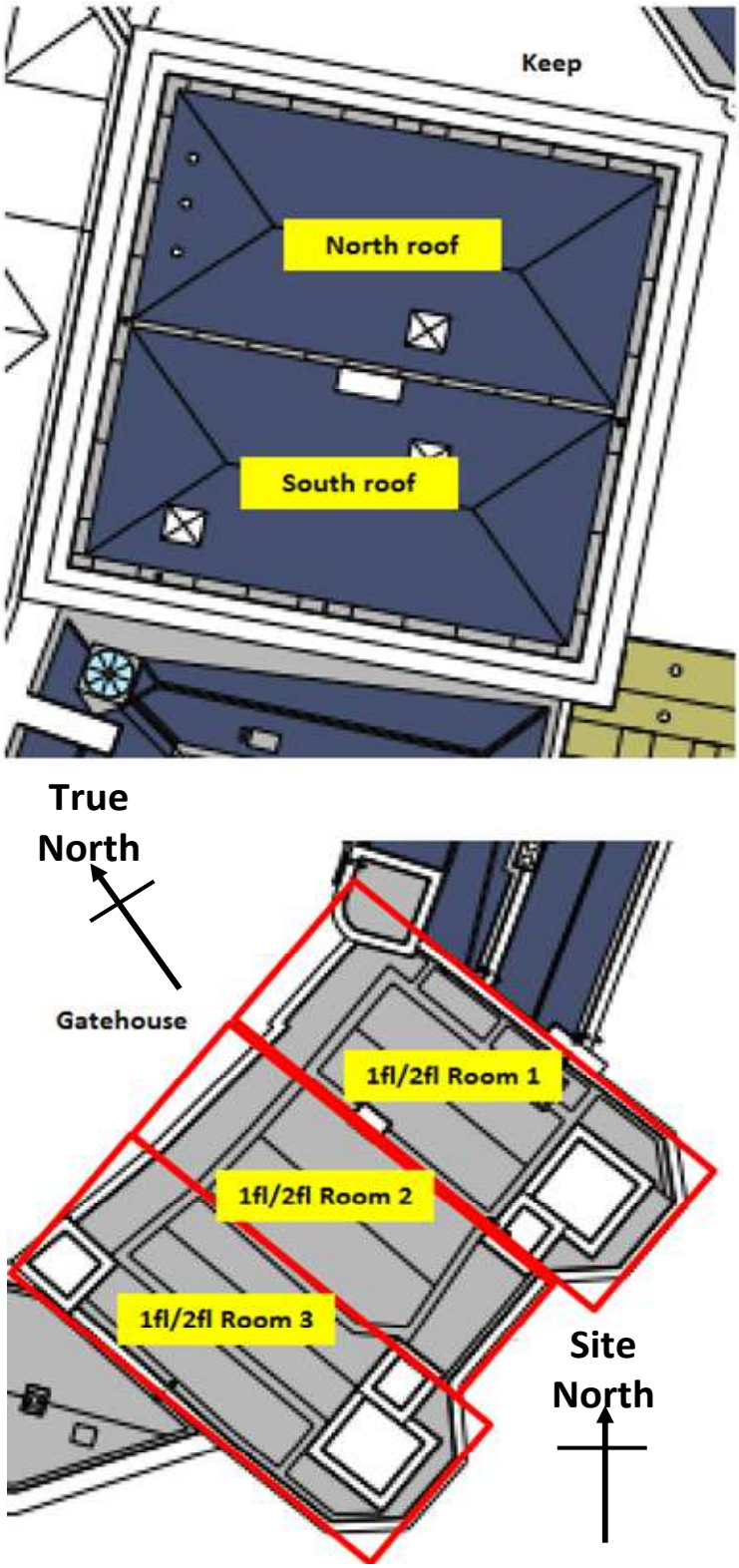


Figure 2: Simple plan of Lancaster Castle to show the position of the Keep and the Gatehouse (after Building Design Partnership, Manchester)



Figures 3a and 3b: Simple plan of the Keep (top) and the Gatehouse (bottom) Gatehouse (after Building Design Partnership, Manchester)

Figure 4a: View of the support timbers to the undercroft of the Keep (photograph Robert Howard)

Figures 4b and 4c: Views of the doors to the solitary confinement cells in the undercroft of the Keep (photographs Robert Howard)

Figures 4d and 4e: Views of the timbers later inserted into the Great Hall of the Keep (top) and its later pine roof (bottom) (photographs Robert Howard)

Figures 4f and 4g: View of second floor timbers to the Gatehouse (top) and those to the first floor (bottom) (photographs Robert Howard)

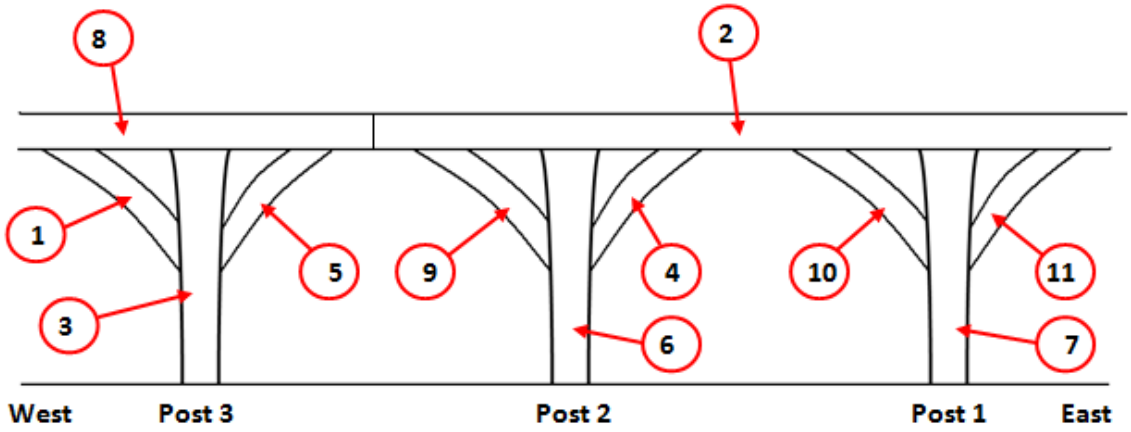
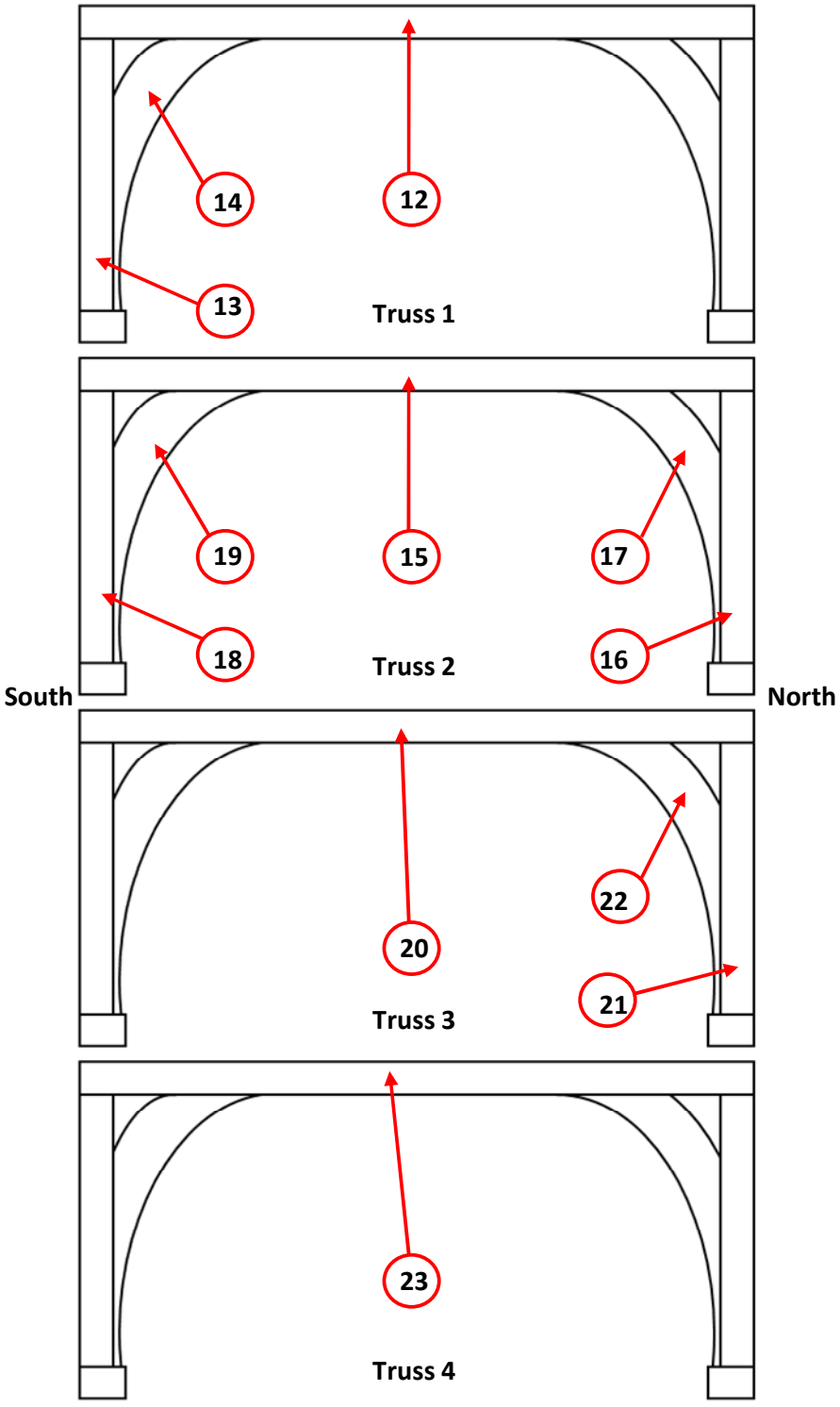
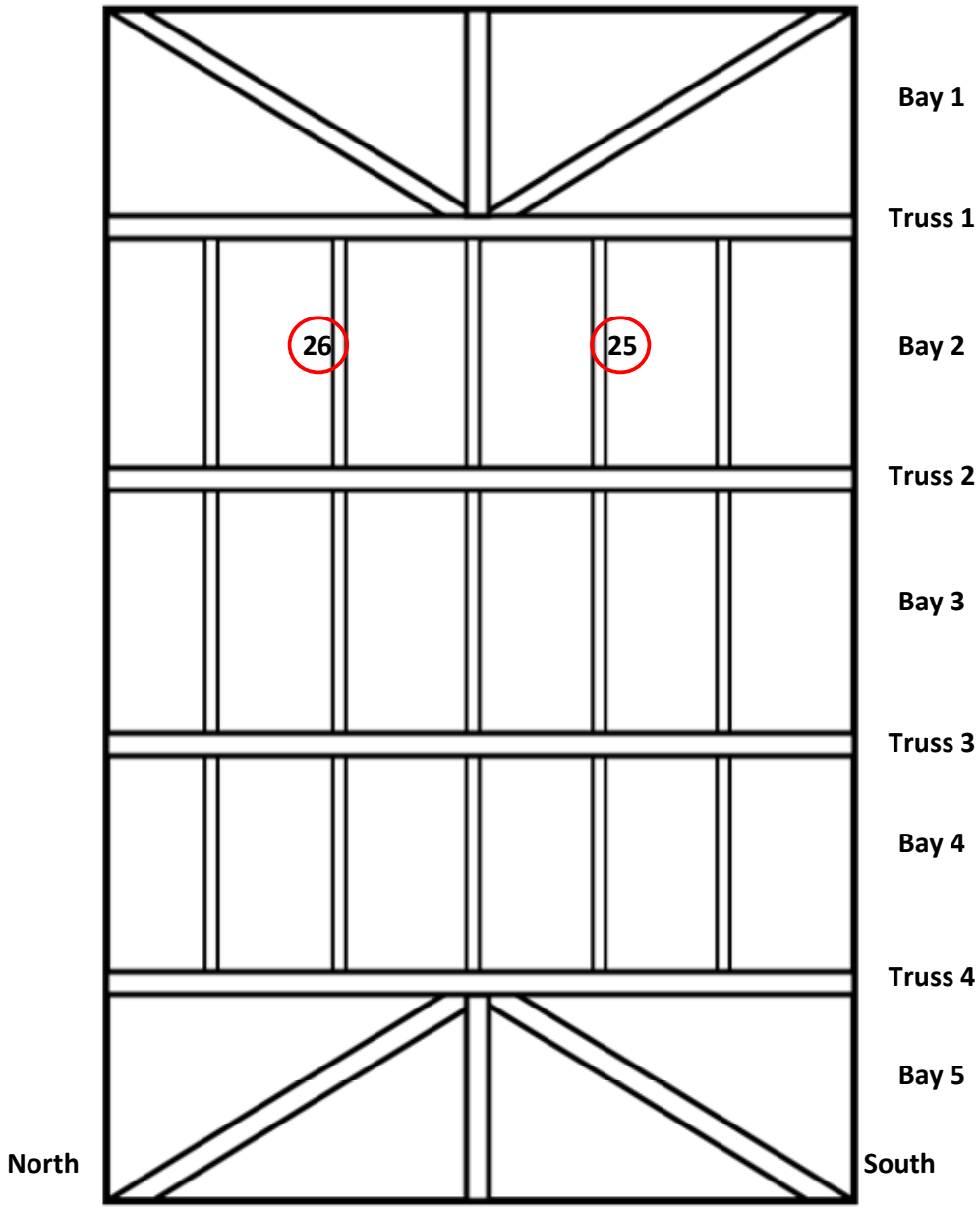


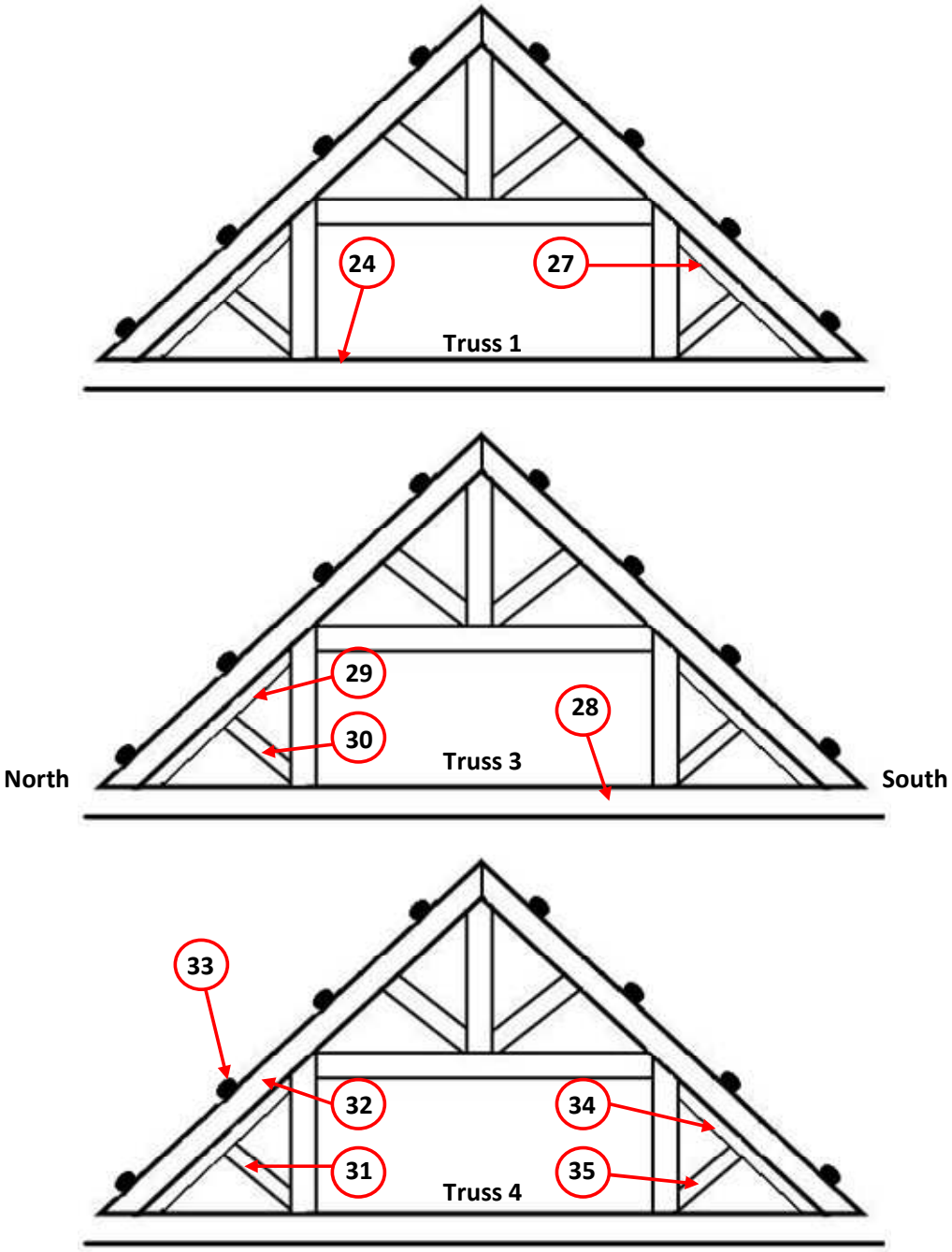
Figure 5: Schematic drawing to locate sampled oak timbers of the support to the undercroft of the Keep



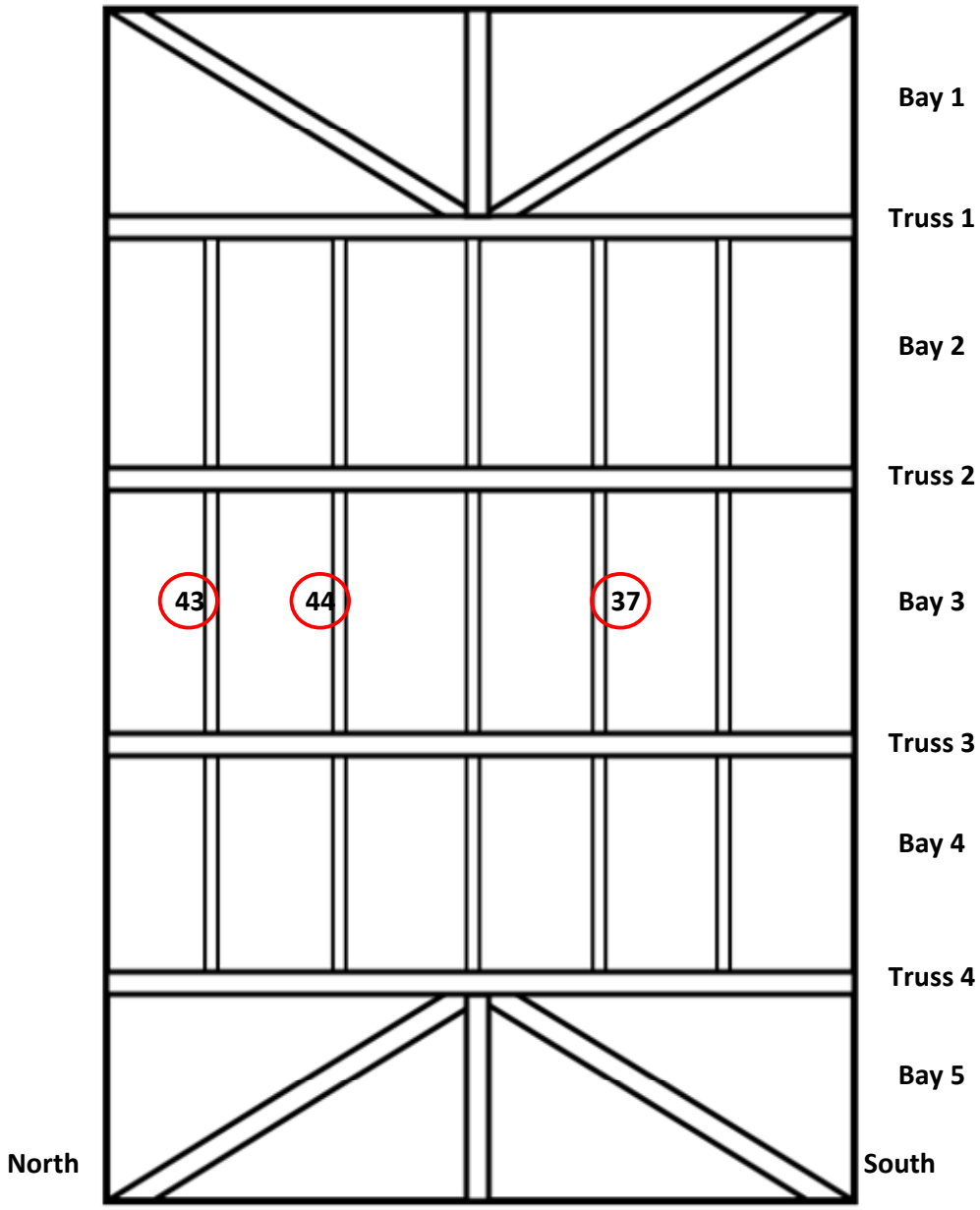
Figures 6a – d: Schematic drawings to locate sampled oak timbers to the Great Hall of the Keep



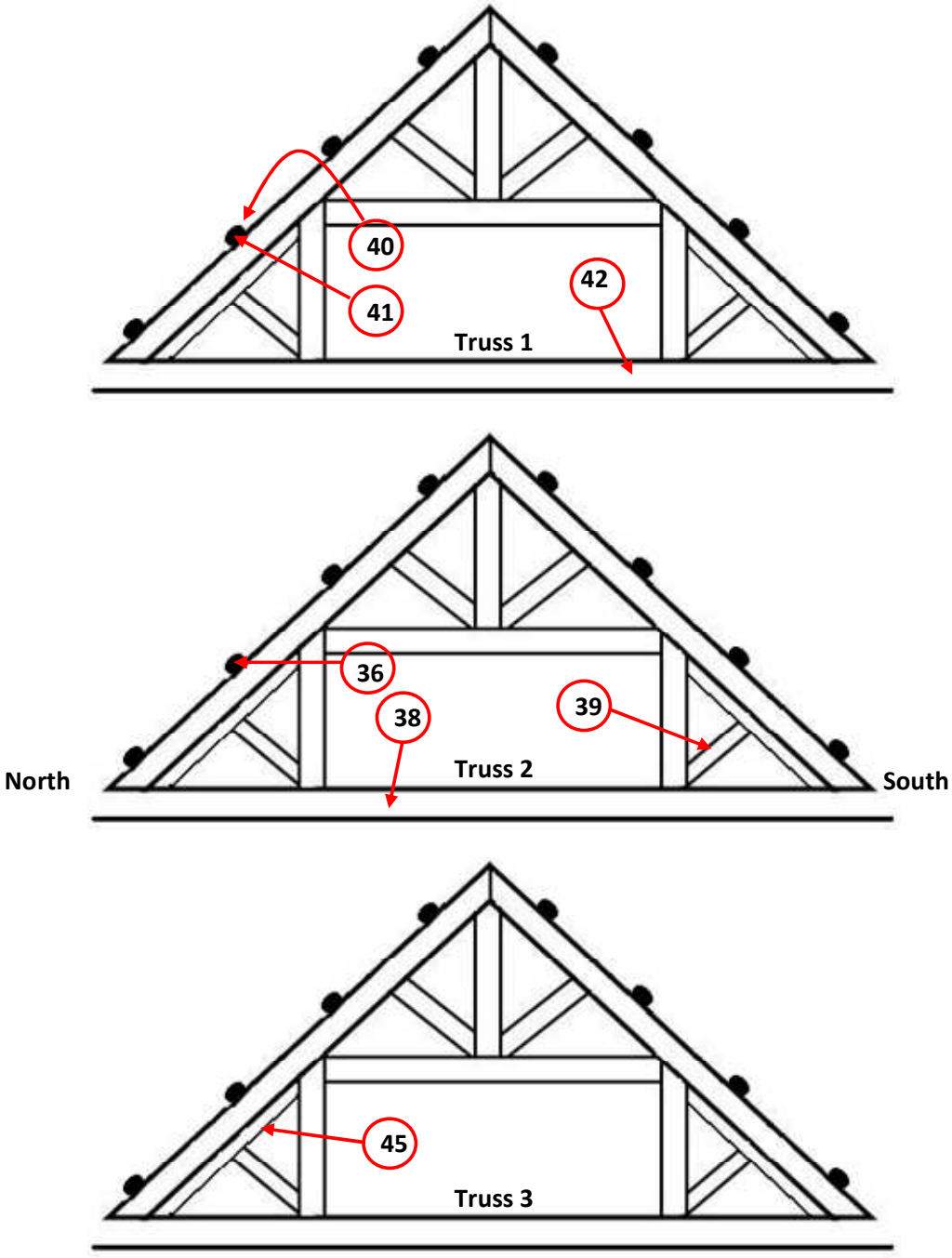
Figures 7a: Schematic plan of the north roof of the Keep to locate sampled pine timbers



Figures 7b–d: Schematic drawings through the trusses of the north roof of the Keep to locate sampled pine timbers



Figures 7e: Schematic plan of the south roof of the Keep to locate sampled pine timbers



Figures 7f–h: Schematic drawings through the trusses of the south roof of the Keep to locate sampled pine timbers

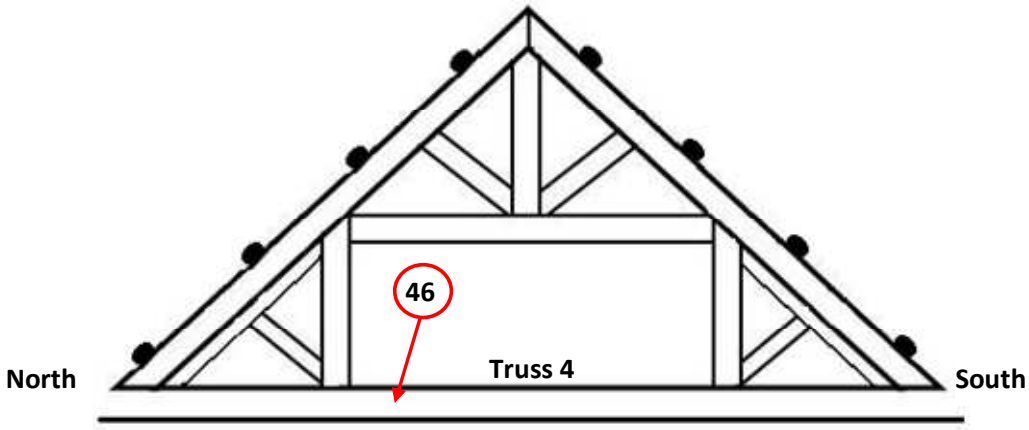
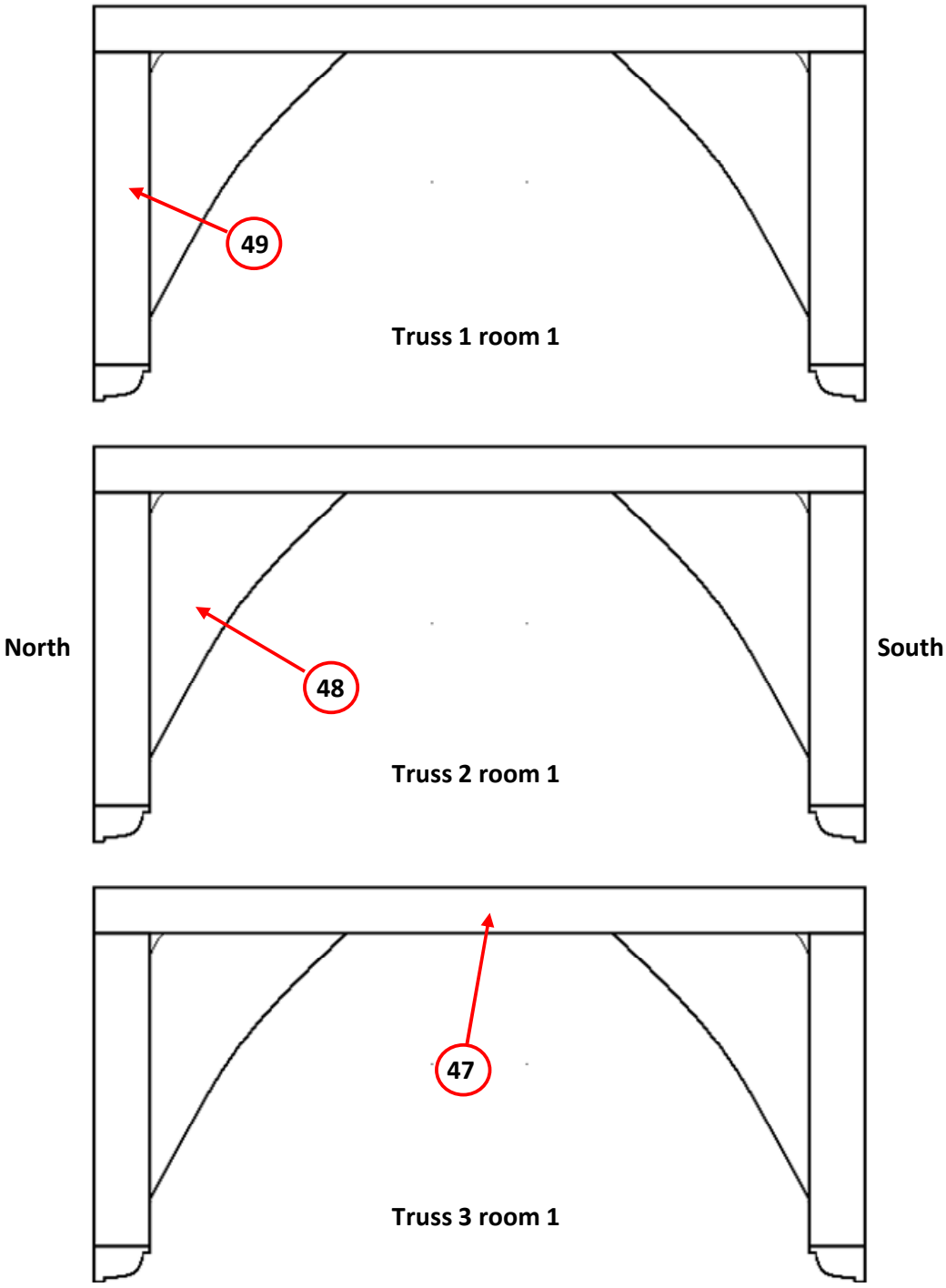
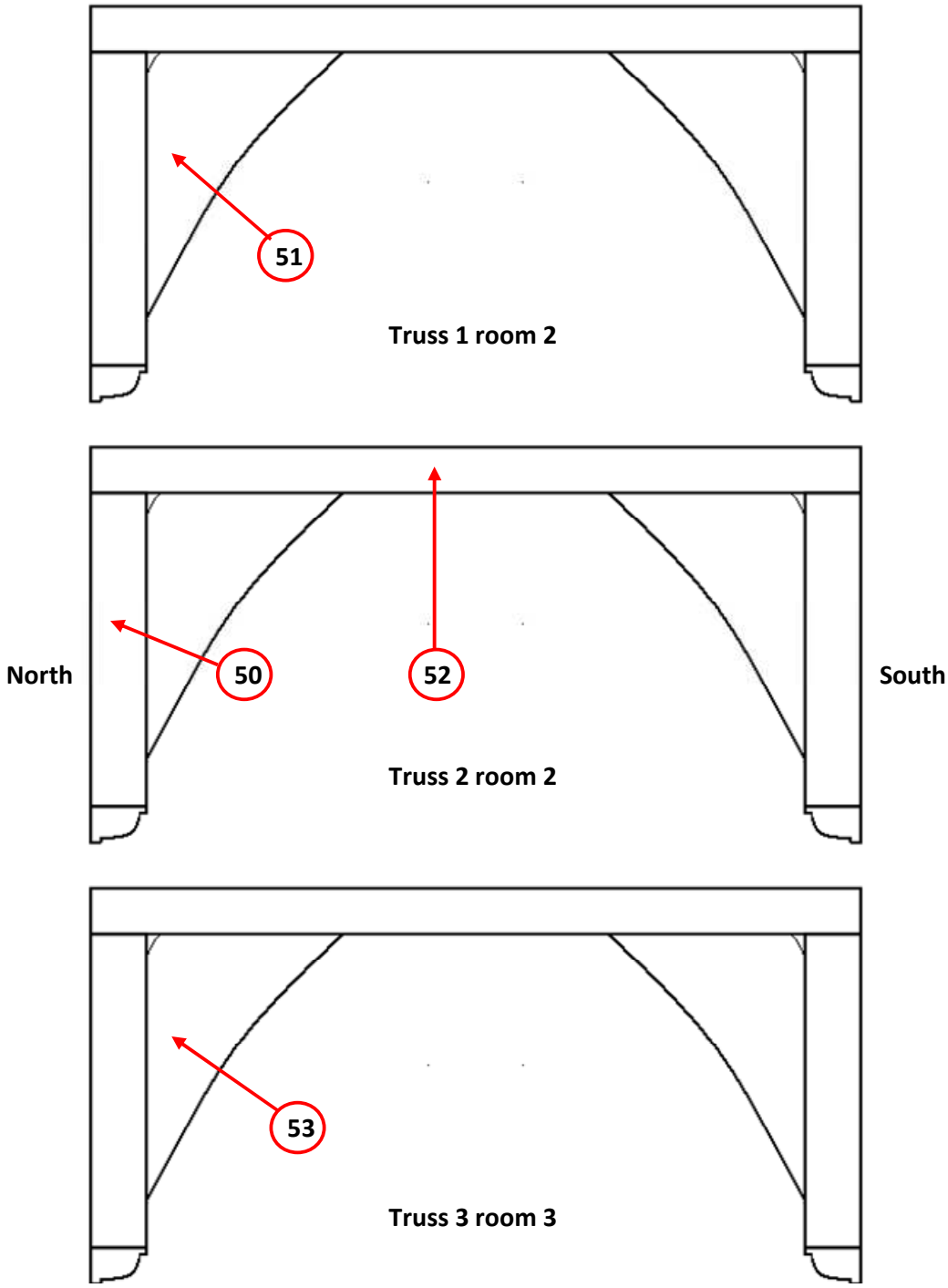


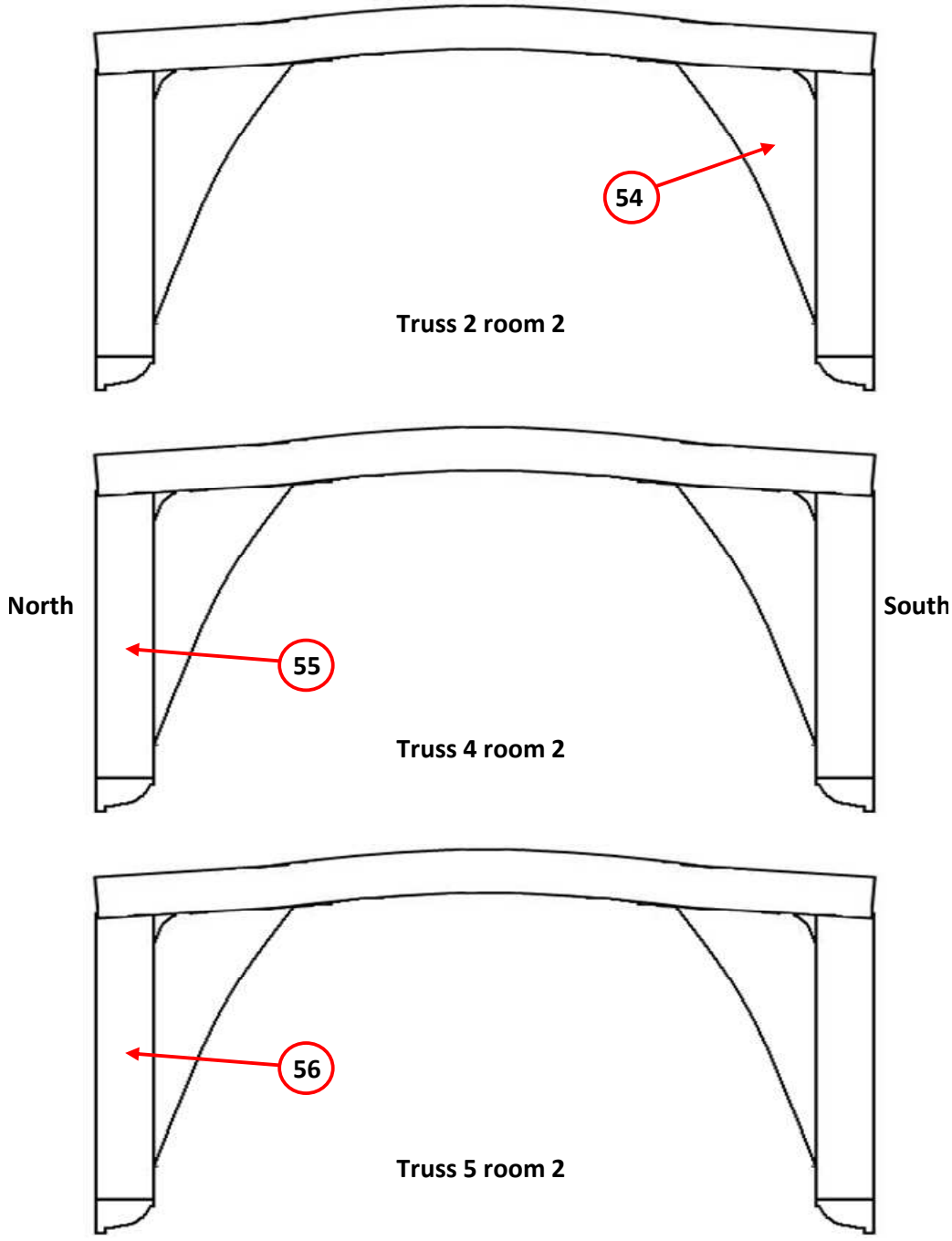
Figure 7i: Schematic drawing through truss of the south roof of the Keep to locate sampled pine timbers



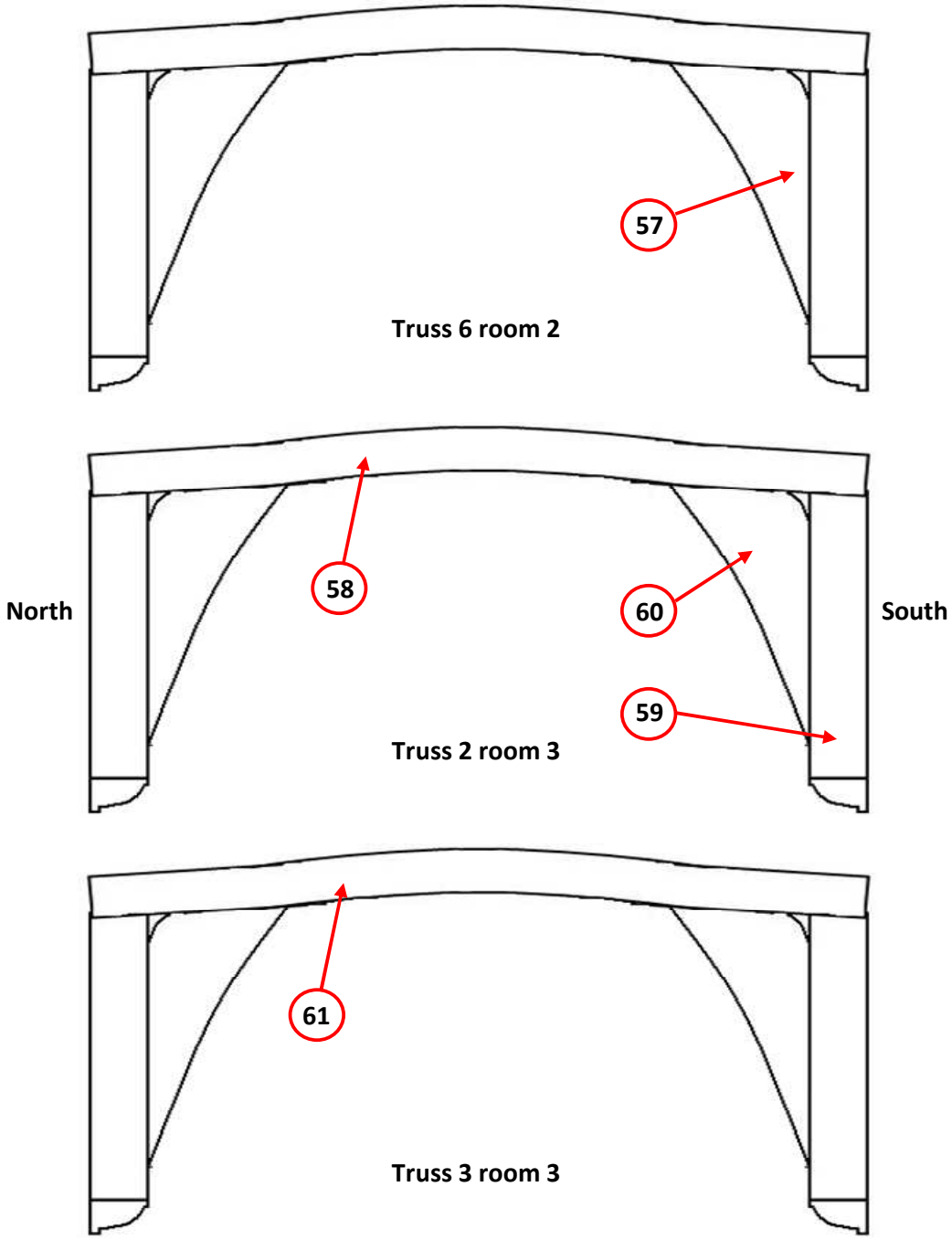
Figures 8a–c: Schematic drawings through the trusses of the first floor of the gatehouse to locate sampled oak timbers



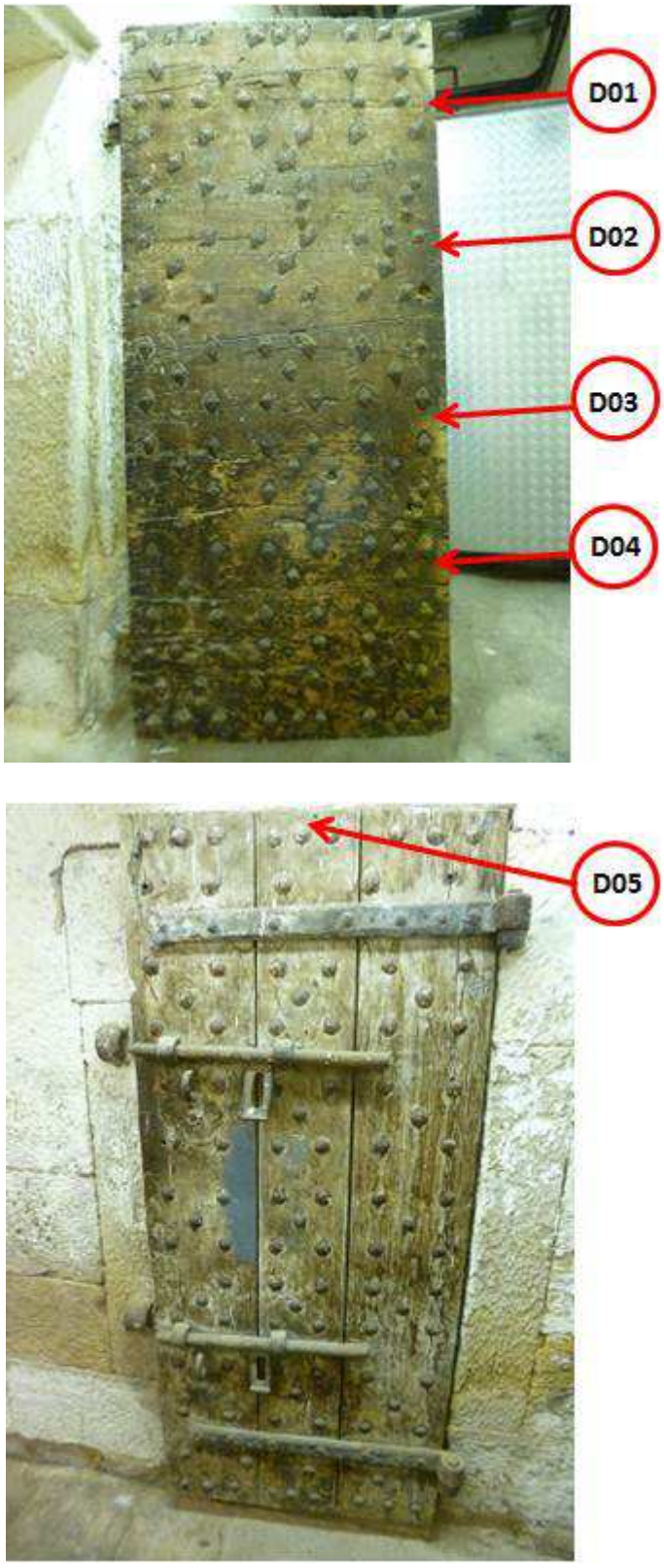
Figures 8d–f: Schematic drawings through the trusses of the first floor of the gatehouse to locate sampled oak timbers



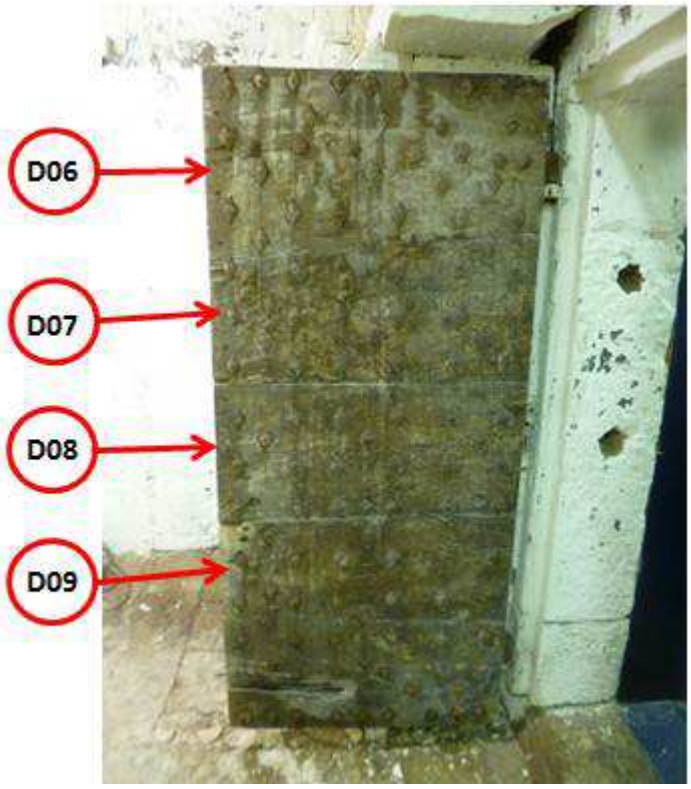
Figures 9a–c: Schematic drawings through the trusses of the second floor of the gatehouse to locate sampled oak timbers



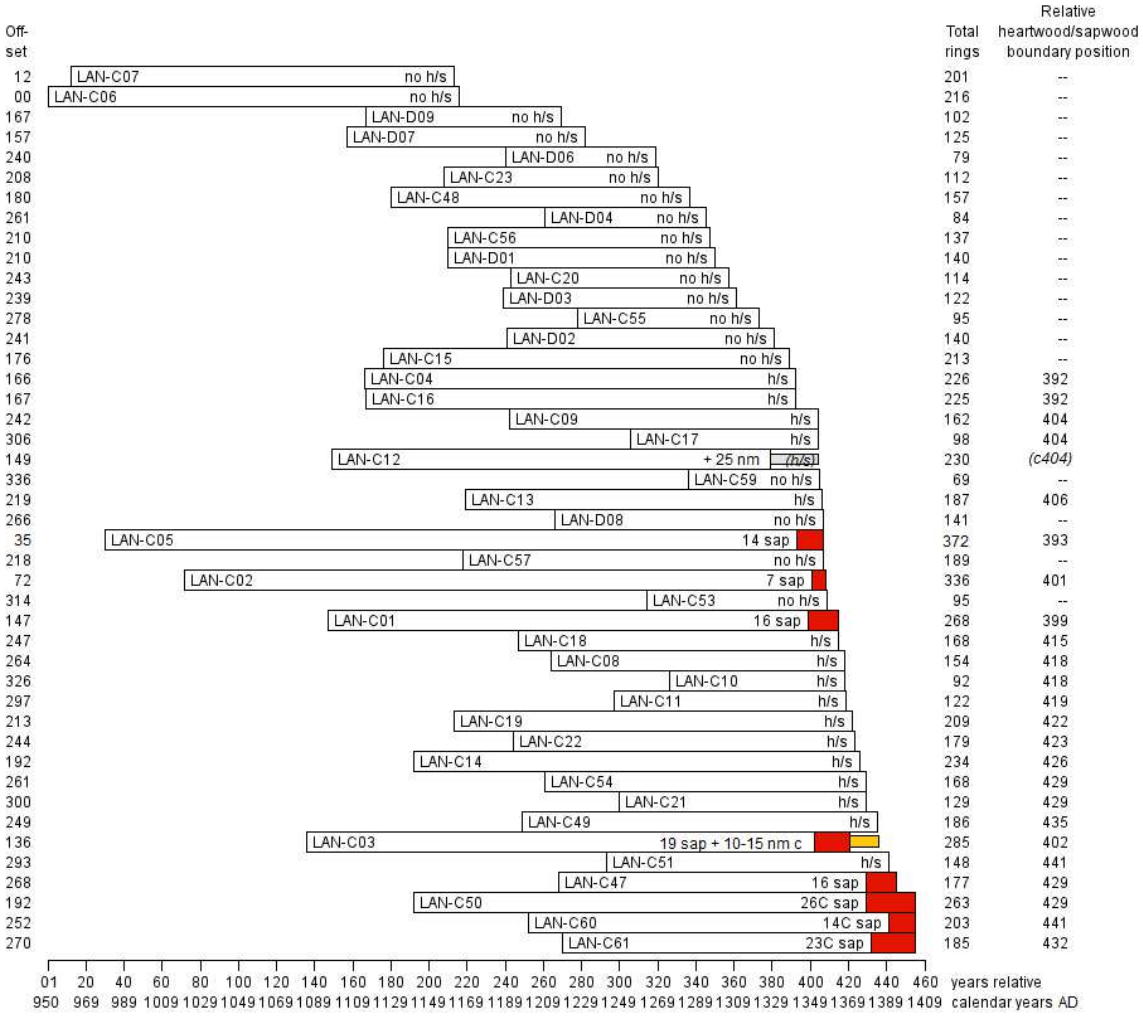
Figures 9d–f: Schematic drawings through the trusses of the second floor of the gatehouse to locate sampled oak timbers



Figures 10a and 10b: Views of the middle door to locate sampled timbers (inner face - top, outer face - bottom) (photographs Robert Howard)



Figures 10c and 10d: Views of the south door to locate sampled timbers (inner face, top, outer face, bottom)



White bars = measured heartwood rings;

Shaded bars = unmeasured heartwood rings

Shaded bars = measured sapwood rings

Shaded bars = estimated unmeasured sapwood rings

C = complete sapwood is retained on the sample

c= complete sapwood retained on the timber, but all or part has been lost from sample in coring

h/s = heartwood/sapwood boundary

Figure 11a: Bar diagram of the samples in site chronology LANCSQ01 in last measured ring date order

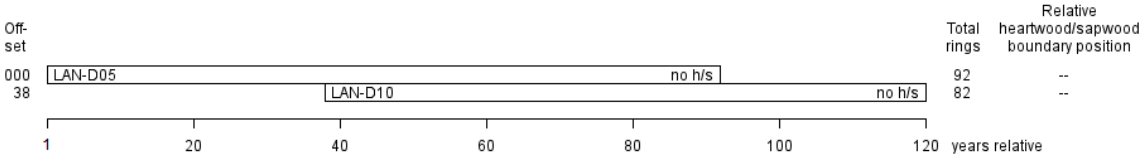
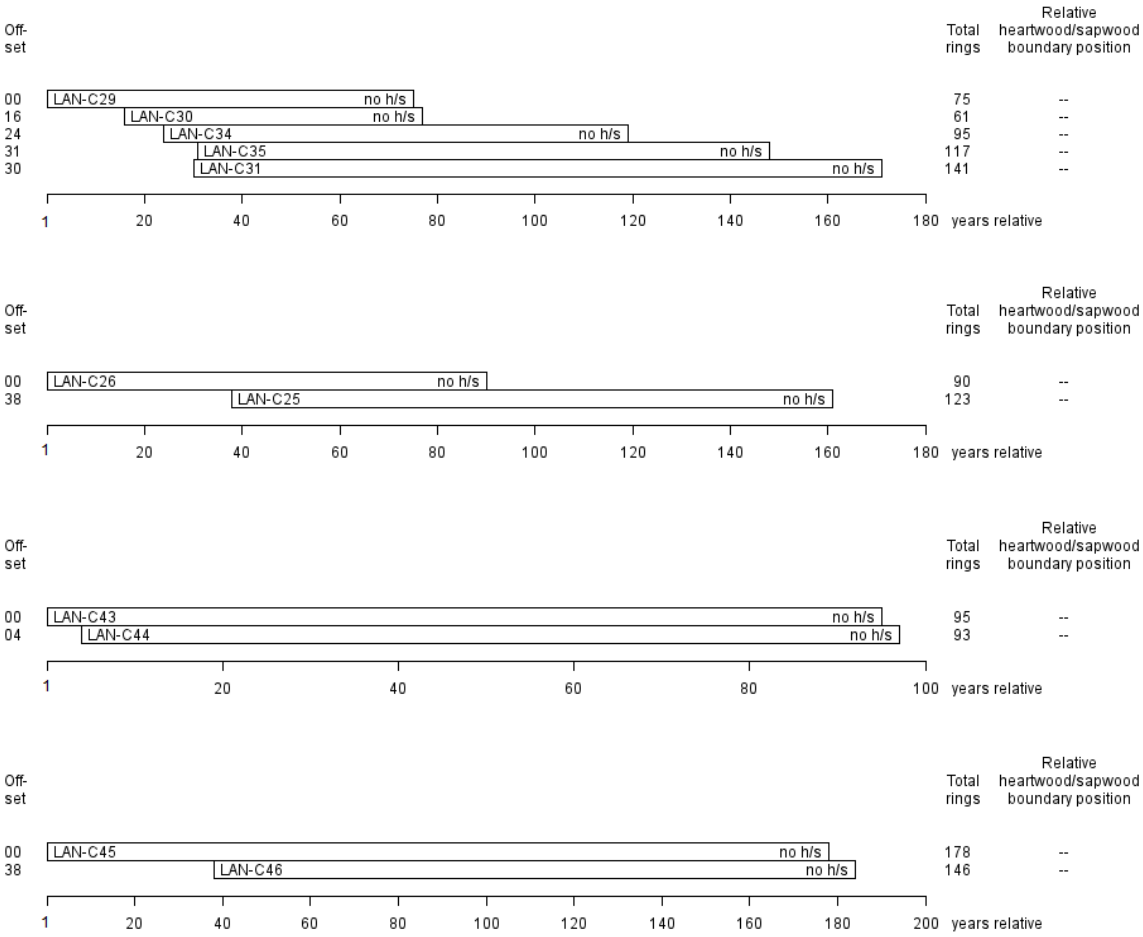
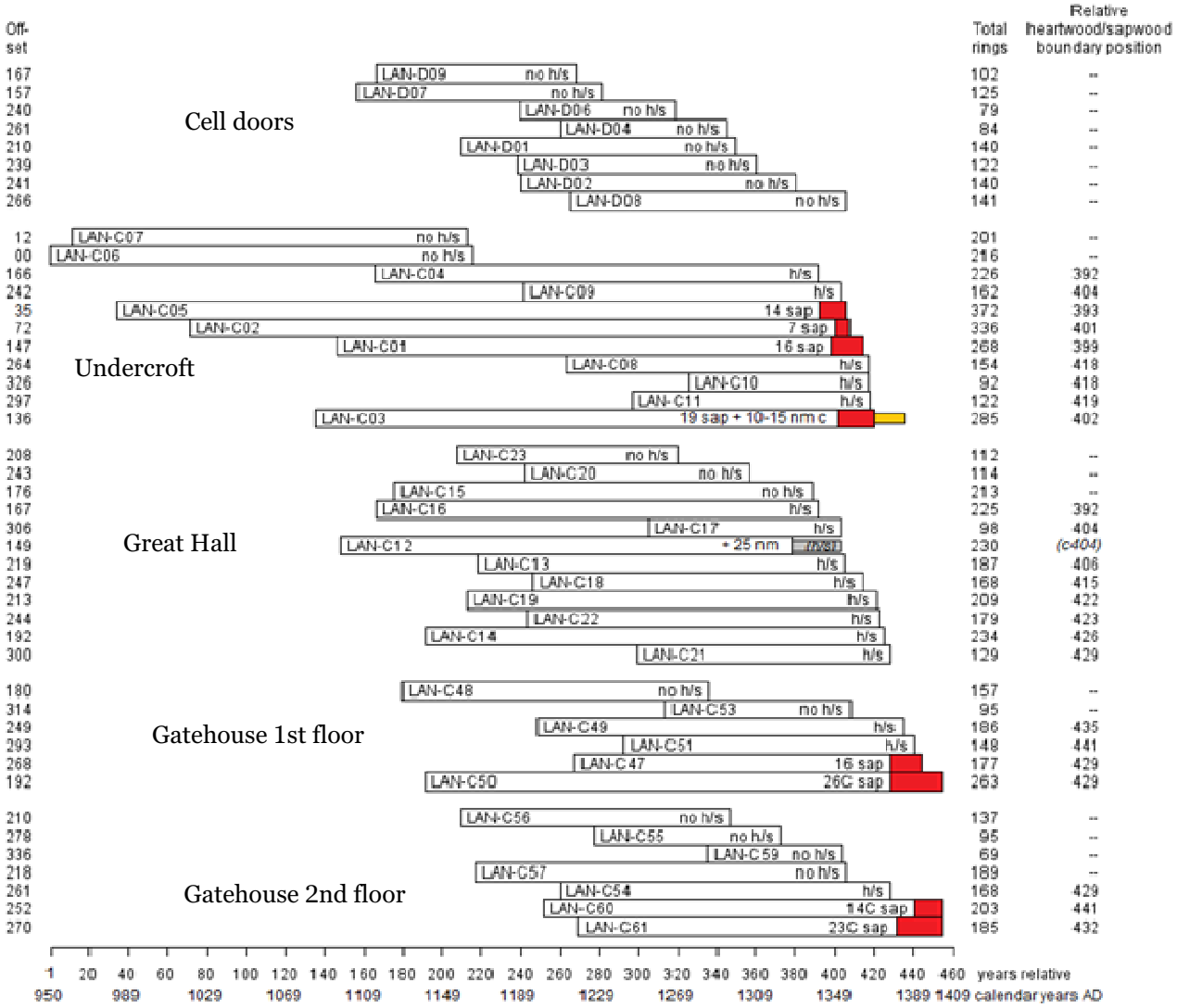


Figure 11b: Bar diagram of the samples in site chronology LANCSQ02 in last measured ring date order



White bars [ ] = heartwood rings
h/s = heartwood/sapwood boundary

Figures 12a–d: Bar diagram of the samples in pine site chronologies LANCSQ03–SQ06 (top to bottom)



White bars = measured heartwood rings;
Shaded bars = unmeasured heartwood rings
Shaded bars = measured sapwood rings
Shaded bars = estimated unmeasured sapwood rings
C = complete sapwood is retained on the sample
c= complete sapwood retained on the timber, but all or part has been lost from sample in coring
h/s = heartwood/sapwood boundary

Figure 13: Bar diagram of the samples in site chronology LANCSQ01 sorted by sample location

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

LAN-C01A 268
103 95 102 73 69 50 104 92 100 85 59 80 58 36 43 41 46 45 63 76
67 65 47 55 66 60 66 67 69 65 58 55 25 39 54 50 57 54 87 71
55 55 77 71 63 78 79 46 78 53 59 53 36 46 98 52 84 67 88 100
71 54 98 126 92 112 117 128 112 147 102 119 182 101 108 139 149 86 55 67
53 80 134 85 119 137 114 110 112 91 110 67 101 129 123 128 95 164 199 145
83 121 219 145 147 125 251 105 112 159 82 83 91 148 188 162 154 134 125 146
126 100 115 100 118 101 98 115 127 137 107 107 126 140 115 72 87 68 65 68
45 79 73 71 78 54 98 90 91 84 95 87 90 68 67 53 84 76 89 101
79 68 72 81 67 69 56 80 86 76 44 85 74 49 64 50 71 65 44 59
63 64 66 74 64 67 75 58 62 85 67 71 75 56 68 69 75 67 87 80
74 64 35 58 56 57 40 39 45 56 36 40 54 42 53 51 59 52 46 66
62 62 71 57 65 64 65 75 62 80 64 82 78 60 57 64 53 74 92 62
95 92 67 75 99 83 78 70 97 63 69 69 79 70 44 70 69 76 67 61
82 73 96 71 114 106 84 126
LAN-C01B 268
109 93 100 68 54 62 106 78 105 79 43 77 56 35 44 41 49 42 64 71
76 63 48 62 70 56 69 67 66 78 52 50 32 41 50 55 51 55 83 76
51 60 74 78 69 76 76 57 70 64 62 44 46 49 119 48 76 74 82 110
77 65 101 107 100 103 122 139 132 156 114 121 178 122 127 135 144 64 49 87
44 83 135 90 126 135 121 107 100 106 104 71 104 129 121 139 95 159 205 151
81 135 201 143 146 128 235 95 118 164 82 86 88 153 178 156 148 142 135 171
131 100 121 96 114 103 93 126 121 131 109 120 130 150 118 78 87 68 74 59
46 75 81 68 75 56 93 93 87 97 98 82 92 69 65 52 87 63 87 98
83 71 77 84 60 77 51 87 90 63 56 85 65 57 53 50 65 59 60 65
62 67 53 74 69 68 65 65 57 82 72 78 78 59 59 77 80 66 81 85
75 56 44 55 53 62 53 35 36 50 37 42 48 35 61 47 62 37 43 68
59 72 51 85 71 62 61 71 69 90 72 75 86 49 59 56 60 75 93 79
88 93 65 61 105 82 75 75 93 65 66 72 80 62 52 71 65 75 68 56
84 70 97 68 121 116 87 112
LAN-C02A 336
105 94 84 46 48 58 76 67 90 107 114 49 46 56 47 49 76 82 80 93
99 51 58 42 70 101 98 85 85 100 53 54 41 70 81 77 60 81 98 66
51 53 33 25 51 73 60 71 89 64 93 48 46 85 82 93 64 60 74 57
50 43 44 60 59 59 50 63 39 60 39 50 42 39 42 38 39 44 30 39
30 45 34 42 40 45 36 35 29 32 26 25 41 50 52 28 36 32 63 60
53 42 55 48 49 46 28 39 29 40 46 57 56 60 50 40 42 52 41 42
40 42 39 29 40 29 30 30 40 70 50 53 45 39 49 48 40 31 56 39
45 44 42 46 37 57 65 78 46 57 62 50 43 33 33 42 62 59 67 42
59 50 51 40 26 37 36 59 75 70 68 95 97 154 143 125 98 118 121 139
112 98 65 92 83 75 85 123 85 84 64 50 81 70 78 78 71 70 64 117
117 129 150 182 135 123 165 145 144 115 119 84 117 114 90 81 102 115 144 121
91 142 128 133 121 104 81 128 86 85 81 59 79 82 84 61 64 67 65 65
51 45 53 57 52 56 73 70 52 55 58 70 62 72 89 104 72 95 93 74
56 71 71 75 96 63 81 59 90 94 73 74 68 79 59 69 54 53 76 89
71 53 62 109 83 84 105 100 121 128 126 77 63 66 68 71 81 42 54 76
37 62 62 84 59 62 74 43 37 31 46 40 54 59 50 59 46 53 56 35
43 43 53 41 34 40 47 46 37 28 58 54 37 52 53 58
LAN-C02B 336

77 99 63 60 57 68 79 72 96 104 119 56 40 52 58 52 82 84 85 82
116 46 66 48 82 114 103 83 75 104 62 48 39 67 76 64 60 80 89 58
51 42 41 35 39 76 56 61 86 64 85 50 50 86 76 95 68 60 71 62
46 43 44 57 60 56 49 65 43 59 35 53 42 38 43 39 35 42 35 35
29 51 41 32 42 35 46 42 28 32 17 32 42 52 40 28 35 39 60 47
50 37 55 45 52 48 32 33 28 39 48 56 59 56 48 42 51 47 46 42
32 42 40 34 36 37 32 28 37 67 49 50 46 39 53 43 40 34 52 34
46 48 42 50 37 60 62 75 43 59 60 45 51 29 40 39 49 64 43 62
62 46 53 40 25 39 37 57 78 61 82 98 109 156 143 120 106 134 110 151
118 100 58 92 85 71 84 118 87 83 68 45 79 72 81 81 70 67 64 121
130 148 153 187 146 125 179 146 139 100 131 87 110 118 87 81 101 120 134 128
103 131 142 115 134 100 87 118 90 87 73 65 79 83 77 68 56 69 75 64
34 48 50 57 49 56 65 84 50 46 66 71 65 68 89 115 68 87 91 93
48 77 74 81 96 65 71 68 81 90 62 72 74 75 59 73 56 56 69 87
72 56 64 100 87 81 100 90 134 137 115 62 50 59 71 67 75 49 54 65
55 56 54 74 62 62 73 57 39 25 40 43 53 59 46 48 51 50 50 48
38 46 50 45 25 40 50 40 37 31 59 65 40 43 57 58
LAN-C03A 285
80 61 81 74 48 74 60 58 56 50 54 55 52 47 75 51 55 56 44 59
53 81 74 109 90 76 67 64 67 85 91 98 119 80 91 71 66 103 87 105
67 73 64 58 64 63 91 74 75 107 90 118 96 110 107 81 92 92 80 90
94 103 100 155 89 104 76 127 87 122 107 103 103 154 125 89 96 85 68 81
51 54 59 81 65 87 67 96 89 90 65 65 75 87 70 84 81 84 78 85
67 78 65 67 77 70 59 52 67 68 81 87 93 96 89 87 97 104 53 73
71 64 65 69 90 81 56 67 75 63 78 84 81 61 56 74 75 80 81 84
71 64 82 84 60 59 57 45 44 58 18 42 48 62 56 56 60 60 59 54
59 73 66 84 70 62 67 77 65 65 59 67 59 56 56 50 50 48 60 77
73 63 81 91 68 62 59 78 73 75 53 68 59 78 68 61 66 71 75 68
62 74 75 71 62 64 72 72 54 63 53 74 35 31 46 56 57 40 32 42
50 43 39 50 43 53 56 52 44 58 46 53 59 53 45 54 58 56 48 62
53 52 53 59 56 53 54 58 56 74 46 59 51 62 50 43 47 40 50 55
36 46 45 40 53 36 46 51 49 59 31 50 52 44 37 46 46 28 33 29
62 28 34 34 56
LAN-C03B 285
90 56 73 69 52 79 59 60 50 51 54 54 48 53 79 58 54 43 56 61
65 78 81 105 97 77 69 68 76 89 85 94 116 86 86 74 71 103 85 107
74 66 70 61 74 71 92 85 75 107 94 114 99 110 106 75 89 89 75 100
82 106 96 156 93 107 78 121 96 121 102 103 104 151 125 90 95 81 70 77
57 42 76 79 67 81 78 98 84 87 75 60 76 90 73 77 84 76 87 92
79 71 62 67 84 68 56 59 64 68 92 85 101 93 84 82 92 106 57 73
64 75 64 65 85 81 65 64 73 73 78 78 79 68 46 70 80 72 85 80
82 78 92 74 61 60 60 48 35 51 23 44 46 62 64 57 53 57 54 59
56 79 65 84 64 65 65 79 65 68 64 56 66 51 58 46 56 42 66 71
68 62 75 86 68 69 59 75 71 78 62 59 65 78 68 65 59 71 93 68
72 78 81 71 56 53 81 74 64 65 53 63 42 36 41 52 46 47 29 45
54 43 50 41 45 53 52 50 47 56 53 53 52 62 41 55 66 54 51 56
61 53 54 55 48 44 53 56 57 62 48 44 57 55 56 40 44 40 58 52
33 37 43 46 43 33 47 55 50 59 28 50 47 45 40 43 40 40 40 34
39 20 28 47 64
LAN-C04A 226
154 152 181 171 279 229 360 353 173 176 190 230 284 158 167 126 185 260 267 285
200 242 239 282 328 278 230 220 181 200 164 206 178 250 207 182 162 250 223 220
246 190 200 206 205 168 140 114 107 115 79 87 117 101 77 121 114 126 76 71

84 82 109 135 115 107 120 120 109 109 101 100 89 116 128 149 112 150 146 183
217 183 165 150 140 139 109 97 71 75 74 68 62 71 78 56 62 62 115 109
79 71 61 45 56 62 51 53 71 75 65 54 46 51 44 34 37 40 51 65
53 57 62 74 74 76 60 75 87 81 70 79 72 81 90 75 39 78 78 65
68 75 59 83 57 70 76 56 83 71 90 67 93 76 50 59 59 81 76 83
106 100 83 62 106 81 74 70 85 96 110 96 151 120 99 103 133 87 87 96
80 83 66 68 78 94 87 66 62 106 76 75 96 101 100 93 70 88 104 96
84 78 75 65 68 86 62 56 71 76 88 89 100 90 73 59 71 74 93 109
84 84 93 81 84 107
LAN-C04B 226
177 139 189 176 295 248 372 403 196 196 212 246 290 127 150 145 241 231 283 264
176 239 242 284 321 299 232 210 196 200 162 209 178 237 205 170 189 240 237 218
232 189 216 203 207 162 170 104 115 103 71 100 115 84 88 122 114 127 72 81
87 79 100 140 113 104 115 128 112 102 101 112 91 129 134 129 103 150 146 171
240 181 152 145 146 149 106 101 78 80 67 69 65 73 78 53 60 64 115 114
75 76 60 49 54 51 59 52 66 75 67 50 43 51 46 40 37 37 50 64
53 57 61 68 82 71 59 75 89 84 81 77 68 84 85 75 40 84 73 78
66 67 65 72 64 63 75 64 74 59 87 63 96 81 51 60 59 79 73 83
106 100 84 58 100 82 73 84 74 110 104 100 147 114 78 134 142 87 79 98
82 80 74 66 77 97 86 72 52 109 62 74 100 97 100 93 71 97 102 109
79 74 81 68 71 78 68 71 91 52 87 87 83 91 86 59 76 78 90 106
86 91 95 80 83 107
LAN-C05A 298
101 77 55 71 36 31 48 50 49 44 65 59 41 74 89 65 81 95 54 57
29 30 31 58 41 46 58 69 58 53 57 26 32 33 48 41 57 72 96 70
51 75 65 68 58 107 84 98 51 39 39 46 59 65 61 86 82 89 56 48
52 54 73 76 89 74 84 88 47 52 64 62 90 96 96 160 114 88 67 62
50 76 80 96 82 100 79 61 47 91 78 86 90 108 82 75 60 92 53 53
85 91 100 95 118 125 115 79 228 184 146 89 101 75 81 56 34 48 64 53
71 46 55 58 46 42 35 29 46 45 64 106 95 96 60 103 79 67 110 106
103 115 92 62 31 55 55 73 59 95 113 105 67 68 78 110 85 124 84 78
100 89 112 95 84 65 168 93 123 134 106 114 106 90 125 125 114 121 114 91
104 106 90 104 115 87 115 105 85 50 48 46 43 59 68 66 62 95 60 59
68 33 59 46 82 78 65 56 59 67 87 90 68 93 107 62 96 68 81 46
59 81 49 75 70 98 87 77 78 96 78 106 78 54 51 56 75 48 68 56
62 57 73 75 70 55 58 44 58 50 69 43 55 50 59 52 52 37 60 56
56 50 68 49 44 51 38 37 52 41 54 58 56 45 46 49 47 43 49 42
36 40 40 50 33 51 29 41 40 50 45 59 57 69 48 66 56 76
LAN-C05B 240
91 62 68 39 33 41 52 54 51 62 54 45 67 67 60 74 78 55 42 31
25 30 53 58 56 58 74 58 61 53 35 37 33 50 47 66 67 104 73 50
73 58 71 56 87 78 87 50 39 41 41 70 70 70 74 85 84 33 48 48
53 70 71 95 65 84 72 41 50 65 60 82 92 90 132 100 85 66 58 50
75 77 103 80 100 76 74 64 67 79 71 81 112 75 65 57 92 48 62 92
96 89 91 108 117 99 53 78 82 90 65 79 71 71 60 54 51 76 54 65
59 50 73 48 46 46 28 48 37 56 70 84 67 53 73 56 57 92 85 76
93 75 53 39 45 42 56 54 68 109 108 123 96 78 123 129 117 85 96 129
76 111 95 92 73 146 89 123 115 105 131 104 107 164 157 139 159 131 125 115
108 125 140 169 87 131 114 95 59 38 39 37 54 68 57 59 79 60 55 69
40 65 52 81 81 82 74 75 83 109 84 57 93 108 79 81 68 88 54 75
79 57 65 56 89 90 62 74 79 75 100 88 59 54 56 96 64 75 53 80
LAN-C05C 213
82 103 79 114 94 96 65 162 110 141 105 92 119 116 103 139 139 132 186 180

135 117 103 92 100 103 73 111 103 114 52 41 32 37 50 61 66 57 91 52
53 75 42 58 59 85 78 67 53 59 81 90 99 67 115 121 85 105 66 85
50 68 86 63 75 66 89 86 54 72 92 67 83 74 50 56 56 82 51 79
51 75 57 67 78 70 54 48 45 51 56 64 39 50 42 53 47 53 42 54
54 60 45 68 39 48 47 42 35 40 45 57 69 56 45 46 53 50 48 44
60 43 45 37 76 46 39 42 54 75 83 58 86 90 73 71 87 75 73 101
121 101 113 100 131 118 110 103 96 82 89 71 76 65 50 40 40 58 64 43
26 31 42 30 39 41 36 60 36 42 39 79 121 56 64 42 40 46 31 57
64 53 50 53 50 49 40 30 37 37 46 65 38 59 49 47 59 62 58 56
53 63 43 42 46 62 31 31 52 42 40 38 68
LAN-C05D 130
65 91 52 59 50 82 82 70 51 79 66 100 99 64 104 142 87 85 63 89
56 64 92 64 58 56 69 76 55 62 67 64 77 62 41 55 53 69 46 73
46 60 51 61 78 66 50 53 36 46 52 58 41 46 35 50 53 53 52 57
46 50 57 63 45 47 45 29 33 35 46 46 70 58 46 49 46 50 50 46
61 53 52 36 70 53 42 51 56 82 77 75 90 93 72 68 99 75 67 131
114 110 123 89 118 123 116 109 93 78 84 62 74 62 37 43 48 43 64 43
25 26 46 25 32 42 29 60 39 56
LAN-C06A 216
215 120 110 121 196 278 142 149 159 188 184 166 142 132 125 87 117 88 133 144
103 61 94 78 91 130 98 125 94 125 125 90 125 142 164 175 150 105 127 99
116 132 104 104 112 157 204 138 96 93 123 148 114 107 115 131 120 135 175 148
109 97 90 115 96 117 88 99 45 42 36 32 26 37 25 29 28 24 29 25
31 34 38 28 29 26 23 28 26 23 30 28 28 27 25 25 22 38 37 53
35 32 31 47 29 43 32 37 33 50 55 62 67 53 47 35 65 73 83 57
65 57 51 46 48 70 60 68 75 81 67 75 57 62 45 73 74 54 73 75
58 75 79 70 54 65 71 79 75 60 65 39 53 53 25 45 37 47 61 65
49 43 37 38 46 57 53 48 56 47 60 67 74 68 75 83 68 68 46 28
46 62 66 59 78 103 55 73 71 83 81 75 77 78 84 90 97 95 85 89
89 78 70 103 78 71 83 77 68 92 84 71 74 68 61 91
LAN-C06B 216
223 125 110 116 198 276 142 147 163 183 196 183 157 119 114 94 108 91 150 147
95 50 94 88 107 125 103 116 91 125 124 90 128 148 161 164 140 108 121 103
117 123 108 105 108 156 205 146 96 92 120 142 114 106 120 126 121 137 185 147
107 87 85 119 95 112 94 97 39 42 38 42 26 42 31 26 35 31 23 31
21 29 34 28 26 26 31 32 21 25 21 36 29 31 17 21 30 45 45 42
25 33 30 35 36 47 32 37 31 50 68 68 65 53 45 40 68 67 81 64
65 62 57 40 49 57 62 64 79 78 67 76 58 56 46 75 65 58 56 76
65 57 79 67 57 70 70 88 76 73 65 35 48 53 28 42 38 47 62 65
46 43 40 40 41 58 51 51 50 59 50 68 74 71 78 75 71 67 47 35
50 53 62 59 64 125 46 83 70 86 75 75 74 72 80 74 94 90 93 87
96 75 75 99 84 78 81 63 77 92 101 63 70 67 66 85
LAN-C07A 201
107 115 89 104 129 119 227 215 139 113 134 100 95 112 110 128 80 134 110 83
153 162 116 160 130 115 111 103 113 137 120 121 112 169 180 162 129 110 127 115
117 103 110 100 81 89 89 84 76 67 103 112 78 103 114 123 90 103 72 88
106 107 88 82 92 107 115 98 110 104 87 104 70 86 70 140 120 112 93 95
78 64 64 64 65 59 93 75 71 96 89 85 57 89 104 107 97 74 103 75
83 59 62 57 79 90 85 87 89 56 75 82 91 143 104 84 90 95 70 71
79 98 100 123 128 100 102 106 81 103 81 65 77 66 63 84 87 78 96 59
56 66 58 76 66 81 84 86 75 89 65 52 54 75 68 59 64 59 84 68
87 126 82 82 80 85 75 46 66 59 83 77 85 94 98 113 126 125 119 90
88 84 66 82 84 101 103 128 103 103 83 160 84 104 106 100 112 134 122 106

145
LAN-C07B 201
107 115 94 100 133 117 223 199 153 113 134 102 95 106 116 123 83 135 123 93
165 152 124 151 130 104 114 96 114 146 122 117 113 153 174 167 125 115 135 127
107 110 117 101 92 89 94 81 71 85 119 112 78 97 126 128 90 94 74 79
112 101 92 76 95 106 112 107 106 104 89 104 71 85 71 143 118 103 103 85
84 63 59 73 54 62 89 78 75 100 105 80 65 79 85 104 101 89 115 64
71 73 60 60 79 85 89 81 89 65 75 72 89 145 106 88 93 92 79 67
78 96 101 119 128 99 99 111 87 105 78 65 72 64 71 76 86 84 99 53
53 74 56 65 75 82 86 87 84 83 59 57 54 76 62 62 68 58 84 68
96 117 84 88 92 74 72 55 68 62 80 68 84 100 93 103 128 129 123 98
82 85 68 75 90 100 106 136 94 100 93 151 93 100 106 109 100 127 128 108
141
LAN-C08A 154
103 73 82 92 103 63 72 77 73 75 97 100 73 84 75 78 99 75 63 85
92 101 85 88 92 94 87 73 91 105 92 106 85 76 90 82 89 83 48 78
57 89 66 83 71 85 89 86 85 74 121 98 93 87 112 85 71 67 71 93
92 103 114 128 101 99 99 86 81 97 71 89 114 124 140 129 107 121 126 128
98 101 107 131 95 95 140 118 119 96 71 112 91 78 104 154 101 134 120 135
126 114 100 96 104 103 89 92 91 81 84 90 87 112 96 101 72 66 95 94
101 95 74 96 114 96 92 78 91 89 82 106 60 88 81 87 87 78 109 100
95 95 87 100 103 87 81 93 86 109 87 79 71 102
LAN-C08B 154
99 72 85 98 98 60 73 80 74 69 98 103 70 83 81 75 97 76 66 82
96 102 82 92 91 90 89 80 87 112 86 106 85 76 96 82 83 91 50 72
50 75 76 79 81 85 75 87 92 85 117 105 92 80 125 76 66 71 69 92
98 105 117 139 100 96 89 76 89 96 78 91 114 131 140 127 109 132 133 124
101 101 105 133 103 104 129 112 125 95 71 104 98 82 104 137 98 123 106 139
123 118 95 91 109 104 90 89 89 87 84 85 82 125 110 98 71 64 109 92
92 98 73 96 110 100 98 83 80 87 76 110 64 95 75 86 85 86 110 90
109 93 81 110 90 87 83 102 84 103 84 81 68 109
LAN-C09A 162
183 189 195 204 242 195 183 224 155 166 137 144 100 89 92 78 89 108 144 116
116 110 132 135 153 146 128 115 121 128 72 73 114 154 124 133 131 136 122 101
85 117 117 112 86 67 92 104 106 106 92 144 117 130 100 89 92 109 107 85
79 85 93 92 96 109 104 131 106 106 132 92 137 129 121 135 168 181 89 66
83 140 106 128 220 224 241 176 181 168 179 177 169 178 279 344 377 303 240 306
338 298 306 212 227 230 180 162 187 206 223 192 151 221 178 151 200 246 352 437
281 265 203 206 209 237 232 171 145 183 140 112 99 119 125 140 155 169 106 100
133 136 160 236 146 178 173 184 161 126 82 102 108 118 96 103 114 100 93 82
125 143
LAN-C09B 162
223 180 202 201 244 192 184 214 162 164 137 139 98 96 89 78 96 105 137 123
117 103 130 133 157 141 135 114 117 135 75 77 111 167 121 135 130 144 128 95
94 115 121 114 76 71 99 92 107 92 101 137 121 130 95 96 92 106 104 92
79 87 90 89 101 109 114 118 103 106 135 96 137 128 119 134 170 186 93 64
85 137 111 132 220 221 232 174 179 165 160 179 165 204 303 350 378 306 242 291
336 275 301 252 210 218 190 171 182 182 253 181 143 221 182 157 199 259 332 415
294 250 239 209 234 245 230 184 149 201 140 108 93 118 130 138 150 159 110 100
134 148 161 215 130 175 172 184 171 121 78 118 101 125 81 98 106 103 88 95
109 167
LAN-C10A 92
164 101 107 162 127 165 182 208 184 212 219 171 232 196 239 266 274 250 203 179

165 302 127 114 171 160 148 123 89 104 123 128 132 198 197 268 329 275 207 338
251 214 333 195 270 328 217 256 193 192 154 157 189 160 185 219 196 254 189 273
196 217 202 212 167 138 101 97 96 120 109 90 149 193 171 153 163 115 121 115
93 145 157 146 133 235 98 184 181 122 116 156
LAN-C10B 92
161 103 101 150 138 153 188 197 182 214 224 172 232 203 242 255 260 225 192 194
166 280 123 115 160 154 161 121 92 100 113 129 131 196 182 266 329 275 226 332
253 218 325 193 264 328 212 259 182 198 167 160 196 165 179 207 200 249 191 289
189 225 205 212 163 143 103 103 96 122 109 87 140 195 178 154 153 115 128 112
95 141 166 145 138 231 90 183 181 120 131 131
LAN-C11A 122
96 89 96 137 68 54 75 74 78 71 75 73 68 58 62 48 48 40 56 42
44 67 82 57 55 67 64 89 60 89 35 39 50 60 73 87 91 135 160 213
172 235 214 241 260 236 182 123 136 117 143 96 86 118 120 132 100 77 82 102
92 104 160 113 178 178 179 148 192 139 100 154 112 220 201 118 136 146 153 134
142 159 149 168 134 146 153 87 137 140 151 200 154 139 128 76 90 57 143 114
87 153 176 157 148 115 142 131 200 137 228 252 193 140 252 126 231 203 199 165
176 156
LAN-C11B 122
109 84 87 130 67 49 69 73 82 71 66 71 70 60 58 57 41 35 52 53
46 82 62 53 60 66 66 82 58 84 45 37 48 63 64 83 96 130 165 210
169 240 204 250 250 246 186 121 123 121 150 93 80 128 110 128 104 74 84 100
91 110 154 114 176 175 173 149 185 134 106 155 125 218 207 110 131 140 157 138
133 161 143 161 139 147 150 96 135 133 159 207 160 131 129 91 83 71 139 92
107 153 171 157 151 107 142 121 195 143 218 248 211 140 255 115 234 201 190 173
165 161
LAN-C12A 230
220 203 129 170 203 170 149 197 165 162 200 148 107 62 120 182 126 171 128 148
74 68 75 78 99 103 108 84 85 86 32 42 52 77 94 86 96 67 96 106
121 107 92 139 65 81 69 92 99 96 85 99 79 95 96 78 72 95 54 53
48 64 45 59 65 59 56 57 43 51 56 56 42 67 70 51 62 50 40 64
50 42 37 40 34 37 34 31 28 37 46 58 57 49 64 67 64 73 57 57
46 43 53 43 46 42 42 35 43 40 54 78 70 54 53 54 37 54 42 46
41 46 45 50 40 51 62 85 62 54 79 65 57 60 45 75 65 47 69 74
90 82 82 87 102 81 102 116 114 100 104 103 97 96 76 84 100 92 87 87
71 72 62 66 60 65 59 68 68 83 90 54 50 43 40 43 45 59 64 56
57 65 86 71 68 65 70 71 71 78 71 75 84 106 80 90 62 76 69 47
45 39 51 41 33 21 40 50 36 54 56 73 65 73 68 52 72 68 64 81
58 76 78 59 53 35 31 37 31 28
LAN-C12B 230
197 182 128 168 204 177 148 167 146 166 205 127 106 71 114 166 146 146 110 146
69 71 64 91 87 125 85 85 87 90 41 44 48 75 97 89 100 61 100 105
121 103 100 135 77 73 72 84 100 96 97 92 85 95 97 83 70 92 51 53
55 65 53 51 73 60 60 56 46 51 56 62 51 64 69 56 60 53 42 60
54 37 35 37 42 26 39 29 28 42 43 64 60 56 60 59 70 68 56 66
43 45 46 46 47 44 39 42 34 46 60 65 67 63 50 52 39 51 43 42
45 45 46 46 40 53 60 73 53 64 78 67 65 56 49 69 74 53 60 80
94 81 85 88 106 96 92 117 118 100 106 96 106 90 79 81 95 91 87 82
66 75 72 56 59 63 64 65 62 80 78 56 56 43 41 46 46 53 68 49
47 61 87 70 68 52 75 74 71 84 66 75 85 110 80 96 65 75 71 49
41 40 50 40 33 28 37 46 41 49 53 75 60 79 71 49 70 67 71 79
60 76 80 55 47 31 30 43 29 27
LAN-C13A 187

204 221 265 256 302 174 203 254 171 206 210 217 200 284 158 167 82 179 225 138
242 235 193 149 173 226 189 156 160 160 146 149 139 110 154 109 99 133 103 123
171 146 178 146 145 140 140 167 112 118 109 100 110 78 101 96 134 109 128 148
149 162 175 137 96 93 153 89 148 134 122 118 110 115 109 153 104 125 140 131
178 150 175 174 121 112 106 131 162 142 142 122 113 143 95 122 133 116 101 153
131 88 96 93 106 135 132 139 199 183 139 167 174 118 151 133 162 153 149 162
157 143 202 187 218 212 131 144 178 95 61 98 97 93 56 100 175 137 108 87
203 162 146 170 120 111 122 159 110 147 100 97 112 128 99 86 72 81 62 118
87 68 58 88 100 118 148 144 134 140 128 138 139 137 116 136 151 90 121 107
140 147 162 111 117 134 163
LAN-C13B 187
204 213 273 241 311 165 206 268 169 201 214 221 200 271 170 168 78 177 226 142
241 239 193 152 161 223 177 157 154 157 143 155 131 113 153 106 106 128 109 126
181 142 175 143 142 143 135 171 116 117 95 106 111 86 90 91 123 132 125 152
150 160 171 134 96 101 148 89 146 112 125 115 108 118 120 145 103 126 139 139
175 145 183 170 112 118 112 128 165 128 141 129 116 140 93 125 132 113 101 149
135 77 93 93 109 134 143 125 203 184 132 169 175 120 145 139 170 152 142 175
151 140 204 196 228 209 128 137 180 97 64 94 99 93 72 93 171 110 112 100
200 168 140 168 125 106 118 150 109 152 94 103 131 118 100 81 64 71 64 118
92 70 53 93 96 124 153 137 124 134 134 139 135 140 121 133 141 84 109 106
148 132 172 129 124 134 150
LAN-C14A 234
254 209 159 204 203 234 221 209 245 177 226 169 207 240 234 205 213 134 132 142
151 146 114 128 110 116 146 164 155 154 154 190 150 192 188 181 164 101 103 84
110 86 138 98 67 89 97 160 177 176 140 131 173 167 134 136 96 125 110 167
110 118 100 110 78 71 109 138 144 170 151 151 171 165 195 154 111 122 126 168
134 150 135 189 165 131 193 159 160 120 127 96 128 95 99 137 167 143 150 163
177 237 174 162 188 206 177 204 216 219 141 101 162 134 140 171 136 230 171 146
181 151 143 156 174 153 203 99 55 58 66 78 98 81 83 81 69 68 96 83
87 93 87 86 108 82 85 71 98 85 73 103 84 82 80 93 75 59 65 90
78 62 66 93 110 75 81 104 93 123 97 96 76 83 91 115 142 109 103 149
115 121 90 56 84 64 109 97 90 68 90 93 103 214 168 201 170 160 191 186
162 156 165 188 125 147 181 182 158 119 141 101 132 75 90 77 67 100 92 108
78 87 148 123 210 186 143 137 89 119 196 141 210 209
LAN-C14B 234
258 205 179 177 209 234 220 188 269 212 221 170 209 203 233 211 200 131 125 125
150 152 107 132 117 110 143 152 158 158 154 196 144 197 175 183 168 101 106 95
105 84 148 93 53 75 107 167 147 182 137 146 153 170 143 122 118 112 110 150
100 126 106 106 81 75 101 142 150 160 142 157 172 154 198 162 112 107 128 179
131 145 142 179 166 125 193 150 165 117 125 94 121 97 92 143 168 145 151 145
195 240 184 146 182 202 179 201 215 227 137 101 170 156 154 185 161 214 151 162
215 144 132 125 163 154 200 94 55 56 75 65 100 81 87 79 72 62 107 83
88 91 91 89 102 80 85 73 95 84 81 102 84 90 68 87 76 53 62 93
82 60 64 103 89 72 87 108 85 105 115 103 86 82 88 131 122 126 110 139
116 117 92 61 75 68 113 98 84 67 92 88 111 208 176 206 168 156 189 180
156 150 166 189 123 146 179 192 152 113 151 96 131 74 91 69 75 96 82 117
77 82 144 146 206 184 131 135 105 133 169 150 199 205
LAN-C15A 213
145 109 163 91 137 161 150 163 162 192 184 191 151 150 275 210 179 170 172 195
156 197 181 235 203 200 147 220 208 146 210 153 239 199 203 104 147 153 175 154
134 131 165 275 101 187 131 134 132 123 151 98 105 117 112 153 100 89 103 76
79 90 89 140 203 112 85 92 106 100 120 100 114 143 98 123 100 117 90 79
85 70 82 160 126 112 81 90 87 79 92 68 67 65 68 75 67 64 84 96

77 90 84 100 85 84 68 69 99 87 78 84 94 100 81 87 93 112 117 130
125 123 132 96 128 123 93 109 100 87 80 97 102 115 85 83 134 68 89 81
79 59 103 107 68 67 72 46 82 115 118 108 96 66 108 115 100 106 105 67
81 100 109 99 93 103 90 96 111 90 68 70 60 43 54 92 81 54 54 87
75 68 55 84 104 84 73 78 81 83 76 87 86 92 108 118 120 161 90 90
93 78 90 88 93 81 93 102 128 144 115 128 146
LAN-C15B 213
132 105 167 91 145 159 146 173 155 192 181 194 162 135 259 214 169 167 150 179
171 191 171 250 203 203 177 208 196 151 202 178 224 206 197 106 162 136 169 132
130 144 157 278 93 175 128 129 131 131 139 104 108 117 118 146 114 85 101 76
84 90 90 135 184 118 81 87 109 101 117 95 107 148 102 118 98 99 76 84
84 71 97 164 127 115 84 82 80 84 96 66 50 68 78 80 69 62 89 88
86 93 88 96 84 74 81 70 99 78 80 84 96 100 81 89 88 106 128 137
118 112 125 103 135 118 92 107 97 87 75 95 83 117 90 88 133 75 84 79
76 61 95 116 70 67 65 53 78 119 125 106 98 73 104 114 107 96 96 79
89 78 121 100 83 100 84 112 112 84 59 77 56 46 62 78 85 54 61 87
72 69 53 76 108 92 69 85 85 62 71 96 95 76 118 125 134 159 91 90
96 78 96 81 88 85 100 96 125 165 105 137 146
LAN-C16A 225
233 188 149 103 96 111 202 177 157 128 106 57 39 48 58 94 104 101 168 113
101 130 111 125 176 118 91 74 102 137 89 62 121 118 103 97 114 97 109 117
97 96 114 127 93 103 105 89 78 102 175 196 220 189 212 168 243 269 225 322
228 191 241 185 118 114 142 123 98 81 150 146 248 298 204 123 118 207 256 192
196 135 171 167 192 136 192 171 140 170 123 101 129 159 181 149 184 156 140 162
187 116 149 145 169 125 132 136 153 140 143 180 206 187 143 128 127 137 153 109
146 167 156 165 171 146 181 122 116 142 177 144 170 143 147 133 119 100 146 115
117 114 127 145 106 159 99 93 83 96 103 193 131 75 83 66 74 71 66 89
81 74 93 90 113 145 111 106 133 116 111 71 82 112 128 118 153 134 121 99
78 66 57 58 61 56 51 60 93 109 65 55 77 65 83 96 91 87 74 115
81 96 87 81 77 83 116 56 62 66 69 56 63 66 62 80 112 120 134 133
130 145 150 141 156
LAN-C16B 225
229 197 140 101 89 121 201 173 134 142 105 55 41 44 58 94 101 103 144 130
105 128 111 125 176 108 80 74 108 141 76 74 116 108 99 110 115 99 100 117
100 99 103 118 100 94 100 94 84 103 199 228 234 203 226 157 250 281 245 332
214 178 263 197 128 116 160 119 99 85 135 150 265 287 217 121 120 203 251 198
184 128 175 175 194 145 192 178 142 166 122 107 113 150 187 155 178 164 138 162
188 133 146 144 173 127 132 134 151 143 143 162 195 184 149 140 116 153 146 143
162 178 150 171 163 159 177 118 119 145 162 149 163 146 147 136 118 85 131 146
118 112 133 137 109 156 97 78 91 106 126 182 131 79 78 65 75 78 73 88
92 85 81 84 96 123 125 118 140 141 106 76 84 106 122 121 159 121 125 88
81 65 54 59 69 38 39 71 96 104 68 52 81 62 93 97 72 83 93 97
77 95 86 77 87 95 107 63 53 73 56 57 62 71 50 87 112 137 136 147
141 149 150 131 161
LAN-C17A 98
259 324 290 342 365 291 348 207 268 191 242 168 278 260 155 210 133 166 183 196
238 276 221 230 308 345 260 348 296 231 296 267 307 367 393 397 434 360 329 301
295 243 170 172 173 112 146 119 79 92 106 81 114 160 170 303 272 215 162 201
193 208 210 187 122 138 145 134 89 81 96 73 78 68 63 66 75 71 70 90
68 65 80 76 93 83 84 91 80 100 71 56 69 65 75 78 106 155
LAN-C17B 98
270 319 292 343 348 303 350 200 253 219 225 174 268 245 180 196 137 179 182 181
251 278 210 235 307 342 265 343 293 242 296 273 284 370 399 406 440 328 316 289

296 259 167 165 175 106 143 125 79 102 103 88 116 164 171 297 289 234 153 197
192 212 213 182 129 140 144 136 80 84 78 78 75 70 66 59 59 71 78 83
63 74 87 73 77 78 90 84 85 96 61 59 78 65 75 84 93 153
LAN-C18A 168
167 154 167 137 180 150 170 111 127 105 116 131 148 166 217 128 121 110 112 123
100 76 87 106 108 109 96 85 167 127 125 154 132 170 157 65 35 67 80 50
65 53 70 47 55 57 89 91 75 68 122 88 108 102 96 75 89 85 50 60
35 21 20 20 51 52 50 33 43 40 32 53 68 46 87 56 59 62 96 112
120 92 96 115 117 115 112 142 129 122 168 117 131 165 156 181 204 214 169 183
210 170 139 157 103 176 94 98 132 112 89 92 153 137 133 155 121 107 140 169
136 178 196 209 186 124 168 98 121 108 97 148 81 113 84 126 132 143 244 181
171 178 243 225 176 181 140 158 226 127 166 149 175 161 143 137 103 187 137 118
100 100 131 132 147 100 152 178
LAN-C18B 168
162 143 170 129 190 149 156 123 113 102 114 141 148 169 217 141 111 114 112 116
85 83 92 108 124 116 89 92 160 114 125 167 122 174 157 79 34 58 84 49
62 64 53 53 53 60 75 78 65 79 131 79 110 106 92 72 96 82 44 60
39 23 27 25 37 45 57 42 39 32 33 58 60 62 90 47 70 71 106 107
114 96 96 124 107 122 110 140 137 122 169 110 129 162 153 171 207 214 173 165
226 162 150 150 107 175 89 103 128 114 90 95 151 130 139 151 131 106 137 160
146 179 193 212 194 112 165 106 121 100 106 136 87 101 90 125 140 148 251 174
163 190 230 219 192 181 146 150 234 144 162 152 171 148 148 125 111 176 137 130
90 102 125 169 121 106 151 172
LAN-C19A 209
103 99 77 100 83 142 120 108 113 122 122 95 139 90 111 92 75 94 82 83
82 114 89 55 76 107 160 192 166 159 171 172 157 124 124 137 137 131 165 136
130 110 124 113 104 143 156 182 162 144 135 182 176 164 151 119 145 150 232 143
167 132 166 161 167 190 145 154 121 123 112 127 100 103 112 134 135 165 125 139
168 166 169 132 159 195 206 196 164 171 113 159 143 169 175 154 201 192 171 164
131 161 135 126 148 201 121 73 67 62 68 60 59 64 76 62 58 81 71 84
121 93 134 150 118 124 93 108 113 108 122 116 118 106 112 86 74 73 112 108
111 81 118 146 165 105 146 143 129 131 145 125 143 145 138 157 167 144 168 143
122 89 72 68 58 92 85 75 68 94 112 146 198 168 175 150 161 153 166 151
148 148 150 119 134 150 168 121 153 145 105 129 113 106 83 70 113 112 134 108
123 179 146 153 148 121 132 111 147
LAN-C19B 209
100 100 74 88 87 135 130 111 121 111 117 105 131 96 111 102 76 79 84 97
76 110 83 53 75 108 161 201 169 153 175 164 157 132 125 127 152 127 159 145
135 104 125 114 98 155 153 169 161 143 140 179 170 166 150 114 143 157 235 143
155 143 160 156 171 191 150 154 120 123 115 125 110 95 118 125 150 141 122 154
181 171 141 168 157 187 195 185 187 157 123 142 157 156 178 150 206 200 174 156
157 162 140 131 143 205 119 68 62 77 59 66 61 65 78 60 59 79 71 92
114 101 131 142 106 140 93 103 131 104 119 117 112 91 117 91 81 83 93 109
102 78 119 152 170 96 146 149 137 126 137 117 128 159 125 146 164 161 177 126
114 94 65 71 59 93 88 68 79 93 118 154 201 159 179 157 153 172 165 173
147 140 151 115 149 160 173 138 125 161 100 134 103 96 82 64 115 118 133 128
126 192 138 145 145 119 127 129 144
LAN-C20A 114
480 450 452 418 335 214 443 242 317 267 353 256 242 90 71 141 178 313 253 228
225 228 160 153 219 150 192 226 176 125 120 253 286 229 168 266 208 206 170 168
121 154 131 98 135 147 130 177 128 131 176 196 130 194 221 176 203 171 187 109
107 93 128 115 89 90 125 99 73 111 100 86 137 117 84 93 103 71 103 116
109 112 118 149 159 137 156 144 218 170 210 268 176 139 103 65 71 208 184 183

223 168 106 114 90 84 53 110 92 122 77 78 78 134
LAN-C20B 114
477 506 463 395 364 246 459 239 331 264 346 260 253 100 70 150 171 324 251 225
225 226 160 162 221 146 189 232 171 115 120 250 290 237 151 273 215 215 176 168
118 142 143 89 135 153 112 192 131 135 182 193 139 179 203 181 207 151 195 107
107 95 121 115 78 93 135 79 81 118 85 84 142 122 96 81 113 70 105 100
134 109 105 156 165 128 155 142 221 175 239 250 166 157 96 76 78 198 193 172
221 172 98 109 85 84 68 100 79 134 78 77 82 134
LAN-C21B 129
110 100 92 83 81 79 96 102 88 73 68 66 100 61 75 77 62 50 81 135
112 105 102 124 112 98 80 91 78 76 87 107 94 105 100 112 95 92 104 116
121 137 103 103 113 100 89 106 75 49 83 92 84 94 96 120 108 79 68 96
116 112 109 87 85 102 114 103 97 96 106 125 121 128 114 95 76 76 90 109
106 104 110 115 102 133 131 139 131 131 121 111 135 129 120 168 79 91 119 125
107 145 135 139 121 152 173 87 94 131 104 122 97 97 107 97 145 135 117 129
111 130 126 101 162 153 111 121 169
LAN-C21B 129
106 100 88 93 68 89 86 96 90 80 64 74 97 60 79 72 63 47 83 135
108 103 105 130 107 98 82 85 76 75 83 103 87 97 107 102 101 96 109 117
104 137 96 114 104 104 97 106 65 60 87 82 97 93 103 116 112 73 75 90
110 103 110 96 71 113 114 99 95 102 125 115 123 135 109 103 98 88 84 115
109 101 106 112 114 156 133 151 131 148 108 126 145 138 128 144 89 100 142 121
123 142 151 141 140 146 146 82 109 137 106 127 85 104 107 90 150 135 108 125
120 135 124 105 156 150 114 119 170
LAN-C22A 179
127 159 165 87 107 71 71 125 101 95 99 71 94 80 72 114 148 134 135 132
144 110 120 116 134 108 102 99 87 93 100 88 78 85 85 87 102 79 66 74
82 93 63 78 90 89 84 89 85 120 105 88 100 117 99 125 100 116 80 105
107 93 109 116 125 129 111 93 106 85 134 143 84 68 117 107 101 82 71 100
98 87 98 92 89 103 103 94 78 100 115 81 71 85 128 123 114 81 110 148
135 81 84 93 79 67 70 104 103 81 68 107 133 135 107 168 159 121 145 124
101 153 103 109 118 123 116 125 121 150 115 123 143 160 158 103 124 109 131 150
108 225 165 96 130 162 137 153 121 105 126 181 118 147 135 175 159 131 112 181
174 154 123 112 160 161 135 178 177 186 123 126 156 132 108 128 140 144 162
LAN-C22B 179
129 156 156 100 102 79 87 125 103 108 95 89 101 75 77 106 160 151 116 116
140 112 124 114 112 115 101 105 82 108 106 85 85 85 102 82 114 71 71 67
85 83 60 78 78 88 82 78 78 131 97 82 110 110 100 119 96 109 85 114
105 94 115 112 126 120 128 95 96 81 143 142 87 79 107 117 95 87 75 104
107 91 98 93 90 87 112 92 82 103 118 76 77 84 126 118 117 82 103 153
143 80 75 96 90 59 75 104 98 77 69 113 130 134 107 166 160 120 143 132
105 142 107 101 117 128 109 132 117 154 117 118 146 165 156 103 116 112 143 140
109 228 165 108 128 158 145 143 128 108 121 178 112 138 145 169 150 132 110 178
162 146 128 128 153 162 133 162 174 196 122 119 167 131 115 128 137 134 165
LAN-C23A 112
208 104 107 89 124 157 134 120 96 141 113 178 138 166 130 147 112 121 117 107
119 119 135 91 132 111 119 94 106 132 107 188 253 172 161 167 168 204 190 138
123 121 112 177 143 133 77 92 106 107 107 136 141 154 126 126 153 151 170 140
93 100 109 125 101 117 103 167 125 104 118 125 121 99 109 90 117 106 98 145
123 128 150 151 151 135 127 134 162 199 165 148 137 139 101 100 107 112 111 140
132 198 135 114 114 129 103 109 108 116 86 148
LAN-C23B 112
199 105 111 84 124 159 162 135 107 136 106 171 139 175 117 141 112 125 126 98

117 123 128 87 131 110 118 86 117 139 100 182 266 148 141 153 201 192 195 140
117 121 124 181 126 157 83 83 110 102 114 125 147 162 120 136 153 153 167 134
92 102 109 123 103 117 104 170 126 112 120 109 133 97 100 95 109 112 101 148
140 108 149 153 164 123 135 128 167 167 153 154 145 134 98 92 117 100 131 120
122 139 123 128 103 133 121 103 115 122 88 146
LAN-C24A 118
114 93 96 112 144 104 83 78 64 94 104 75 74 79 87 85 89 78 76 83
83 96 78 69 78 95 88 119 82 102 82 73 55 73 103 119 134 96 96 134
159 136 101 92 134 107 92 67 64 66 100 105 81 77 72 77 82 64 79 75
66 60 58 91 79 82 67 53 76 67 83 86 72 96 81 67 79 68 106 92
60 52 77 62 62 62 60 62 60 67 45 35 34 34 45 62 67 82 59 42
48 56 56 50 42 35 32 35 44 50 61 64 64 57 68 48 37 71
LAN-C24B 118
114 99 104 102 142 112 82 84 67 92 104 84 73 82 93 72 93 82 78 80
79 94 71 64 69 92 90 114 91 96 75 72 57 75 108 128 115 92 110 137
164 128 108 87 136 107 92 66 63 70 93 101 71 81 64 75 71 60 80 71
60 54 63 88 75 82 71 55 75 67 82 85 71 95 79 67 82 71 101 90
65 60 57 64 60 64 60 58 66 72 54 39 29 31 47 59 70 82 54 45
48 62 56 50 44 35 33 27 47 51 54 68 60 60 56 53 40 74
LAN-C25A 123
104 90 78 94 127 164 146 109 83 87 100 100 89 100 93 61 57 44 59 48
51 62 40 64 42 39 32 51 44 49 61 44 44 37 57 85 54 53 55 37
71 69 46 42 41 32 35 34 48 50 51 100 85 56 49 85 64 57 59 57
42 64 67 57 68 50 42 45 45 60 56 43 46 42 67 67 87 65 70 78
80 61 89 86 71 75 57 59 57 75 63 75 67 53 60 46 38 54 47 60
61 51 60 57 51 54 54 54 62 76 78 78 57 73 64 46 53 51 43 45
39 42 57
LAN-C25B 123
108 87 72 102 120 159 147 113 87 79 112 98 84 99 92 58 62 40 62 50
46 67 41 62 41 37 33 52 42 48 60 46 46 37 61 85 50 60 50 41
67 69 46 38 45 32 33 33 50 50 52 101 87 51 50 82 56 65 55 56
45 66 64 54 64 55 44 46 45 64 54 46 46 43 65 62 74 69 73 76
78 69 82 89 75 69 59 51 62 71 65 73 63 47 60 48 39 55 52 58
68 51 59 60 53 49 57 51 63 69 78 84 54 70 67 46 54 54 42 44
42 46 57
LAN-C26A 90
215 172 173 174 169 160 192 179 194 154 159 114 85 98 112 159 289 247 185 164
152 191 203 188 161 100 53 47 38 32 32 50 54 51 51 63 70 72 67 54
44 85 96 121 121 106 83 77 96 120 69 78 87 65 56 40 53 42 39 50
47 59 50 35 38 55 63 51 57 54 67 54 81 140 79 95 79 50 95 95
75 50 52 44 55 42 62 67 62 148
LAN-C26B 90
217 176 178 171 171 160 204 167 196 166 148 108 86 99 100 162 287 255 182 164
162 176 202 188 159 106 57 42 39 35 34 46 60 46 50 64 65 71 70 53
43 82 96 126 116 110 80 83 89 117 69 86 84 63 54 45 51 40 40 50
50 53 51 39 40 54 61 48 59 62 68 51 79 140 82 93 73 60 91 100
64 53 51 45 52 48 62 68 61 142
LAN-C27A 109
308 242 236 263 313 221 211 189 212 194 167 235 205 223 213 200 217 286 221 234
236 171 203 173 216 284 167 179 153 148 143 132 143 159 200 195 187 123 162 176
181 150 131 100 118 176 156 112 115 152 148 143 117 146 154 178 165 126 112 126
123 112 132 150 121 116 102 89 82 67 71 64 76 71 82 90 120 75 68 78
96 91 70 84 96 81 79 98 137 135 96 95 79 103 84 105 94 78 67 87

75 90 121 90 68 66 73 59 62
LAN-C27B 109
313 248 234 257 314 219 208 192 216 194 167 237 199 232 217 210 223 302 245 240
218 156 197 170 229 282 167 188 167 156 148 137 129 162 168 220 153 129 156 160
189 152 129 103 112 176 152 121 116 148 149 144 113 146 148 193 164 139 125 134
118 115 127 162 120 110 98 92 78 71 68 59 79 69 79 87 118 90 67 81
98 96 76 90 96 84 76 88 137 115 115 102 87 95 89 97 90 87 64 91
75 93 112 100 75 68 70 66 62
LAN-C28A 190
82 88 132 138 117 107 102 141 155 121 127 106 91 96 84 110 107 122 119 126
78 98 120 117 123 133 129 139 144 149 190 137 79 89 67 103 155 130 121 122
143 117 150 184 173 163 113 125 162 172 126 114 157 178 140 113 117 113 157 126
123 173 196 170 159 146 107 96 68 141 160 179 156 141 150 154 120 121 107 107
92 100 81 123 135 103 109 101 126 171 164 137 162 153 139 73 98 92 101 106
98 93 75 79 97 90 111 96 95 88 78 87 98 86 87 87 82 115 121 112
93 97 63 85 79 101 101 108 91 81 59 43 57 81 66 78 69 79 50 48
45 48 57 53 78 78 57 51 65 67 56 59 59 47 62 43 68 59 50 50
49 53 42 57 67 53 38 37 58 59 60 54 44 39 39 38 45 37 43 40
21 25 30 26 28 42 34 22 34 40
LAN-C28B 190
92 94 130 140 119 111 102 126 158 119 116 108 90 94 87 107 113 123 118 121
98 82 121 113 114 137 130 135 146 162 191 135 82 89 78 102 140 132 132 117
132 110 150 189 173 157 117 127 155 175 135 117 154 170 139 120 106 117 160 132
120 171 200 163 170 140 121 84 76 137 153 184 148 156 146 164 143 115 115 109
93 104 89 115 132 98 116 102 119 178 167 145 159 148 148 78 96 90 98 103
94 91 71 78 98 97 109 100 91 86 78 90 102 81 91 77 84 115 125 108
96 98 64 77 79 102 107 110 85 84 59 50 56 76 67 79 78 67 52 52
41 52 56 59 75 75 64 47 62 68 53 65 59 50 62 45 56 56 53 46
57 50 46 56 59 59 31 47 65 59 70 50 54 36 35 40 45 32 43 41
22 25 25 27 28 37 40 22 27 35
LAN-C29A 75
211 237 297 271 405 343 276 321 301 167 228 214 242 230 260 203 289 363 164 42
168 274 282 317 290 276 280 392 259 253 298 187 259 329 200 213 220 176 129 126
159 132 125 146 134 157 221 214 157 104 146 131 135 110 98 115 153 135 123 159
156 121 142 185 161 103 137 100 101 76 66 83 82 76 62
LAN-C29B 75
214 237 300 266 406 336 253 325 307 174 230 205 249 214 264 209 301 350 176 49
185 282 279 334 271 282 284 393 264 257 301 185 264 323 204 207 222 182 136 120
164 135 117 143 122 165 234 218 153 103 145 140 131 120 90 118 150 132 115 155
164 128 145 184 150 106 141 100 97 81 64 83 79 73 58
LAN-C30A 61
413 451 179 92 346 406 296 297 321 349 267 423 335 303 353 221 327 364 264 341
235 207 150 160 148 162 112 126 131 144 163 189 125 123 153 140 153 110 136 139
154 131 130 130 137 85 100 103 135 81 106 93 83 81 67 79 82 82 84 57
81
LAN-C30B 61
424 452 178 92 342 400 298 300 325 351 287 429 328 307 347 222 332 361 271 335
244 199 147 163 156 155 119 125 129 142 162 192 132 115 150 143 153 117 135 137
146 135 139 128 123 92 96 103 129 78 105 100 82 81 62 78 85 86 80 57
94
LAN-C31A 141
272 202 290 393 312 351 260 207 171 190 184 262 214 189 167 176 193 213 137 121
173 180 224 178 128 176 189 175 158 177 151 97 115 117 142 85 119 104 115 87

56 85 125 132 125 92 107 81 95 101 92 43 62 85 65 81 71 65 59 86
101 101 117 93 61 46 128 114 81 107 70 54 48 43 43 54 39 56 45 42
45 70 71 70 76 75 51 54 60 51 40 61 118 71 59 59 71 50 43 49
50 46 45 54 60 47 47 43 49 47 44 39 46 45 40 49 39 42 39 34
35 35 44 35 35 45 61 49 34 40 53 37 37 45 40 46 46 53 45 49
40
LAN-C31B 141
265 222 283 385 320 336 250 218 186 186 187 257 209 203 175 178 199 214 139 118
160 186 223 178 131 182 188 175 177 183 146 101 106 123 140 79 117 107 112 87
77 83 117 134 123 90 112 79 90 105 83 43 69 84 63 81 71 67 64 84
98 93 117 79 57 50 125 115 82 107 73 51 50 40 48 53 36 54 46 45
50 65 70 68 76 76 50 56 57 51 40 65 120 65 60 56 71 50 43 50
51 43 49 53 62 45 48 45 48 49 43 32 51 41 45 46 40 38 42 35
25 43 45 33 39 40 62 46 35 43 56 37 37 46 38 43 49 49 51 42
44
LAN-C32A 135
254 363 326 287 63 24 28 43 59 142 142 198 230 286 318 300 219 217 200 181
214 178 151 204 264 283 274 257 203 239 196 161 176 159 154 175 155 239 185 314
280 358 262 243 192 187 113 184 162 152 133 146 150 156 201 162 167 296 262 223
198 182 179 154 125 181 147 126 110 86 110 126 98 84 121 140 87 78 93 62
72 122 133 163 165 110 115 125 89 106 81 103 152 71 65 50 68 51 47 70
81 87 103 71 78 78 126 93 85 75 51 56 34 18 34 41 51 64 79 62
57 55 69 55 65 50 55 40 59 61 63 93 87 40 68
LAN-C32B 135
257 364 321 282 59 29 28 46 54 134 144 203 221 298 307 301 232 204 205 183
210 181 146 198 285 283 259 245 210 254 199 163 179 165 146 200 129 229 198 295
275 337 296 251 195 214 104 168 171 140 135 147 143 155 200 159 157 304 263 228
203 184 176 149 128 180 143 128 115 84 113 118 100 84 128 140 87 77 93 63
70 112 134 169 165 109 129 132 87 93 92 119 153 75 67 50 65 53 48 65
81 92 93 68 69 78 121 81 84 73 47 52 33 16 38 37 50 74 75 61
56 53 69 55 67 46 53 37 65 58 68 75 86 43 68
LAN-C33A 96
60 48 49 68 60 51 56 48 75 87 66 62 47 58 56 42 53 57 67 68
71 86 119 132 89 116 137 99 92 66 99 117 119 110 119 114 96 102 78 69
62 55 73 87 94 44 61 78 77 98 117 78 97 60 85 82 92 93 14 23
25 38 37 45 54 55 61 60 100 116 132 77 97 110 97 81 71 88 66 63
56 64 61 56 64 48 40 78 76 57 51 64 44 71 73 45
LAN-C33B 96
56 45 56 67 60 41 62 46 77 91 67 60 56 57 58 41 59 56 65 72
67 89 120 135 86 123 135 96 97 72 100 117 123 113 120 113 96 101 83 69
63 54 74 82 105 46 54 79 73 97 108 82 100 60 78 86 92 93 13 21
28 38 35 46 55 58 62 58 100 108 146 78 95 104 100 77 75 84 71 56
57 60 60 60 65 46 42 81 76 53 55 63 46 68 65 46
LAN-C34A 95
315 267 231 353 288 239 292 210 216 314 266 266 246 201 161 150 154 214 141 155
165 171 243 264 164 110 164 139 153 125 109 156 165 169 160 183 171 112 139 123
154 92 117 104 96 98 60 87 118 90 98 79 106 82 78 85 79 50 68 75
53 53 56 50 75 74 104 90 128 96 82 56 128 112 81 85 64 51 31 34
43 44 37 35 25 45 31 50 48 44 50 48 34 39 63
LAN-C34B 95
301 268 226 328 312 225 295 210 201 310 268 269 239 196 160 146 167 203 132 157
164 172 250 260 177 122 161 135 154 139 103 160 160 172 171 193 176 118 139 123
143 107 137 103 109 105 60 92 115 89 107 76 104 85 75 85 78 46 64 78

54 59 54 57 76 84 95 91 117 87 92 49 120 121 76 87 64 46 37 32
42 43 35 34 23 39 32 46 50 48 50 43 37 34 79
LAN-C35A 117
229 270 271 254 268 304 229 121 141 181 168 127 159 169 175 177 172 114 91 125
143 164 156 128 168 193 188 153 153 146 121 121 146 144 109 142 102 87 74 67
79 79 76 87 69 103 76 67 70 81 53 84 84 69 81 65 67 67 97 117
110 149 82 75 66 120 114 67 91 60 59 55 46 54 68 63 54 37 52 50
62 71 53 62 53 46 44 62 45 35 53 59 53 41 48 68 67 42 50 50
59 63 59 54 60 64 48 54 48 40 32 31 35 39 42 40 54
LAN-C35B 117
224 271 280 241 284 319 235 142 141 164 169 153 160 162 182 164 185 113 90 132
148 171 155 121 162 199 189 150 157 148 114 116 145 159 100 143 103 92 78 60
84 76 79 89 65 106 73 67 73 82 48 81 81 75 78 65 64 68 103 114
112 146 92 68 65 118 115 67 93 53 59 50 51 49 70 70 51 46 45 53
64 71 48 60 54 48 45 62 43 43 37 57 54 46 50 65 54 46 51 53
56 64 64 54 59 59 53 52 53 35 29 40 34 32 35 37 54
LAN-C36A 85
343 299 301 353 255 180 187 250 228 239 269 276 262 158 68 24 22 46 52 101
100 155 153 139 133 132 133 107 85 126 120 208 160 130 128 171 167 183 160 173
125 121 187 176 160 164 156 156 112 120 97 110 146 128 139 143 117 196 195 173
159 132 170 159 129 104 142 154 131 154 137 94 110 128 129 137 164 160 140 170
142 136 116 118 150
LAN-C36B 85
358 305 310 353 249 180 196 240 241 218 265 275 269 160 75 18 21 41 56 107
111 139 155 133 134 129 139 105 92 119 131 208 154 145 120 135 168 190 171 160
134 105 204 181 173 162 139 166 122 129 84 116 150 118 139 143 118 195 217 198
170 121 176 156 134 114 134 162 123 156 134 86 111 138 125 130 163 167 142 160
137 131 115 123 155
LAN-C37A 59
80 100 132 169 129 146 123 117 147 123 146 179 202 207 149 126 142 143 122 125
117 135 126 131 131 128 112 83 57 57 73 103 117 125 96 103 96 85 88 103
101 84 69 85 67 75 72 114 85 58 70 72 82 67 78 64 50 69 55
LAN-C37B 59
82 99 135 159 125 152 118 120 147 126 147 175 210 198 142 118 152 145 117 126
108 148 127 130 127 129 111 80 52 64 82 100 125 128 103 89 92 90 83 117
102 85 68 82 70 71 76 105 90 67 69 72 80 64 72 62 50 71 54
LAN-C38A 154
225 255 196 205 201 233 189 197 220 243 251 236 240 282 143 64 90 101 153 182
258 306 264 207 231 203 196 242 314 292 294 211 209 179 162 171 179 161 185 242
214 215 150 154 170 220 205 140 128 145 81 76 63 64 95 104 134 128 156 148
206 204 131 159 184 194 173 165 120 135 140 81 82 117 142 100 78 82 85 74
93 81 100 105 136 173 125 83 88 95 107 108 71 101 89 106 75 65 59 110
94 82 56 85 66 50 65 65 49 58 74 68 75 100 67 50 72 55 47 65
46 52 59 59 53 53 56 68 57 80 50 51 79 98 84 75 78 82 104 104
80 81 63 57 62 53 48 60 63 64 54 80 59 59
LAN-C38B 154
229 266 200 199 200 231 195 192 225 239 251 241 240 289 129 71 99 100 151 181
250 305 260 210 213 202 191 250 310 286 274 217 207 196 154 156 184 173 191 243
209 203 154 157 167 210 204 142 121 154 87 59 71 71 101 104 114 118 164 150
182 212 140 157 186 194 170 151 119 155 134 84 84 126 134 105 77 80 85 81
93 72 105 101 134 183 116 92 84 93 106 100 78 105 87 105 73 66 58 108
93 73 66 82 65 52 66 57 53 61 68 71 75 96 65 58 72 50 43 65
46 58 59 54 59 55 62 59 59 71 59 51 82 100 82 67 80 87 102 97

84 81 65 56 62 50 53 57 64 62 55 87 71 65
LAN-C40A 110
151 149 217 184 204 199 151 83 136 194 209 293 313 275 209 155 133 189 264 164
199 115 189 228 145 123 134 168 128 156 182 106 157 200 150 160 154 125 118 108
109 148 123 87 101 65 78 68 65 64 123 90 87 89 80 47 46 71 70 66
56 50 48 41 54 59 89 54 72 71 67 48 37 28 35 48 48 45 41 55
48 71 65 42 22 27 42 62 62 53 62 82 78 92 55 83 63 39 40 69
50 35 31 37 42 32 43 35 45 84
LAN-C40B 110
149 155 213 180 204 200 149 83 136 195 217 287 315 266 200 158 130 187 258 166
233 125 187 214 153 120 132 162 132 157 172 111 164 192 157 132 143 122 127 101
104 128 135 104 96 77 75 70 60 67 123 103 89 88 82 50 45 75 75 61
56 43 54 58 69 60 68 67 67 73 64 43 38 33 39 44 48 48 42 54
46 73 59 46 23 26 39 64 68 64 68 78 81 92 57 84 54 40 37 64
45 38 28 40 39 34 43 41 48 82
LAN-C41A 161
200 225 306 284 210 219 222 180 198 198 281 201 176 185 191 181 159 164 161 128
155 125 60 33 34 60 75 146 151 129 150 183 161 128 117 146 89 106 102 100
96 113 106 151 139 129 151 136 181 181 145 124 93 104 112 95 103 90 82 117
110 109 145 134 128 110 110 128 117 78 82 84 93 89 57 76 53 95 75 115
117 92 89 75 110 84 96 87 89 80 89 82 70 71 88 75 63 46 34 32
38 43 39 46 42 42 39 39 35 32 35 50 55 51 56 62 84 79 43 46
31 33 34 42 51 59 41 71 63 55 59 42 76 99 100 75 37 84 80 48
67 50 46 62 46 32 42 40 37 43 43 59 56 65 56 62 58 50 53 76
126
LAN-C41B 161
209 231 300 283 207 225 214 189 209 191 262 200 182 176 184 185 165 162 158 128
153 132 53 38 34 63 72 146 135 146 144 180 156 124 125 134 88 120 96 100
98 104 122 143 129 137 142 146 176 189 142 128 85 103 113 100 100 91 83 118
107 107 151 134 120 117 109 131 117 79 79 79 104 86 56 73 57 92 74 114
117 96 84 76 112 87 96 82 96 68 96 78 74 68 89 75 65 48 36 24
33 43 45 50 41 41 36 42 34 27 35 50 53 55 53 59 83 82 44 42
31 34 34 40 51 61 46 65 64 53 64 38 79 97 99 69 43 84 71 57
62 51 45 58 50 36 41 37 46 47 39 53 55 59 61 61 62 43 53 78
128
LAN-C42A 112
378 583 470 538 489 389 391 414 402 371 321 384 441 407 371 408 314 321 295 246
250 256 218 230 292 309 298 292 310 300 302 347 229 254 254 243 234 210 251 251
155 140 158 128 154 121 106 128 114 103 137 93 112 104 125 203 193 117 84 135
166 101 88 73 82 125 118 152 112 109 93 125 99 70 96 101 96 100 81 103
68 88 95 128 110 145 103 73 64 81 103 79 101 85 114 118 125 106 109 96
94 80 70 88 62 57 70 44 40 52 62 81
LAN-C42B 112
405 584 462 531 493 393 394 397 408 382 291 378 437 418 385 414 312 337 276 244
259 234 232 215 320 293 295 293 325 294 312 362 232 251 229 232 257 213 263 253
149 137 165 132 152 115 102 125 112 99 128 100 109 110 129 204 190 116 81 137
159 103 82 74 89 121 129 159 103 113 90 122 100 75 92 109 85 94 83 102
74 88 98 119 119 143 103 71 70 81 95 86 96 89 103 122 134 111 103 90
103 80 74 86 63 59 68 48 48 58 64 78
LAN-C43A 95
98 70 95 173 184 271 218 157 151 268 301 250 237 285 246 209 210 202 185 171
190 192 201 184 185 182 220 143 120 117 133 135 128 114 117 140 136 173 129 109
109 150 166 153 253 218 170 232 160 146 110 84 125 115 120 105 123 115 84 71

89 107 118 104 101 118 127 122 116 114 121 114 103 118 135 128 124 184 167 151
171 129 150 136 127 100 82 110 136 123 124 159 159 130 115
LAN-C43B 95
86 92 96 171 184 268 219 156 149 272 303 246 235 284 252 211 207 203 189 178
189 187 200 183 185 180 225 142 117 114 132 125 129 115 118 142 142 164 129 109
113 147 159 160 254 212 179 214 156 153 114 82 129 114 121 106 128 107 84 65
86 96 128 103 104 119 123 117 118 120 125 114 108 106 137 131 137 177 170 146
168 132 140 125 125 104 91 108 131 132 125 162 156 137 112
LAN-C44A 93
196 241 221 175 180 259 304 254 237 291 254 227 245 198 207 207 246 232 208 196
186 196 214 172 204 196 197 211 215 170 164 160 183 164 141 101 134 168 198 187
225 187 190 227 192 189 132 92 135 139 160 133 145 126 92 57 68 81 84 110
106 121 104 109 96 114 135 135 155 149 139 110 143 176 148 144 146 120 110 125
104 81 50 103 134 121 143 137 116 86 71 75 106
LAN-C44B 93
193 234 215 185 180 281 307 256 239 286 256 232 239 206 190 210 235 223 216 189
188 196 219 165 199 205 205 207 227 167 178 160 167 162 148 103 137 177 203 190
223 181 182 221 184 189 131 91 132 140 162 136 144 116 100 58 67 73 92 108
103 123 109 114 101 96 136 139 146 154 145 108 138 161 153 121 157 121 120 119
99 84 59 99 126 120 132 137 112 95 75 75 104
LAN-C45A 178
101 98 86 89 78 119 102 95 102 110 127 126 104 112 111 104 122 116 144 137
146 108 131 89 123 101 98 85 92 97 96 98 110 129 110 109 120 121 100 87
100 74 77 71 68 75 89 132 122 95 92 85 71 107 82 89 52 51 98 85
65 53 78 64 64 62 76 75 77 64 76 82 83 121 142 121 98 109 104 110
128 81 50 64 103 120 104 87 90 95 87 96 71 71 53 59 48 70 87 79
84 76 89 57 75 70 70 43 65 85 65 46 73 73 75 54 62 62 62 71
65 50 50 71 85 79 71 76 75 51 68 71 67 50 96 98 95 48 51 57
54 63 79 101 68 95 109 73 58 68 68 65 73 59 58 21 28 44 53 56
65 57 60 60 70 60 78 78 78 64 53 62 78 88 105 96 100 109
LAN-C45B 178
101 98 84 89 81 116 102 94 99 108 129 128 107 108 108 104 123 114 141 138
146 110 130 82 130 94 103 83 89 97 96 100 107 135 113 106 125 121 100 89
96 87 66 70 74 71 87 127 116 97 90 88 69 100 84 94 54 55 96 89
67 57 75 66 57 66 74 86 71 63 73 84 85 121 139 118 118 106 101 110
121 75 57 59 101 125 98 93 92 100 100 89 87 62 49 57 50 74 81 85
72 84 85 57 81 64 71 43 60 95 60 45 62 78 72 55 61 68 59 69
68 48 52 68 83 78 73 79 71 53 71 70 68 48 92 96 96 48 59 57
51 62 79 100 70 89 107 77 62 68 66 67 78 62 53 26 32 42 54 50
68 56 61 59 69 61 84 72 84 59 53 61 75 96 112 85 93 101
LAN-C46A 146
53 71 78 64 45 58 53 57 44 86 80 69 57 58 54 66 46 91 57 54
68 66 50 44 58 33 43 41 48 57 58 49 43 56 40 38 52 56 59 87
83 85 96 76 69 84 67 123 115 67 94 61 81 67 67 47 49 64 41 58
78 55 49 78 67 87 92 83 84 46 105 117 65 73 42 64 73 53 42 62
63 67 57 41 65 76 71 85 53 53 58 82 88 96 69 53 104 87 103 62
57 71 51 68 90 82 78 87 65 86 54 85 63 84 60 53 50 29 30 53
37 52 48 56 48 60 75 60 74 81 75 60 50 54 75 92 92 110 69 91
109 76 78 65 84 75
LAN-C46B 146
47 69 78 64 47 54 55 54 50 79 80 75 61 55 47 70 49 92 59 54
74 66 56 44 55 35 44 42 53 56 61 42 43 51 41 31 57 51 66 86
98 86 90 72 71 85 74 125 98 69 91 67 80 70 71 53 53 57 42 52

85 57 55 73 69 81 92 80 85 52 97 125 60 74 43 60 70 59 45 63
58 71 57 42 62 57 85 74 52 59 65 73 89 102 75 57 105 95 107 64
56 70 59 64 92 71 88 79 67 76 64 78 62 64 57 60 54 28 31 59
46 54 59 48 51 62 71 57 76 87 68 54 52 57 72 92 96 110 85 87
112 80 73 64 84 73
LAN-C47A 177
206 171 181 162 135 156 167 173 120 118 174 167 188 133 142 139 107 108 96 117
112 108 113 137 110 170 158 148 164 210 192 169 168 178 142 135 119 137 130 148
110 110 107 96 124 100 123 117 119 93 127 62 62 75 63 82 60 84 96 123
96 90 131 120 106 123 101 129 118 125 126 103 132 160 145 160 144 135 106 129
92 95 60 76 81 47 53 118 106 76 85 117 93 95 82 62 60 81 85 81
68 84 70 93 96 84 71 76 79 69 81 75 60 53 73 90 77 120 93 108
118 137 127 107 105 103 115 184 109 118 159 159 144 134 143 128 112 128 123 111
83 140 106 128 96 121 124 131 169 190 106 114 114 105 149 125 151 165 104 104
115 152 94 123 91 78 87 121 101 77 59 62 75 96 90 70 114
LAN-C47B 177
199 167 184 159 130 155 163 184 117 116 169 180 184 138 141 126 126 94 97 112
112 117 111 120 122 159 157 163 171 203 192 173 153 203 121 117 132 142 135 160
104 115 105 100 134 103 125 123 109 104 131 78 68 82 72 77 72 77 104 120
110 98 121 123 107 118 104 125 117 128 118 105 139 155 148 156 150 135 109 129
89 92 63 75 75 54 53 117 100 71 89 109 98 100 82 62 57 78 90 87
65 85 67 93 89 86 76 81 80 68 84 71 52 60 71 87 75 124 93 103
110 127 143 109 105 94 112 181 106 121 150 178 144 128 158 128 128 121 119 109
81 135 106 132 85 128 128 128 178 193 115 100 110 111 156 120 145 173 103 101
121 143 102 126 83 81 100 110 103 85 66 56 78 90 98 78 118
LAN-C48A 157
130 151 159 219 249 359 218 222 214 259 160 178 180 135 83 87 117 125 141 138
114 125 122 176 128 142 142 111 99 124 130 94 110 109 81 99 92 111 117 135
138 111 107 142 131 117 123 106 110 141 130 101 126 126 126 118 84 90 118 187
203 165 142 154 148 170 145 117 99 108 114 152 150 150 129 151 112 128 188 179
203 170 231 173 239 192 175 165 152 142 171 165 151 151 175 181 156 151 193 194
205 171 175 147 168 171 148 156 209 199 177 145 184 261 207 233 249 277 183 241
204 222 162 178 168 212 204 199 202 184 146 134 143 181 168 179 133 148 156 134
131 150 125 139 118 113 143 189 162 153 199 197 160 142 165 162 164
LAN-C48B 157
125 140 173 215 263 380 232 228 226 271 186 167 191 142 98 96 119 141 141 123
132 111 149 192 135 153 143 118 99 131 121 88 120 100 80 90 96 105 111 132
131 115 111 136 123 112 114 107 105 168 142 95 137 122 134 117 79 82 123 190
189 178 137 143 157 165 148 120 101 100 116 117 143 154 125 153 110 139 179 171
214 170 226 187 226 187 170 159 134 152 162 178 151 155 181 171 173 146 206 184
205 175 177 159 168 168 143 160 206 209 166 155 187 272 201 219 259 279 195 244
206 234 156 179 168 210 202 206 211 188 137 153 148 188 178 189 122 169 146 153
134 146 134 125 95 140 156 192 170 171 210 193 165 155 143 162 139
LAN-C49A 186
161 113 121 121 157 92 97 75 71 127 108 134 150 137 140 169 118 145 141 98
110 112 144 128 108 117 150 177 147 177 134 190 102 117 92 106 103 78 95 114
113 97 97 102 135 97 78 82 89 64 98 75 67 81 60 47 53 45 35 57
59 60 61 84 75 73 112 82 100 129 131 71 65 79 92 60 60 76 98 85
121 93 120 95 98 114 151 139 100 70 52 76 104 118 130 131 126 107 99 90
76 79 93 82 52 60 82 81 67 65 65 89 112 135 117 81 74 76 65 112
121 135 132 112 93 67 67 81 91 158 74 68 63 82 100 96 104 92 93 107
96 97 90 103 115 96 150 81 96 100 94 121 109 123 105 100 91 88 59 48
84 84 96 93 102 100 87 108 100 103 103 101 89 100 81 88 93 103 98 104

84 90 93 80 72 106
LAN-C49B 186
186 105 128 125 155 83 105 67 88 108 121 127 155 119 144 142 128 146 137 105
118 137 146 142 110 128 145 169 139 184 149 184 103 115 93 114 103 74 93 110
97 96 100 102 146 94 78 81 100 65 94 71 85 78 64 43 50 50 53 53
60 63 65 89 84 75 128 81 110 126 145 81 75 82 104 53 51 60 85 90
121 99 109 100 93 107 140 121 101 68 56 75 95 108 119 130 121 117 96 83
72 79 91 84 51 60 89 78 71 61 69 86 109 137 119 74 78 71 64 123
125 128 132 120 90 64 67 83 84 146 77 68 60 83 100 96 116 95 91 105
96 88 96 109 115 97 162 93 101 93 90 119 99 115 115 109 81 92 64 47
83 78 93 84 105 94 86 112 112 103 91 112 109 64 94 93 81 103 103 103
104 89 90 72 78 100
LAN-C50A 263
96 120 90 156 167 141 100 175 202 191 185 196 171 136 91 87 96 98 95 71
94 132 110 107 80 97 96 133 67 98 89 101 111 106 105 68 89 109 82 96
79 84 72 53 65 76 66 106 124 125 114 78 154 123 137 77 85 85 80 93
77 100 85 64 76 56 71 103 100 107 82 84 84 96 135 100 89 85 104 103
88 93 76 95 96 87 88 83 101 98 84 59 109 104 59 98 87 92 93 106
125 128 103 89 87 109 110 150 105 144 81 57 68 131 104 76 96 101 78 64
96 79 73 70 70 84 134 93 51 64 60 57 64 57 75 74 72 84 90 114
98 93 82 91 115 94 87 80 81 89 93 134 103 84 77 76 65 58 44 67
59 53 52 78 80 60 68 87 68 93 93 58 73 75 76 64 75 68 83 68
74 94 52 70 75 59 93 42 43 35 50 48 68 84 70 84 74 84 69 79
56 56 64 60 53 57 64 60 60 47 63 56 65 43 40 41 37 49 53 65
62 57 62 46 51 61 46 50 51 50 44 48 46 47 39 40 31 24 35 39
34 32 33 42 32 50 53 31 47 59 61 63 65 76 85 81 77 78 83 54
66 73 75
LAN-C50B 263
100 120 92 154 170 133 97 178 196 188 184 200 162 141 89 87 94 100 96 66
92 126 113 105 76 99 95 128 75 96 81 100 111 103 96 78 87 114 79 98
82 78 65 58 63 72 58 110 125 128 107 85 160 117 139 81 82 85 81 87
81 112 79 59 75 60 73 100 107 98 85 95 81 101 136 107 92 86 105 107
82 93 81 98 96 90 88 78 104 92 88 65 103 103 65 100 82 92 89 125
117 129 106 92 90 107 104 146 113 151 81 56 72 121 100 81 98 98 80 67
96 76 78 68 68 89 134 73 59 63 62 58 57 62 76 75 65 87 96 117
98 91 84 99 109 90 86 78 84 84 93 134 89 88 80 70 68 56 53 64
58 54 51 79 82 59 62 91 71 96 90 57 72 72 68 71 83 69 82 64
71 106 46 73 71 57 78 48 35 40 56 46 71 88 77 76 68 86 72 81
56 56 65 65 45 61 68 60 56 49 62 56 56 50 42 47 40 50 53 62
61 56 62 41 62 62 53 43 48 52 37 40 54 48 37 37 39 34 37 32
37 36 28 53 30 40 53 40 44 62 53 65 68 68 81 87 73 75 90 65
65 71 74
LAN-C51A 148
326 250 287 221 250 276 349 207 241 175 180 157 266 207 267 193 239 193 187 200
128 167 207 145 151 139 221 182 174 153 121 128 128 155 198 162 196 228 276 158
150 213 167 118 145 178 159 186 169 183 221 196 151 142 192 106 60 105 117 105
120 82 114 140 126 129 162 143 144 168 162 125 122 128 102 159 137 129 196 243
197 184 197 212 348 353 203 175 175 245 244 164 268 241 190 209 174 175 202 209
212 224 217 171 194 220 259 227 265 250 254 200 179 184 131 171 141 184 213 168
175 165 146 196 203 134 133 140 121 154 115 143 122 118 136 162 159 142 119 125
79 150 171 189 169 187 131 192
LAN-C51B 148
320 256 272 234 250 273 323 198 225 169 163 139 280 185 267 188 232 196 184 205

126 156 213 148 159 150 168 167 178 142 116 124 123 146 196 175 196 229 265 171
153 190 174 123 131 173 156 185 167 189 212 200 166 133 208 115 60 98 118 115
109 98 112 143 123 139 144 132 123 143 160 128 117 120 105 158 143 143 190 227
203 193 193 220 345 358 187 174 187 258 235 175 275 231 206 193 190 178 202 200
181 215 226 160 183 196 244 221 258 232 257 205 185 182 137 171 143 187 215 170
184 175 156 193 199 140 128 135 112 153 129 140 126 112 155 165 171 139 138 93
90 156 173 185 158 183 140 181
LAN-C53A 95
509 566 577 709 721 698 572 575 454 525 362 447 476 571 641 456 510 603 500 532
431 417 498 467 361 517 377 433 381 479 359 315 299 378 259 287 350 286 298 248
196 371 321 290 195 325 374 321 240 241 124 159 146 195 182 154 155 162 212 231
118 160 150 252 215 151 113 87 137 218 197 209 207 175 171 200 203 198 194 182
160 187 132 193 261 208 174 181 224 190 208 151 168 162 137
LAN-C53B 95
530 561 582 688 721 701 575 557 464 530 364 387 475 606 612 461 509 586 496 543
414 424 500 450 383 508 397 409 394 469 354 334 295 375 228 301 358 290 298 232
206 365 325 291 204 309 381 325 233 250 121 156 144 195 184 151 167 153 218 225
124 151 154 251 202 140 105 82 165 221 185 229 192 182 179 206 207 206 197 191
187 178 130 198 241 212 176 174 213 171 218 143 182 147 155
LAN-C54A 168
156 133 115 204 160 192 162 140 153 208 231 172 182 182 164 141 119 166 173 155
135 125 103 103 119 91 135 160 132 107 113 121 132 133 146 157 176 153 171 128
124 121 102 126 128 156 162 137 173 138 100 107 89 97 102 96 112 137 98 87
79 82 77 56 67 88 72 85 78 87 115 107 100 99 92 110 91 71 114 107
142 142 131 101 93 85 89 73 66 101 89 60 56 46 64 81 56 50 67 84
71 85 62 59 70 75 69 57 79 57 54 64 73 53 50 71 75 75 69 61
44 66 69 87 115 118 106 119 118 106 96 102 93 104 104 106 93 125 130 112
106 94 126 109 126 124 89 84 107 108 137 103 96 99 94 106 77 71 87 106
78 86 57 81 95 69 82 93
LAN-C54B 168
173 131 114 188 168 192 154 154 142 191 223 178 181 184 157 145 119 160 166 141
131 132 100 111 124 89 135 160 132 112 110 121 143 122 150 157 179 164 172 128
123 114 106 120 135 157 151 137 166 136 93 113 86 98 101 98 110 146 92 78
85 87 71 56 70 90 73 82 70 87 116 106 98 96 92 106 96 64 114 107
144 151 123 103 98 89 84 73 54 104 85 59 54 39 64 84 62 60 64 84
78 82 57 59 65 76 78 60 76 51 55 64 75 54 50 70 77 70 75 59
53 62 65 93 115 115 112 114 122 96 96 103 100 106 109 90 93 127 132 123
104 97 124 109 115 131 90 77 106 107 140 107 95 93 91 104 83 68 91 100
81 93 67 83 90 69 84 102
LAN-C55A 95
144 160 166 156 126 105 159 154 138 200 154 185 196 193 178 271 250 185 261 293
262 275 350 435 214 231 347 393 315 388 300 462 237 204 418 217 273 256 266 199
353 384 182 332 206 164 207 281 260 237 201 196 245 265 215 221 241 165 200 187
246 215 243 236 223 243 200 153 142 176 145 103 147 164 165 168 125 171 209 176
93 159 236 199 190 135 178 134 170 172 162 137 152 234 201
LAN-C55B 95
136 166 148 158 129 117 150 156 134 209 176 185 188 193 182 248 255 173 256 251
255 275 364 432 239 223 345 375 321 392 290 453 235 196 435 214 260 278 265 204
346 371 183 332 221 156 203 267 274 251 196 198 254 268 218 229 238 164 194 184
255 212 231 245 225 240 199 146 153 180 146 103 138 159 174 159 118 173 206 181
106 175 218 193 190 143 175 133 163 165 150 144 143 240 194
LAN-C56A 137
199 128 231 219 173 140 130 134 125 179 114 153 137 125 53 116 163 117 116 163

153 145 138 132 142 204 182 183 128 185 189 215 234 207 196 230 228 171 152 151
101 151 129 178 137 134 151 148 162 187 179 162 123 120 156 145 142 137 120 117
129 123 102 111 128 134 129 125 134 171 140 126 134 110 142 143 96 115 110 120
103 91 111 140 134 135 159 139 142 146 163 143 144 168 137 151 145 140 138 125
143 147 213 120 144 153 118 88 134 214 116 121 96 97 99 106 128 108 115 111
129 87 110 112 111 101 114 130 130 118 123 161 140 159 149 105 156
LAN-C56B 137
195 146 229 212 175 133 101 140 124 183 107 162 135 126 100 113 168 111 125 159
166 137 148 139 152 207 186 194 120 189 224 220 250 214 161 221 208 175 139 160
107 145 137 184 145 129 151 126 153 178 195 150 134 120 150 145 140 128 115 115
129 126 104 106 123 137 128 120 140 162 146 126 140 105 140 143 93 120 117 112
107 90 112 132 134 145 166 143 130 151 154 150 133 170 143 162 140 141 124 139
140 140 206 135 157 136 121 84 164 193 109 134 105 97 94 105 125 111 115 127
125 125 109 106 113 106 106 122 126 131 129 153 153 141 141 131 145
LAN-C57A 189
164 170 158 124 116 159 143 124 129 99 117 130 137 141 178 142 127 123 103 114
91 156 154 126 117 107 125 128 153 131 104 121 106 121 95 111 86 78 100 99
139 136 125 167 119 104 110 118 153 99 110 98 92 112 106 137 101 120 95 98
121 98 117 79 79 88 100 113 76 103 110 86 116 128 118 159 101 94 103 129
134 132 145 151 123 79 99 155 153 126 104 107 114 95 103 96 107 93 92 102
108 112 89 103 71 84 71 68 100 137 124 106 111 115 131 140 106 117 121 146
166 140 145 150 145 122 134 106 96 84 81 81 63 63 55 47 46 51 71 59
50 77 75 90 88 50 40 49 54 62 76 70 62 76 70 67 37 44 75 43
53 49 50 43 62 50 63 68 56 64 69 58 72 60 59 56 53 58 54 68
73 68 46 59 62 50 63 65 94
LAN-C57B 189
180 172 147 116 110 148 156 119 121 99 119 128 134 141 174 142 125 120 99 119
87 152 157 128 108 110 125 126 154 132 93 116 106 119 92 108 83 85 103 96
140 137 122 159 125 103 103 120 147 107 103 96 92 115 110 141 96 123 102 98
114 107 117 76 85 79 109 109 71 106 103 93 109 124 122 157 105 103 100 134
123 139 142 146 120 87 100 155 153 118 103 112 120 101 106 96 117 86 96 93
110 126 81 103 69 82 60 69 104 145 115 113 119 113 131 125 116 129 106 161
169 152 134 162 146 125 138 87 102 88 103 63 66 68 55 50 43 53 66 59
51 71 79 90 90 46 43 46 53 68 71 68 56 85 68 62 44 50 68 41
54 53 46 43 53 59 64 67 57 61 68 62 76 50 59 62 56 60 49 62
75 62 58 61 58 57 53 69 90
LAN-C58A 97
61 85 94 74 94 109 95 106 114 83 150 159 104 209 169 150 167 137 141 214
185 157 186 237 178 225 194 181 196 211 205 294 267 203 203 146 273 214 167 259
209 197 218 193 165 201 252 131 201 188 206 189 115 95 142 153 229 145 104 163
135 169 155 148 167 164 127 181 195 159 158 183 210 214 162 150 127 191 142 190
190 168 175 143 131 125 169 139 167 153 115 94 151 100 105 177 220
LAN-C58B 97
64 92 94 76 84 102 87 112 102 89 154 149 109 207 175 150 187 130 141 217
175 160 187 213 184 216 178 180 215 221 209 293 253 212 185 143 264 210 162 211
189 162 189 178 156 196 239 139 181 182 200 189 107 85 142 134 218 167 110 164
131 187 137 156 173 154 121 193 190 160 148 187 207 212 160 154 133 196 130 187
181 187 167 156 114 135 171 135 168 155 118 97 150 104 101 162 218
LAN-C59A 69
256 282 398 412 288 280 360 464 387 301 238 259 253 241 239 235 196 193 194 311
331 229 190 307 259 279 270 205 239 219 345 275 295 209 196 162 196 146 137 121
143 126 135 106 104 113 125 127 100 154 121 112 114 117 132 122 116 104 95 118
78 78 104 115 119 115 102 82 140

LAN-C59B 69
286 278 395 410 299 275 361 458 387 312 246 267 250 237 235 195 200 200 184 296
300 218 172 297 273 273 273 198 259 218 332 278 285 211 191 175 193 147 145 131
125 126 142 101 112 103 125 128 98 159 121 107 112 125 132 117 118 103 93 117
77 81 102 115 121 111 106 89 118
LAN-C60A 203
129 150 98 96 72 60 79 109 156 172 169 141 181 146 141 140 108 107 80 94
75 81 113 132 92 69 100 100 86 65 54 51 73 70 65 77 110 160 117 103
101 125 167 150 140 128 128 135 125 100 74 78 104 117 92 114 107 100 78 71
68 70 66 94 85 81 104 99 73 81 54 50 62 67 93 98 75 93 104 117
89 87 120 116 108 83 87 76 92 157 161 129 110 89 83 87 64 48 64 96
70 56 45 79 91 56 64 65 54 65 46 44 51 48 51 60 64 59 67 68
81 65 57 56 59 56 52 51 41 50 71 86 76 103 85 80 91 84 97 85
91 98 89 90 71 66 87 92 98 85 97 78 66 60 57 63 46 92 110 118
103 121 101 87 110 105 81 88 93 88 125 107 82 96 91 111 107 107 96 80
58 53 70 102 96 84 114 77 85 137 123 125 145 151 153 107 121 118 90 89
99 154 129
LAN-C60B 203
129 146 93 101 65 53 83 110 133 189 185 136 190 144 144 134 95 98 85 102
73 87 108 139 96 73 101 90 96 64 60 50 73 68 63 71 112 151 114 100
102 121 164 146 146 108 135 123 120 113 77 78 105 122 88 112 110 96 77 79
76 59 70 77 78 87 120 95 87 59 62 65 57 68 90 95 73 95 106 117
93 88 118 106 112 92 81 70 93 164 167 135 117 85 81 85 67 46 64 93
57 57 51 73 89 58 65 64 60 59 50 45 48 46 50 67 56 65 67 71
64 56 60 60 68 51 65 64 49 48 71 84 73 90 79 87 82 94 93 96
88 93 102 90 62 66 94 96 96 92 85 79 70 53 65 59 53 87 113 111
118 109 102 85 112 98 91 93 96 90 134 103 90 102 87 103 111 100 106 70
61 58 71 99 94 87 106 75 96 142 115 122 143 153 151 105 124 119 87 115
87 147 125
LAN-C61A 185
125 181 176 143 167 192 177 148 174 192 220 188 173 146 192 216 164 205 193 202
179 207 216 207 167 186 150 203 203 176 174 182 157 135 128 145 160 154 114 150
126 133 138 119 153 160 149 114 174 95 48 53 52 78 73 81 79 93 79 90
117 112 134 121 110 118 120 153 135 114 116 134 132 137 134 107 89 136 99 61
90 90 64 79 109 160 175 110 108 158 150 140 174 157 124 165 183 172 167 145
148 186 199 181 138 127 155 109 143 118 122 130 140 142 130 213 166 163 180 198
199 181 149 127 164 196 123 146 172 202 132 120 119 139 171 137 140 130 104 168
162 187 125 128 134 98 137 143 90 130 109 106 100 106 103 116 69 85 117 124
81 100 103 78 91 115 112 87 91 63 97 108 85 102 94 100 82 87 98 123
87 69 93 130 115
LAN-C61B 185
117 180 186 145 167 194 173 147 191 185 221 191 173 136 194 221 166 217 207 193
186 198 224 204 157 183 147 196 200 177 169 210 155 133 139 145 157 156 117 153
129 132 137 104 149 155 154 117 173 93 50 39 55 71 75 82 92 90 88 89
103 112 129 129 106 114 120 156 139 91 122 134 126 123 142 104 103 140 86 67
80 80 71 70 110 168 164 117 105 159 140 143 184 153 134 159 171 165 169 168
149 182 195 190 132 137 161 116 134 120 128 129 137 143 136 207 155 159 194 194
205 168 157 116 161 208 127 150 193 203 135 121 124 146 165 138 147 121 103 166
155 181 128 137 137 101 136 140 100 128 128 109 94 91 120 109 69 89 99 140
94 103 105 81 81 123 114 74 92 75 96 111 93 94 106 91 93 86 107 111
85 85 85 128 110
LAN-D01A 140
200 200 180 150 100 100 120 130 150 200 130 200 180 140 110 100 70 60 70 120

70 100 110 100 80 90 100 100 80 100 100 110 100 140 200 300 220 150 200 190
150 150 160 200 110 130 140 100 90 110 180 170 130 150 170 130 150 120 130 100
110 130 140 120 130 150 160 140 200 130 170 150 100 100 80 100 60 100 100 110
100 100 80 130 100 90 80 80 70 90 90 50 40 60 60 30 60 40 40 50
50 50 50 40 60 50 60 50 80 80 80 70 80 80 100 100 130 100 110 100
110 90 100 80 80 70 110 150 150 140 100 100 110 100 120 100 100 90 120 100
LAN-D01B 140
200 170 180 140 120 110 130 120 160 200 150 200 170 150 100 90 80 70 60 100
80 100 110 100 70 100 100 110 100 100 100 120 110 100 200 300 220 150 200 190
150 150 150 200 120 140 150 90 80 100 170 180 130 170 170 150 160 130 130 120
120 120 130 110 130 150 170 150 200 130 150 140 100 100 80 100 50 90 80 100
80 80 80 130 100 80 80 70 80 80 100 70 50 70 60 50 60 50 50 60
70 50 50 40 50 60 50 50 90 100 80 70 80 80 120 90 120 120 100 100
100 80 80 80 70 70 80 130 140 100 100 100 100 130 150 100 100 100 150 100
LAN-D02A 140
300 270 400 320 400 330 130 220 180 130 120 150 180 100 160 200 130 110 130 180
220 200 200 230 230 290 310 200 150 130 150 150 130 140 160 200 230 270 270 200
200 140 150 130 180 80 150 160 200 130 130 120 190 170 150 120 110 100 100 120
120 70 110 100 80 80 90 80 110 100 100 90 70 80 110 120 70 130 120 100
70 90 100 100 110 150 110 120 120 110 100 130 130 90 70 90 130 120 110 100
100 110 110 120 100 80 80 70 80 80 110 120 100 80 90 80 90 100 100 100
100 90 90 90 90 80 90 100 100 80 70 80 70 80 100 90 100 90 100 80
LAN-D02B 140
300 250 400 370 330 200 150 220 200 130 120 160 200 100 150 200 130 100 180 200
200 170 200 250 230 300 230 180 160 130 150 160 120 150 170 270 200 250 220 200
200 140 150 120 170 80 130 150 200 140 150 130 180 170 170 130 110 100 100 90
120 70 100 100 80 90 80 100 100 80 80 90 70 80 100 120 70 130 110 80
80 60 100 100 110 150 110 100 120 100 100 120 100 80 70 110 130 120 120 100
80 120 120 100 80 90 80 100 90 90 100 100 100 80 100 90 100 100 100 100
100 80 90 100 80 80 90 80 90 80 80 60 90 90 90 100 110 100 100 80
LAN-D03A 122
100 150 200 180 150 200 280 200 100 200 190 150 150 160 170 100 120 120 80 100
140 200 160 150 150 150 160 170 170 150 150 140 150 130 150 150 170 140 140 170
150 120 130 120 120 130 150 90 130 120 170 150 120 100 170 150 170 150 170 130
160 140 160 100 170 150 130 100 110 100 100 110 100 130 100 130 120 140 80 130
100 70 80 90 110 110 130 130 150 130 120 130 110 110 130 130 120 120 110 130
130 140 130 130 130 130 80 90 70 60 50 70 90 100 90 60 70 70 70 80
80 90
LAN-D03B 122
100 150 200 180 150 200 250 280 180 200 200 150 150 160 170 120 130 120 80 100
150 200 180 140 150 170 150 170 170 150 160 130 150 150 150 160 170 140 160 170
150 130 120 120 100 120 130 100 130 150 170 150 130 110 170 150 170 170 170 130
170 150 160 90 170 150 130 130 120 100 110 120 100 140 80 130 120 140 90 130
120 70 90 80 110 120 120 130 150 120 130 120 110 100 140 120 110 120 110 130
130 150 120 140 120 130 80 90 70 60 50 70 90 100 80 80 70 70 80 80
90 80
LAN-D04A 84
110 100 80 100 100 100 80 70 80 70 80 80 80 100 80 80 80 80 80 70
80 60 80 70 100 70 80 80 100 100 90 70 100 90 110 110 100 90 110 120
120 60 100 90 90 100 90 100 100 100 80 130 70 130 140 120 70 150 140 100
100 120 150 110 140 150 140 140 150 130 80 100 90 80 70 80 100 110 100 110
100 120 100 100
LAN-D04B 84

100 100 80 100 100 100 90 80 70 60 70 80 70 100 100 80 70 80 70 70
70 60 80 70 100 80 80 70 100 100 90 80 100 100 110 110 100 80 120 120
110 60 90 90 90 80 90 90 100 100 80 130 70 110 150 120 70 150 150 100
100 100 140 110 120 130 140 130 120 130 100 100 90 80 60 90 110 100 100 100
120 100 100 100
LAN-D05A 92
50 50 60 80 100 150 240 120 150 220 170 250 200 220 230 150 140 170 150 170
200 300 200 230 240 230 220 160 190 170 270 230 210 240 280 260 230 230 300 200
190 120 140 110 170 270 230 260 160 170 180 140 200 120 180 220 220 220 170 190
100 200 160 150 140 120 150 100 120 170 100 130 150 150 110 140 170 160 130 150
120 130 220 150 130 160 150 100 100 150 110 150
LAN-D05B 92
50 50 60 80 100 150 240 100 170 210 160 240 200 210 250 210 150 170 150 180
210 300 200 230 250 220 220 170 200 170 290 230 220 250 290 260 230 230 300 200
190 130 140 100 170 260 240 250 170 150 180 140 190 130 200 230 210 210 160 180
120 200 160 140 120 120 150 100 120 170 100 120 160 140 110 150 170 150 130 140
120 120 200 150 170 160 150 100 100 150 100 150
LAN-D06A 79
400 350 300 270 300 370 300 250 350 380 210 200 230 250 150 170 200 100 160 180
300 230 200 200 180 230 270 210 200 210 150 170 160 250 280 250 200 160 200 200
150 180 190 160 130 200 100 180 190 200 250 250 170 260 250 270 280 210 150 300
100 70 50 90 90 100 120 150 120 150 200 140 150 100 150 170 150 120 210
LAN-D06B 79
400 350 300 300 250 320 280 280 350 400 200 200 220 250 150 170 230 140 150 200
250 230 210 200 200 210 280 230 180 210 150 170 170 250 280 250 200 170 200 180
170 180 180 150 100 180 100 190 200 270 250 250 150 270 230 270 180 220 150 300
100 70 50 100 100 100 110 140 120 150200 140 150 100 160 170 150 130 230
LAN-D07A 125
100 70 110 100 90 70 100 70 80 180 130 180 120 170 180 160 230 180 170 210
250 240 200 280 180 350 300 290 340 220 150 150 110 230 400 150 280 190 240 120
120 160 190 100 140 150 200 130 130 160 120 110 120 130 70 60 60 70 50 50
80 90 110 90 100 110 130 90 90 100 80 80 140 100 110 150 150 110 100 100
100 70 100 120 130 140 120 150 190 200 150 140 120 100 80 100 120 80 70 70
80 80 100 100 80 70 80 80 90 100 80 100 80 70 90 90 100 110 100 80
90 100 80 100 90
LAN-D07B 125
100 80 120 100 90 80 90 60 80 130 140 170 130 190 170 180 250 170 170 200
260 240 180 300 160 310 320 300 350 230 160 150 120 240 400 140 280 200 240 140
130 150 190 100 190 150 210 100 100 130 110 100 120 120 70 80 70 70 50 70
70 100 110 100 120 110 140 80 90 100 70 70 120 100 110 150 150 120 100 100
100 70 100 130 100 130 130 150 200 190 130 140 120 100 80 100 120 70 70 70
80 60 80 120 100 80 70 90 90 100 100 90 80 70 90 100 100 100 100 80
80 90 80 100 90
LAN-D08A 141
200 250 200 170 150 120 150 120 200 210 180 150 200 160 150 180 200 150 140 210
90 110 140 150 120 110 100 150 140 170 170 150 150 100 110 100 70 90 100 100
80 100 80 80 80 70 100 50 90 100 100 50 120 140 50 70 80 70 90 100
110 80 70 80 100 80 90 80 60 80 100 110 100 120 110 100 150 180 130 100
100 100 100 70 100 120 120 110 80 100 110 100 110 120 110 130 130 150 140 130
130 140 130 120 120 110 90 100 100 100 100 130 120 140 100 100 110 110 130 150
100 110 120 110 70 60 60 50 50 80 30 80 80 80 70 80 70 100 90 80
50
LAN-D08B 139

200 250 180 200 150 160 150 170 200 210 170 150 180 160 150 170 200 140 150 200
90 110 130 150 170 110 100 130 140 170 150 150 100 110 110 100 60 80 80 80
70 80 80 110 100 80 80 70 90 100 100 70 120 120 70 60 80 80 80 100
100 90 80 100 90 80 100 80 70 80 100 100 120 130 110 100 150 180 130 100
90 100 100 80 100 100 120 100 90 110 100 100 110 120 100 130 140 140 140 150
130 130 140 130 120 120 100 100 110 140 100 120 110 140 100 100 90 130 120 150
100 120 110 100 70 60 80 50 50 80 40 50 80 80 70 80 100 80 80
LAN-D09A 102
300 300 190 250 280 240 300 200 230 250 310 310 220 300 210 340 350 330 400 220
150 150 150 240 280 180 250 280 310 190 150 170 210 120 240 180 220 180 160 190
150 100 120 120 80 70 80 70 80 70 90 120 140 100 140 140 150 120 100 100
100 110 150 130 140 160 170 120 120 100 100 70 100 170 180 150 150 170 210 230
170 160 170 110 100 130 140 70 80 100 60 80 100 150 100 100 100 80 100 110
100 120
LAN-D09B 102
300 300 200 280 350 300 300 200 200 250 250 300 220 330 200 330 320 330 400 220
120 170 140 230 280 200 250 230 320 190 170 150 220 120 240 190 210 180 170 200
150 100 120 130 70 80 80 70 80 70 100 110 140 100 130 150 150 120 100 100
100 100 150 120 150 160 160 120 110 100 120 70 100 160 170 130 150 170 220 230
170 180 170 110 90 130 130 70 80 90 70 70 100 110 100 90 90 100 110 110
100 110
LAN-D10A 82
400 150 160 120 150 140 200 250 260 210 150 190 200 110 170 140 250 200 170 170
100 100 110 150 170 110 100 120 150 100 70 150 150 140 150 180 100 200 250 120
150 160 150 150 250 110 150 220 180 100 100 180 100 130 170 80 110 150 120 150
160 150 180 170 180 130 210 200 180 220 130 120 120 140 140 120 120 150 120 150
150 200
LAN-D10B 82
400 170 150 130 150 150 200 250 280 230 150 200 200 120 170 130 240 220 160 170
100 100 100 150 170 110 100 130 150 100 70 150 150 140 170 170 90 180 250 170
150 170 150 150 220 130 180 220 170 100 120 180 120 130 160 70 130 150 130 160
150 160 180 160 150 160 210 200 200 240 130 110 110 130 130 120 150 130 120 150
170 200

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 Nottingham Tree-ring Dating Laboratory's Monograph, *An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Buildings* (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

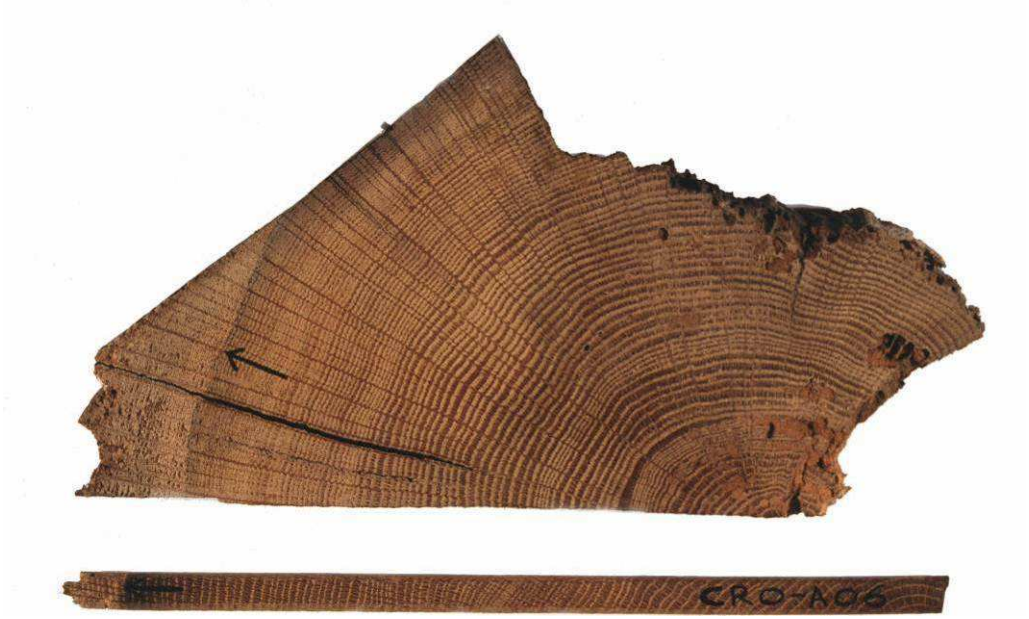


Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

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 Figure 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 complement 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

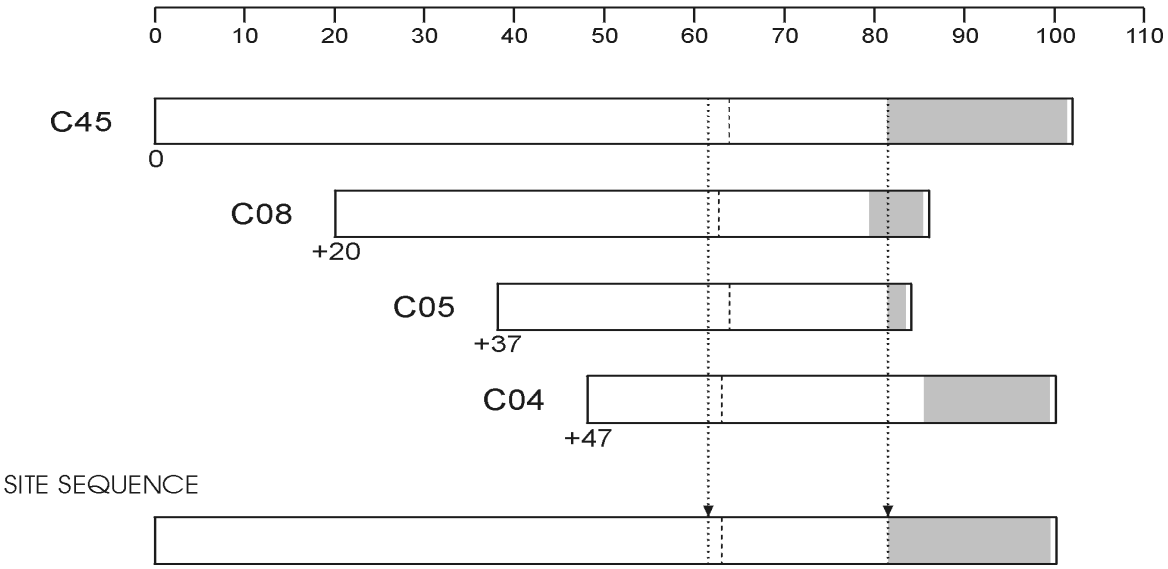


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

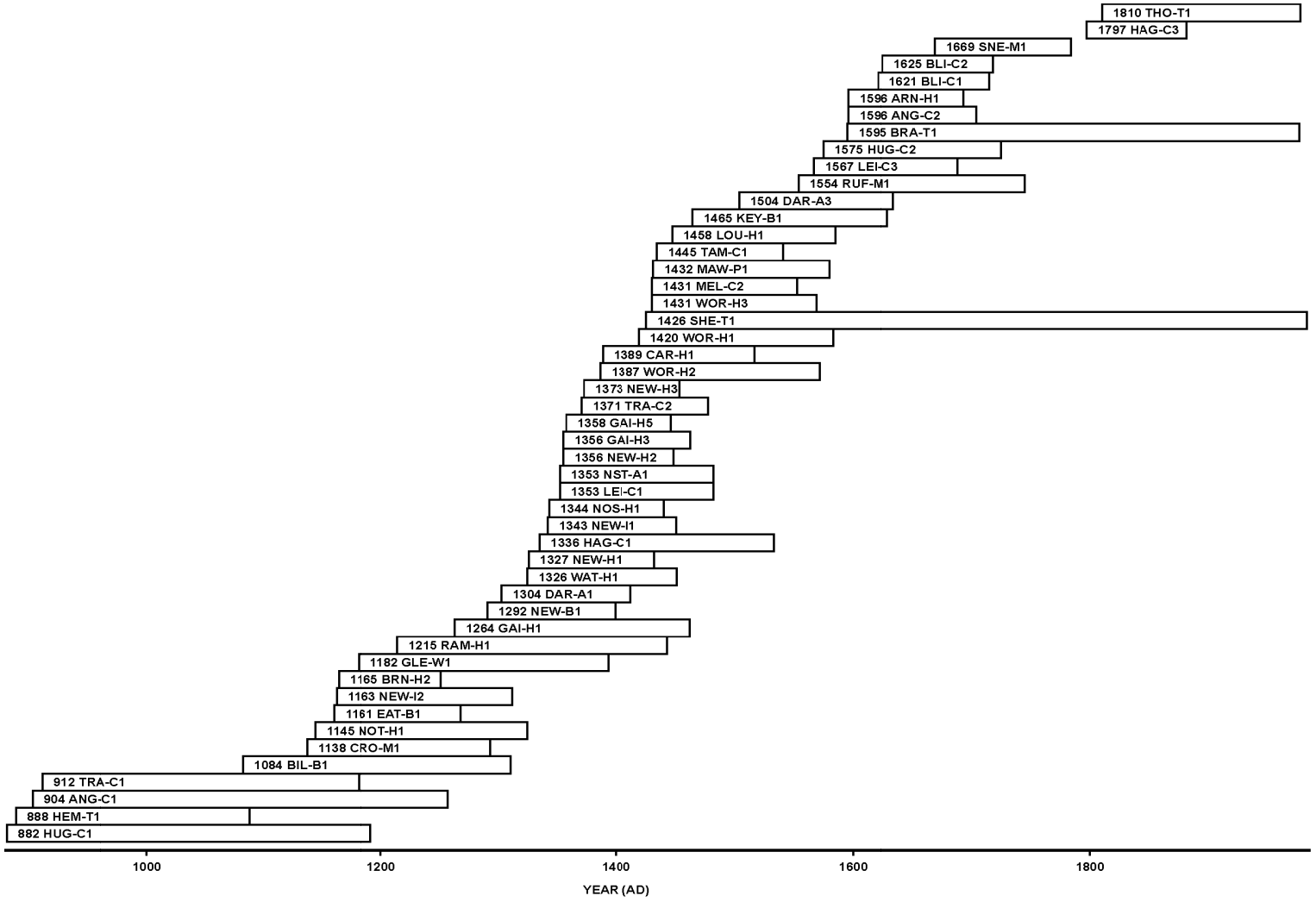
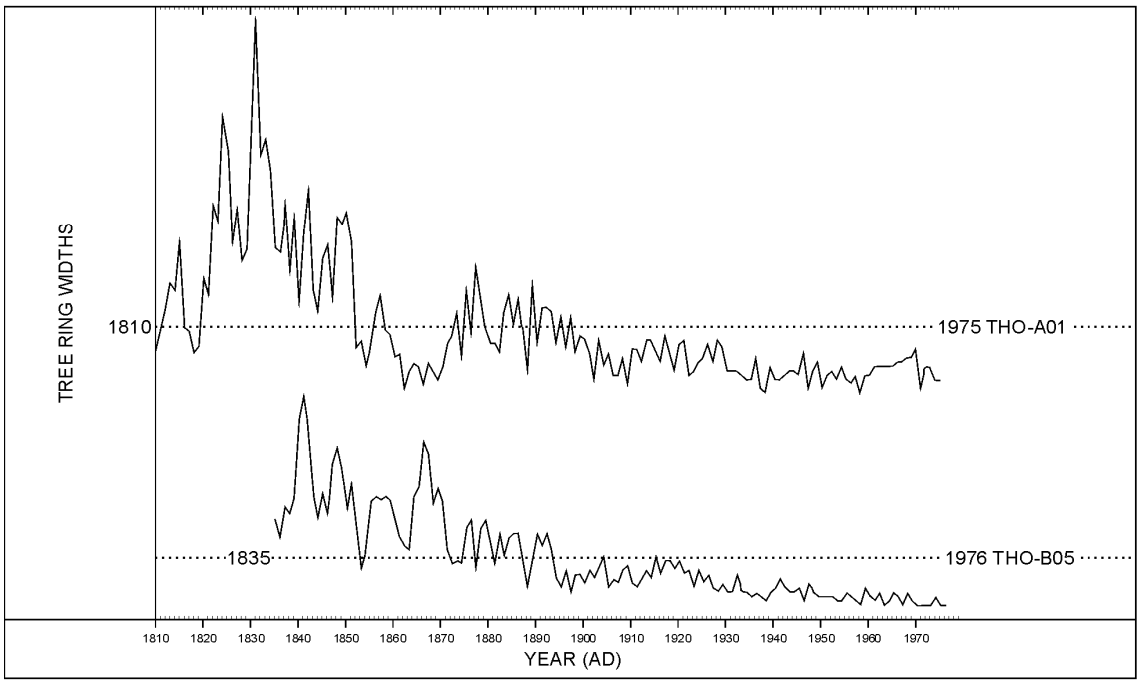


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

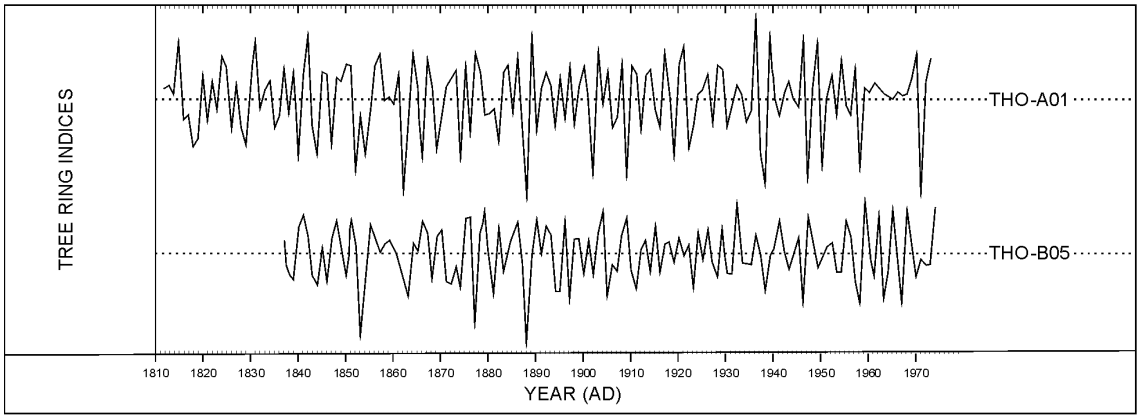


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

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**

Laxton, 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

Historic England Research and the Historic Environment

We are the public body that looks after England's historic environment. We champion historic places, helping people understand, value and care for them.

A good understanding of the historic environment is fundamental to ensuring people appreciate and enjoy their heritage and provides the essential first step towards its effective protection.

Historic England works to improve care, understanding and public enjoyment of the historic environment. We undertake and sponsor authoritative research. We develop new approaches to interpreting and protecting heritage and provide high quality expert advice and training.

We make the results of our work available through the Historic England Research Report Series, and through journal publications and monographs. Our online magazine Historic England Research which appears twice a year, aims to keep our partners within and outside Historic England up-to-date with our projects and activities.

A full list of Research Reports, with abstracts and information on how to obtain copies, may be found on www.HistoricEngland.org.uk/researchreports

Some of these reports are interim reports, making the results of specialist investigations available 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, you should consult the author before citing these reports in any publication. Opinions expressed in these reports are those of the author(s) and are not necessarily those of Historic England.

The Research Report Series incorporates reports by the expert teams within the Investigation& Analysis Division of the Heritage Protection Department of Historic England, alongside contributions from other parts of the organisation. It replaces the former Centre for Archaeology Reports Series, the Archaeological Investigation Report Series, the Architectural Investigation Report Series, and the Research Department Report Series

ISSN 2059-4453 (Online)