Historic England

Scientific Dating

Somerton Castle, Castle Lane, Boothby Graffoe, Lincolnshire

Tree-ring Analysis of Oak Timbers

Alison Arnold and Robert Howard

Discovery, Innovation and Science in the Historic Environment

Research Report Series no. 46-2016

Research Report Series 46-2016

SOMERTON CASTLE, CASTLE LANE, BOOTHBY GRAFFOE, LINCOLNSHIRE

TREE-RING ANALYSIS OF OAK TIMBERS

Alison Arnold and Robert Howard

NGR: SK 9543 5876

ISSN 2059-4453 (Online)

The Research Report Series incorporates reports by the expert teams within the Investigation & Analysis Division of the Research Group 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.

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

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

SUMMARY
Analysis undertaken on samples from the south-east tower floor, the garderobe, the main range, and the west wing resulted in the successful dating of 22 timbers, with an additional eight timbers having been dated previously from the roof of the south-east tower.
In the main range two first-floor ceiling beams and a ground-floor lintel are dated as felled in the range AD 1573–98, whilst the timbers of the roof and a ground-floor ceiling beam were felled in the very early AD 1760s. In the west wing a ground floor and a first-floor ceiling beam and a ground-floor lintel have been dated as felled in the range AD 1648–66, whilst the roof contains timber felled in, or around, AD 1760. The previously dated timbers from the roof of the south-east tower were felled in the range AD 1757–82 but in addition two ceiling beams may also be contemporary or slightly later with a felling date range of AD 1767–92. No samples from the garderobe were dated.

CONTRIBUTORS
Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS
The Laboratory would like to thank David Francis, contractor on site, for facilitating access and Jonathan Clark of FAS Heritage and Mark Hoare of Hoare Ridge & Morris for their invaluable on-site advice. Drawings used within this report were provided by both Hoare Ridge & Morris and FAS Heritage. Thanks are also due to Cathy Tyers and Shahina Farid of the Historic England Scientific Dating Team for commissioning this work and for their advice and assistance throughout this programme of dendrochronology.

ARCHIVE LOCATION
Lincolnshire Historic Environment Record
Planning Services
Environment and Economy Directorate
Witham Park House
Waterside South
Lincoln
LN5 7JN

DATE OF INVESTIGATION
2015

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

CONTENTS

INTRODUCTION

The Grade I listed Somerton Castle is located approximately 1.6km west of Boothby Graffoe in Lincolnshire (Figs 1–2). It was largely rebuilt in the latter part of the thirteenth century by Antony Bek, Bishop of Durham, after he inherited it from his mother. It is stone built, quadrangular and had circular towers at the angles, curtain walls and was surrounded by a moat. Of the original building, only the three storey, south-east tower (Fig 3) and the ground floors of the north-east and north-west towers, the south front, and part of the curtain wall remain. The description below is based on Nicholas Cooper's interim report on the castle (2013).

In AD 1309 the castle was given to King Edward II, remaining as royal property until the reign of Henry VII who transferred it to the Duchy of Lancaster. In AD 1525 and again in AD 1601 the castle was described as being in a very decayed state with only some walls still standing, although between these dates other documents suggest it was at least partly habitable as a tenant farmer had servants living in one of the towers. The survey of the castle in AD 1601 called for repairs or new construction at the castle to provide a residence for the tenant farmer.

Thomas Disney of Carlton-le-Moorland bought the castle in AD 1629 but is thought to have already been living in a house built on the site by this time as in AD 1622 he is described as 'esquire of Somerton Castle'. By AD 1644 the property had been sold to Sir Edward Hussey of Honington, transferring to his son Charles in AD 1648 who died in AD 1664. The estate was passed in turn to Charles' heir, Edward of Welbourne (d AD 1724), to Edward's son Henry (d AD 1729) and then jointly to Jane Hatcher and Thomas Pochin. On Jane's death in AD 1734 her share of the estate was sold to Montagu Cholmeley of Easton with the Pochin share being sold to the Cholmeleys in AD 1770. As these families had substantial houses elsewhere it is thought unlikely that they ever lived at Somerton Castle. Indeed, the Marfleet family, who later bought the property and estate and in whose ownership it stayed until the late-nineteenth century, are known to have farmed Somerton by AD 1765.

Main range

Located to the west of the south-east tower is a two-storey plus attics, three-bay range, built of course rubble (Fig 3). The roof over this part of the building comprises principal rafter and collar trusses supporting a single tier of staggered purlins (Fig 4). Exposed timbers of the first floor consist of three main bridging beams, between which are common joists, whilst at ground-floor level only two main bridging beams and a small number of joists are visible (Fig 5). Other potentially historic timbers are a number of window and door lintels. This range is thought to date to the early-seventeenth century.

West wing

To the west of the main range is a two-storey plus attics L-shaped wing, built of ashlar. The roof over this part of the building differs to that of the main range only in that it has a double tier of staggered purlins (Fig 4). The ground and first-floor ceiling frames consist of two main bridging beams with common joists between (Fig 6); there are some door and window lintels which also look potentially historic. This range is believed to be mid-seventeenth century in date.

South-east tower

The roof over the south-east tower is conical in shape (Fig 7) and has previously been tree-ring dated as being constructed using timber felled in the range AD 1757–82, demonstrating a re-roofing of the tower in the second half of the eighteenth century (Arnold and Howard 2015). There are two ceiling beams visible at first-floor level (Fig 8); as there was reported to be no timberwork in this tower in AD 1601 these are also likely to be associated with the later alterations to the castle.

Garderobe

Between the south-east tower and the main range is a small garderobe (Fig 3), the hipped roof of which comprises common rafters and hip rafters sitting on wall plates (Fig 9). The date of this roof is unknown but it is thought likely to be seventeenth century or later.

SAMPLING

A dendrochronological survey was requested by Ben Robinson, Historic England Heritage at Risk Advisor, to inform advice relating to listed building consent and hence the repair programme of this scheduled monument which has been on the Heritage at Risk register for some years.

Forty-nine timbers from the south-east tower floor, the garderobe, the main range, and the west wing were sampled by coring. Samples were taken from roof timbers, ceiling timbers and lintels which appeared likely to be associated with key phases of the historical development of this building. A number of lintels could be seen to be unsuitable for analysis as they were cut from fast grown trees and thought unlikely to have sufficient growth rings. Each sample was given the code SOM-C and numbered 13–61, following on from the samples obtained from the south-east tower roof in a separate privately funded investigation (Arnold and Howard 2015) undertaken shortly before this investigation was commissioned by Historic England. The location of all of the sampled timbers, including those of the south-east tower roof, has been marked on Figures 10–13. Further details relating to the samples can be found in Table 1. Trusses and ceiling beams have been numbered from east to west (main range and west wing) and north to south (south-east tower and southern part of the west wing).

ANALYSIS AND RESULTS

Sixteen of the new samples, seven from the garderobe roof, two from the main range, and seven from the west wing had too few rings for secure dating and so were rejected prior to measurement. This rejection rate is disappointing but it should be noted that sampling was adversely affected by access issues preventing some of the timbers from being cored in the ideal direction to maximise the number of rings in the sample, especially in the somewhat cramped garderobe. The remaining 33 new samples were prepared by sanding and polishing and their growth-ring widths measured; the data of these measurements, in addition to those from the south-east tower roof, are given at the end of the report. All suitable samples, from both phases of sampling, were then compared with each other by the Litton/Zainodin grouping programme (see Appendix), resulting in 40 samples matching to form six groups.

Three samples, all from the main range, matched each other and were combined at the relevant offset positions to form SOMCSQ01, a site sequence of 79 rings (Fig 14). This site sequence was compared against a series of reference chronologies with which it was found to match consistently and securely at a first-ring date of AD 1482 and a last-measured ring date of AD 1560. The evidence for this dating is given in Table 2.

Two samples from the west wing matched and were combined at the relevant offset positions to form SOMCSQ02, a site sequence of 86 rings (Fig 15). This site sequence was compared against a series of reference chronologies and was found to match at a first-ring date of AD 1560 and a last-measured ring date of AD 1645. The evidence for this dating is given in Table 3.

Nineteen samples, a mixture of south-east tower, main range, and west wing samples, matched each other and were combined at the relevant offset positions to form SOMCSQ03, a site sequence of 111 rings (Fig 16). This site sequence was compared against a series of reference chronologies for oak where it was found to span the period AD 1650–1760. The evidence for this dating is given in Table 4.

Five samples, from the south-east tower and the main range grouped to form SOMCSQ04, a site sequence of 73 rings (Fig 17). This site sequence was compared against a series of reference chronologies for oak where it was found to span the period AD 1689–1761. The evidence for this dating is given in Table 5.

Two further site sequences of three (Fig 18) and eight (Fig 19) samples, SOMCSQ05 and SOMCSQ06 respectively, were constructed but attempts to date these by comparing them against the reference chronologies were unsuccessful.

The ungrouped samples were then compared individually against the reference chronologies. Sample SOM-C59, from the west wing, was successfully dated at a first-ring date of AD 1526 and a last-measured ring date of AD 1647 (Table 6).

INTERPRETATION

Analysis has resulted in the successful dating of 30 timbers from the south-east tower, the main range, and the west wing. To aid interpretation each area is dealt with separately below and illustrated in Figure 20. Felling date ranges, where necessary, have been calculated using the estimate that mature oak trees in this region have 15–40 (95% confidence range) sapwood rings.

Main range

Nine of the samples taken from timbers in this part of the building have been successfully dated and indicate that there are two separate felling phases represented.

Three samples, taken from two first-floor ceiling beams and a ground-floor door lintel, are substantially earlier than the rest of the samples but appear to be coeval. All three have the heartwood/sapwood boundary ring present. The average heartwood/sapwood boundary ring date for these three samples is AD 1558, giving an estimated felling date for the timbers represented of AD 1573–98.

Two of the remaining six dated samples have complete sapwood. Sample SOM-C26, taken from a purlin, has complete sapwood and a last-measured ring, and hence felling date, of AD 1760, whilst SOM-C37, from a ground-floor ceiling beam is felled a year later in AD 1761. The four other dated samples, all from the roof, have broadly contemporary heartwood/sapwood ring dates suggestive of a single felling. The average heartwood/sapwood boundary ring for these four samples is AD 1742, giving an estimated felling date for the timbers represented of AD 1757–82, consistent with these timbers also having been felled in the early AD 1760s.

West wing

Eleven of the samples taken from timbers in this part of the building have been successfully dated and again indicate that there are two separate felling phases represented.

Three of these samples, taken from two ceiling beams (one ground floor and one first floor) and a ground floor window lintel, have similar heartwood/sapwood boundary ring dates and appear likely to be coeval. The average date of the heartwood/sapwood boundary ring is AD 1626. This allows an estimated felling date to be calculated for the three timbers represented to within the range AD 1648–66, allowing for sample SOM-C59 having a last-measured ring date of AD 1647 with incomplete sapwood.

The remaining eight samples are all from the roof. One of these samples, SOM-C41, has complete sapwood and the last-measured ring date of AD 1760, the felling date of the timber represented. Another six samples have similar heartwood/sapwood boundary ring dates. The average of these is AD 1743, allowing an estimated felling date to be calculated for the six timbers represented to within the range AD 1758–83, consistent with these samples also having been felled in, or around, AD 1760.

The final dated sample from the west wing does not have the heartwood/sapwood boundary ring and so an estimated felling date cannot be calculated for the timber. However, with a last-measured ring date of AD 1737, the estimated felling date would be AD 1753 at the earliest which is not inconsistent with this sample also having been felled in, or around, AD 1760.

South-east tower

Ten samples taken from timbers in this part of the building have been successfully dated, including two ceiling beams and the eight previously dated from the roof.

Seven of these samples, all from the roof, have similar heartwood/sapwood boundary ring dates, suggestive of a single felling. The average of these is AD 1742, allowing an estimated felling date to be calculated for the seven timbers represented to within the range AD 1757–82. The remaining sample from the roof does not have the heartwood/sapwood boundary and so an estimated felling date cannot be calculated for the timber. However, with a last-measured ring date of AD 1731, the estimated felling date would be AD 1747 at the earliest. Given the good level of similarity that this sample has with the other roof samples, especially against samples SOM-C10 and SOM-C12 which it matches at $t = 11.2$ and $t = 11.6$ respectively, it is thought likely that this sample was also felled in AD 1757–82.

The two samples taken from ceiling beams both have the heartwood/sapwood boundary ring which appears slightly later than those of the roof samples. The average heartwood/sapwood boundary of these two samples is AD 1752, giving an estimated felling date for the two timbers represented of AD 1767–92.

DISCUSSION

The earliest timbers identified by the tree-ring analysis were in the main range where two first-floor ceiling beams and a lintel over a door at ground-floor level between this range and the west wing were found to have been felled in AD 1573–98. If these three timbers relate to the primary construction of this range then the results suggest the main range dates to the latter part of the sixteenth century when the castle was owned by the Duchy of Lancaster. Previously, this range had been thought to date to the early-seventeenth century and assumed to post-date a survey undertaken in AD 1601 which had described it as being in an extremely derelict state with no surviving timberwork. It may be that the survey was inaccurate or possibly that work commenced immediately upon completion of the survey utilising timber felled in anticipation, or alternatively that the work reused timbers from elsewhere.

In addition, a lintel and two ceiling beams in the west wing were also felled substantially earlier than the majority of the dated timbers. These beams are now known to have been felled in AD 1648–66. It was thought that west wing was constructed *c* AD 1660, a date now supported by the identification of three mid-seventeenth century timbers. This would have been whilst the castle was in the ownership of Sir Charles Hussey.

The dated timbers from the roofs of the main range and west wing and a single ceiling beam from the main range all appear likely to have been felled in the early AD 1760s, indicating a substantial programme of building works being undertaken at this point in time, including the re-roofing of both of these two areas of the castle. The south-east tower roof is known to contain timber felled in AD 1757–82, suggesting construction in the second half of the eighteenth century and most likely to be contemporary with the re-roofing works undertaken in the main range and west wing. Two first-floor ceiling beams in the south-east tower may also belong to the same programme of work or may have been inserted at a slightly later date, having a felling date range of AD 1767–92. During the AD 1760s the castle and estate were jointly owned by

Montagu Cholmeley and William Pochin but this work seems likely to have been undertaken by the Marfleet family who were farming the estate at this time.

The tree-ring analysis has successfully identified a number of timbers in both the main range and west wing that appear likely to have been associated with the primary construction of these two areas. It has also demonstrated the undertaking of an extensive programme of work in the second half of the eighteenth century that included the re-roofing of a large portion of the castle and the insertion/replacement of ceiling beams in the south-east tower.

It is unfortunate that two of the site sequences created from samples taken from the castle are undated. The most usual reasons for site sequences to be undated are that they are short and/or poorly replicated. Although site sequence SOMCSQ06 is well replicated, containing eight samples, neither it nor SOMCSQ05 are particularly long sequences, at 77 and 62 rings, respectively. Additionally, both of the chronologies contain samples with relatively high mean sensitivity, indicating that their ring sequences are more variable and some of the samples also have bands of narrow rings. Together, this may have had the effect of masking the climatic signal necessary for successful dating. However, although presently undated, the other two site sequences can also tell us something about the relationship between the areas sampled. SOMCSQ05 contains two samples from truss 1 of the main range roof and a sample from truss 4 of the west wing roof. Although it is not possible to say when these three timbers were felled, it can be said, by looking at the relative heartwood/sapwood boundary ring positions (Fig 18) that all three are likely to be coeval. The second undated site sequence, SOMCSQ06, also contains samples from the roof of the main range, four samples from the south-east tower roof, and a sample from the door cill of the garderobe. Again, by looking at the relative heartwood/sapwood boundary ring positions (Fig 19), it can be seen that all samples, regardless of where they are from, are likely to be coeval.

BIBLIOGRAPHY

Arnold, A J, Howard, R E, and Litton, C D, 2002a *Tree-ring Analysis of Timbers from Finchale Priory Barn, Brasside, Durham*, Centre for Archaeol Rep, **99/2002**

Arnold, A J, Howard, R E, Laxton, R R, and Litton, C D, 2002b *The Urban Development of Newark-on-Trent: A Dendrochronological Approach*, Centre for Archaeol Rep, **95/2002**

Arnold, A J, Howard, R E, Laxton, R R, and Litton, C D, 2003 *Tree-ring Analysis of Timbers from the Standing at the Bucks Head, Debenham, Suffolk*, Centre for Archaeol Rep, **41/2003**

Arnold, A J, Howard, R E, and Litton, C D, 2004a *Tree-ring Analysis of Timbers from Fell Close, Healeyfield, near Consett, County Durham*, Centre for Archaeol Rep, **35/2004**

Arnold, A J, Howard, R E, and Litton, C D, 2004b *Tree-ring Analysis of Timbers from Kibworth Harcourt Post Mill. Kibworth Harcourt, Leicestershire*, Centre for Archaeol Rep, 7**6/2004**

Arnold, A J, Howard, R E, and Litton, C D, 2004c *Tree-ring Analysis of Samples from the Roof of the 'Red Wing' Croome Court, Croome D'Abitot, near Upton upon Severn, Gloucestershire*, Centre for Archaeol Rep, **80/2004**

Arnold, A J, Howard, R E, Litton, C D, and Dawson, G, 2005 *The Tree-ring Dating of a Number of Bellframes in Leicestershire*, Centre for Archaeol Rep, **5/2005**

Arnold, A J, and Howard, R E, 2006 *Kingsbury Hall, Kingsbury, Warwickshire, Tree-Ring Analysis of Timbers*, Centre for Archaeol Rep, **53/2006**

Arnold, A J, Howard, R E, and Litton, C D, 2006 *Tree-ring Analysis of Samples from Middleton Hall, Middleton, Warwickshire*, English Heritage Res Dept Rep Ser, **13/2006**

Arnold, A J, and Howard, R E 2007 Nottingham Tree-ring Dating Laboratory, *Vernacular Architect*, **38**, 106–14

Arnold, A J, Howard, R E, and Litton, C D, 2008a Nottingham Tree-ring Dating Laboratory: results, *Vernacular Architect*, **39**, 119–28

Arnold, A J, Howard, R E, and Hurford, M, 2008b Tree-ring analysis of timbers from 101 Meeting Street, Quorn, Leicestershire, unpubl computer file *QRNASQ01*, NTRDL

Arnold, A J, Howard, R E, and Litton, C D, 2008c Nottingham Tree-ring Dating Laboratory: additional dendrochronology dates, *Vernacular Architect*, **39**, 107–11

Arnold, A and Howard, R, 2014 *Church of St Mary, Churchgate, Stockport, Greater Manchester: Tree-Ring Analysis of Timbers from the Vestry Roof*, English Heritage Res Rep Ser, **56/2014**

Arnold A J and Howard, R E, 2015 *Somerton Castle, Lowfields, Navenby, Lincolnshire: Tree-ring Analysis of Timbers from the South-east Tower Roof*, NTRDL rep

Arnold, A, Howard, R, and Tyers, C, forthcoming a *Kirby Hall, Deene, Corby, Northamptonshire -Tree-ring Analysis of Oak Timbers*, Historic England Res Rep Ser,

Arnold, A, Howard, R, and Tyers, C, forthcoming b *Ledston Hall, Hall Lane, Ledston, Leeds, West Yorkshire - Tree-ring Analysis of Oak Timbers*, Historic England Res Rep Ser

Cooper, N, 2013 *Somerton Castle, Lincolnshire: interim report*, unpubl

Groves, C, Locatelli, C, and Howard, R E, 2004 *Tree-ring Analysis of Oak Timbers from Church Farm, Bringhurst, Leicestershire*, Centre for Archaeol Rep, **56/2004**

Howard, R E, Laxton, R R, and Litton C D, 1990 unpubl Oliver Cromwell's House, Ely, Cambridgeshire, unpublished computer file *ELYASQ01,* NUTRDL

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1992 unpubl Catholme, Staffs, unpubl computer file *CATHSQ03,* NUTRDL

Howard, R E, Laxton, R R, Litton, C D, Morrison A, Sewell, J, and Hook, R, 1995a Nottingham University Tree-Ring Dating Laboratory: Derbyshire, Peak Park and RCHME dendrochronological Survey 1994–95, *Vernacular Architect*, **26**, 53–4

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1995b Nottingham University Tree-Ring Dating Laboratory: results, *Vernacular Architect*, **26**, 47–53

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1996 Nottingham University Tree-Ring Dating Laboratory: results, *Vernacular Architect*, **27**, 78–81

Howard, R E, Laxton, R R, and Litton, C D, 2000a *Tree-ring Analysis of Timbers from The Barn and Cottage, Abbey Farm, Thetford, Norfolk*, Anc Mon Lab Rep, **48/2000**

Howard, R E, Laxton, R R, and Litton, C D, 2000b *Tree-ring Analysis of Timbers from the Buildings and Living Trees at Stoneleigh Abbey, Stoneleigh, Warwickshire*, Anc Mon Lab Rep, **80/2000**

Hurford, M, Arnold, A J, Howard, R E, and Tyers, C 2008 *Tree-ring Analysis of Timbers from Flore's House, High Street, Oakham, Rutland*, English Heritage Res Dep Res Ser, **94/2008**

Hurford, M, Arnold, A J, Howard, R E, and Tyers, C 2009 *The Old Hall, West Auckland, County Durham – Tree-ring Analysis of Timbers*, English Heritage Res Dep Res Ser, **75/2009**

Hurford, M, Howard, R E, and Tyers, C, 2010a *Pitchforks and Numbers 1 and 2 Greasley Cottage, Main Street, Norwell, Nottinghamshire: Tree-Ring Analysis of Timbers*, English Heritage Res Dep Rep Ser, **50/2010**

Hurford, M, Howard, R E, and Tyers, C, 2010b *The Old House, Main Street, Norwell, Nottinghamshire: Tree-Ring Analysis of Timbers*, English Heritage Res Dep Rep Ser, **52/2010**

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**

TABLES

Table 1: Details of samples taken from Somerton Castle, Castle Lane, Boothby Graffoe, Lincolnshire

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
South-east Tower						
Roof						
SOM-C01	Centre post	61	02	1686	1744	1746
SOM-C02	PH1	50	h/s	1694	1743	1743
SOM-C03	PH2	96	11	1657	1741	1752
SOM-C04	H3	71	h/s	----	----	----
SOM-C05	H4	63	h/s	----	----	----
SOM-C06	H7	65	h/s	----	----	----
SOM-C07	R42	67	h/s	----	----	----
SOM-C08	SP1	74	h/s	1667	1740	1740
SOM-C09	SP3	72	h/s	1674	1745	1745
SOM-C10	SP4	90	h/s	1654	1743	1743
SOM-C11	SP6	82	--	1650	----	1731
SOM-C12	S08	83	h/s	1656	1738	1738
First-floor						
SOM-C13	Ceiling beam (northernmost)	46	h/s	1706	1751	1751
SOM-C14	Ceiling beam (southernmost)	58	h/s	1695	1752	1752
Garderobe						
Roof						
SOM-C15	Rafter 2, east side	NM	--	----	----	----
SOM-C16	Rafter 5, east side	NM	--	----	----	----
SOM-C17	Wall plate, west side	NM	--	----	----	----
SOM-C18	Wall plate, east side	NM	--	----	----	----
SOM-C19	Wall plate. north side	NM	--	----	----	----
SOM-C20	Rafter 6, south side	NM	--	----	----	----
SOM-C21	North jamb, opening	NM	--	----	----	----
SOM-C22	Bottom cill, opening	60	10	----	----	----

Table 1: continued

Main range						
Roof						
SOM-C23	North principal rafter, truss 1	53	12	----	----	----
SOM-C24	Collar, truss 1	61	h/s	----	----	----
SOM-C25	South principal rafter, truss 1	58	08	----	----	----
SOM-C26	North purlin, truss 1-2	64	18C	1697	1742	1760
SOM-C27	North principal rafter, truss 2	50	02	1694	1741	1743
SOM-C28	Collar, truss 2	57	h/s	----	----	----
SOM-C29	South principal rafter, truss 2	53	h/s	1689	1741	1741
SOM-C30	North principal rafter, truss 3	NM	--	----	----	----
SOM-C31	South purlin, truss 2-3	76	h/s	1668	1743	1743
SOM-C32	North purlin, truss 2-3	91	06	1660	1744	1750
SOM-C33	South principal rafter, truss 3	NM	--	----	----	----
SOM-C34	South purlin, truss 1-2	62	08	----	----	----
First floor						
SOM-C35	North-south ceiling beam (easternmost)	51	h/s	1509	1559	1559
SOM-C36	North-south ceiling beam (westernmost)	58	h/s	1503	1560	1560
Ground floor						
SOM-C37	North-south ceiling beam (westernmost)	61	16C	1701	1745	1761
SOM-C38	Lintel 1, door to west wing	55	--	----	----	----
SOM-C39	Lintel 2, door to west wing	74	h/s	1482	1555	1555
West wing						
Roof						
SOM-C40	North principal rafter, truss 4	71	10	1681	1741	1751
SOM-C41	South principal rafter, truss 4	56	16C	1705	1744	1760
SOM-C42	Collar, truss 4	52	15	----	----	----
SOM-C43	North common rafter 1, bay 4	NM	--	----	----	----
SOM-C44	North principal rafter, truss 5	75	h/s	1666	1740	1740
SOM-C45	South principal rafter, truss 5	75	h/s	1670	1744	1744
SOM-C46	Collar, truss 5	87	10	1671	1747	1757

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)
SOM-C47	North purlin, bay 5	77	h/s	1668	1744	1744
SOM-C48	North purlin, bay 6	NM	--	----	----	----
SOM-C49	North common rafter 6, bay 6	82	--	1656	----	1737
SOM-C50	North common rafter 1, bay 7	NM	--	----	----	----
SOM-C51	East common rafter 1, bay 9	NM	--	----	----	----
SOM-C52	East common rafter 2, bay 9	NM	--	----	----	----
SOM-C53	West lower purlin, bay 9	69	h/s	1673	1741	1741
SOM-C54	West common rafter 4, bay 9	50	--	----	----	----
First floor						
SOM-C55	Ceiling beam (northernmost)	52	h/s	----	----	----
SOM-C56	Ceiling beam (southernmost	86	24	1560	1621	1645
Ground floor						
SOM-C57	Ceiling beam (northernmost)	82	15	1564	1630	1645
SOM-C58	Ceiling beam (southernmost)	61	h/s	----	----	----
SOM-C59	North window, inner lintel	122	20	1526	1627	1647
SOM-C60	North window, outer lintel	NM	--	----	----	----
SOM-C61	Lintel 2, door between north and south parts	NM	--	----	----	----

KEY:
*NM = not measured;
**h/s = the heartwood/sapwood boundary is the last measured ring; C = complete sapwood retained on the sample, last measured ring is the felling date

Table 2: Results of the cross-matching of site sequence SOMCSQ01 and relevant reference chronologies when the first-ring date is AD 1482 and the last-measured ring date is AD 1560

Reference chronology	*t*-value	Span of chronology	Reference
St Nicholas' Church, Bringhurst, Leicestershire	10.1	AD 1502–1687	Arnold *et al* 2005
Oliver Cromwell's House, Ely, Cambridgeshire	8.3	AD 1480–1611	Howard *et al* 1990 unpubl
Flore's House, Oakham, Rutland	7.6	AD 1408–1591	Hurford *et al* 2008
Kingsbury Hall, Kingsbury, Warwickshire	7.6	AD 1391–1564	Arnold and Howard 2006
Bucks Head, Debenham, Suffolk	7.6	AD 1507–1585	Arnold *et al* 2003
Wakelyn Old Hall, Hilton, Derbyshire	7.6	AD 1415–1573	Arnold *et al* 2008a
Kirby Hall, Deene, Corby, Northamptonshire	7.2	AD 1378–1795	Arnold *et al* forthcoming a

Table 3: Results of the cross-matching of site sequence SOMCSQ02 and relevant reference chronologies when the first-ring date is AD 1560 and the last-measured ring date is AD 1645

Reference chronology	*t*-value	Span of chronology	Reference
Middleton Hall, Warwickshire	6.0	AD 1579–1662	Arnold *et al* 2006
Ledston Hall, Ledston, West Yorkshire	5.8	AD 1424–1668	Arnold *et al* forthcoming b
Abbey Farm Barns, Thetford, Norfolk	5.7	AD 1556–1628	Howard *et al* 2000a
The Old Hall, West Auckland, County Durham	5.5	AD 1425–1698	Hurford *et al* 2009
Fell Close, Healeyfield, Consett, County Durham	5.4	AD 1496–1651	Arnold *et al* 2004a
Finchale Priory Barn, Brasside, Durham	5.4	AD 1449–1677	Arnold *et al* 2002a
15/17 St John's Street, Wirksworth, Derbyshire	5.1	AD 1586–1676	Howard *et al* 1995a

Table 4: Results of the cross-matching of site sequence SOMCSQ03 and relevant reference chronologies when the first-ring date is AD 1650 and the last-measured ring date is AD 1760

Reference chronology	*t*-value	Span of chronology	Reference
Pitchforks, Norwell, Nottinghamshire	11.7	AD 1624–1747	Hurford *et al* 2010a
Potterdike House, Lombard Street, Newark-upon-Trent, Nottinghamshire	9.4	AD 1603–1740	Arnold *et al* 2002b
The Old House, Norwell, Nottinghamshire	8.7	AD 1653–1742	Hurford *et al* 2010b
Old Barn, Shottery, Stratford-upon-Avon, Warwickshire	7.3	AD 1591–1735	Howard *et al* 1996
Kibworth Harcourt Mill. Leicestershire	7.1	AD 1582–1773	Arnold *et al* 2004b
Croome Court, Worcestershire	7.1	AD 1639–1753	Arnold *et al* 2004c
Kirby Hall, Deene, Corby, Northamptonshire	6.8	AD 1378–1795	Arnold *et al* forthcoming a

Table 5: Results of the cross-matching of site sequence SOMCSQ04 and relevant reference chronologies when the first-ring date is AD 1689 and the last-measured ring date is AD 1761

Reference chronology	*t*-value	Span of chronology	Reference
Kibworth Harcourt Mill. Leicestershire	7.3	AD 1582–1773	Arnold *et al* 2004b
Church Farm, Bringhurst, Leicestershire	7.0	AD 1664–1781	Groves *et al* 2004
Kirby Hall, Deene, Corby, Northamptonshire	6.6	AD 1378–1795	Arnold *et al* forthcoming a
Houghton Mill, Cambridgeshire	6.5	AD 1683–1806	Loader *pers comm*
Catholme, Staffordshire	6.2	AD 1649–1750	Howard *et al* 1992 unpubl
St John The Baptist Church, Grimstone, Leicestershire	6.2	AD 1674–1754	Arnold *et al* 2005
Bradgate Trees. Leicestershire	5.9	AD 1595–1975	Laxton and Litton 1988

Table 6: Results of the cross-matching of sample SOM-C59 and relevant reference chronologies when the first-ring date is AD 1526 and the last-measured ring date is AD 1647

Reference chronology	*t*-value	Span of chronology	Reference
St Stephen's Church, Sneinton, Nottinghamshire	7.5	AD 1484–1654	Arnold and Howard 2007
101 Meeting Street, Quorn, Leicestershire	7.5	AD 1489–1658	Arnold *et al* 2008b
Stoneleigh Abbey, Stoneleigh, Warwickshire	7.3	AD 1398–1658	Howard et al 2000b
Hipper Hall, Walton, Derbyshire	7.2	AD 1454–1615	Howard *et al* 1995a
5–7 Regent St, Hinckley, Leicestershire	6.9	AD 1502–1624	Arnold *et al* 2008c
St Mary's Church, Colston Bassett, Nottinghamshire	6.8	AD 1465–1609	Howard *et al* 1995b
St Mary's Church, Stockport, Manchester	6.8	AD 1510–1623	Arnold and Howard 2014

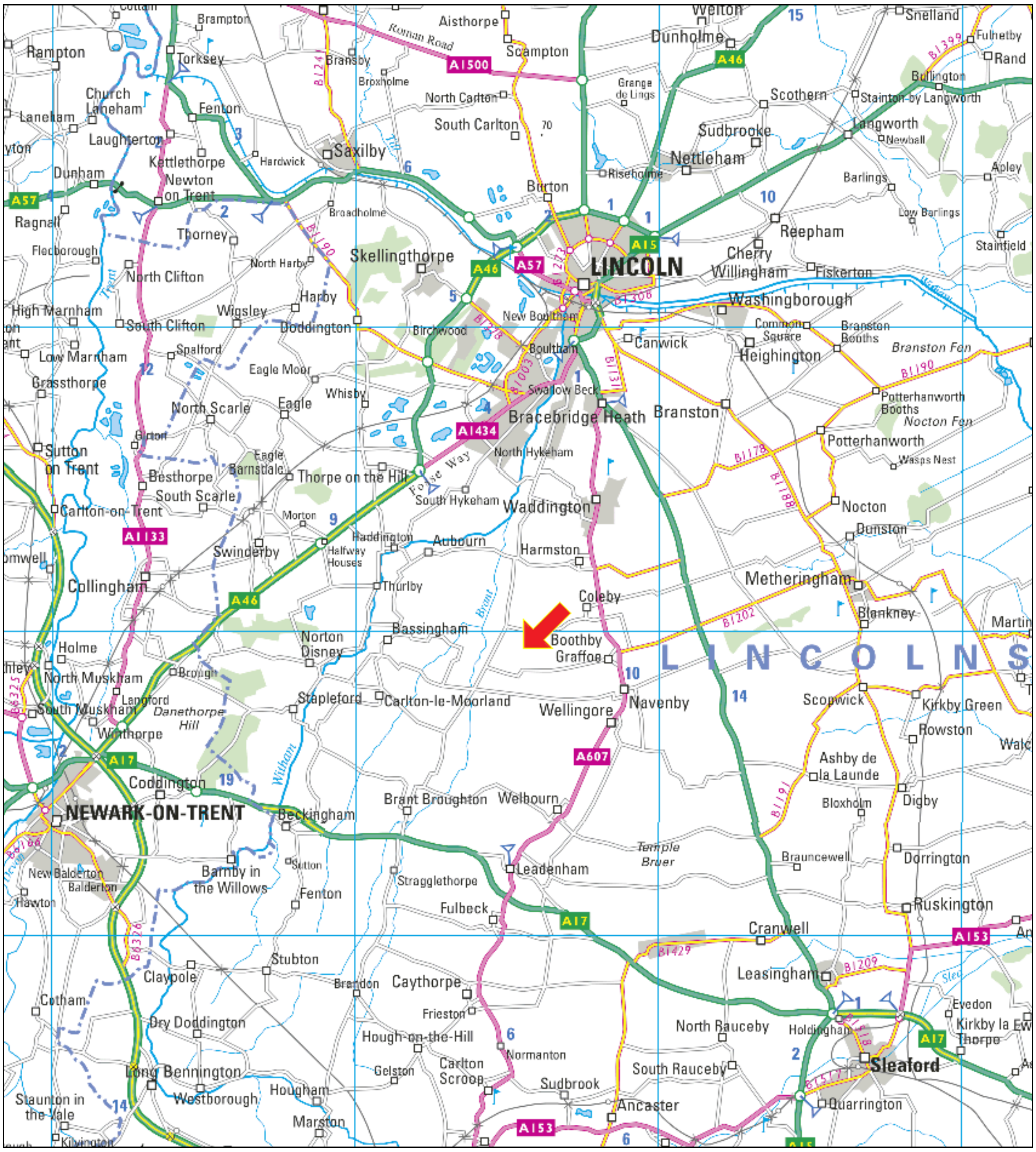


Figure 1: Map to show the general location of Somerton Castle, arrowed. ©Crown Copyright and database right 2016. All rights reserved. Ordnance Survey Licence number 100024900

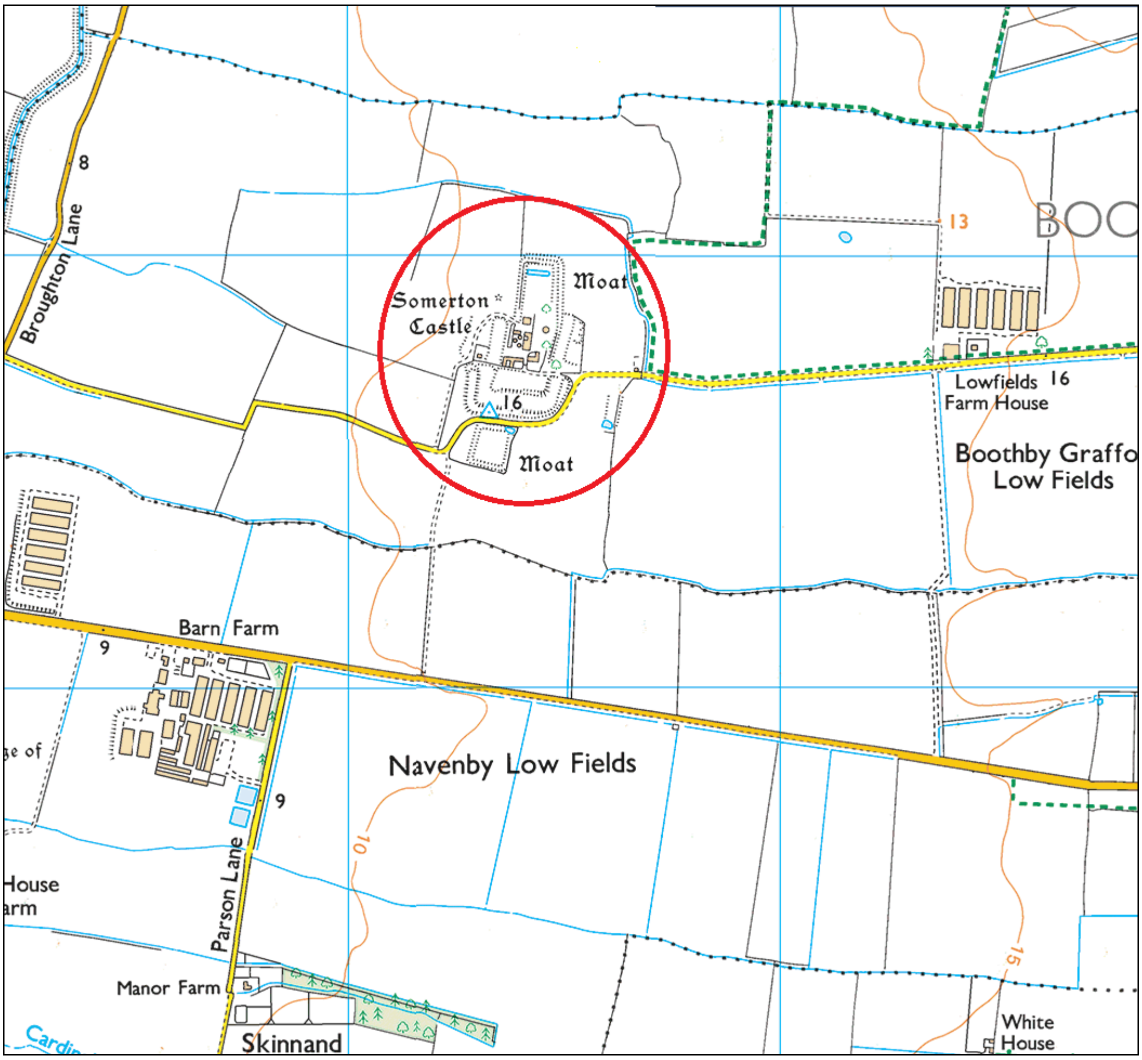


Figure 2: Map to show the Somerton Castle site, circled. ©Crown Copyright and database right 2016. All rights reserved. Ordnance Survey Licence number 100024900

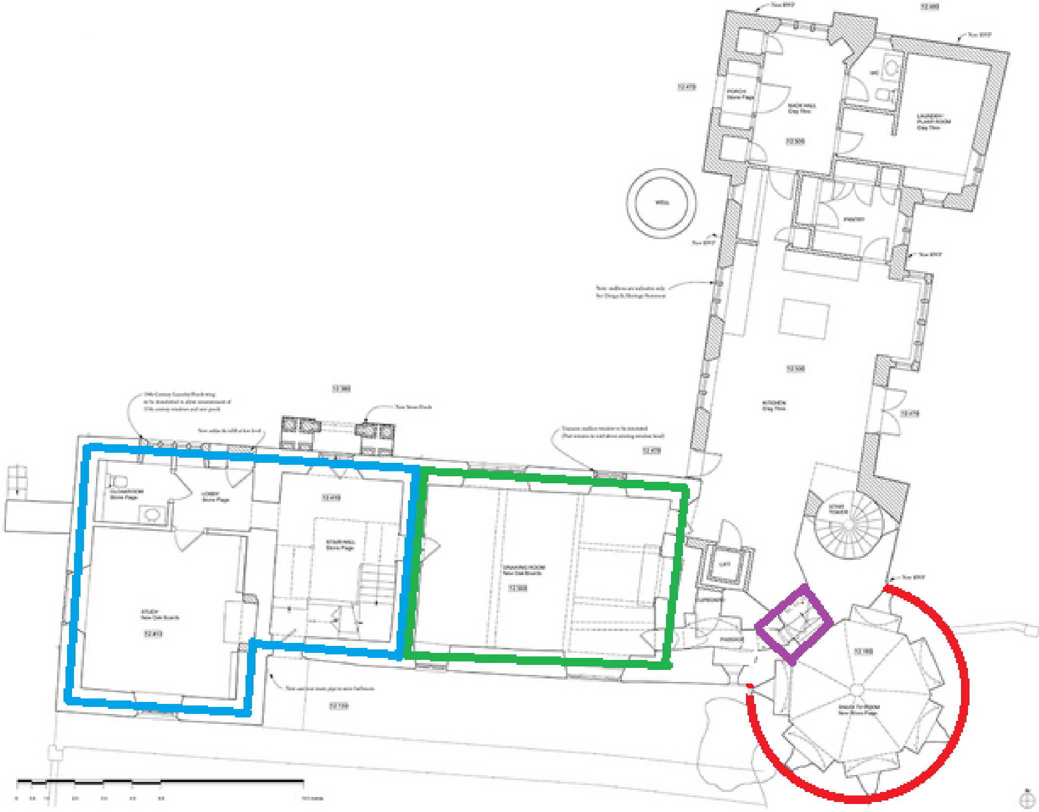


Figure 3: Ground-floor plan showing the location of the main range (green), the west wing (blue), the south-east tower (red), and the garderobe (purple)(after Hoare Ridge & Morris)

Figure 4: Main range (foreground) and west wing roofs, photograph taken from the east (Alison Arnold)

Figure 5: Main range; ground-floor ceiling, photograph taken from the west (Alison Arnold)

Figure 6: West wing, ground-floor ceiling, photograph taken from the north (Alison Arnold)

Figure 7: South-east tower roof, photograph taken from the north-west (Alison Arnold)

Figure 8: South-east tower ceiling, photograph taken from the south (Alison Arnold)

Figure 9: Garderobe roof, photograph taken from the north (Alison Arnold)

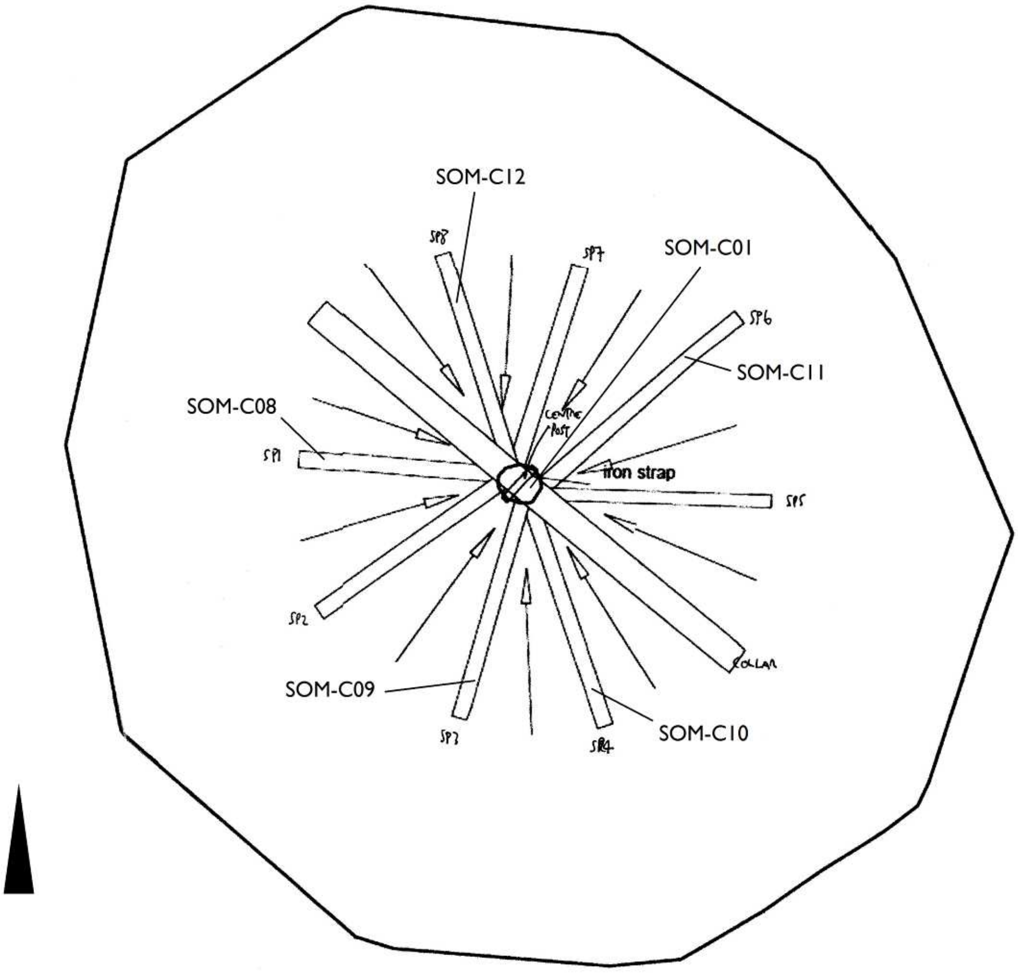


Figure 10: Plan of the tower timbers, showing the location of samples SOM-C01 and SOM-C08–12 (after Hoare Ridge & Morris)

Figure 11: Roof plan, showing the location of samples SOM-C02–07, SOM-C15–34, and SOM-C40–54 (after FAS Heritage)

Figure 12: First-floor plan, showing the location of samples SOM-C13–14, SOM-C35–36, and SOM-C55–56 (after FAS Heritage)

Figure 13: Ground-floor plan, showing the location of samples SOM-C37–39 and SOM-C57–61 (after FAS Heritage)

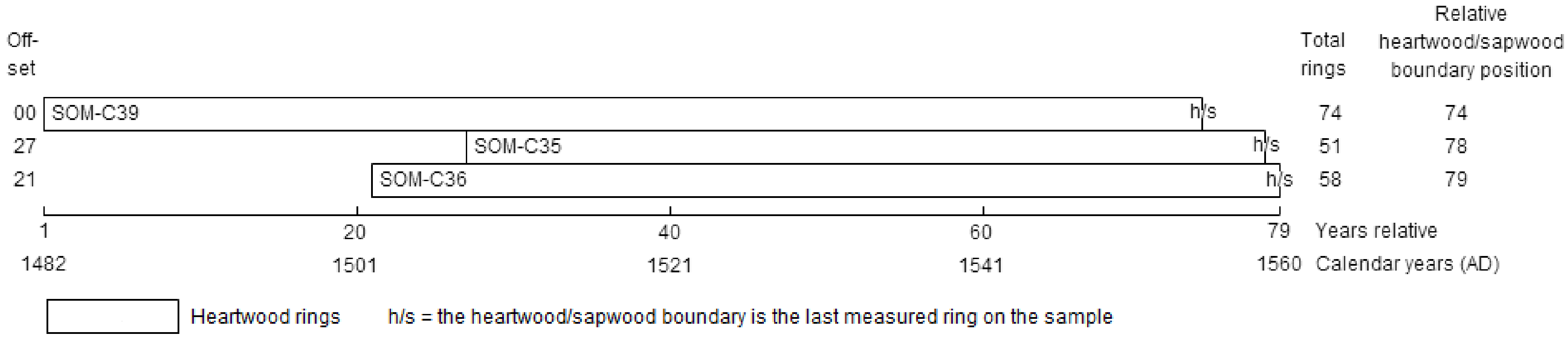


Figure 14: Bar diagram to show the relative position of samples in site sequence SOMCSQ01

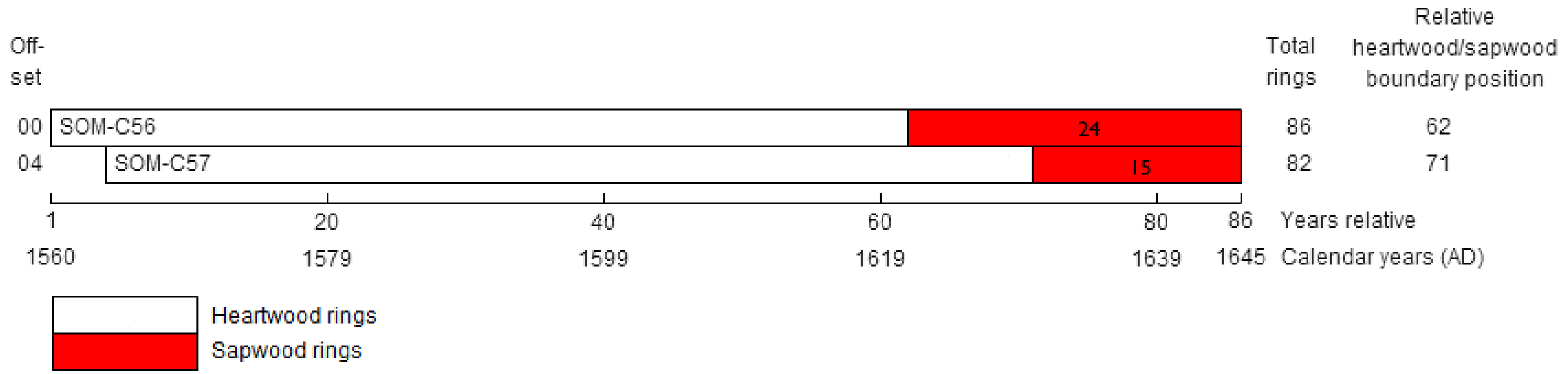


Figure 15: Bar diagram to show the relative position of samples in site sequence SOMCSQ02

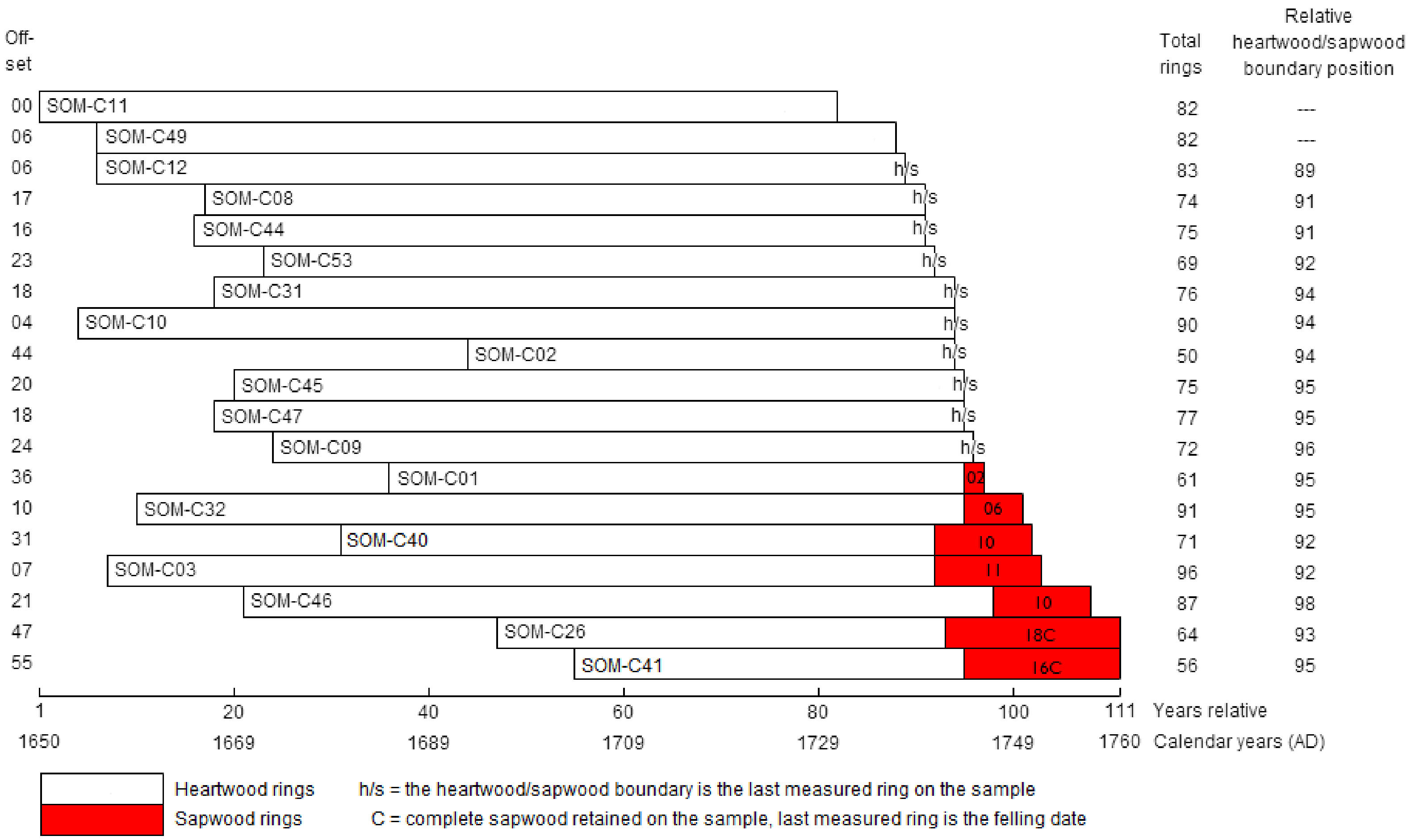


Figure 16: Bar diagram to show the relative position of samples in site sequence SOMCSQ03

Figure 17: Bar diagram to show the relative positions of samples in site sequence SOMCSQ04

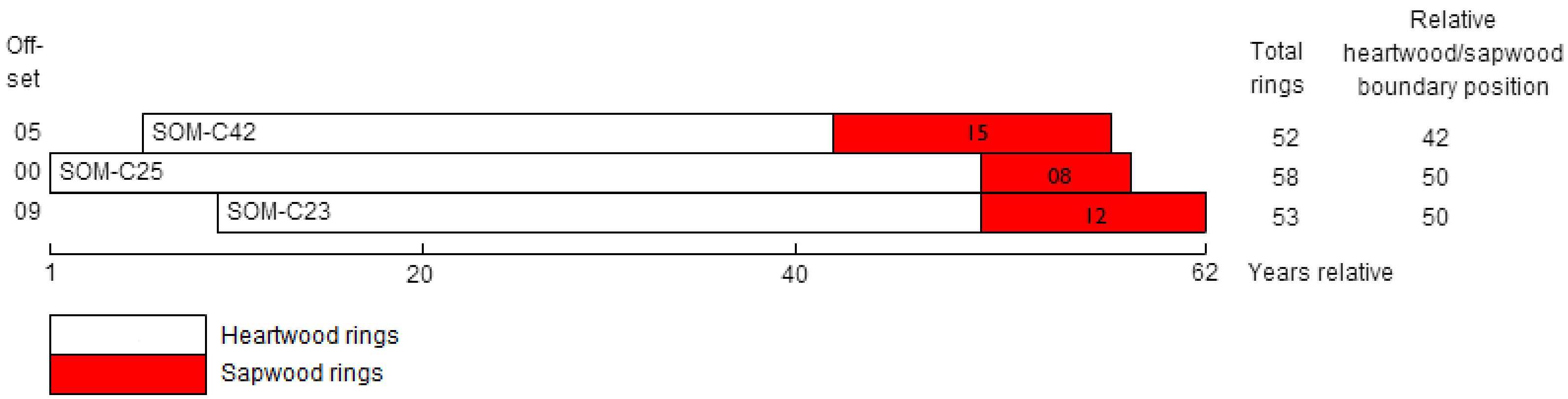


Figure 18: Bar diagram to show the relative position of samples in undated site sequence SOMCSQ05

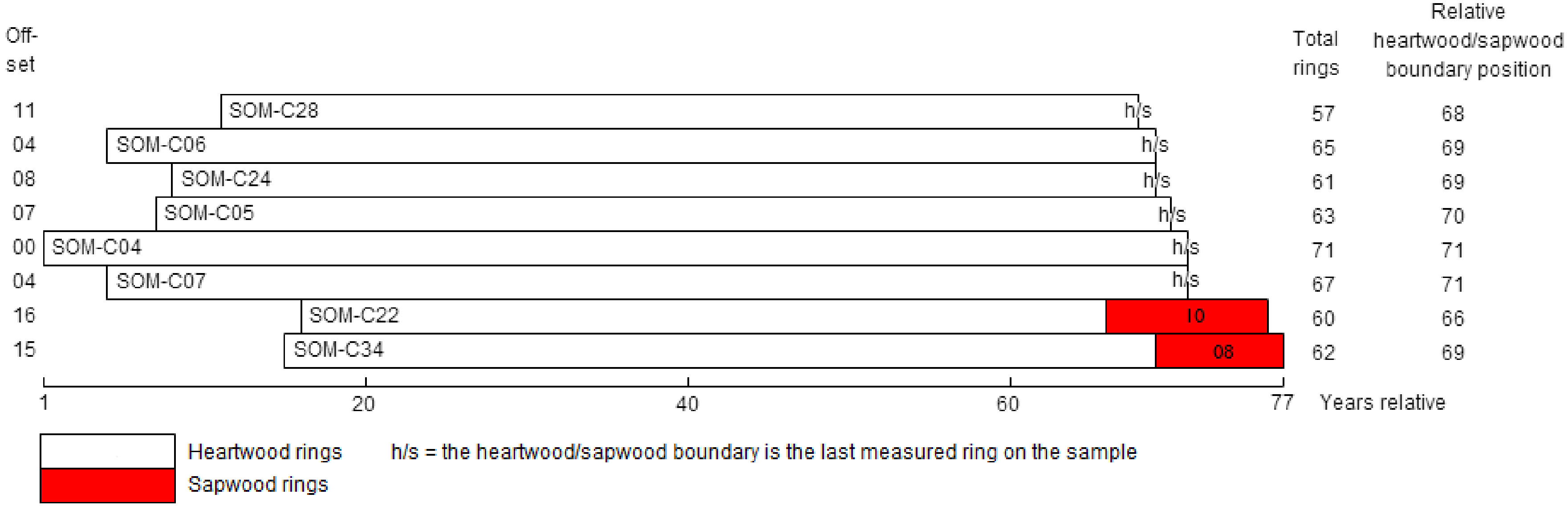


Figure 19: Bar diagram to show the relative positions of samples in undated site sequence SOMCSQ06

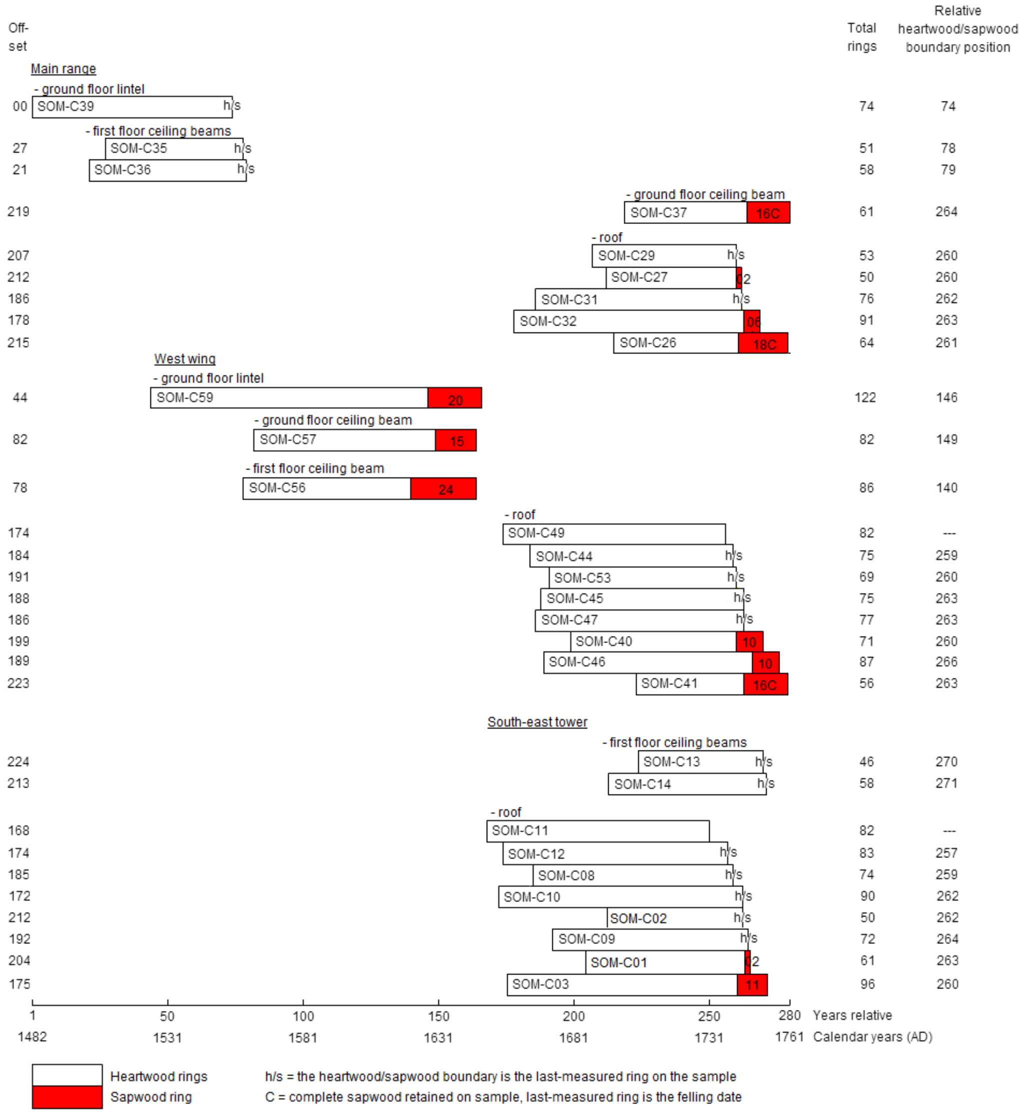


Figure 20: Bar diagram of all dated samples, sorted by area and element

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

SOM-C01A 61
163 223 162 129 80 179 132 135 153 65 59 63 81 74 92 130 190 258 242 120
188 201 166 142 207 264 252 217 162 149 159 146 149 226 274 297 260 108 147 165
194 230 199 219 179 152 207 138 153 197 170 80 74 132 112 119 118 133 114 143
91
SOM-C01B 61
165 222 167 127 94 194 122 129 152 63 59 57 86 73 85 139 193 262 244 120
194 211 166 139 217 264 241 215 162 164 147 143 158 219 267 293 266 106 139 158
192 233 195 215 177 148 207 142 150 204 174 78 83 122 113 114 113 135 118 141
72
SOM-C02A 50
91 146 210 200 233 161 170 167 144 193 201 114 195 141 110 121 110 180 201 228
137 131 137 111 104 178 207 226 192 81 84 130 139 122 126 150 150 118 133 100
130 155 114 64 64 72 92 86 80 82
SOM-C02B 50
183 150 205 206 221 152 179 172 162 215 206 127 186 152 96 123 121 179 196 234
157 145 138 106 99 174 210 227 194 76 88 131 160 123 124 141 149 138 125 86
120 165 110 71 64 95 80 84 77 106
SOM-C03A 96
103 272 128 128 149 141 85 57 69 117 126 181 149 149 180 187 201 154 103 153
193 170 188 285 256 243 177 72 121 250 190 177 106 77 139 136 197 131 108 146
171 192 127 144 141 140 193 216 117 162 130 99 102 93 141 164 202 103 84 95
75 62 134 148 172 160 81 89 134 170 126 115 132 118 126 102 85 110 179 104
46 78 102 93 84 84 90 97 93 82 112 88 84 78 117 114
SOM-C03B 96
121 278 124 140 150 146 82 58 69 110 125 172 155 155 182 182 196 161 113 151
194 175 197 279 257 235 171 83 119 260 196 178 103 83 139 151 184 122 110 145
179 184 134 137 131 147 189 209 100 152 129 90 121 102 150 170 194 101 87 93
75 67 137 148 172 162 82 82 134 171 125 112 131 128 125 112 86 127 186 98
53 69 102 105 90 75 83 119 69 90 125 99 74 84 114 92
SOM-C04A 71
207 177 152 111 194 167 63 35 96 165 193 159 88 109 168 194 182 179 148 178
221 232 156 137 119 63 92 78 92 66 152 162 160 95 100 97 140 112 104 104
130 68 62 48 106 129 87 72 104 128 145 76 108 52 36 48 183 351 399 380
396 409 352 143 83 162 274 270 363 409 330
SOM-C04B 71
222 183 148 116 215 167 58 29 90 152 199 180 86 109 170 197 186 178 154 174
220 228 157 136 122 68 80 92 87 82 137 155 168 98 95 103 149 113 102 111
129 69 58 54 101 125 89 76 95 120 148 72 113 48 37 51 177 354 397 381
402 423 355 151 83 155 288 272 366 403 336
SOM-C05A 63
183 131 187 217 217 81 104 143 167 184 154 97 67 102 104 86 95 101 54 91
76 60 36 74 106 165 66 83 50 55 65 64 71 65 42 33 28 46 45 34
39 30 32 36 35 32 24 24 42 222 307 338 292 263 346 287 129 127 232 288
250 327 227
SOM-C05B 63
189 119 182 214 217 76 106 140 169 180 151 96 73 103 98 76 82 104 50 91
72 56 41 71 108 162 64 76 58 51 57 73 67 59 46 29 29 44 47 38
36 27 34 39 34 30 21 22 42 223 305 333 290 266 342 272 126 124 223 283

249 321 165
SOM-C06A 65
301 231 79 35 97 170 247 218 112 148 199 159 210 193 124 173 197 215 156 155
124 86 112 133 83 77 136 154 137 95 73 101 153 103 99 114 148 110 85 94
153 168 95 118 170 145 120 91 88 43 32 117 299 457 596 466 250 297 201 92
56 119 197 199 284
SOM-C06B 65
322 218 96 38 81 164 260 210 119 141 206 167 212 197 132 170 201 207 159 158
114 93 112 135 91 74 133 151 138 100 75 90 157 105 96 114 147 109 84 98
151 165 100 116 178 142 128 94 80 41 57 88 300 454 598 462 244 287 204 91
58 116 202 195 214
SOM-C07A 67
253 425 158 75 305 295 278 220 134 121 213 256 204 209 156 137 102 100 121 124
129 81 129 134 140 138 135 123 112 65 45 48 38 40 60 52 47 50 38 36
59 55 42 37 41 32 38 39 66 28 20 63 75 64 79 106 92 127 115 67
44 86 199 167 222 263 246
SOM-C07B 67
219 430 165 70 321 300 293 207 131 113 217 232 198 216 154 139 99 105 122 119
122 80 126 130 139 136 131 118 113 64 43 47 33 43 56 51 47 45 43 39
55 52 50 39 31 28 43 43 47 35 27 69 75 54 82 105 111 131 122 54
46 72 179 174 224 252 174
SOM-C08A 74
150 252 210 213 155 316 207 127 67 65 106 215 240 266 235 233 185 153 148 220
231 195 140 109 112 74 106 148 121 144 155 163 168 181 180 177 169 197 109 106
117 125 136 131 149 136 141 109 113 94 79 92 114 112 118 101 71 70 81 96
97 80 79 75 72 58 52 53 85 96 78 77 104 74
SOM-C08B 74
149 251 214 222 156 322 191 129 71 63 101 222 213 275 262 232 190 146 155 222
234 192 158 106 114 92 97 135 123 143 155 181 168 187 178 178 178 197 112 109
115 130 135 127 151 140 139 113 116 95 85 87 111 114 113 110 50 77 84 99
101 83 77 65 77 59 47 59 82 94 77 88 112 95
SOM-C09A 72
182 97 79 138 172 249 296 257 331 219 164 176 241 220 173 120 86 157 122 123
166 142 163 198 171 139 136 131 118 100 117 88 92 112 110 74 87 106 118 101
83 110 79 77 73 87 86 98 83 53 65 79 100 102 78 87 95 85 81 67
74 117 156 119 94 152 119 108 96 103 71 107
SOM-C09B 72
179 89 87 132 174 252 306 254 323 216 174 178 251 232 170 127 68 174 123 102
168 147 168 199 195 140 134 135 123 105 112 108 107 101 123 83 82 105 121 94
91 113 86 65 80 88 82 88 85 50 63 79 101 104 79 82 93 87 76 80
71 126 151 120 95 152 109 100 105 98 86 100
SOM-C10A 90
95 201 104 205 236 241 229 133 107 112 75 65 104 130 192 155 135 123 216 187
104 41 45 90 187 178 222 171 185 125 93 101 184 149 114 87 66 111 83 109
117 87 89 110 116 101 88 100 83 79 114 82 89 93 83 81 100 118 115 130
99 101 115 73 101 111 136 133 113 58 60 79 91 99 79 71 75 68 55 52
42 90 104 89 70 114 63 83 81 93
SOM-C10B 90
107 211 105 200 234 253 223 130 109 115 70 70 100 139 186 158 135 123 215 193
98 44 45 89 184 173 231 173 182 130 93 96 182 153 117 84 66 109 89 111
120 88 85 112 116 96 85 91 86 85 107 74 84 97 76 74 75 108 104 119
107 104 116 70 98 113 132 124 116 51 72 87 82 96 77 62 78 80 59 50
48 92 98 79 63 120 70 74 70 61

SOM-C11A 82
48 97 169 153 204 222 211 171 236 164 189 106 83 94 74 63 64 89 164 135
121 105 179 272 182 82 101 199 235 192 197 152 199 129 98 134 179 147 133 84
70 125 92 149 139 108 137 151 172 153 125 110 103 100 115 81 74 94 99 109
114 132 120 126 91 89 69 63 74 83 94 96 102 42 48 60 61 83 60 69
73 83
SOM-C11B 82
64 93 165 149 208 220 209 175 237 158 182 106 87 101 73 62 69 95 161 133
121 109 180 265 184 82 105 209 233 188 194 158 197 126 104 136 182 146 133 84
66 131 87 145 146 105 139 149 174 151 128 109 101 100 117 81 73 93 101 113
112 131 130 125 78 87 68 63 74 79 90 91 106 40 45 61 64 84 75 57
67 82
SOM-C12A 83
110 210 233 213 208 120 120 113 76 73 111 144 202 148 160 154 258 214 117 53
48 92 184 175 189 162 190 130 90 101 188 162 115 64 67 90 78 105 101 99
106 122 130 114 96 96 107 102 124 86 95 110 104 102 113 125 119 126 104 115
120 73 104 126 133 159 110 52 62 95 91 98 76 66 69 62 55 51 47 91
96 82 69
SOM-C12B 83
121 215 233 205 210 125 126 122 77 67 115 139 206 155 160 145 246 215 125 57
44 98 178 170 194 161 199 141 100 109 198 166 111 70 67 86 84 106 102 96
102 133 135 117 102 96 108 103 131 93 93 114 109 106 115 115 127 120 110 119
112 85 101 118 138 154 126 58 59 72 114 92 83 66 68 63 55 37 52 83
93 81 70
SOM-C13A 46
79 210 317 304 103 109 124 141 125 257 208 224 171 140 143 322 359 214 309 355
374 374 373 386 403 271 369 298 360 386 357 269 330 332 236 291 339 303 289 360
321 259 287 217 185 176
SOM-C13B 46
86 197 311 307 106 110 165 149 130 244 235 213 163 144 138 323 364 222 295 373
379 368 384 366 393 274 357 306 358 400 362 277 316 327 237 286 362 302 295 362
321 260 283 236 188 180
SOM-C14A 58
48 99 127 150 169 99 77 44 60 167 156 177 165 170 150 67 148 169 180 150
395 234 254 184 204 178 359 431 232 278 252 342 306 327 306 345 307 368 242 284
321 383 335 377 377 255 357 291 275 315 380 398 357 380 305 244 335 217
SOM-C14B 58
60 86 132 151 176 92 86 41 84 134 171 166 167 177 151 83 136 162 208 159
380 241 230 184 214 168 361 430 234 297 270 356 335 310 292 344 314 377 254 289
332 373 325 386 367 261 345 290 275 313 381 394 365 373 311 239 331 225
SOM-C22A 60
397 378 304 326 371 329 333 363 319 301 343 323 167 218 243 251 247 107 78 77
85 69 80 93 98 62 76 57 93 122 68 61 68 82 55 51 42 30 30 36
64 128 258 251 261 310 299 97 77 166 265 246 268 340 253 259 251 196 206 203
SOM-C22B 60
408 376 314 325 367 329 356 356 319 302 344 339 167 215 241 243 247 104 84 80
84 80 91 92 104 70 77 51 84 108 64 71 59 85 60 38 52 35 30 25
70 139 262 241 263 311 294 100 72 147 244 243 280 334 264 257 253 181 224 208
SOM-C23A 53
197 307 221 548 401 435 255 102 38 53 52 55 57 116 163 152 146 226 220 326
353 289 252 346 320 262 330 195 335 216 215 210 308 198 117 156 293 219 249 359
223 242 278 207 284 262 254 203 231 200 197 151 138
SOM-C23B 53

193 324 219 547 404 436 259 97 40 54 53 45 68 112 180 159 137 226 224 325
352 285 253 345 323 268 323 187 339 209 208 203 299 203 114 162 290 217 256 346
215 250 290 199 272 270 261 202 229 199 196 149 148
SOM-C24A 61
93 180 228 250 208 147 223 242 195 217 194 187 167 137 133 147 162 116 154 106
100 105 123 161 135 76 81 68 128 51 93 67 76 57 70 75 142 144 83 107
121 106 132 94 84 48 65 89 176 391 314 300 269 320 282 127 145 271 354 269
274
SOM-C24B 61
83 177 248 236 211 162 217 245 191 213 196 181 159 154 126 123 163 112 158 121
95 113 118 165 135 78 79 82 118 68 77 71 60 57 77 71 151 137 81 114
123 108 128 90 92 54 73 87 182 377 321 294 276 311 287 132 133 273 353 272
259
SOM-C25A 58
162 200 180 259 203 203 268 212 289 288 275 257 303 355 385 178 87 36 50 40
28 48 152 247 266 190 424 228 291 316 245 182 286 248 210 251 157 231 149 163
209 354 223 109 164 349 253 285 366 185 311 252 196 256 336 279 203 199
SOM-C25B 58
176 181 176 205 228 193 252 203 285 249 272 260 292 371 376 189 79 39 51 48
24 46 141 249 262 182 426 233 302 302 235 178 303 267 228 239 153 224 157 162
223 351 213 108 165 349 242 287 361 187 303 248 195 263 342 271 195 217
SOM-C26A 64
62 94 86 104 126 149 230 313 262 444 373 258 144 172 91 177 85 81 110 95
66 64 93 130 123 109 92 144 112 154 163 137 140 150 126 106 107 68 56 84
76 109 75 45 45 51 69 101 95 115 70 124 120 112 108 123 97 75 114 107
73 49 75 46
SOM-C26B 64
62 89 95 100 132 156 230 341 299 355 370 251 132 155 99 184 76 88 102 98
58 65 93 130 126 102 97 150 110 137 148 119 130 148 127 119 123 73 46 80
70 111 85 49 29 45 69 111 86 112 69 127 109 113 101 122 100 82 106 93
74 53 66 47
SOM-C27A 49
270 282 242 242 197 219 205 334 763 571 383 568 500 465 415 142 220 306 305 206
393 341 376 252 309 322 405 317 226 280 233 227 175 246 208 225 180 168 141 159
168 133 109 128 172 125 118 142 131
SOM-C27B 50
312 269 272 246 238 191 219 193 330 760 572 384 562 502 464 397 145 228 300 303
217 414 346 365 263 300 320 412 314 231 274 244 220 169 246 218 223 176 173 135
165 163 135 92 122 161 127 129 146 151
SOM-C28A 57
144 188 119 221 270 167 195 177 186 158 165 161 166 177 123 193 156 105 108 126
121 160 82 66 81 97 67 81 43 59 39 43 46 67 81 51 51 56 58 68
49 69 42 33 55 144 178 155 180 144 188 189 82 98 207 271 232
SOM-C28B 57
143 178 125 212 276 170 193 173 182 171 160 164 161 172 109 200 158 104 110 111
130 162 81 72 74 102 55 84 46 52 39 46 45 68 88 40 57 55 48 74
54 54 41 37 58 131 184 146 194 138 196 187 76 94 198 299 226
SOM-C29A 53
130 252 377 234 387 383 290 339 235 243 203 204 247 571 752 515 322 404 396 412
379 166 231 292 409 250 327 279 256 155 179 229 256 243 209 271 266 256 173 254
205 235 174 131 135 146 139 122 84 109 160 126 104
SOM-C29B 53
163 288 383 228 401 381 291 340 241 235 202 210 252 576 760 504 314 404 401 411

372 167 221 305 402 251 328 282 257 156 186 222 257 245 205 270 269 258 171 251
208 234 175 129 129 146 142 127 88 111 156 130 107
SOM-C31A 76
175 149 255 352 228 204 205 142 110 230 189 177 317 149 157 130 94 87 199 204
176 165 97 86 81 110 168 228 225 220 244 236 214 149 134 163 161 146 197 163
189 143 139 204 201 188 129 185 127 116 147 179 208 211 162 103 83 128 134 110
128 144 112 96 113 116 84 155 144 91 129 166 125 103 97 114
SOM-C31B 76
182 141 262 358 231 202 198 142 107 235 190 175 317 156 157 124 101 83 192 212
173 165 98 80 81 103 178 221 224 219 246 232 212 149 143 161 159 146 193 168
179 140 152 201 207 191 130 184 136 118 141 187 213 208 165 102 89 128 127 112
136 142 102 101 107 104 99 154 147 94 124 182 108 102 106 108
SOM-C32A 91
173 211 204 225 110 89 111 160 207 147 177 269 185 179 189 105 85 197 170 123
219 182 258 183 113 88 161 181 208 190 108 84 103 138 159 219 255 220 233 181
175 166 131 166 172 130 187 150 154 110 93 154 141 133 74 127 95 101 104 144
193 205 214 132 117 137 186 177 191 201 146 125 138 98 104 146 142 95 98 139
105 103 101 136 125 185 137 128 132 127 130
SOM-C32B 91
172 207 205 236 102 102 106 154 202 151 178 268 184 190 191 108 87 186 172 126
215 182 251 178 109 95 160 183 215 185 109 95 98 127 171 215 244 207 242 183
175 170 129 161 176 128 188 141 154 121 88 151 138 145 77 118 95 107 117 148
193 223 220 138 105 143 166 168 171 197 132 124 128 102 100 145 154 94 98 132
108 104 106 131 123 188 135 131 133 128 120
SOM-C34A 62
327 378 468 233 334 368 288 240 273 258 186 280 278 159 207 232 184 189 106 106
90 78 88 112 79 112 94 69 39 52 72 65 63 59 75 74 82 75 49 49
60 105 139 66 79 118 140 162 84 84 153 206 186 219 213 153 126 126 114 127
165 131
SOM-C34B 62
318 393 466 220 322 357 281 239 272 245 180 283 267 164 203 241 191 179 107 101
93 74 87 110 87 105 97 57 57 48 65 66 60 56 88 74 72 78 47 49
74 81 148 74 73 118 140 160 86 79 150 199 194 209 206 159 133 114 116 119
195 124
SOM-C35A 51
447 583 396 500 425 331 369 263 148 236 272 225 191 281 216 200 185 206 218 204
172 190 268 209 256 260 313 262 191 228 209 274 253 212 193 133 154 111 75 142
210 168 211 148 177 174 173 121 87 117 129
SOM-C35B 51
479 573 389 464 430 324 380 248 146 241 276 215 196 276 218 208 170 220 199 205
177 172 271 206 269 254 309 281 192 232 212 261 243 225 188 139 141 109 85 138
207 170 219 146 159 182 173 127 86 110 132
SOM-C36A 58
133 120 177 205 204 227 199 242 230 273 313 281 293 238 165 315 338 281 283 250
224 266 233 300 196 216 214 128 188 198 189 170 307 357 353 346 282 258 210 193
234 269 266 167 90 206 274 200 215 152 146 164 190 199 101 109 136 187
SOM-C36B 58
141 125 183 204 210 200 205 240 238 280 314 273 272 238 170 315 336 279 283 256
212 264 247 287 198 219 217 139 192 186 202 172 322 355 357 344 277 265 207 192
242 271 269 165 86 211 272 204 194 155 142 166 189 196 100 108 138 183
SOM-C37A 61
458 421 491 567 310 349 292 266 311 100 187 295 397 286 402 293 306 200 170 320
553 502 331 391 352 385 327 271 389 415 374 341 313 366 350 321 181 215 328 221

256 257 182 207 311 246 216 172 221 174 258 275 234 241 186 243 186 177 157 171
122
SOM-C37B 61
456 427 483 568 312 352 284 259 298 112 180 307 405 299 404 307 318 200 180 328
561 511 349 384 348 395 334 274 395 418 375 338 321 390 369 318 185 221 342 224
254 267 185 210 314 247 205 175 222 173 252 276 230 241 186 237 210 147 163 159
131
SOM-C38A 55
286 314 265 349 249 198 198 155 219 192 169 183 133 172 139 117 148 242 190 148
139 145 103 94 74 104 253 157 166 255 373 574 422 396 322 408 448 445 311 302
277 396 424 356 331 232 294 260 270 289 316 344 342 379 339
SOM-C38B 55
286 313 269 345 242 203 190 152 208 191 172 185 132 171 138 119 153 238 188 158
118 136 99 103 64 111 248 161 160 261 379 571 424 403 324 414 448 441 320 288
281 400 415 345 341 223 297 253 292 293 327 356 347 376 318
SOM-C39A 74
201 207 106 205 102 180 175 123 142 112 102 133 195 236 254 297 218 183 171 112
59 75 101 172 178 122 148 168 165 166 192 142 143 149 185 81 203 230 196 221
245 179 220 183 205 201 201 153 112 268 203 185 171 258 216 212 214 178 169 144
100 168 179 250 134 96 155 181 160 153 90 122 138 183
SOM-C39B 74
178 185 109 199 107 185 188 113 139 108 94 123 185 244 257 290 208 185 170 111
68 72 104 164 185 119 165 166 164 157 197 138 145 144 183 83 200 228 197 218
251 177 226 180 200 213 199 155 129 261 195 180 164 259 222 208 214 181 162 150
90 173 186 235 147 74 175 185 162 154 94 115 143 183
SOM-C40A 71
303 376 349 272 150 354 238 184 103 215 416 384 408 296 204 157 211 260 237 187
262 186 193 281 167 241 279 278 104 111 122 295 306 165 209 200 132 95 159 186
219 169 95 183 107 128 162 93 133 180 115 116 117 65 49 93 70 135 83 61
72 98 100 132 126 144 64 120 103 77 101
SOM-C40B 71
301 388 365 278 151 360 256 192 98 219 422 384 423 294 221 153 214 282 249 185
264 195 192 281 152 247 287 275 124 115 126 297 314 164 202 195 128 95 166 186
225 164 105 183 105 126 164 98 118 179 120 123 113 65 55 90 75 141 81 60
70 105 88 144 133 139 67 123 103 82 93
SOM-C41A 56
175 286 386 315 236 295 246 383 262 185 203 194 154 122 191 197 195 187 130 220
150 205 200 194 211 202 183 194 145 86 92 92 90 136 233 116 102 192 210 213
233 271 123 224 219 158 175 173 128 103 82 156 93 70 77 53
SOM-C41B 56
160 293 394 325 249 296 266 397 278 181 195 192 159 121 197 187 217 218 131 221
152 194 212 179 221 184 181 189 150 85 91 93 96 137 221 128 107 203 206 199
249 280 120 223 224 155 182 167 135 103 114 127 90 75 74 56
SOM-C42A 52
64 204 168 235 246 185 114 106 105 94 77 76 51 51 47 55 33 63 126 159
175 223 235 229 159 177 188 184 174 183 169 95 142 85 78 128 159 70 66 81
138 127 180 176 94 136 151 162 198 163 97 121
SOM-C42B 52
72 203 172 237 236 184 112 99 110 85 97 67 51 52 53 45 46 59 122 150
161 235 225 227 158 169 192 186 178 179 170 113 169 87 72 129 171 69 62 79
138 134 169 184 98 136 145 122 205 148 103 134
SOM-C44A 75
87 155 235 186 271 257 179 200 76 49 34 87 114 108 196 170 202 146 93 124

164 195 200 102 110 122 161 163 203 148 171 178 197 200 220 227 164 150 173 115
189 186 140 110 112 166 194 168 163 125 124 117 151 136 183 193 194 72 117 130
161 172 143 166 211 145 158 109 161 158 178 116 99 139 110
SOM-C44B 42
202 183 200 201 156 144 171 106 170 187 129 103 100 170 179 167 163 136 141 110
131 165 182 207 186 73 117 130 157 188 145 155 225 142 158 104 142 166 171 122
100 108
SOM-C45A 75
165 200 141 94 125 33 36 42 58 79 176 168 182 110 72 91 183 141 63 42
62 52 47 103 93 51 30 37 45 38 53 77 156 134 118 81 142 139 101 109
195 225 205 166 137 75 110 113 159 168 262 240 219 70 95 135 155 126 113 167
103 85 90 63 85 133 105 55 56 132 96 64 58 85 71
SOM-C45B 75
106 196 146 96 122 36 37 40 54 88 172 166 182 110 69 92 174 140 66 45
54 55 50 98 99 46 31 40 47 36 53 80 155 129 128 86 136 162 79 109
189 227 202 168 145 73 112 106 162 163 267 225 220 68 98 151 144 137 109 171
106 87 91 65 82 139 100 59 63 131 90 65 67 76 78
SOM-C46A 87
188 184 199 234 164 151 226 195 226 266 252 291 246 197 213 262 185 168 76 84
125 123 219 198 199 234 218 193 140 127 138 122 150 202 155 238 171 143 135 143
212 225 275 151 163 168 136 126 206 250 251 208 127 147 140 124 128 142 202 146
159 152 147 118 154 162 113 114 134 124 137 175 154 161 135 154 195 238 276 250
265 249 214 148 235 206 163
SOM-C46B 87
192 180 198 233 170 136 221 212 224 237 232 307 255 189 205 256 189 170 78 78
130 125 216 198 200 242 219 197 136 128 131 128 154 201 155 241 168 145 138 149
208 221 279 153 154 172 139 129 200 267 231 216 133 142 136 130 123 142 199 146
154 153 128 124 154 152 110 121 132 122 133 176 154 166 137 149 196 231 272 255
265 246 211 151 226 234 144
SOM-C47A 77
168 186 179 245 254 252 296 248 228 323 307 323 324 374 425 329 207 264 274 268
199 114 127 182 139 192 289 328 319 263 257 201 175 226 191 220 332 200 289 221
149 107 93 145 192 154 104 129 135 135 115 194 230 284 247 143 143 109 101 99
117 115 97 178 157 151 144 161 145 101 100 138 121 108 133 129 145
SOM-C47B 77
170 188 177 253 245 260 283 253 221 322 310 316 305 374 413 332 207 301 260 269
217 114 123 177 139 186 294 321 323 261 243 193 176 254 204 219 348 193 290 218
152 111 90 147 191 151 121 129 136 130 126 190 225 283 257 144 139 105 110 96
115 118 107 165 157 148 146 160 147 99 99 137 126 116 132 129 133
SOM-C49A 82
199 201 197 164 183 118 107 96 56 60 113 108 158 147 184 155 121 145 205 115
102 135 160 112 140 82 124 92 53 74 122 111 87 81 60 70 67 69 75 70
70 83 100 96 109 89 71 57 98 57 82 73 95 77 52 65 74 61 61 83
73 47 39 47 72 71 98 57 41 63 69 58 63 53 68 54 60 59 42 66
67 46
SOM-C49B 82
190 202 194 155 188 134 113 97 49 68 111 100 166 144 184 147 120 140 212 119
99 157 160 109 143 87 124 87 55 71 123 117 83 79 62 70 62 69 77 60
68 94 88 105 111 86 71 64 106 48 86 65 104 68 55 70 76 59 63 86
65 45 35 49 72 61 104 60 41 63 66 62 66 51 65 58 59 57 47 53
77 54
SOM-C53A 69
246 287 121 129 143 145 132 161 163 214 184 119 157 155 144 117 65 87 97 110

104 165 157 166 141 132 104 115 114 120 131 186 127 180 173 140 100 99 143 178
144 134 118 132 114 117 185 225 235 204 96 129 118 128 127 166 149 147 155 147
129 123 133 144 103 78 98 107 90
SOM-C53B 69
196 265 123 128 149 134 131 166 149 218 174 116 159 164 140 109 70 85 123 97
121 160 156 168 138 122 100 114 119 106 137 178 125 183 175 137 103 116 142 170
163 117 124 144 120 122 186 240 242 209 112 124 112 115 130 157 145 139 169 150
128 121 142 150 99 72 108 112 87
SOM-C54A 50
179 201 210 314 245 289 185 171 121 91 164 134 119 146 226 147 137 124 114 134
212 136 215 132 100 184 201 146 191 189 206 209 224 199 165 200 206 245 323 281
222 272 205 183 156 178 226 177 208 208
SOM-C54B 50
197 212 224 301 249 291 178 168 123 97 149 151 122 151 210 159 149 138 124 131
209 144 211 141 96 177 201 154 187 181 204 210 227 199 163 194 203 237 327 270
238 268 204 178 162 178 216 187 220 213
SOM-C55A 52
437 396 313 436 437 464 319 293 243 350 212 297 316 317 270 332 278 302 317 303
248 235 237 224 210 469 406 353 279 323 187 231 315 267 250 256 192 63 56 73
79 102 149 150 171 191 243 224 218 155 179 289
SOM-C55B 52
473 386 297 448 465 505 321 278 237 355 207 297 312 334 259 332 273 302 323 301
242 238 242 224 200 474 409 355 279 322 191 230 307 266 248 269 185 67 52 72
79 97 149 148 170 192 238 214 210 149 189 293
SOM-C56A 76
147 141 192 153 97 144 147 164 199 420 596 703 863 721 707 569 443 481 431 402
522 431 454 494 604 410 498 439 440 625 548 268 195 211 262 337 370 353 322 317
304 249 144 175 191 154 211 280 244 199 213 189 240 208 168 229 134 140 155 190
191 149 252 226 138 124 98 112 148 198 135 129 158 108 103 130
SOM-C56B 49
407 381 339 296 230 127 163 174 135 182 227 220 199 203 180 235 195 154 226 141
115 166 175 179 157 233 223 149 108 105 114 154 192 142 116 148 111 102 142 87
94 81 100 156 214 115 129 152 110
SOM-C57A 82
205 188 184 104 168 172 204 186 152 181 166 172 124 148 194 189 225 223 205 212
241 235 308 244 195 184 136 108 79 127 191 150 165 110 120 90 80 82 60 72
91 118 131 122 132 110 128 102 129 134 105 83 91 94 138 103 143 135 149 110
91 72 78 103 97 135 116 113 152 125 111 115 83 127 105 102 140 154 92 136
122 196
SOM-C57B 82
172 194 191 138 173 186 184 192 163 169 176 166 126 150 194 186 226 225 203 229
223 226 302 244 197 179 140 100 85 129 185 151 163 118 109 97 77 88 58 66
95 113 114 128 127 109 129 103 130 128 95 85 96 80 145 115 138 130 157 111
78 70 76 120 91 134 116 114 150 123 106 99 92 132 101 102 134 169 88 142
122 179
SOM-C58A 61
124 131 133 223 244 249 177 209 201 154 324 178 262 290 223 114 174 227 258 288
313 217 308 209 318 259 196 233 239 147 282 273 296 208 271 263 188 305 169 177
211 241 223 213 224 292 356 239 215 257 268 271 316 322 192 186 282 244 187 263
236
SOM-C58B 61
122 147 102 256 194 214 176 140 174 163 279 172 243 243 216 113 158 226 255 274
304 218 323 233 317 258 202 226 163 158 274 275 293 219 275 271 197 277 168 173

214 262 229 205 231 272 361 245 221 258 267 289 312 317 193 194 269 246 189 251
223
SOM-C59A 122
297 310 341 339 214 330 293 278 289 356 308 304 297 290 343 253 150 251 265 217
201 185 236 236 240 299 221 245 200 218 160 105 159 188 209 219 257 204 247 208
192 167 155 177 204 188 208 215 182 178 153 135 119 210 173 158 167 168 207 216
191 143 126 149 136 150 146 178 197 177 175 97 123 137 147 132 130 136 145 132
142 127 166 181 139 135 123 126 118 125 126 129 140 118 126 132 131 112 67 50
75 68 63 75 50 72 99 71 58 84 75 103 119 101 102 101 101 99 87 115
122 105
SOM-C59B 122
285 326 333 346 210 339 288 272 298 356 318 304 293 300 357 237 147 248 263 221
208 182 233 245 244 267 230 248 208 222 166 99 165 185 208 228 250 194 243 213
191 171 155 179 201 187 212 212 187 169 152 139 125 206 169 163 169 169 201 214
187 144 130 139 136 152 143 178 198 172 171 110 123 146 138 135 131 134 145 121
145 132 162 177 139 124 139 120 124 121 135 126 136 123 126 124 139 111 62 52
78 65 62 71 50 76 107 73 63 80 89 89 131 105 94 114 102 98 87 116
134 108

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 1998). 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.

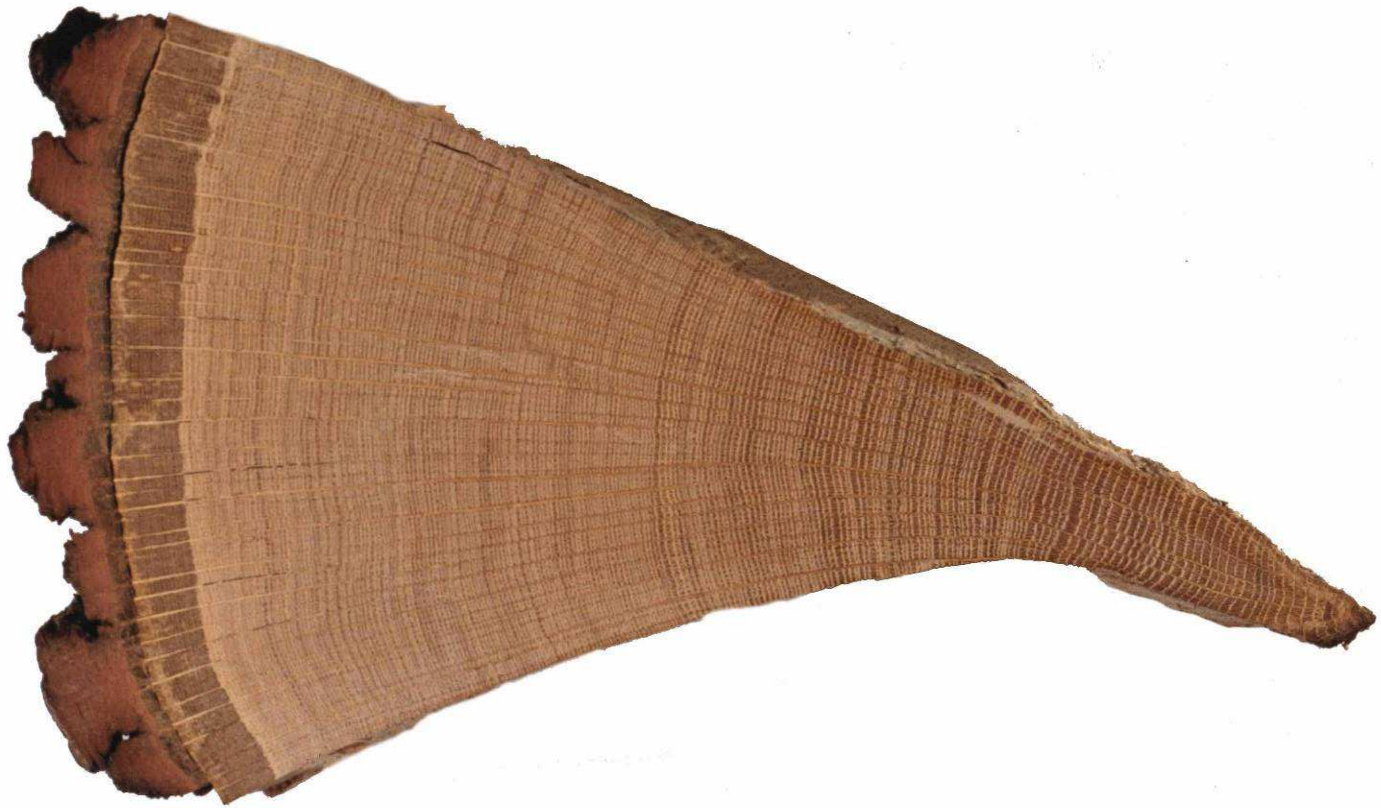


Figure A1: A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976

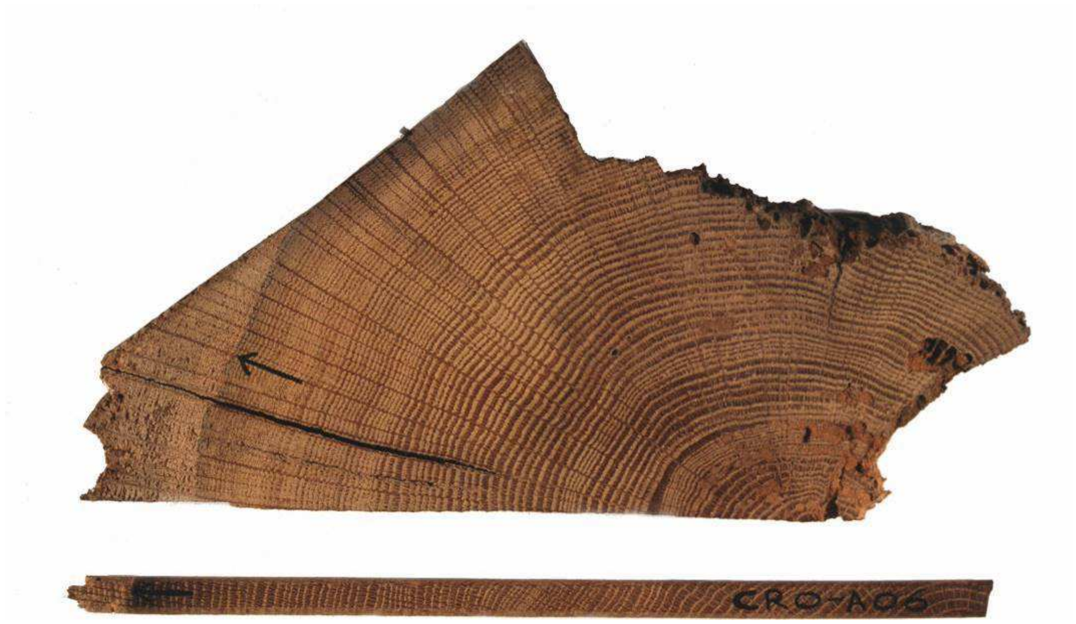


Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

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

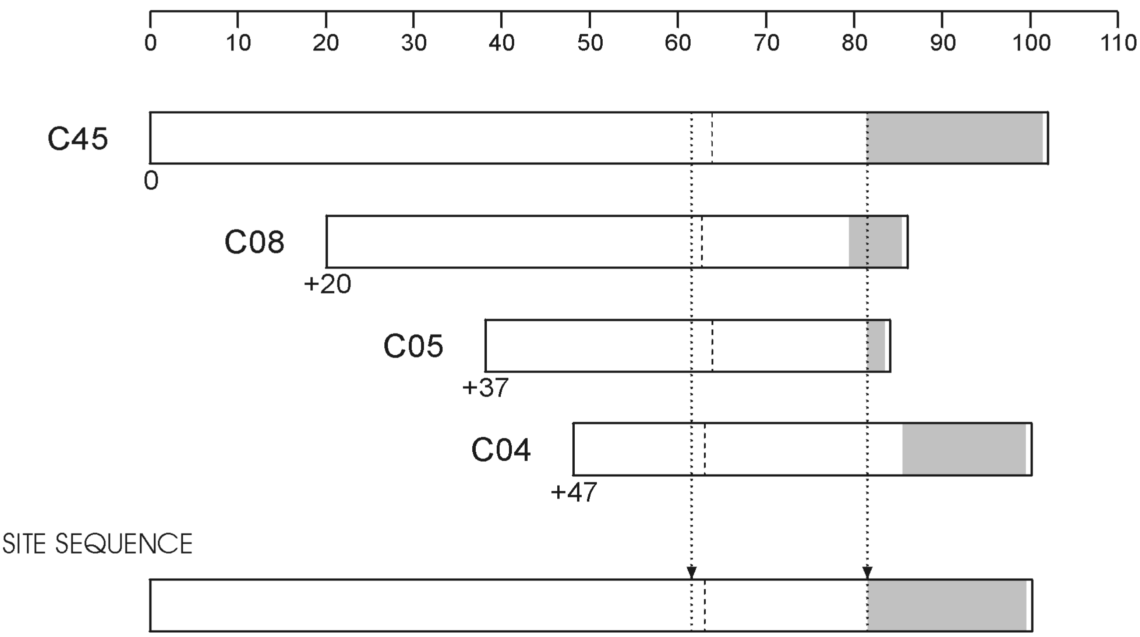


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

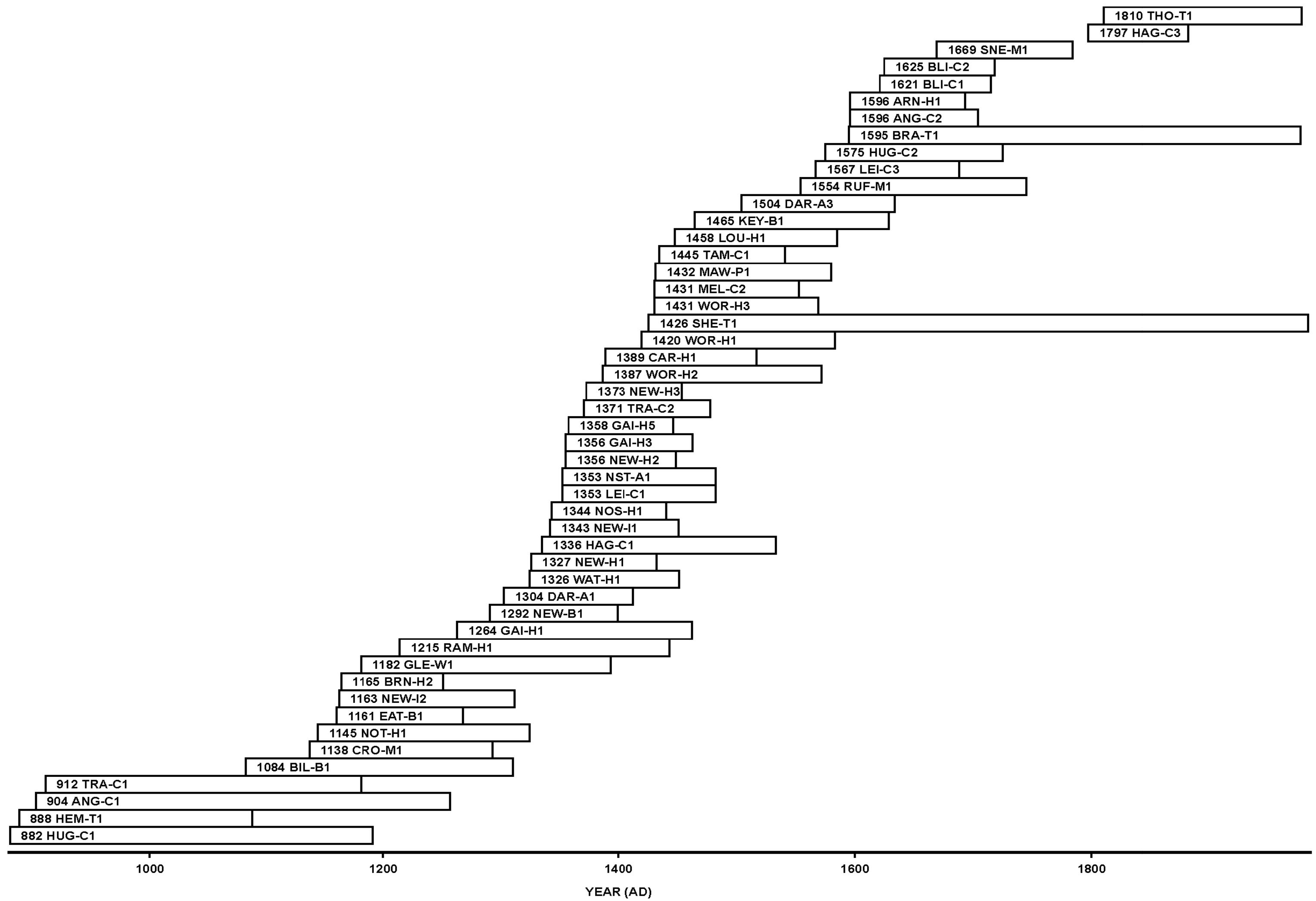
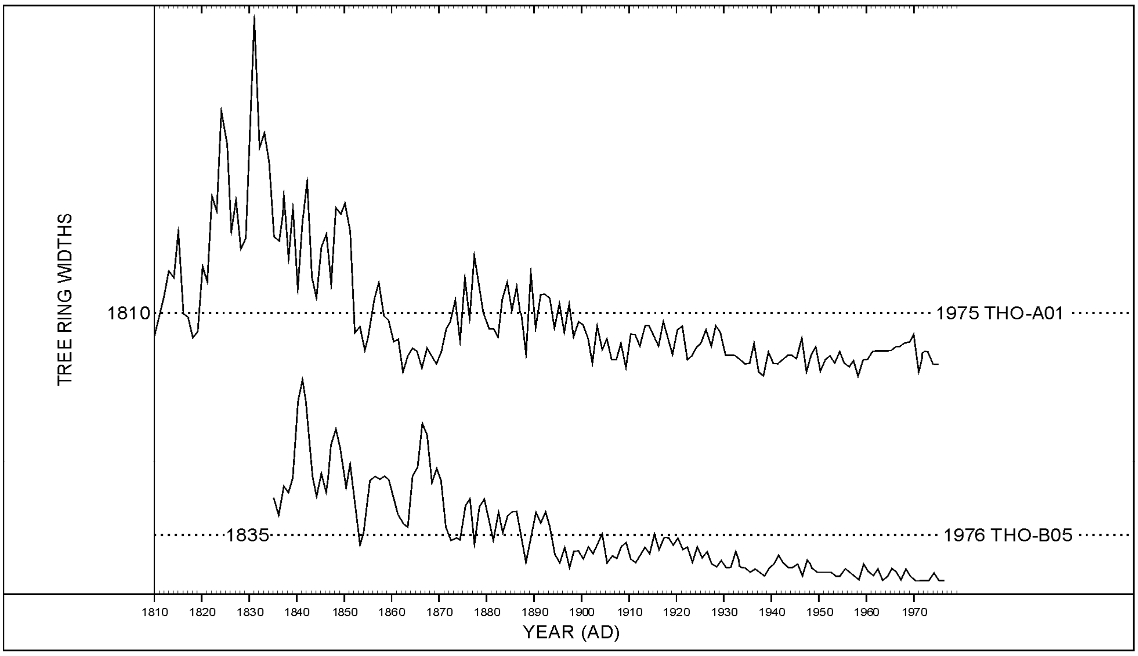


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

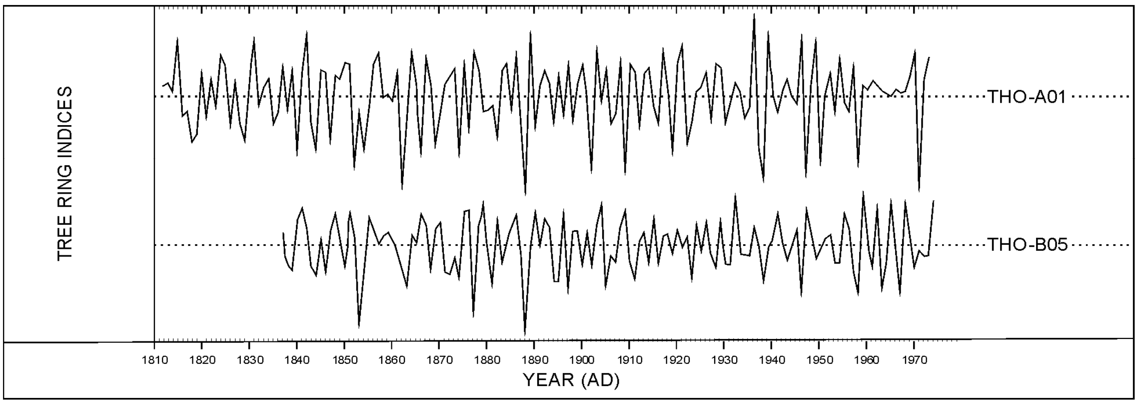


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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**

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1992 List 44 no 17 - Nottingham University Tree-Ring Dating Laboratory: tree-ring dates for buildings in the East Midlands, *Vernacular Architect*, **23**, 51–6.

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)