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# Clifton Hall Tower, Clifton, Near Penrith, Cumbria

## Tree-ring Analysis of Timbers

Alison Arnold and Robert Howard

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## SUMMARY

In 2015 a previously unsampled but potentially historically significant main beam associated with the second floor floor-frame of the Clifton Hall Tower was sampled and analysed in conjunction with 17 samples originally analysed in 2002/3 in order to ascertain whether any more of these previously obtained samples could now be dated. The new sample was successfully dated and proved to be coeval with the previously dated joist associated with the first floor floor-frame. Interpretation of sapwood on these two samples indicates that these timbers have an estimated felling date range of AD 1539–64. It was not possible to date any additional samples from those originally analysed. Thus the dating evidence for the remaining samples is the same with five timbers from the roof being felled in, or about, AD 1740, a second floor ceiling timber having an estimated felling date range of AD 1576–1601, and two other roof timbers that could be associated with either of the sixteenth century fellings identified or could represent separate fellings. Finally another second floor ceiling beam was unlikely to have been felled before AD 1484 and again could be associated with the sixteenth century fellings but could also represent a separate potentially earlier felling.

## CONTRIBUTORS

Alison Arnold and Robert Howard

## ACKNOWLEDGEMENTS

The Nottingham Tree-ring Dating Laboratory would like to thank Andrew Davison (Historic England Principal Inspector of Ancient Monuments) for requesting this programme of tree-ring analysis, as well as Derrick Hodgson (English Heritage Conservation Maintenance - Maintenance Project Manager) for his help in arranging access and assisting with sampling. We would also like to thank Shahina Farid and Cathy Tyers (Historic England Scientific Dating Team) for commissioning this programme of tree-ring analysis and for their help and assistance during analysis.

## ARCHIVE LOCATION

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## DATE OF INVESTIGATION

2015

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# INTRODUCTION

Clifton Hall tower lies at the northern extremity of Clifton and is approximately 3.5km south east of Penrith along the medieval road to Kendal (Figs 1a–b). The tower is the only part of Clifton Hall, the manor house of the Wybergh family, which survived demolition in the early-nineteenth century. It is roughly 10m by 8m and of three storeys. The date of the tower's construction is uncertain but on architectural evidence it is usually considered to be a late-fifteenth century addition to the late-fourteenth century original hall.

The principal room of the tower, with its large fireplace, large window, and its gardrobe chamber, occupied the first floor. The original entry was at this level with a newel stair in the south-west corner giving access to the second floor and the roof. The ground floor was originally self-contained, entry being gained through a door in the north wall.

At some point later part of the south wall was rebuilt to allow for the insertion of a new ground-floor fireplace and its chimney. Other alterations to the tower were associated with the building of a new hall to the south involving the insertion of new doorways through the south wall of the tower, and the extension of the newel stair to the ground floor.

The original roof of the tower does not survive, with only the corbels which carried its tiebeams giving any clue as to its form. This first roof was replaced by a hipped roof with king posts supporting a ridge. On architectural grounds it is unlikely that such a roof would be earlier than the mid-sixteenth century. This present roof contains quantities of reused material, as evidenced by the redundant mortices, joint beds, and peg holes. There also appears to be quantities of twentieth century repair timbers.

Clifton Hall, including all the post-medieval extensions, was demolished in the nineteenth century when the present Hall Farm was built. The tower is an English Heritage guardianship site and a Scheduled Monument.

# SAMPLING

An earlier programme of sampling and analysis by tree-ring dating of timbers from this tower was commissioned by English Heritage in 2002 and reported on in 2003 (Arnold *et al* 2003a). The purpose of this was to provide a better understanding of the building to assist with its interpretation for visitors. At that time samples were obtained from the roof, and from the main cross-beams and joists of the first floor floor-frame and the second floor ceiling frame. It was hoped that sampling would show how much, if any, of the roof or floors survived from the original build, and possibly show at what date the original roof was replaced by the present hipped covering. Given the extensive reuse of material it was thought that some intimation of intermediate repair dates might also be evidenced.

This second episode of sampling was requested by Andrew Davison in respect of a major second floor floor-beam which required replacement. This timber was set aside at the tower so that a dendrochronological assessment could be made, this assessment concluding that it was indeed suitable for tree-ring analysis. Thus it was sampled by coring, being given the code CHT-A (for Clifton Tower, site 'A) and numbered '18' following on from the 17 samples obtained in the previous programme of analysis (Table 1). Where possible the sampled timbers are shown on drawings and a photograph provided by English Heritage, these given here as Figures 2a–e.

Sampling in 2002/3 was of a limited nature due to various timbers appearing to be unsuitable for analysis and also access being unsafe. It had therefore been agreed that, if the 2015 repair works allowed safer access, sampling of previously inaccessible timbers could be undertaken if appropriate. Unfortunately access to the timbers in question was still not possible, and thus they remain unsampled.

## ANALYSIS AND RESULTS

The newly acquired sample, CHT-A18, was prepared by sanding and polishing and its annual growth ring widths were measured. The data of these measurements, along with those of the 17 samples obtained in the earlier programme of analysis are given at the end of this report. The data of all 18 samples were compared with each other by the Litton/Zainodin grouping procedure (see Appendix), this comparative process producing, as before, two groups of cross-matching samples.

The first group is as before and comprises five samples, CHT-A02, CHT-A03, CHT-A06, CHT-A07, and CHT-A08 (Fig 3). These five samples form site chronology CHTASQ01, having an overall length of 86 rings, and dated as having a first ring date of AD 1655 and a last measured ring date of AD 1740. The updated evidence for this dating is given in Table 2.

The second group now comprises four samples, CHT-A09, CHT-A10, and CHT-A14, as before, but also CHT-A18 (Fig 3). The growth-ring widths of these four samples were combined at their indicated relative off-set positions to form a new site chronology CHTASQ02, with a combined overall length of 92 rings. Site chronology CHTASQ02 is dated as having a first ring date of AD 1446 and a last measured ring date of AD 1537. The evidence for this dating is given in Table 3.

Samples CHT-A04 and CHT-A11 had both previously been dated individually (Fig 3), the updated evidence for this dating is given in Tables 4 and 5.

Each site chronology and the two dated individuals were then compared with the seven remaining samples. There was, however, no further satisfactory cross-matching and despite comparing these seven ungrouped and previously undated samples with a full range of relevant reference chronologies for oak, including those reference chronologies not available when the original analysis was undertaken, these seven samples remain undated.

This analysis may be summarised thus:

| Site chronology | Number of samples | Number of rings | Date span AD (where dated) |
|---|---|---|---|
| CHTASQ01 | 5 | 86 | 1655–1740 |
| CHTASQ02 | 4 | 92 | 1446–1537 |
| CHT-A04 | 1 | 122 | 1440–1561 |
| CHT-A11 | 1 | 62 | 1408–1469 |
| Ungrouped | 7 | --- | undated |

## INTERPRETATION

The 2002/3 analysis of roof and floor timbers of Clifton Hall tower successfully dated ten samples, whilst this analysis has successfully dated the additional second floor floor-beam, leaving seven samples still ungrouped and undated.

### Site chronology CHTASQ01

The latest, or most recent, material remains the five samples of site chronology CHTASQ01 that represent roof timbers. One of the samples in this group, CHT-A08, retains complete sapwood, this meaning that it has the last ring produced by the tree it represents before it was felled. This last complete sapwood ring, and thus the felling of the tree, is dated AD 1740.

The amount of sapwood, and the relative position of the heartwood/sapwood boundary, on the other four samples in site chronology CHTASQ01 is such that it is very likely that the timbers they represent were felled in, or about, AD 1740 as well. As may be seen from Table 1 and Figure 3, the overall position of this boundary varies by only 10 years, from relative position 60 (AD 1714) on sample CHT-A02 to relative position 70 (AD 1724) on sample CHT-A08, such similarity being indicative of timbers cut as part of a single episode of felling.

### Site chronology CHTASQ02

The two floor timbers, represented by samples CHT-A14 and CHT-A18, and dated as part of site chronology CHTASQ02, are earlier than the roof timbers above. Both samples retain the heartwood-sapwood boundary, this meaning that although they have lost all their sapwood rings, it is only the sapwood rings that have been lost. This heartwood-sapwood boundary is dated to AD 1528 on sample CHT-A14 and AD 1520 on sample CHT-A18, and they appear likely to be coeval. The average heartwood/sapwood boundary date of the two samples is AD 1524 and, using a 95% confidence interval of 15–40 for the number of sapwood rings the trees are likely to have had, gives the timbers an estimated felling date in the range AD 1539–64.

The other two samples, CHT-A09 and CHT-A10, dated as part of site chronology CHTASQ02 are without the heartwood/sapwood boundary. This means that not only have they lost all their sapwood rings, but an unknown number of heartwood rings as well. In such a situation it is not possible to provide a felling date range for either timber but, with last heartwood ring dates of AD 1514 and AD 1537, felling is likely to have been after AD 1529 and AD1552, respectively.

### Individually dated sample CHT-A04

Sample CHT-A04, representing a second floor timber at ceiling level, has been dated individually with a last measured ring date of AD 1561. Given that this last ring is at the heartwood/sapwood boundary, this would give the timber an estimated felling date of AD 1576–1601.

### Individually dated sample CHT-A11

The earliest timber, a second floor ceiling timber, detected in this analysis is represented by sample CHT-A11. This sample has a last ring date of AD 1469, but is without the heartwood/sapwood boundary meaning that its felling date again cannot be reliably determined. However, allowing for the usual minimum number of sapwood rings, it is likely to have been felled after AD 1484.

## CONCLUSION

The analysis by dendrochronology clearly demonstrates the presence of timbers with different felling dates within the tower (Fig 3), a not unexpected finding given the structural evidence for reuse, insertion, and modification.

It is clear that a number of roof timbers were felled in, or about, AD 1740, this probably representing the date at which the present hipped roof replaced the original roof. The two dated purlins from the roof (CHT-A09 and CHT-A10) could be associated with either the mid-sixteenth century felling identified or the later-sixteenth century felling identified, or could represent different fellings in sixteenth century or even potentially the seventeenth century, if they represent the inner part of heavily trimmed trees.

The second floor ceiling level contains one timber (CHT-A04) estimated as being felled AD 1576–1601 and one timber (CHT-A11) being felled after AD 1484. This latter timber could therefore be associated with the either of the sixteenth century fellings identified or alternatively could represent a separate, potentially earlier, felling. The floor frames also contain some sixteenth century timbers, represented by samples CHT-A14 and CHT-A18, which, having an estimated felling date of AD 1539–64, are the earliest of the positively identified fellings.

Although compared with reference data for all parts of England, there is a clear tendency for the earlier timbers from Clifton Hall tower to have the highest levels of similarity with chronologies made up of data from other sites in northern England. This suggests that the trees used for these timbers are likely to be from a relatively local woodland source. The later timbers on the other hand tend to cross-match best with material from the Midlands. This, however, may well be a reflection of the more limited chronological coverage available for the later-seventeenth and eighteenth centuries rather than a genuine indication that the later timber has been sourced from further afield.

Of the 18 samples obtained, seven still remain ungrouped and undated. None of these seven samples shows any problems with its annual growth rings, such as distortion or compression, which would make cross-matching and dating difficult, and all have sufficient numbers of rings for reliable analysis. It is possible, given the evidence for reuse and insertion, that these timbers are of different dates and/or woodland sources, this in effect making them 'singletons'. While, as seen here, single samples can be dated, this is often more difficult than with well replicated groups. It is in any case, not unusual in any programme of tree-ring analysis to find that some samples remain undated, often for no apparent reason.

# BIBLIOGRAPHY


Arnold, A J, Howard, R E, and Litton, C D, 2003a *Tree-ring Analysis of Timbers from Clifton Hall Tower, Clifton, near Penrith, Cumbria,* Centre for Archaeol Rep, 23/2003

Arnold, A J, Howard, R E, and Litton, C D, 2003b *Tree-ring Analysis of Timbers from Dilston Castle, Dilston Hall, Corbridge, Northumberland*, Centre for Archaeol Rep, 88/2003

Arnold, A J, Howard, R E, and Litton, C D, 2004a *Tree-ring Analysis of Timbers from the Moot Hall, Market Place, Hexham, Northumberland,* Centre for Archaeol Rep, 41/2004

Arnold, A J, Howard, R E, and Litton, C D, 2004b *Tree-ring Analysis of Timbers from the Timber Loft, The College, Durham,* Centre for Archaeol Rep, 14/2004

Arnold, A J, Howard, R E, and Litton, C D, 2004c *Tree-ring Analysis of Timbers from Dacre Hall, Lanercost Priory, Brampton, near Carlisle, Cumbria*, Centre for Archaeol Rep, 48/2004

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, Howard, R E, and Litton, C D, 2006 *Tree-ring Analysis of Timbers from Low Harperley Farmhouse, Wolsingham, County Durham*, English Heritage Res Dept Rep Series, 6/2006

Arnold, A J, Howard, R E, and Litton, C D, 2008 *Shenton Hall, Shenton, Leicestershire, Tree-ring Analysis of Timbers from the Dovecote,* English Heritage Res Dept Rep Ser, 22/2008

Arnold, A J, Howard, R E, and Hurford, M, *2009 Abbey Gatehouse and Number 1 The Square, Blanchland, Northumberland: Tree-ring Analysis of Timbers*, English Heritage Res Dept Rep Ser, 47/2009

Arnold, A J, and Howard, R E, 2009 unpubl Tree-ring Analysis of Timbers from 1–3 North Gate, Newark Nottinghamshire – Nottingham Tree-ring Dating Laboratory unpubl computer file NWKUSQ01

Arnold, A J, and Howard, R E, 2013 *Auckland Castle, Bishop Auckland, County Durham: Tree-ring Analysis of Timbers*, English Heritage Res Dept Rep Ser, 48/2013

Arnold, A J, and Howard, R E, 2013 unpubl Howley Hall, Morley, West Yorkshire; Tree-ring Analysis of Timbers – Nottingham Tree-ring Dating Laboratory unpubl computer file HOWASQ03

Arnold, A J, and Howard R E, 2014 *Dandra Garth, Garsdale, Cumbria; Tree-ring Analysis of Timbers,* English Heritage Res Dept Rep Ser, 22/2014

Hillam, J and Groves C M, 1991 *Tree-ring analysis of oak timbers from Aydon Castle, Corbridge, Northumberland*, Anc Mon Lab Rep*,* 42/1991

Howard, R E, Laxton, R R, and Litton, C D, 1988 unpubl Tree-ring Analysis of Timbers from Sarehole Mill, Hall Green, Birmingham – Nottingham Tree-ring Dating Laboratory unpublished computer file SARMSQ01

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1992 unpubl Tree-ring Analysis of Timbers from Catholme, Staffordshire – Nottingham Univ Tree-Ring Dating Laboratory unpublished computer file CATHSQ03

Howard, R E, Laxton, R R, Litton, C D, Morrison A, Sewell, J, and Hook, R, 1993 List 49 – Nottingham University Tree-Ring Dating Laboratory: Derbyshire, Peak Park and RCHME dendrochronological Survey 199–92, *Vernacular Architect*, 24, 43–4

Howard, R E, Laxton, R R, Litton, C D, Morrison A, Sewell, J, and Hook, R, 1994 List 58 – Nottingham University Tree-Ring Dating Laboratory: Derbyshire, Peak Park and RCHME dendrochronological Survey 1992–93, *Vernacular Architect*, 25, 41–3

Howard, R E, Laxton, R R, Litton, C D, and Jennings, N, 1997 List 78 no 3– Nottingham University Tree-Ring Dating Laboratory: Dendrochronological Survey of Clay Dabbings on the Solway Plain, *Vernacular Architect*, 28, 133–34

Howard, R E, Laxton, R R, Litton, C D, and Jennings, N, 1998 List 89 nos 1, 8 – Nottingham University Tree-Ring Dating Laboratory: Cumbria mud-walled buildings dendrochronology project, *Vernacular Architect*, 29, 108–10

Howard, R E, Laxton, R R, and Litton, C D, 1999 *Tree-ring Analysis of Timbers from Bretby Hall, Bretby, Derbyshire*, Anc Mon Lab Rep, 43/1999

Howard, R E, Laxton, R R, and Litton, C D, 2001 *Tree-ring Analysis of Timbers from Unthank Hall, Stanhope, County Durham*, Centre for Archaeol Rep, 4/2001

Howard, R E, Laxton, R R, and Litton, C D, 2001b *Tree-ring Analysis of Timbers from Hallgarth Manor Cottages, Hallgarth, Pittington, County Durham*, Centre for Archaeol Rep*,* 86/2001

Howard, R E, Laxton, R R, and Litton, C D, 2002a *Tree-ring Analysis of Timbers from Bearpark Hall Farm Cottages, Bearpark Colliery Road, Bearpark, Durham*, Centre for Archaeol Rep, 58/2002

Howard, R E, Laxton, R R, and Litton, C D, 2002b *Tree-ring Analysis of Timbers from the Rigging Loft and Chapel Undercroft, Trinity House, Broad Chare, Newcastle upon Tyne, Tyne and Wear*, Centre for Archaeol Rep, **63/2002**

Laxton, R R, Litton, C D, Simpson, W G, and Whitley, J P, 1982 Tree-ring Dates for some East Midlands Buildings: Table 1, no.7, *Transaction of the Thoroton Society of Nottinghamshire*, **86**, 76–7

Nayling, N, 2000 *Tree-ring analysis of timbers from Lathom House, Lancashire*, Anc Mon Lab Rep, **5/2000**

Tyers, I, 2000 *Tree-ring analysis of oak timbers from Arches Cottages, Sawley, Lancashire,* Anc Mon Lab Rep, **21/2000**

Tyers, I, 2002 *Tree-ring Analysis of Oak Timbers from Hovingham Hall, Hovingham, North Yorkshire,* Centre for Archaeol Rep, **80/2002**

# TABLES

*Table 1: Details of tree-ring samples from Clifton Hall tower, Clifton, near Penrith, Cumbria*

| Sample number | Sample location | Total rings | Sapwood rings* | First measured ring date AD | Last heartwood ring date AD | Last measured ring date AD |
|---|---|---|---|---|---|---|
| | Roof and second floor ceiling timbers | | | | | |
| CHT-A01 | North principal rafter, truss 1 | 79 | 23C | ------ | ------ | ------ |
| CHT-A02 | North-east hip rafter | 57 | 9 | 1667 | 1714 | 1723 |
| CHT-A03 | Tiebeam, truss 1 | 72 | 11 | 1659 | 1719 | 1730 |
| CHT-A04 | Southern east to west beam, truss 1 - 2 | 122 | h/s | 1440 | 1561 | 1561 |
| CHT-A05 | South-east diagonal ceiling beam | 57 | 13 | ------ | ------ | ------ |
| CHT-A06 | North principal rafter, truss 2 | 70 | 17 | 1666 | 1718 | 1735 |
| CHT-A07 | South principal rafter, truss 2 | 68 | 11 | 1662 | 1718 | 1729 |
| CHT-A08 | Tiebeam, truss 2 | 86 | 16C | 1655 | 1724 | 1740 |
| CHT-A09 | South purlin, truss 1 - 2 | 61 | no h/s | 1454 | ------ | 1514 |
| CHT-A10 | Purlin to west hip | 80 | no h/s | 1458 | ------ | 1537 |
| CHT-A11 | West ceiling beam | 62 | no h/s | 1408 | ------ | 1469 |
| CHT-A12 | North-west diagonal ceiling beam | 55 | 15 | ------ | ------ | 1676?? |
| CHT-A13 | Common rafter to north roof pitch | 56 | h/s | ------ | ------ | ------ |
| | Floor-frame timbers | | | | | |
| CHT-A14 | First floor floor-frame, joist 3 (from east) | 71 | h/s | 1458 | 1528 | 1528 |
| CHT-A15 | First floor floor-frame, joist 4 | 65 | h/s | ------ | ------ | ------ |
| CHT-A16 | First floor floor-frame, joist 6 | 57 | 14 | ------ | ------ | ------ |
| CHT-A17 | First floor floor-frame, cross beam | 58 | h/s | ------ | ------ | ------ |
| CHT-A18 | Second floor floor-frame, cross beam | 89 | 14 | 1446 | 1520 | 1534 |

h/s = the heartwood/sapwood ring is the last ring on the sample

C = complete sapwood is retained on the sample, the last measured ring date is the felling date of the tree

*Table 2: Results of the cross-matching of site sequence CHTASQ01 and relevant reference chronologies when the first-ring date is AD 1655 and the last-ring date is AD 1740*

| Reference chronology | Span of chronology | *t*-value | Reference |
|---|---|---|---|
| | | | |
| The Dovecote, Shenton Hall, Leicestershire | AD 1606–1719 | 7.8 | ( Arnold *et al* 2008 ) |
| Blidworth, Nottinghamshire | AD 1625–1717 | 7.2 | ( Laxton *et al* 1982 ) |
| Lathom House, Lancashire | AD 1633–1726 | 7.1 | ( Nayling 2000 ) |
| Sarehole Mill, Hall Green, Birmingham | AD 1677–1767 | 7.0 | ( Howard 1988 unpubl ) |
| St John The Baptist, Knossington, Leicestershire | AD 1662–1721 | 6.6 | ( Arnold *et al* 2005 ) |
| Catholme, Staffordshire | AD 1649–1750 | 6.6 | ( Howard *et al* 1992 unpubl ) |
| Bretby Hall, Bretby, Derbyshire | AD 1494–1719 | 6.4 | ( Howard *et al* 1999 ) |
| Hovingham Hall, North Yorkshire | AD 1643–1773 | 6.0 | ( Tyers 2002 ) |

*Table 3: Results of the cross-matching of site sequence CHTASQ02 and relevant reference chronologies when the first-ring date is AD 1446 and the last-ring date is AD 1537*

| Reference chronology | Span of chronology | *t*-value | Reference |
|---|---|---|---|
| | | | |
| Welcome Square, Scotby, Cumbria | AD 1460–1564 | 8.7 | ( Howard *et al* 1997 ) |
| Arches Cottages, Sawley, Lancashire | AD 1433–1506 | 7.8 | ( Tyers 2000 ) |
| Dandra Garth, Garsdale, Cumbria | AD 1373–1635 | 6.4 | ( Arnold and Howard 2014 ) |
| Cartledge Hall, Holmesfield, Derbyshire | AD 1459–1581 | 6.2 | ( Howard *et al* 1993 ) |
| Moorhouse Farm, Moorhouse, Cumbria | AD 1469–1608 | 6.0 | ( Howard *et al* 1998 ) |
| Gatehouse, Blanchland Abbey, Northumberland | AD 1326–1532 | 5.9 | ( Arnold *et al* 2009 ) |
| Cruck Barn, Baldwinholme Farm, Cumbria | AD 1431–1568 | 5.6 | ( Howard *et al* 1998 ) |
| Hoyles Farm, Bradfield, Derbyshire | AD 1448–1552 | 5.6 | ( Howard *et al* 1993 ) |

*Table 4: Results of the cross-matching of sample CHT-A04 and relevant reference chronologies when the first-ring date is AD 1440 and the last-ring date is AD 1561*

| Reference chronology | Span of chronology | *t*-value | Reference |
|---|---|---|---|
| | | | |
| Aydon Castle, Corbridge, Northumberland | AD 1424–1543 | 6.5 | ( Hillam and Groves 1991 ) |
| Dilston Castle, Corbridge, Northumberland | AD 1402–1611 | 5.7 | ( Arnold *et al* 2003b ) |
| Moot Hall, Hexham, Northumberland | AD 1341–1539 | 5.7 | ( Arnold *et al* 2004a ) |
| Gatehouse, Blanchland Abbey, Northumberland | AD 1326–1532 | 5.5 | ( Arnold *et al* 2009 ) |
| Low Harperley Farmhouse, Wolsingham, County Durham | AD 1356–1604 | 5.4 | ( Arnold *et al* 2006 ) |
| The Timber Loft, The College, Durham | AD 1402–1541 | 5.3 | ( Arnold *et al* 2004b ) |
| Howley Hall, Morley, West Yorkshire | AD 1415–1632 | 5.2 | ( Arnold and Howard 2013 unpubl ) |
| Auckland Castle, Bishop Auckland, County Durham | AD 1425 –1698 | 5.2 | ( Arnold and Howard 2013 ) |

*Table 5: Results of the cross-matching of sample CHT-A11and relevant reference chronologies when the first-ring date is AD 1408 and the last-ring date is AD 1469*

| Reference chronology | Span of chronology | *t*-value | Reference |
|---|---|---|---|
| | | | |
| Dacre Hall, Lanercost Priory, Brampton, Cumbria | AD 1350–1504 | 8.1 | ( Arnold *et al* 2004c ) |
| Bearpark Hall Cottages, Bearpark, Durham | AD 1355–1490 | 7.9 | ( Howard *et al* 2002a ) |
| Low Harperley Farmhouse, Wolsingham, County Durham | AD 1356–1604 | 7.3 | ( Arnold *et al* 2006 ) |
| The Rigging Loft, Trinity House, Newcastle, Tyne and Wear | AD 1397–1524 | 7.0 | ( Howard *et al* 2002b ) |
| Ughill Manor, Bradfield, South Yorkshire | AD 1349–1504 | 6.8 | ( Howard *et al* 1994 ) |
| 1–3 North Gate, Newark, Nottinghamshire | AD 1339–1523 | 6.7 | ( Arnold and Howard 2009 unpubl ) |
| Unthank Hall, Stanhope, County Durham | AD 1386–1592 | 6.2 | ( Howard *et al* 2001a ) |
| Hallgarth Manor Cottages, Pittington, County Durham | AD 1336–1624 | 6.1 | ( Howard *et al* 2001b ) |

# FIGURES


*Figure 1a: Map to show the location of Clifton. © Crown Copyright and database right 2015. All rights reserved. Ordnance Survey Licence number 100024900*


*Figure 1b: Map to show the location of Clifton Hall tower. © Crown Copyright and database right 2015. All rights reserved. Ordnance Survey Licence number 100024900*

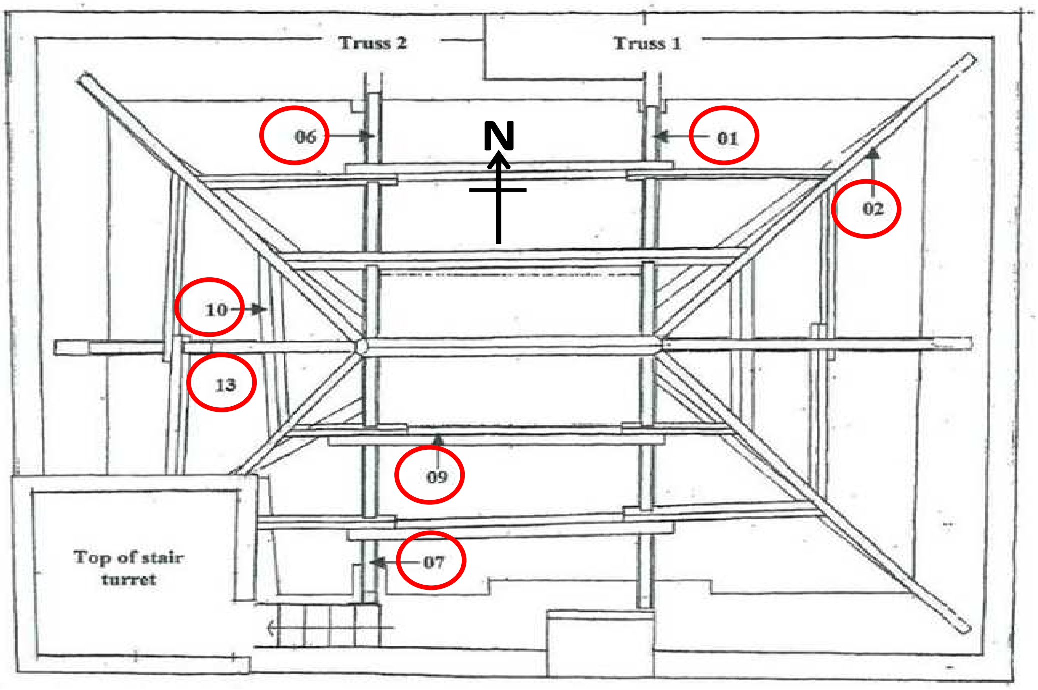



*Figure 2a: Plan at roof level to help locate sampled timbers (after Department of the Environment)*

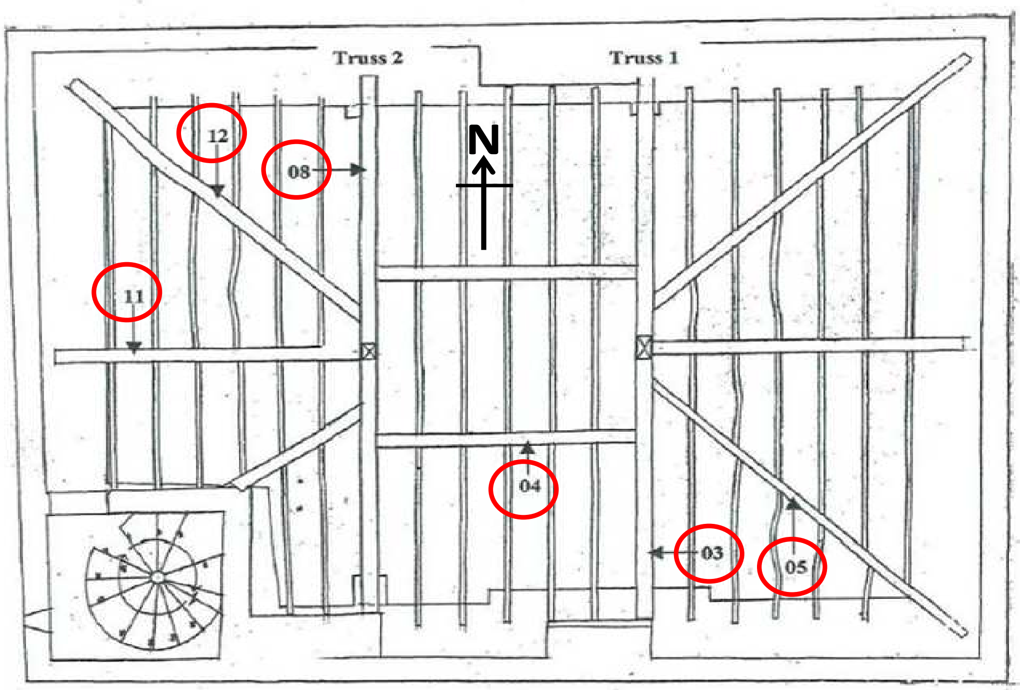



*Figure 2b: Plan at second floor ceiling level to help locate sampled timbers (after Department of the Environment)*

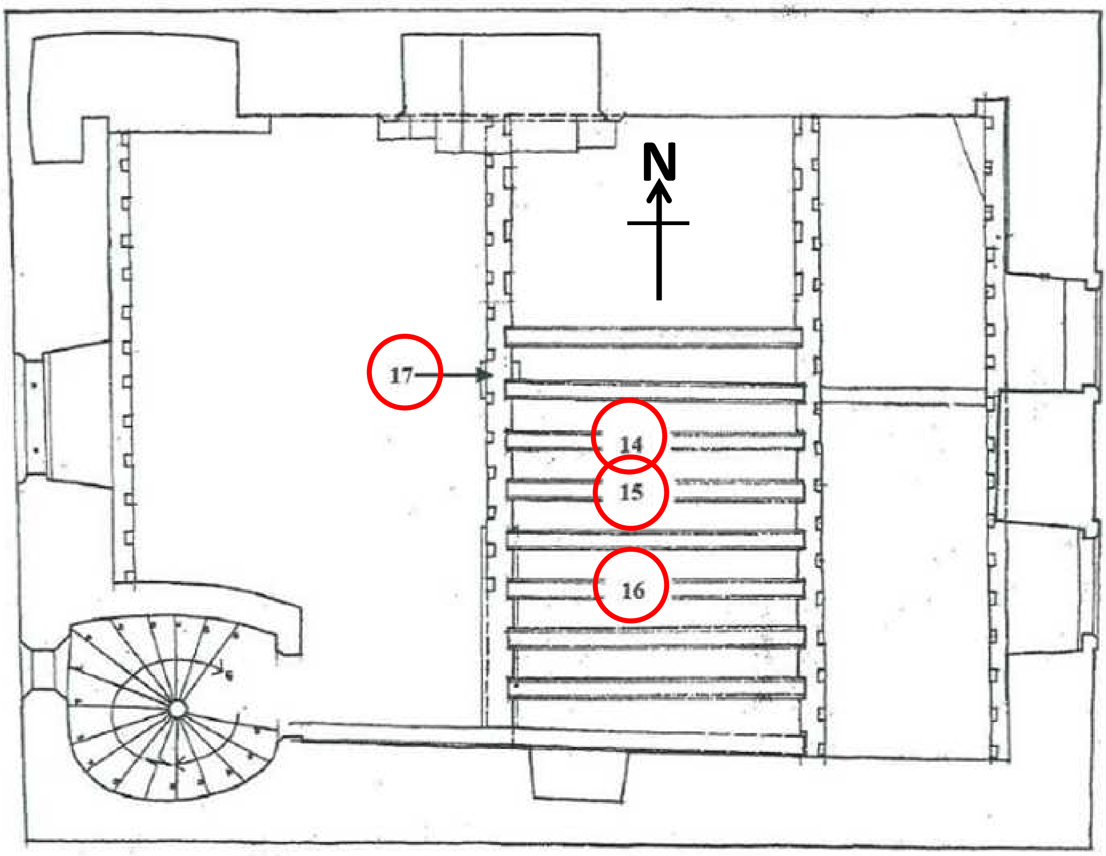



*Figure 2c: Plan at first-floor floor-frame level to help locate sampled timbers (after Department of the Environment)*

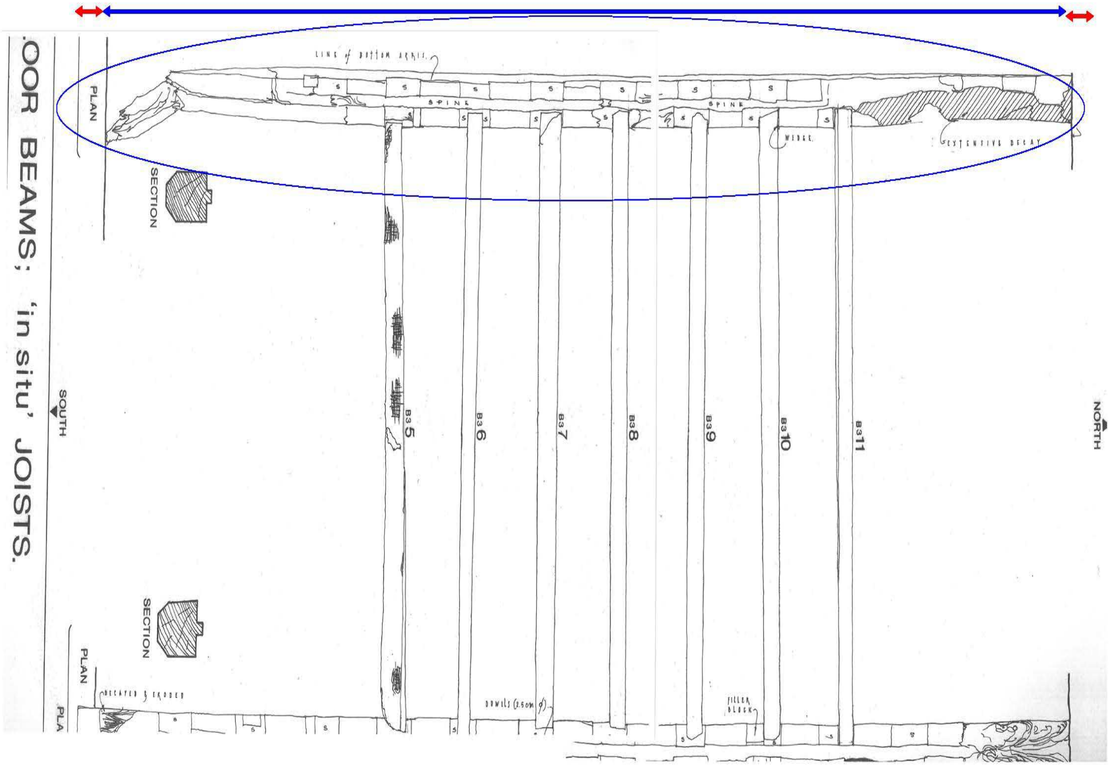
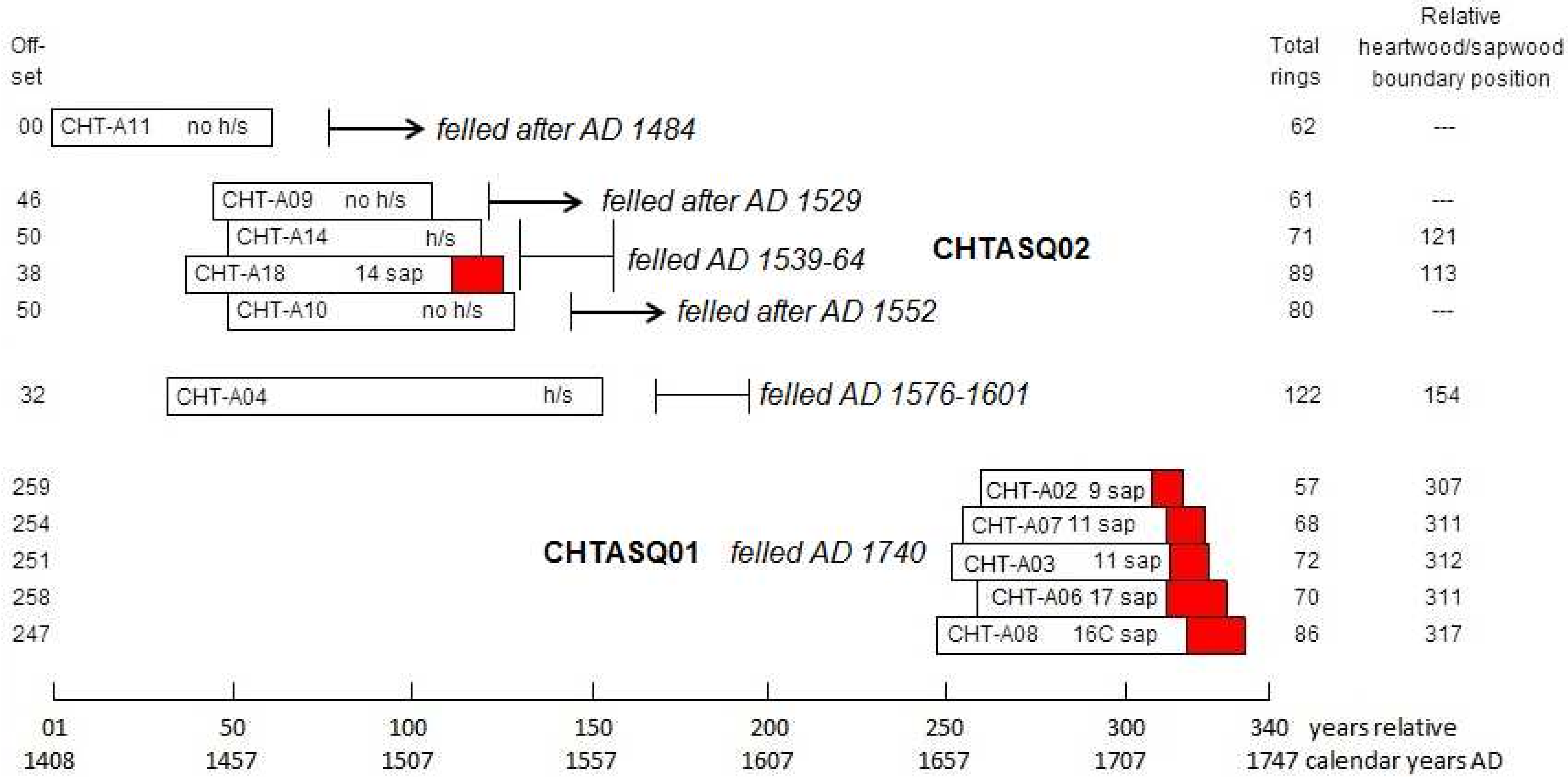


*Figure 2d: Plan showing the second floor floor beam replaced in 2015 (Derrick Hodgson, English Heritage 2014)*

*Figure 2e: Photograph of the second floor floor beam replaced in 2015 (Derrick Hodgson, English Heritage 2014)*




white bars = heartwood rings, shaded bars = sapwood rings; h/s = heartwood/sapwood boundary; C = complete sapwood on sample

*Figure 3: Bar diagram of the dated samples, sorted by felling date, either actual or estimated*

# DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

CHT-A01A 79
165 180 162 132 163 141 187 223 298 251 251 292 272 235 211 168 208 268 289 236
285 187 271 184 220 294 342 292 216 260 233 292 219 218 257 241 266 220 198 201
218 253 234 230 182 191 200 194 167 123 210 224 196 190 244 291 228 206 149 191
142 208 153 169 173 156 137 187 154 193 186 200 167 148 111 65 91 72 116
CHT-A01B 79
209 157 162 149 163 146 195 236 293 256 270 275 272 244 222 169 196 278 284 236
265 197 261 196 233 278 338 310 250 293 220 298 215 214 252 243 259 231 199 201
219 244 234 223 188 199 202 199 174 134 194 228 195 195 248 269 245 190 161 190
143 205 164 157 167 153 141 185 161 192 158 208 158 181 99 73 85 85 116
CHT-A02A 57
245 284 192 178 137 179 214 259 211 297 284 263 307 248 244 328 259 227 186 268
248 238 218 215 273 307 315 339 245 254 253 302 243 222 205 194 271 253 218 266
332 268 375 216 299 374 299 292 284 275 357 292 306 287 223 236 329
CHT-A02B 57
224 298 192 174 129 189 206 275 238 293 276 267 290 252 245 321 272 225 185 267
247 231 223 220 269 318 278 337 232 255 274 297 242 225 199 220 266 255 219 265
307 289 347 226 282 381 340 281 289 290 340 314 288 296 208 257 339
CHT-A03A 72
315 393 385 409 360 469 342 234 194 196 204 246 208 179 236 203 191 233 221 201
181 189 199 262 230 200 163 250 198 181 191 168 226 179 168 186 183 196 172 161
169 123 169 139 177 112 94 146 143 151 143 118 166 191 176 109 156 141 192 167
179 144 135 132 147 130 154 154 126 94 118 154
CHT-A03B 72
351 405 389 412 354 465 336 221 205 201 210 241 217 176 244 192 196 246 200 207
182 181 205 264 202 227 161 247 197 169 201 167 220 183 172 177 190 196 171 150
148 155 172 142 164 123 102 132 151 166 147 121 164 186 183 115 153 141 189 170
163 148 119 134 141 123 149 147 123 100 143 149
CHT-A04A 122
161 203 96 219 177 138 122 108 92 108 99 155 194 221 205 189 171 116 82 100
98 92 80 93 114 107 110 166 176 149 160 153 130 124 137 238 179 174 152 113
174 154 73 82 67 89 85 88 75 52 53 50 42 32 35 62 100 94 83 58
62 44 42 78 115 153 139 130 143 139 140 133 95 115 131 140 124 110 150 127
115 99 117 103 118 108 156 134 154 135 129 145 124 144 194 197 213 266 240 282
260 188 140 87 99 128 131 167 144 140 175 227 142 164 132 129 108 112 183 128
161 191
CHT-A04B 122
181 197 112 240 191 138 124 107 90 114 105 155 189 226 199 205 167 112 90 88
109 91 86 90 112 108 112 162 178 147 147 149 124 123 133 228 198 166 143 147
134 147 75 65 75 88 66 92 71 52 47 51 37 28 31 58 78 93 80 56
60 43 43 82 108 157 142 133 137 142 138 127 98 122 132 131 126 106 153 120
118 95 117 106 126 101 153 144 144 141 135 148 136 137 191 202 217 263 230 292
260 196 155 80 102 122 121 170 148 138 166 224 151 162 135 122 92 117 175 145
154 249
CHT-A05A 57
284 302 363 309 216 259 118 126 241 224 178 137 115 101 100 65 70 98 176 158
188 188 260 250 228 243 171 200 165 200 212 114 104 186 194 161 121 185 172 251
156 155 158 215 150 175 142 161 147 168 107 77 90 113 138 147 182

CHT-A05B 57
258 263 389 334 218 273 131 131 240 224 176 132 116 100 102 73 84 115 176 173
196 225 279 237 217 242 170 205 166 205 207 121 113 188 190 152 121 192 166 246
172 129 167 228 192 182 165 161 167 168 102 71 90 108 132 150 179
CHT-A06A 70
263 129 217 166 194 257 217 249 172 132 208 155 173 208 211 152 290 256 152 114
231 244 183 190 165 209 249 261 181 237 295 198 222 196 180 184 158 220 162 156
176 213 222 244 143 111 151 191 145 209 199 208 221 211 117 119 117 178 167 202
167 133 146 176 208 196 195 190 178 221
CHT-A06B 70
231 127 236 159 222 256 213 231 166 128 209 148 164 195 214 156 293 246 164 116
227 239 180 199 173 203 243 277 196 219 290 201 226 201 175 190 157 220 150 166
193 199 230 233 150 94 159 190 151 203 198 201 231 208 137 126 116 175 176 196
164 139 134 168 207 201 189 209 161 210
CHT-A07A 68
230 216 261 193 219 166 298 216 305 358 267 378 284 226 306 257 319 296 329 207
398 275 194 121 326 392 337 387 198 231 279 247 171 199 316 257 242 188 157 176
173 200 179 151 240 262 221 213 106 95 99 211 127 166 187 203 278 140 144 152
247 156 159 149 160 104 129 172
CHT-A07B 68
231 223 233 193 226 170 296 214 292 362 286 404 311 243 296 251 300 322 308 209
392 273 200 118 323 406 356 371 204 228 284 247 169 203 297 259 234 202 167 206
174 191 184 159 272 253 233 214 112 83 118 204 138 172 181 203 253 159 136 139
256 160 174 143 173 88 114 167
CHT-A08A 87
359 387 312 447 384 354 303 240 221 255 186 163 171 163 218 285 253 199 260 228
201 196 162 217 199 183 170 255 195 196 156 220 187 161 200 143 169 139 158 215
209 270 212 212 194 118 154 129 115 124 121 132 163 176 201 140 147 204 241 141
145 136 205 168 198 160 180 181 187 203 224 285 421 254 225 296 193 263 239 263
233 185 164 234 256 178 223
CHT-A08B 87
373 384 299 437 388 400 298 226 213 276 198 167 175 170 217 286 251 209 282 222
214 192 172 207 202 187 166 264 182 190 154 200 185 165 196 136 169 140 163 221
203 272 206 210 191 128 146 120 129 125 122 124 155 187 201 138 144 212 231 149
145 139 187 181 200 154 170 200 190 211 211 289 405 257 237 255 167 254 238 259
234 194 150 215 276 184 196
CHT-A09A 61
430 372 446 442 386 367 336 275 238 320 347 211 293 313 260 276 252 288 178 197
240 312 294 256 252 295 221 182 122 144 188 205 190 288 248 264 192 200 198 124
168 194 251 172 217 201 211 147 212 159 191 165 203 163 165 149 129 149 160 151
193
CHT-A09B 61
423 375 431 439 374 379 335 275 232 325 357 195 295 325 272 272 246 278 182 196
223 320 295 264 254 297 211 185 113 159 178 192 184 279 266 250 187 197 202 125
159 200 235 171 215 207 206 145 210 173 174 176 188 175 170 127 140 151 138 143
210
CHT-A10A 80
291 288 244 226 232 278 234 203 256 262 215 199 187 179 125 123 176 197 188 215
167 208 169 103 72 131 140 129 146 152 115 120 140 113 166 114 123 171 189 153
149 171 155 113 125 110 147 122 121 95 98 104 87 85 92 110 134 128 105 91
115 136 109 82 95 82 87 92 100 83 46 65 54 77 73 92 97 135 120 115
CHT-A10B 80
276 292 244 222 240 276 237 199 264 256 211 194 197 181 121 150 151 205 189 209

165 213 167 107 70 125 125 141 141 149 133 120 136 116 157 107 133 163 197 141
152 162 154 108 134 124 137 121 111 99 103 95 86 90 90 119 131 118 108 94
110 128 104 104 91 84 71 84 118 70 57 72 62 65 94 86 100 115 111 140
CHT-A11A 62
152 108 146 139 201 222 142 118 120 148 192 140 278 157 179 234 227 165 91 107
124 176 151 182 162 137 130 133 94 123 108 99 86 127 76 119 145 113 73 119
135 131 157 142 215 173 129 118 196 156 75 70 94 83 131 77 80 83 127 109
126 142
CHT-A11B 62
128 130 167 132 210 222 129 122 103 157 192 139 273 161 171 241 221 167 93 107
124 173 150 182 161 137 131 126 104 115 111 106 81 120 82 126 137 112 80 111
141 123 155 143 215 182 121 123 186 164 74 68 89 95 130 77 77 76 135 112
111 156
CHT-A12A 55
124 169 106 69 76 71 102 115 81 115 122 119 83 71 72 118 183 121 193 233
96 96 46 56 70 101 123 93 39 42 43 59 80 100 119 90 87 89 102 113
126 172 161 116 206 166 156 166 200 188 192 179 171 144 226
CHT-A12B 55
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99 100 44 59 72 94 123 89 41 43 39 54 80 109 113 89 84 95 96 104
129 176 159 126 194 165 158 168 194 189 201 165 184 141 223
CHT-A13A 56
315 376 357 359 260 320 132 116 105 118 133 166 286 116 60 60 95 90 113 32
57 58 79 74 90 110 145 116 98 48 56 69 63 48 69 85 88 39 51 44
42 48 33 38 57 68 80 127 114 88 169 223 179 192 183 155
CHT-A13B 56
265 390 360 380 254 319 112 127 106 125 137 159 289 110 64 61 93 92 115 47
71 57 83 70 90 111 139 126 90 50 55 65 61 55 67 81 95 39 44 54
45 43 33 36 62 64 79 129 113 93 168 226 187 185 189 183
CHT-A14A 71
516 527 572 410 462 501 430 477 539 510 453 417 425 324 201 247 257 395 340 262
213 211 154 124 82 115 156 156 135 156 102 99 118 62 61 55 107 121 126 98
119 116 99 81 81 96 71 77 89 132 85 129 115 117 153 156 149 137 131 115
167 187 127 128 123 155 215 177 212 247 265
CHT-A14B 71
524 537 565 395 471 500 442 448 554 504 452 420 436 331 201 236 235 414 349 250
205 213 159 143 72 113 149 150 141 145 104 105 111 67 59 53 106 120 120 104
118 110 106 77 83 89 84 74 93 133 95 119 114 132 151 155 144 132 144 109
175 179 143 131 129 138 219 170 230 227 265
CHT-A15A 65
267 224 187 286 293 388 270 358 347 314 252 267 311 278 252 133 202 268 381 337
340 259 261 252 179 156 155 230 312 309 305 234 293 313 239 117 181 219 376 342
317 316 281 342 292 327 268 223 303 342 201 152 86 70 64 43 51 40 93 96
91 103 109 70 90
CHT-A15B 65
276 224 185 281 289 378 267 362 343 319 250 268 312 281 246 133 194 271 360 340
320 268 251 263 176 152 165 223 309 310 321 222 271 281 238 128 163 226 375 352
324 323 293 353 286 330 265 227 324 334 205 151 89 66 60 54 44 50 84 98
90 102 101 80 82
CHT-A16A 57
257 287 167 171 107 89 86 99 209 267 286 264 261 224 175 130 181 151 134 142
166 148 205 199 218 216 229 239 271 286 153 214 238 248 221 208 186 207 238 218
178 192 160 116 103 86 106 79 92 156 118 99 98 91 121 123 163

CHT-A16B 57
230 286 163 164 105 89 78 131 211 264 280 273 229 200 181 138 181 161 150 140
161 149 183 203 219 235 231 246 276 266 165 233 257 254 214 213 186 219 232 214
187 191 173 121 120 119 87 102 89 142 116 89 100 104 111 128 140
CHT-A17A 58
194 280 334 243 256 341 347 322 201 274 213 185 147 182 308 305 217 315 235 186
161 162 117 117 112 170 182 158 159 162 167 114 105 128 132 176 147 157 177 162
156 202 132 141 158 175 168 117 117 76 62 54 74 68 74 39 41 58
CHT-A17B 58
193 270 322 254 270 322 311 324 218 278 201 185 145 184 309 300 219 313 202 196
178 141 131 104 117 143 181 152 156 182 160 115 113 113 134 184 157 144 165 149
154 198 137 142 162 176 156 115 124 68 59 61 70 78 66 44 48 56
CHT-A18A 89
90 352 459 414 317 372 425 543 564 417 533 400 446 575 621 432 544 482 376 342
364 239 217 253 258 191 95 123 215 190 202 203 203 399 195 134 52 110 175 267
174 244 165 160 175 113 54 62 79 195 222 173 123 149 121 68 56 84 129 104
101 81 73 82 70 86 49 67 79 87 74 62 88 117 106 73 96 83 125 123
108 65 125 90 84 181 154 203 255
CHT-A18B 89
93 361 431 448 318 362 430 544 584 417 533 418 452 586 642 445 551 473 362 340
359 256 226 254 248 220 103 143 225 173 219 205 207 407 193 128 64 108 175 260
171 244 182 148 168 115 68 59 87 192 216 165 132 145 113 75 50 85 125 105
99 91 65 84 77 84 46 68 72 97 65 63 87 112 111 78 90 84 124 199
105 60 122 90 87 168 158 205 249

# APPENDIX: TREE-RING DATING

## The Principles of Tree-Ring Dating

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

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

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

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

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

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

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

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

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

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

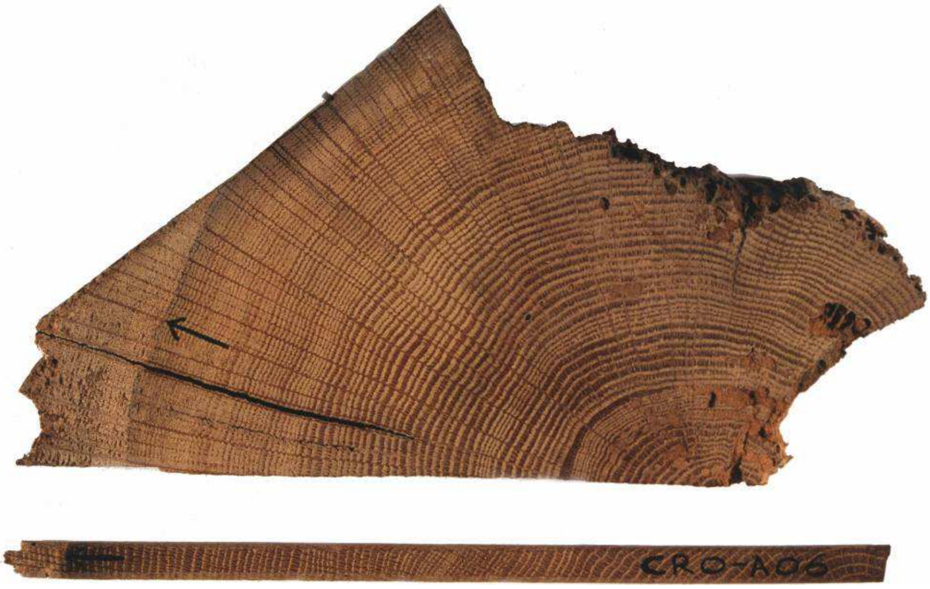



*Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil*

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

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

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

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

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

It is standard practice in our Laboratory first to cross-match as many as possible of the ring-width sequences of the samples in a building and then to form an average from them. This average is called a site sequence of the building being dated and is illustrated in Figure A5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences of the four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. Thus in 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 compliment of, say, 15 to 35 years to the date of the last heartwood ring (called the heartwood/sapwood boundary or transition ring and denoted H/S). Fortunately it is often easy for a trained dendrochronologist to identify this boundary on a timber. If a timber does not have its heartwood/sapwood boundary, then only a *post quem* date for felling is possible.

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

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

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

*t*-value/offset Matrix

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

Bar Diagram

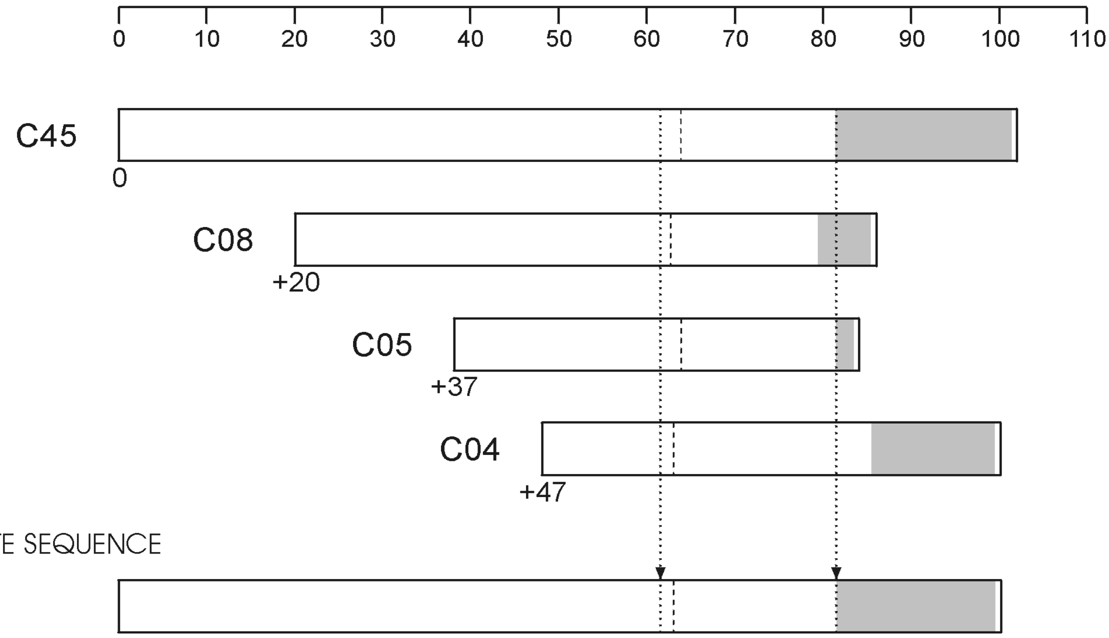



***Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them***

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

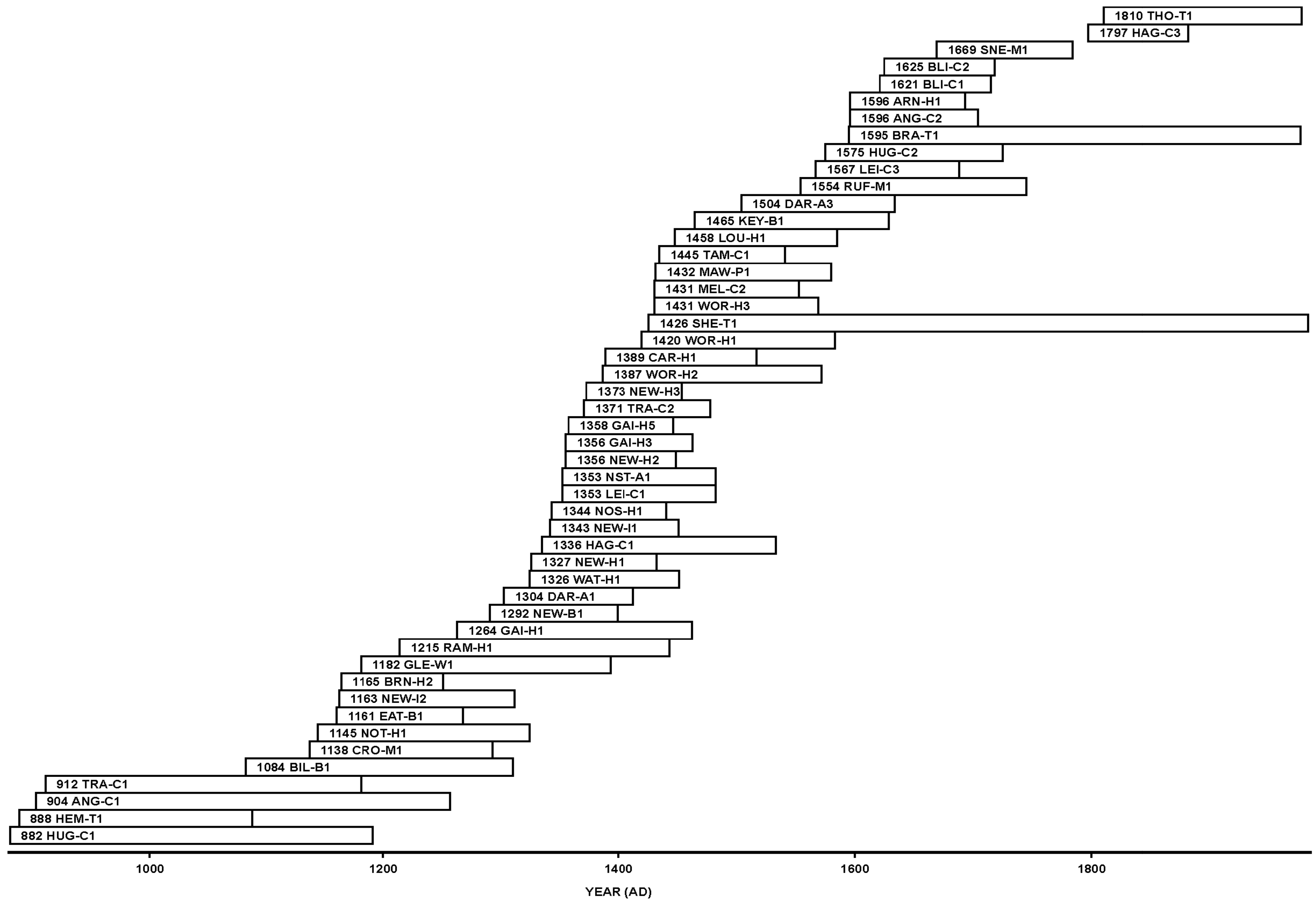
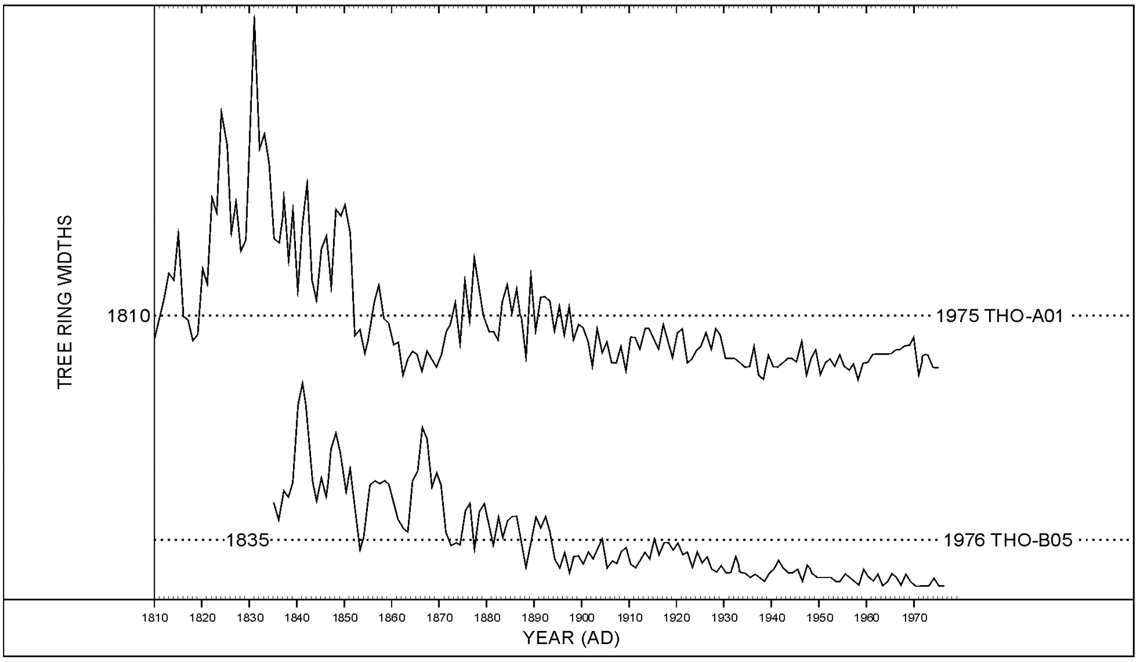



*Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87*

(a)




(b)

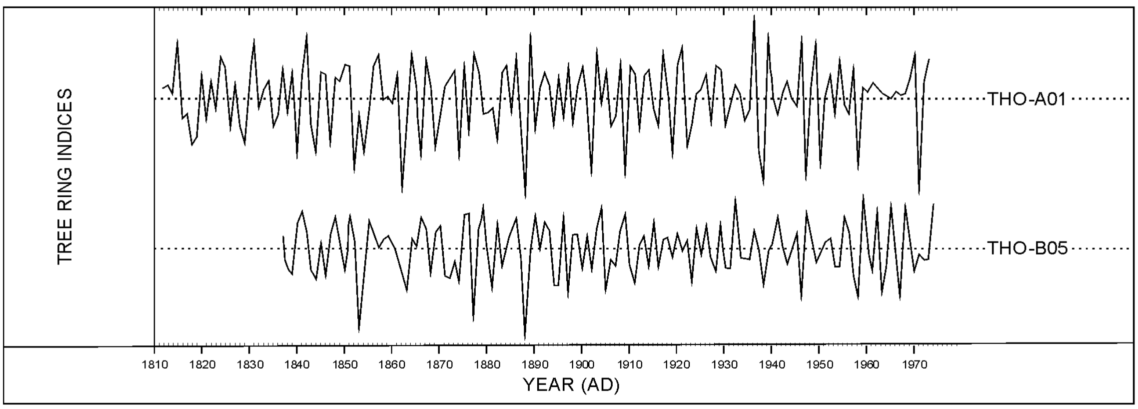



*Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known*

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

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

The growth trends have been removed completely.

## References


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

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

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

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

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

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



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