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The Ashes, Castle Sowerby, Cumbria

Tree-ring Analysis of Oak Timbers

Alison Arnold, Robert Howard, Dana Challinor and Cathy Tyers

Scientific Dating

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Summary

Dendrochronology has demonstrated that the roof and floor of the house are coeval, both thought to utilise timber felled in or around the winter of AD 1561/2. Modifications to the roof undertaken in the nineteenth century included the resetting of purlins from the primary phase, with two of these also thought likely to date to, or around, the winter of AD 1561/2.

Analysis has also shown that some timber reused in the construction of the bottom barn dates to AD 1550–86, with another timber having a *terminus post quem* for a felling date of AD 1534. These timbers may have been salvaged from ranges, since demolished, contemporary with the primary phase identified in the house.

The timbers from the main barn are currently undated.

Contributors

Alison Arnold, Robert Howard, Dana Challinor and Cathy Tyers

Acknowledgements

We would like to thank the owners of the house for allowing assessment and sampling to be undertaken and for their hospitality during these visits, as well as Myra Tolan-Smith (Historic England) for her on-site advice. Thanks are also due to Shahina Farid of the Historic England Scientific Dating Team for her advice and assistance throughout the production of this report. The illustrations used to locate samples are taken from Peter Ryder's excellent report on the building.

Front cover image

The Ashes main house, photograph taken from the east. [© Peter Ryder 2005]

Archive location

Historic England Archive, The Engine House, Fire Fly Avenue, Swindon SN2 2EH

Historic Environment Record

Cumbria Historic Environment Record, Historic Environment Service, South Lakeland House, Lowther Street, Kendal, Cumbria LA9 4DQ

Date of research

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Introduction

This building complex, the house of which is listed at Grade II* (List Entry Number: 1319031 https://historicengland.org.uk/listing/the-list/list-entry/1319031), is located on the west side of the Roe Beck valley, about 13km south of Carlisle, within the former Inglewood Forest (Fig. 1). It has been suggested that it originated as a hunting lodge in the sixteenth century when it consisted of a two-storey plus attics building, aligned north–south with its main frontage facing east (Figs 2 and 3). At some later point a two-storey outshut was added to the west and a separate addition was made to the south.

Extending northwards from the north end of the main house is a long range, which consists of a two-storeyed block (the byre), an arched entry with a low loft above and the main barn. At right-angles to this and running eastwards from the barn is another long range containing the granary and stable (Fig. 4). Finally, at the east end of the granary range, is the single-storey bottom barn (Fig. 5). These two ranges, the barn and the granary, and the modifications/additions to the main house are thought likely to be of a single phase, and probably date to the early nineteenth century.

House

Within the primary build, the ground floor is divided by an east–west passage with the hall to the south and the parlour to the north (Fig. 6). The ground-floor ceiling/first-floor frame is exposed in the hall and passage and consists of three principal moulded beams set north–south but with other heavier, moulded axial joists, running east–west, forming panels of deeply moulded joists (Fig. 7). A portion of the frame over the passage is interrupted by a former stair trap, which was removed in the later twentieth century; some, if not all, of the joists which once occupied this position are stored in the granary (Fig. 8).

The roof over this part of the building consists of five bays separated by four trusses with each truss consisting of principal rafters, tiebeam, jowelled king posts (braced to the ridge) and raking struts, between which are a square-set ridge and common rafters (Fig. 9). Secondary principals have been introduced to raise the eaves level when the outshut (to the west) was added. A number of these timbers display signs of being reused with redundant peg holes and empty mortices/halvings, and the purlins are possibly reset original timbers (Fig. 10).

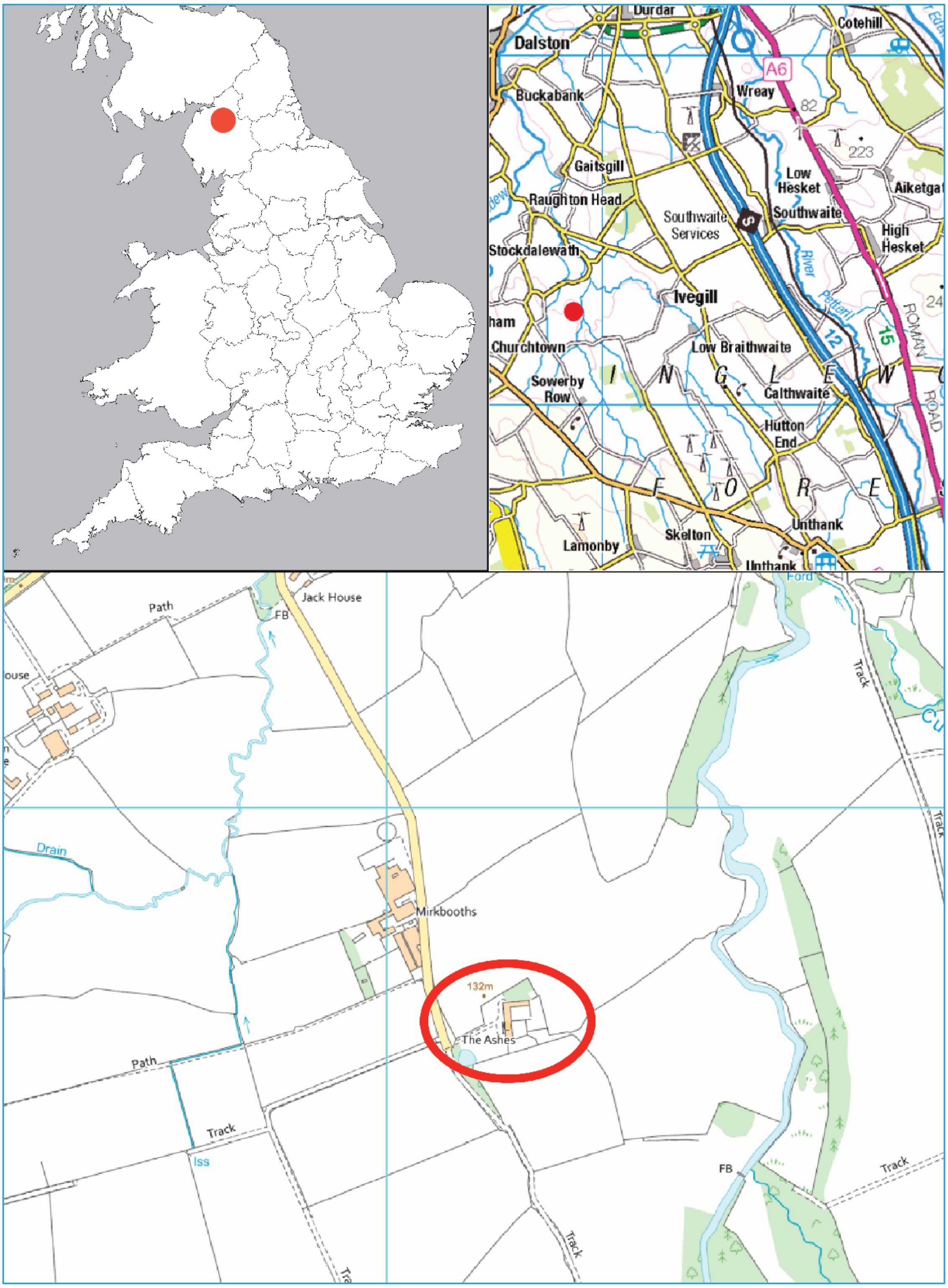

Figure 1: Maps to show the location of The Ashes, Castle Sowerby, Cumbria. Top left on map of England; top right on map at scale 1:106,000, bottom on landscape map scale 1:6000. [© Crown Copyright and database right 2024. All rights reserved. Ordnance Survey Licence number 100024900]

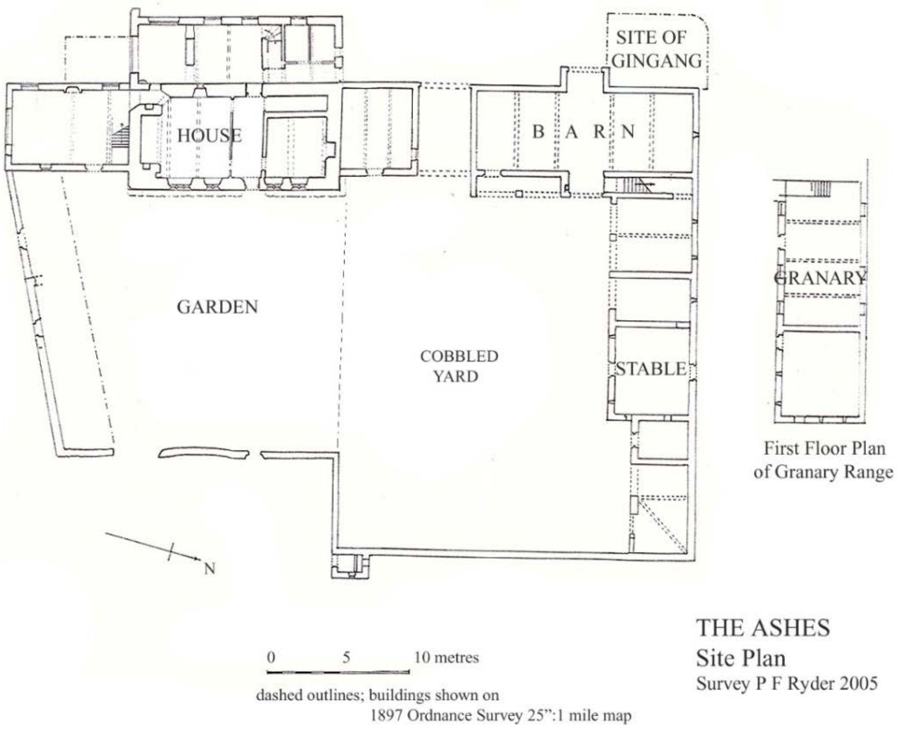

Figure 2: Site plan [after P Ryder, 2005]

Figure 3: The main house, photograph taken from the east. [Alison Arnold]

Figure 4: Main barn (left) and granary, photograph taken from the south. [Alison Arnold]

Figure 5: Bottom barn, photograph taken from the south. [Alison Arnold]

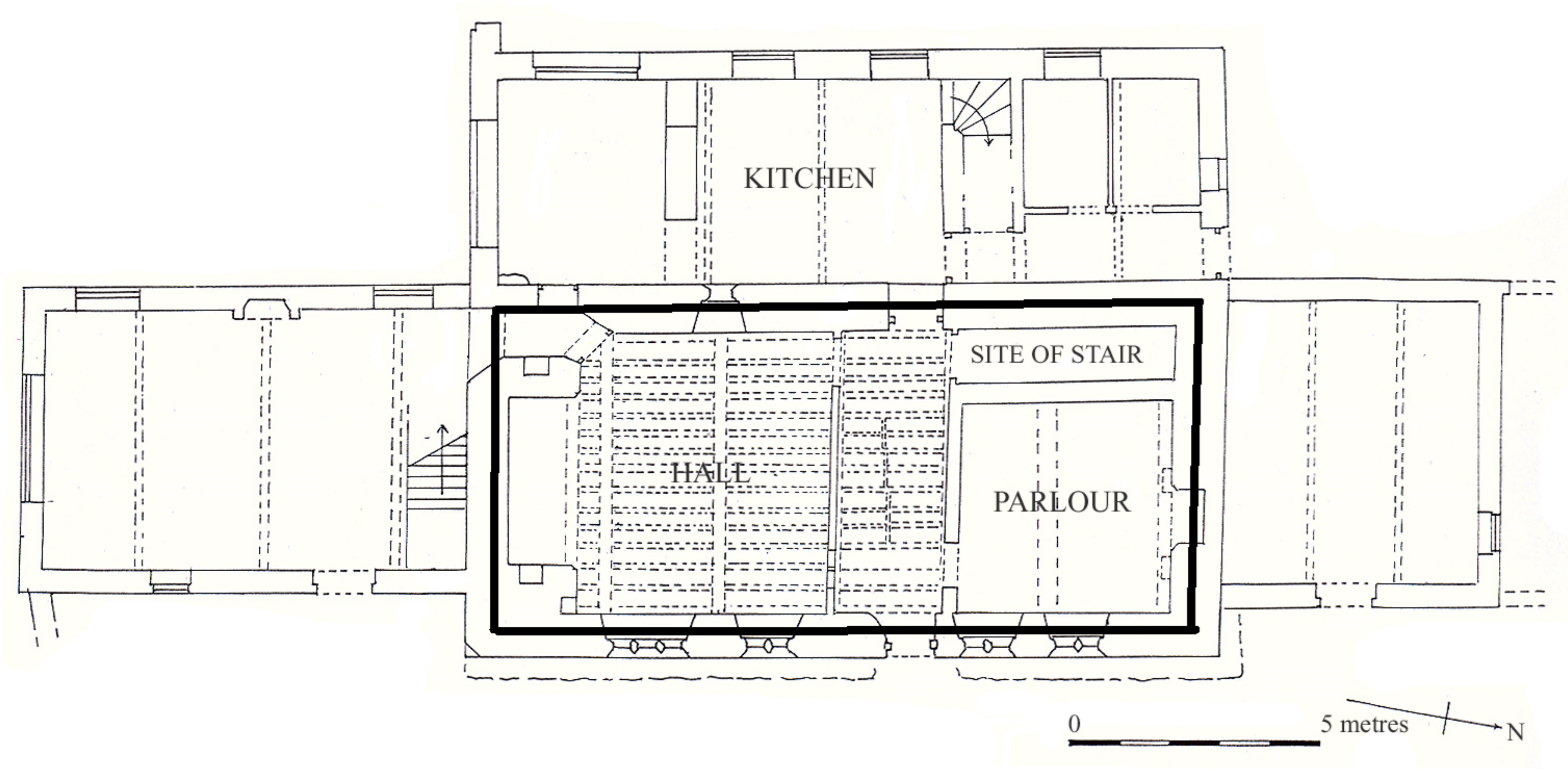

Figure 6: Ground-floor plan of the house, with primary phase outlined. [after P Ryder 2005]

Figure 7: Ceiling/floor frame in the hall, photograph taken from the north. [Alison Arnold]

Figure 8: Ex situ joists stored in the granary. [Alison Arnold]

Figure 9: Roof, truss 2, photograph taken from the south. [Alison Arnold]

Figure 10: Roof, secondary rafters of truss 1, photograph taken from the south. [Alison Arnold]

Main barn

The roof over the main barn consists of four principal-rafter and tiebeam trusses, between which are two tiers of purlins, common rafters and a ridge; the northernmost truss also has a crown post and hip rafter (Fig. 11).

Figure 11: Main barn, roof, photograph taken from the south. [Alison Arnold]

Granary

This building is divided into two parts and is mostly two-storied. The roof consists of four principal-rafter and tiebeam trusses, between which are double purlins, common rafters and a ridge (Fig. 12).

Figure 12: Granary roof, photograph taken from the west. [Alison Arnold]

Bottom barn

In contrast to the adjacent granary, this is narrower, single-storied building which is divided into two spaces by a wall. The roof over consists of two principal-rafter trusses, with purlins between. Many of these timbers show signs of reuse (Fig. 13).

Figure 13: Bottom barn roof, photograph taken from the west. [Alison Arnold]

Sampling

A dendrochronological survey was requested by Myra Tolan-Smith, Historic England Listing Adviser for the North-East and Yorkshire Region, to inform the listing review, and the ensuing revision of the List Entry for the house and associated barns.

In total, core samples were taken from 62 of the timbers from the house, the main barn, and the bottom barn, with a further seven cross-sectional slices being taken from the ex situ joists stored in the granary. Each sample was given the code ASH-S and numbered 01–62. Samples ASH-S01–50 are of oak (*Quercus* spp), with ASH-S51–62 being of pine (*see* below). Further details relating to the samples can be found in Table 1, with core sample locations marked on Figures 14–20. Trusses have been numbered from north to south (house and main barn). The western addition to the house, the byre, and the granary were also assessed for tree-ring dating potential but were found to utilise timbers unsuitable for dendrochronology, being very fast grown with insufficient numbers of growth rings for secure dating purposes.

Table 1: Details of samples taken from The Ashes, Castle Sowerby, Westmorland and Furness, Cumbria

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Bottom Barn						
ASH-S01	North principal rafter - reused	43	h/s	----	----	----
ASH-S02	South principal rafter - reused	105	--	1420	----	1524
ASH-S03	North purlin, east end to truss	NM (32)	03	----	----	----
ASH-S04	North purlin, wall to west end	NM (28)	h/s	----	----	----
ASH-S05	North purlin, truss to wall	NM (30)	02	----	----	----
ASH-S06	South purlin, wall to west end	NM (30)	03	----	----	----
ASH-S07	NE hip rafter - reused	60	h/s	1479	1538	1538
ASH-S08	SW hip rafter - reused	60	h/s	1483	1542	1542
ASH-S09	Hip purlin	44	h/s	----	----	----
ASH-S10	South gable; common rafter	55	19C	----	----	----
ASH-S11	South gable; lintel	71	15	----	----	----
House; roof, primary timbers						
ASH-S12	East principal rafter, truss 1	60	17	----	----	----
ASH-S13	King post, truss 1	71	h/s	1470	1540	1540
ASH-S14	East strut, truss 1	46	h/s	----	----	----
ASH-S15	East principal rafter, truss 2	62	18	----	----	----
ASH-S16	West principal rafter, truss 2	47	13C	1515	1548	1561
ASH-S17	King post, truss 2	80	19	1479	1539	1558
ASH-S18	East principal rafter, truss 3	80	10	----	----	----
ASH-S19	West principal rafter, truss 3	73	h/s	1473	1545	1545
ASH-S20	Tiebeam, truss 3	42	--	----	----	----
ASH-S21	East principal rafter, truss 4	56	10	----	----	----
ASH-S22	West principal rafter, truss 4	75	12C	1487	1549	1561
ASH-S23	East strut, truss 4	53	h/s	1488	1540	1540
ASH-S43	Tiebeam, truss 1	76	--	1459	----	1534

ASH-S44	Tiebeam, truss 2	67	h/s	1479	1545	1545
ASH-S45	South brace, king post truss 2 to ridge	46	07	1503	1541	1548
ASH-S46	King post, truss 3	68	11	1487	1543	1554
ASH-S47	North brace, king post 3 to ridge	58	--	1474	----	1531
ASH-S48	King post, truss 4	55	08	1499	1545	1553
House; roof, secondary timbers						
ASH-S24	East backing rafter, truss 2	NM (18)	03	----	----	----
ASH-S25	West backing rafter, truss 2	50	--	----	----	----
ASH-S26	East backing rafter, truss 3	46	--	----	----	----
ASH-S27	West backing rafter, truss 3	61	13C	----	----	----
ASH-S28	East backing rafter, truss 4	63	02	----	----	----
ASH-S29	West backing rafter, truss 4	NM (19)	h/s	----	----	----
ASH-S30	West upper purlin, north gable to truss 3	44	h/s	----	----	----
ASH-S31	West lower purlin, north gable to truss 3	51	01	----	----	----
ASH-S32	East upper purlin, north gable to truss 3	48	--	----	----	----
ASH-S33	West lower purlin, truss 3 to south gable	75	24	1476	1526	1550
ASH-S49	West upper purlin, truss 3 to south gable	45	--	1500	----	1544
ASH-S50	East upper purlin, truss 3–4	NM (26)	h/s	----	----	----
House; ground-floor ceiling / first-floor frame						
ASH-S34	Axial beam 2	122	h/s	1425	1546	1546
ASH-S35	Axial beam 3	59	16C	----	----	----
ASH-S36	Unmoulded joist – slice	84	--	----	----	----
ASH-S37	Unmoulded joist – slice	88	05	----	----	----
ASH-S38	Joist – slice	72	04	1477	1544	1548
ASH-S39	Joist – slice	61	02	1487	1545	1547
ASH-S40	Joist – slice	57	--	1483	----	1539
ASH-S41	Joist – slice	NM (30)	--	----	----	----
ASH-S42	Joist – slice	69	20C	----	----	----

Main barn (pine timbers)						
ASH-S51	Hip tie	85	--	----	----	----
ASH-S52	Tiebeam, truss 1	83	05	----	----	----
ASH-S53	East principal rafter, truss 2	47	--	----	----	----
ASH-S54	East principal rafter, truss 3	68	--	----	----	----
ASH-S55	West principal rafter, truss 3	87	02	----	----	----
ASH-S56	Tiebeam, truss 3	93	13	----	----	----
ASH-S57	East lower purlin, truss 3-4	90	11	----	----	----
ASH-S58	West lower purlin, truss 3-4	50	04	----	----	----
ASH-S59	East principal rafter, truss 4	44	02	----	----	----
ASH-S60	West principal rafter, truss 4	49	05	----	----	----
ASH-S61	Tiebeam, truss 4	79	23	----	----	----
ASH-S62	East lower purlin, truss 4-south end	47	--	----	----	----

NM (XX) = not measured (ring count), h/s = the heartwood/sapwood boundary is the last-measured ring; C = complete sapwood retained on sample, last-measured ring is the felling date

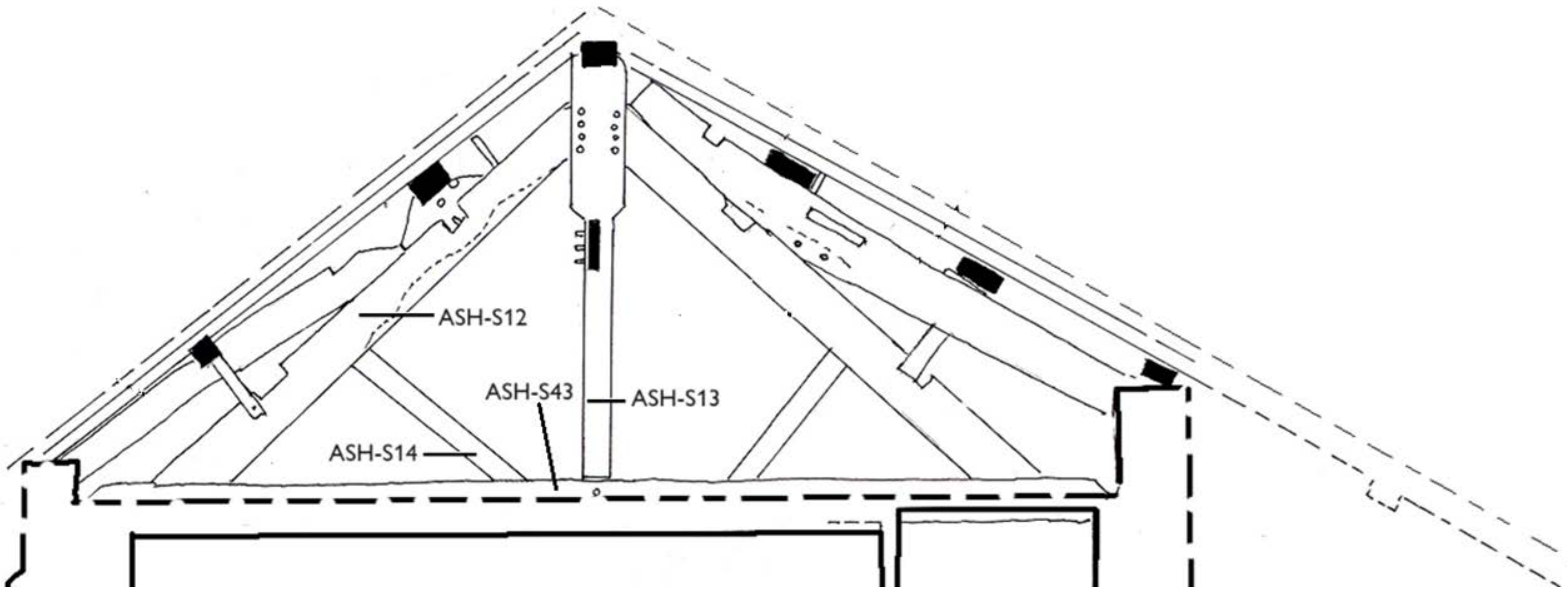

Figure 14: House, truss 1 [representative based on P Ryder’s section, 2005], showing sampled timbers.

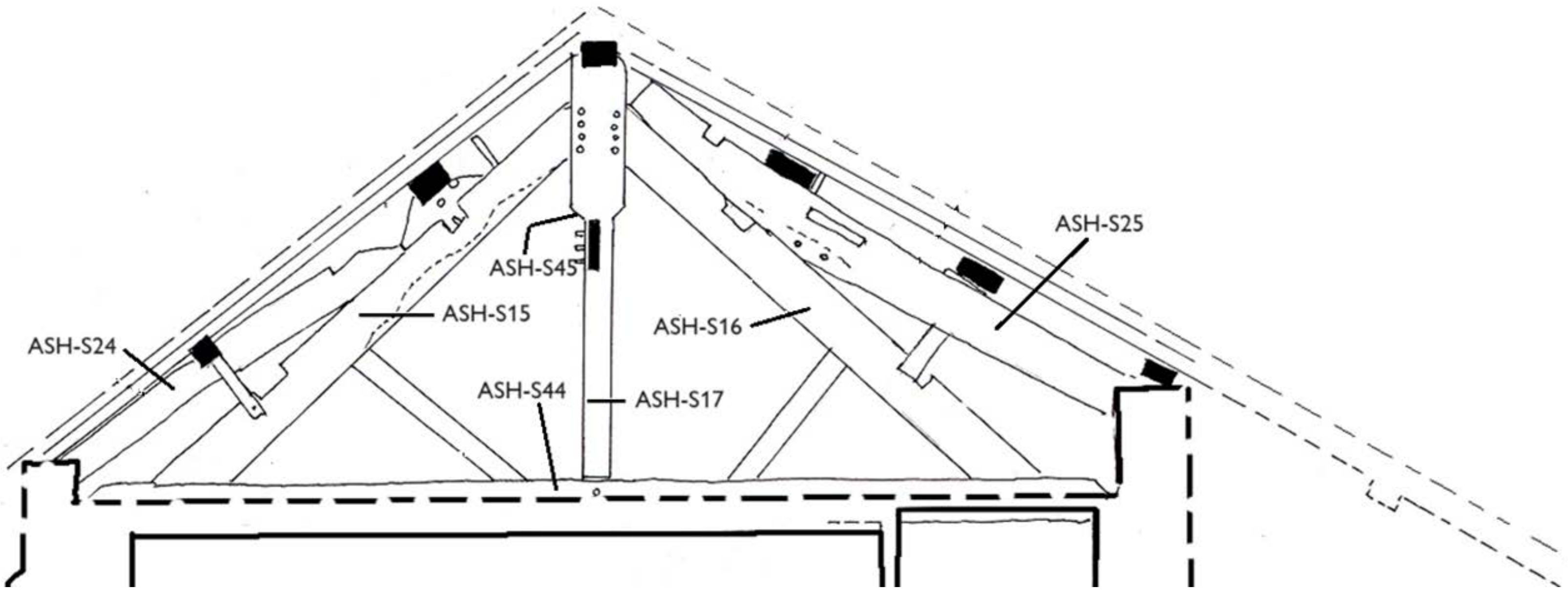

Figure 15: House, truss 2 [representative based on P Ryder’s section, 2005], showing sampled timbers.

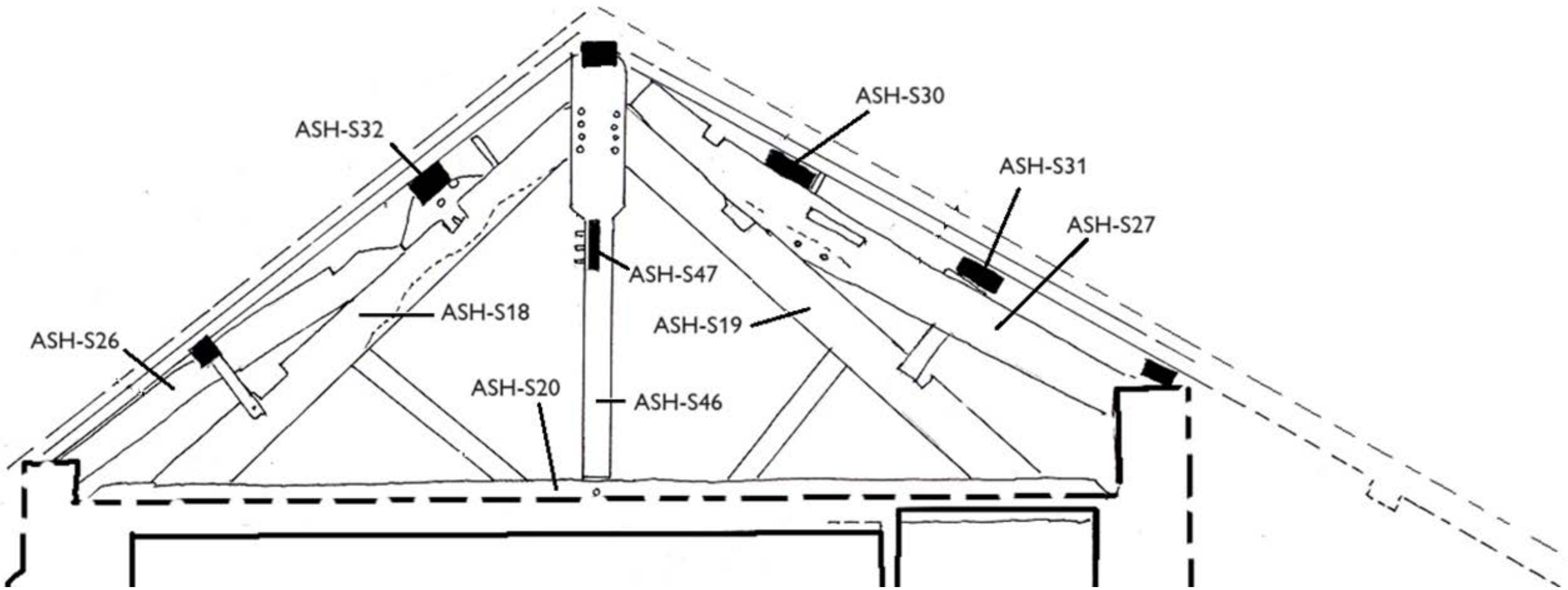

Figure 16: House, truss 3 [representative based on P Ryder's section, 2005], showing sampled timbers.

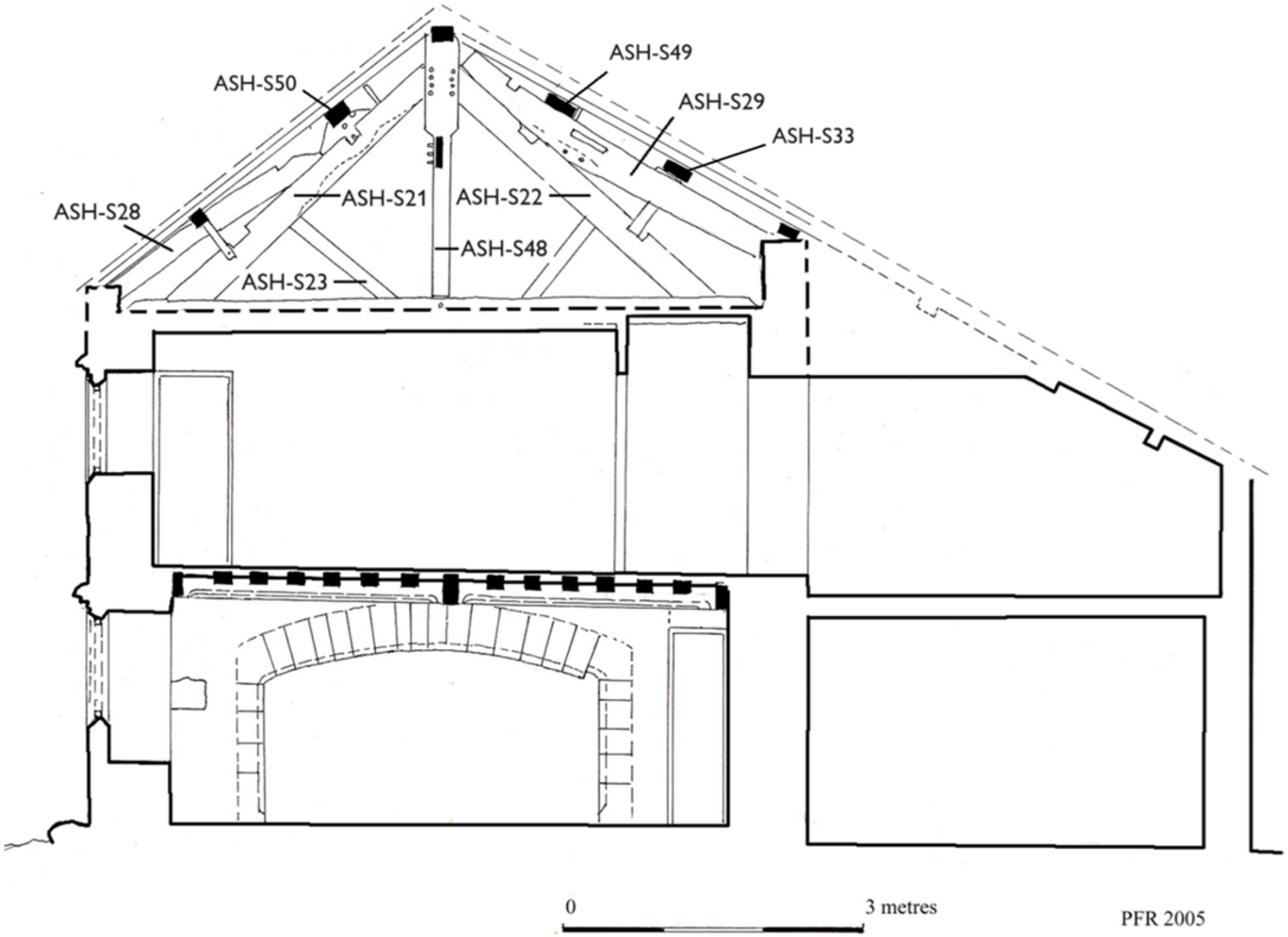

Figure 17: House, cross-section through truss 4, looking south, showing sampled timbers. [after P Ryder, 2005]

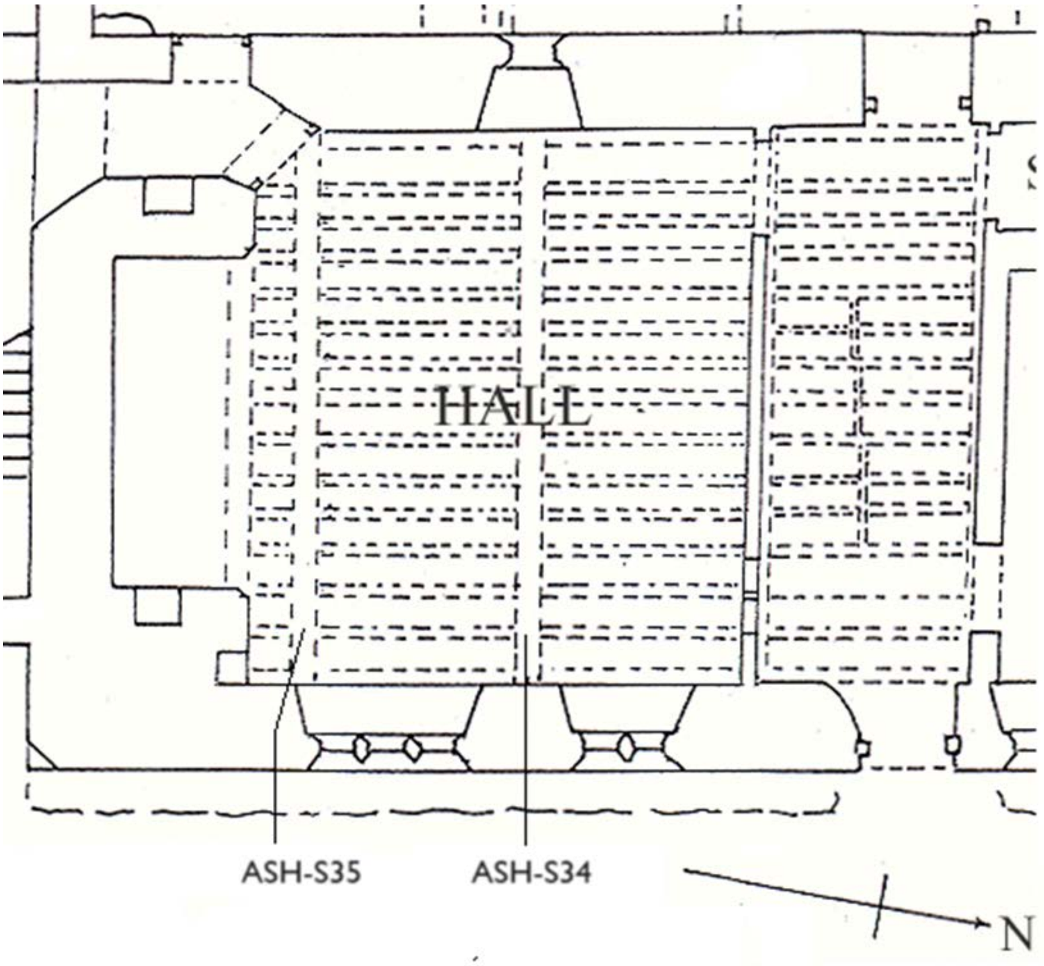

Figure 18: House, ground-floor plan, showing sampled timbers. [after P Ryder, 2005]

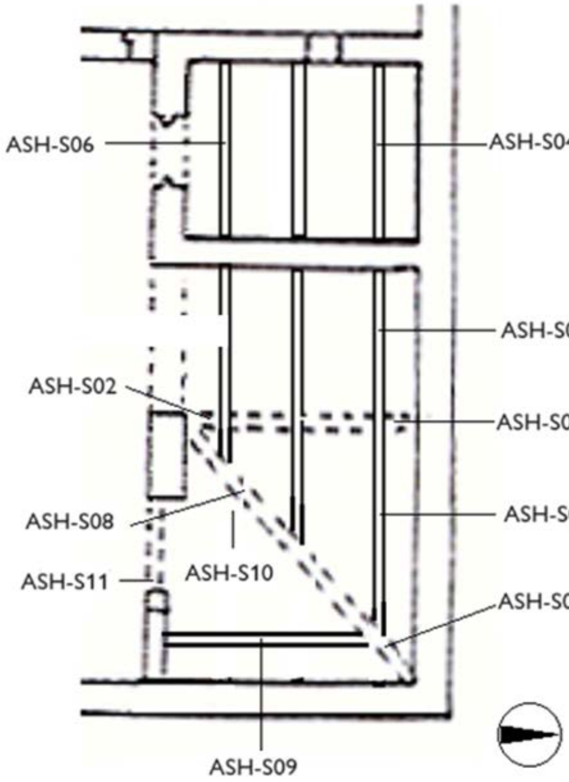

Figure 19: Plan of the bottom barn, showing sampled timbers. [after P Ryder, 2005]

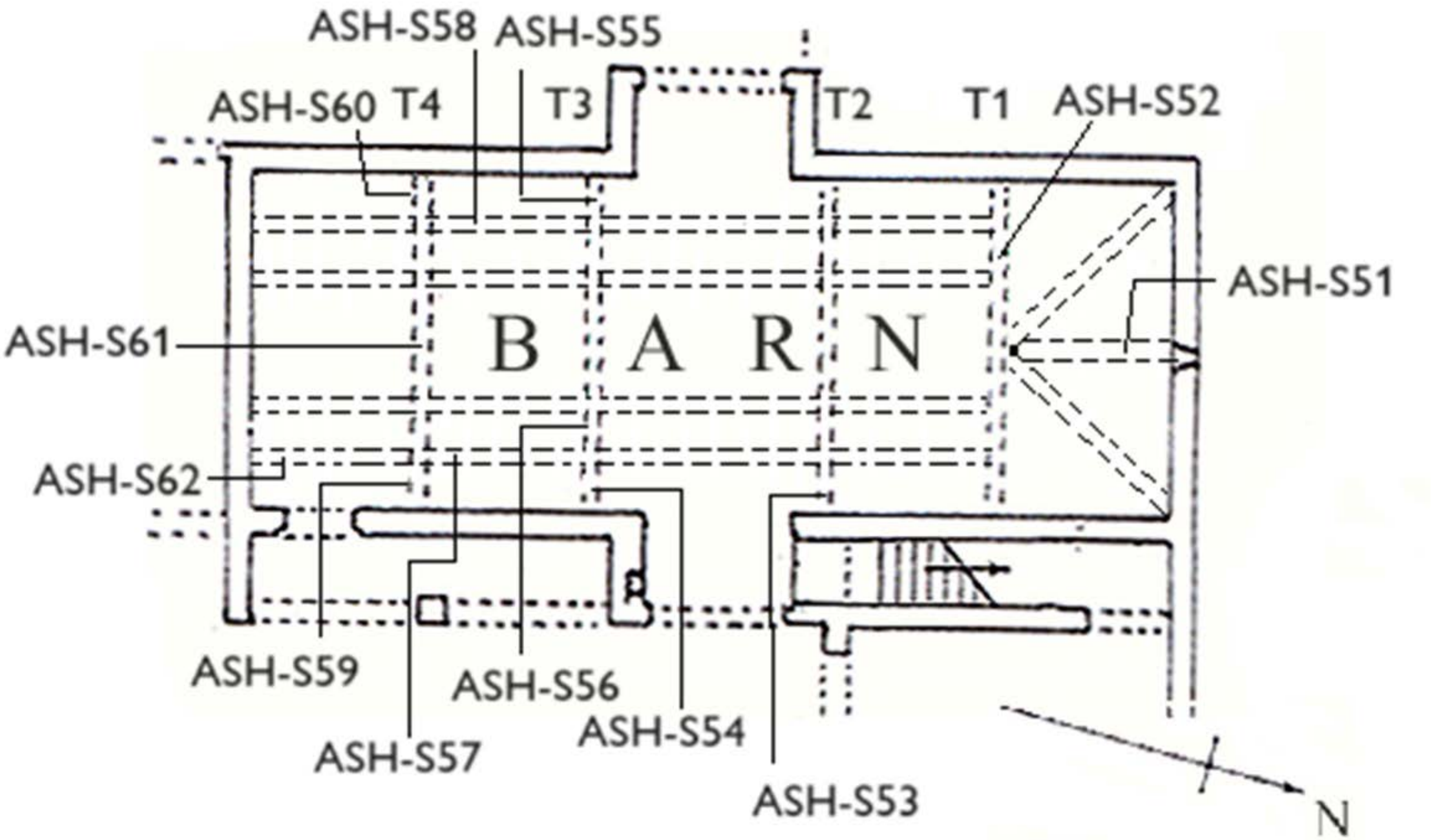

Figure 20: Plan of the main barn, showing sampled timbers. [after P Ryder, 2005]

Wood identification

Twelve dendrochronology cores were submitted for microscopic identification to confirm the conifer species present (Table 2). Standard identification procedures were followed, using a fine razor blade to take thin sections for examination under transmitted light using a Meiji EMZ-2 microscope (up to X400). Allocation to genus was made with reference to identification keys (Gale and Cutler 2000; InsideWood 2014) and modern reference slides from Kew Gardens.

All of the cores were confirmed as *Pinus* sp. (pine), with observed characteristics: abrupt early/late wood transition, presence of resin canals, uniseriate bordered pits, fenestriform cross-field pitting and dentate ray tracheids. This is typical of the native *Pinus sylvestris* or the introduced North American species *Pinus resinosa*. Occasional to moderate insect damage was noted in most cores.

Table 2: Results of wood identifications of tree-ring samples from the main barn

Sample number	Identification
ASH-S51	*Pinus* sp.
ASH-S52A	*Pinus* sp.
ASH-S53	*Pinus* sp.
ASH-S54	*Pinus* sp.
ASH-S55	*Pinus* sp.
ASH-S56	*Pinus* sp.
ASH-S57	*Pinus* sp.
ASH-S58A	*Pinus* sp.
ASH-S59	*Pinus* sp.
ASH-S60	*Pinus* sp.
ASH-S61	*Pinus* sp.
ASH-S62	*Pinus* sp.

Analysis and results

Eight of the samples were found to have less than 35 growth rings and were rejected prior to measurement. The remaining 54 samples were prepared by sanding and polishing, and their growth-ring widths measured. These data are given at the end of the report. The measurements were then divided into those from oak and those from pine samples, and each set of ring-width series were compared with each other by the Litton/Zainodin grouping programme (*see* Appendix). This resulted in 30 samples matching to form five groups, four groups of oak and one group of pine.

Firstly, 18 oak samples matched each other at a minimum value of t = 4.4 and were combined at the relevant offset positions to form ASHSSQ01, a site sequence of 142 rings (Fig. 21). This site sequence was then compared against a series of relevant oak reference chronologies where it was found to span the period AD 1420–1561. The evidence for this dating is given by the t-values in Table 3.

Three other oak samples also grouped, at a minimum value of t = 4.9, and were combined at the relevant offset positions to form ASHSSQ02, a site sequence of 67 rings (Fig. 22). Comparison with the oak chronologies identified a consistent and secure match at a first-ring date of AD 1479 and a last-measured ring date of AD 1545. The evidence for this dating is given by the t-values in Table 4.

A further three oak samples matched each other at a minimum value of t = 6.0 to form a site sequence, ASHSSQ03, of 62 rings (Fig. 23) and two oak samples matched each other at t = 12.7 and were combined to form ASHSSQ04, a site sequence of 90 rings (Fig. 24). Attempts to date these two site sequences and the remaining ungrouped oak samples were unsuccessful, and all remain undated.

Four pine samples matched each other at a minimum value of t = 4.5 and were combined at the relevant offset positions to form ASHSSQ05, a site sequence of 100 rings (Fig. 25). Attempts to date this site sequence and the remaining ungrouped pine samples by comparing them against a series of pine reference chronologies held by laboratories in the British Isles and elsewhere in Europe were unsuccessful and all remain undated.

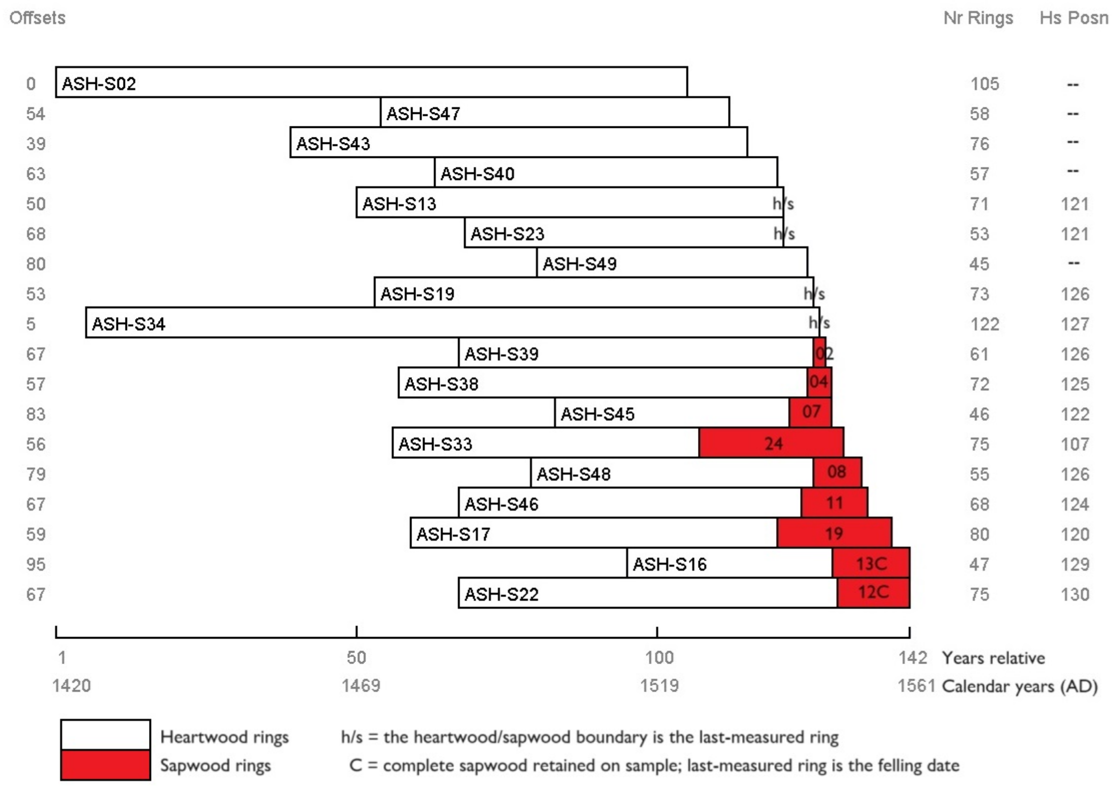

Figure 21: Bar diagram of samples in site sequence ASHSSQ01.

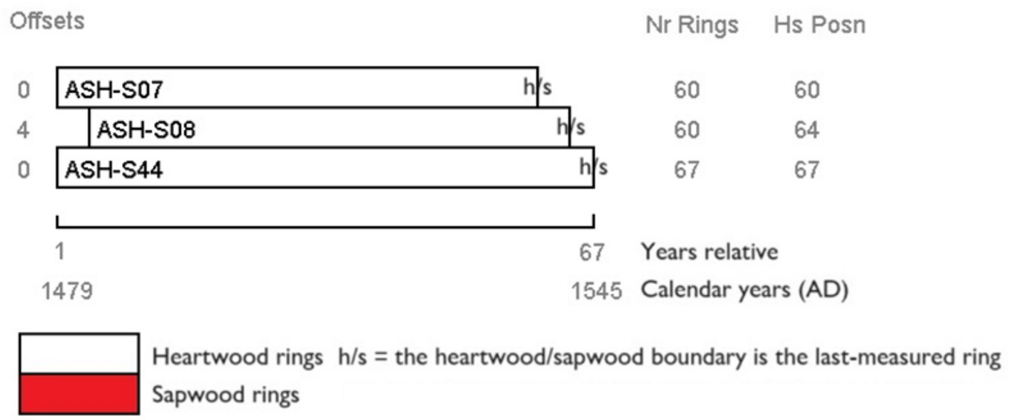

Figure 22: Bar diagram of samples in site sequence ASHSSQ02.

Table 3: Results of the cross-matching of site sequence ASHSSQ01 and relevant reference chronologies when the first-ring date is AD 1420 and the last-measured ring date is AD 1561.

Reference chronology	*t*-value	Span of chronology (AD)	Reference
Girlington Hall, Ovington, County Durham	7.5	1412–1579	Arnold et al. 2019
Welcome Square, Scotby, Cumbria	7.5	1460–1564	Howard et al. 1997
Baldwinholme Farm (cruck barn), Cumbria	7.0	1431–1568	Howard et al. 1998
Thorpe Prebend House, Ripon, North Yorkshire	6.8	1356–1583	Boswijk 1998
Hallgarth Pittington, County Durham	6.7	1336–1624	Howard et al. 2002
Parbold Barn, Lancashire	6.7	1431–1559	Arnold and Howard 2011
Calverley Old Hall, West Yorkshire	6.7	1261–1585	Arnold et al. 2024
Speke Hall, Merseyside	6.5	1387–1598	Howard et al. 1992
Hallfield House, Bradfield, South Yorkshire	6.4	1482–1592	Howard et al. 1996
Nappa Hall, Askrigg, North Yorkshire	6.4	1478–1570	Arnold and Howard 2013
Canons Garth, Helmsley, North Yorkshire	6.4	1381–1668	Arnold and Howard 2014
Finnebrogue House, Downpatrick, Co Down	6.4	1414–1662	Brown pers. comm. 2012

Table 4: Results of the cross-matching of site sequence ASHSSQ02 and relevant reference chronologies when the first-ring date is AD 1479 and the last-measured ring date is AD 1545.

Reference chronology	*t*-value	Span of chronology (AD)	Reference
3 & 4 High Street, West Wycombe, Buckinghamshire	6.2	1464–1553	Miles et al. 2014
Exton Barn, Hampshire	5.8	1376–1546	Miles and Haddon-Reece 1995
Oxwich Castle, Oxwich, Glamorgan	5.7	1459–1630	Dunn et al. 2006
Raybourne Cottage, Billericay, Essex	5.6	1473–1546	Bridge and Miles 2015
Branas-uchaf, Llandrillo, Denbighshire	5.6	1388–1763	Miles et al. 2010
Broomden Barn, Ticehurst, East Sussex	5.4	1457–1577	Tyers pers. comm. 2005
Wilbury House, Newton Tony, Wiltshire	5.4	1449–1579	Miles and Worthington 1999
Gwerfyda, Llanllugan, Montgomeryshire	5.3	1410–1551	Miles et al. 1996
Old Leigh Place, North Leigh, Kent	5.3	1411–1533	Miles et al. 2007
Plumpton Place, East Sussex	5.3	1463–1589	Bridge et al. 2021

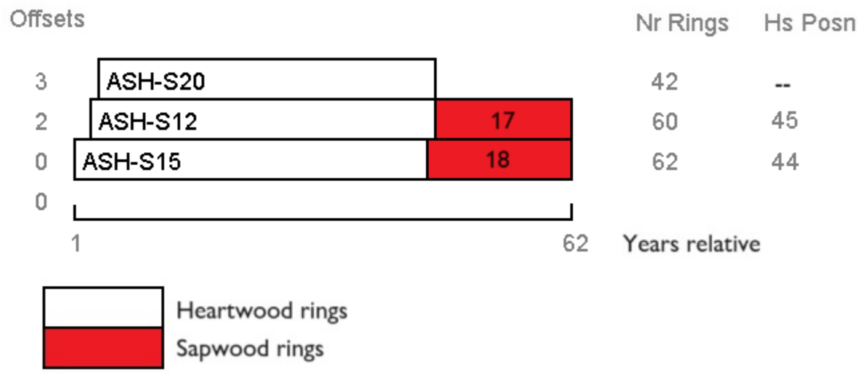

Figure 23: Bar diagram of samples in undated site sequence ASHSSQ03.

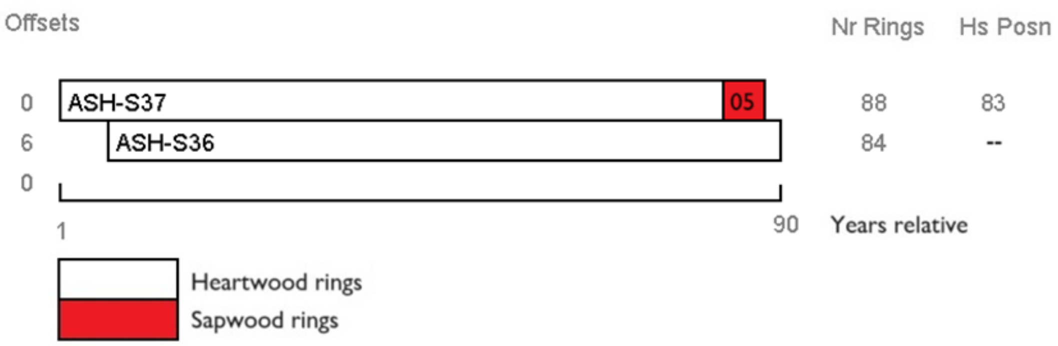

Figure 24: Bar diagram of samples in undated site sequence ASHSSQ04.

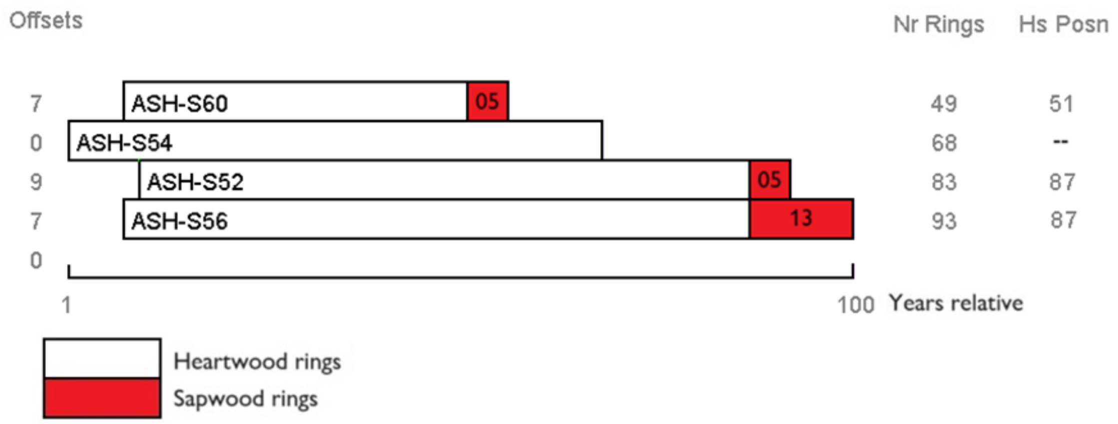

Figure 25: Bar diagram of samples in undated pine site sequence ASHSSQ05.

Interpretation

Tree-ring analysis has resulted in the successful dating of 21 oak samples from the house and bottom barn. These samples have been sorted by area for ease of interpretation (Fig. 26). Where complete sapwood does not survive the sapwood estimate of 10–46 (95% range) sapwood rings has been used to calculate estimated felling date ranges and *termini post quem* for felling dates (English Heritage 1998, 11; Arnold et al. 2019, fig. 9).

House

Samples from 12 of the primary roof timbers have been successfully dated, two of which have complete sapwood. Samples ASH-S16 and ASH-S22 both retain complete sapwood and have the last-measured ring date of AD 1561. When looked at under the microscope it can be seen that both samples have the spring and summer growth cells of the last year measured but none for the following year, showing that the two timbers represented were felled in the winter of AD 1561/2. Eight of the other roof samples have the heartwood/sapwood boundary ring, the dates of which are broadly contemporary and suggestive of a single felling. The average heartwood/sapwood boundary ring date is AD 1542 which, allowing for sample ASH-S17 having a last-measured ring date of AD 1558 with incomplete sapwood, gives an estimated felling date for the timbers represented to within the range AD 1559–88, consistent with these also having been felled in, or around, AD 1561/2. The final two dated samples from this roof do not have the heartwood/sapwood boundary ring and so estimated felling date ranges cannot be calculated for the timbers represented. However, with last-measured ring dates of AD 1531 (ASH-S47) and AD 1534 (ASH-S43) these would have estimated *termini post quem* for felling dates of AD 1541 and AD 1544, respectively.

Samples from two of the timbers of the secondary phase in the roof have also been dated, only one of which has the heartwood/sapwood boundary. Sample ASH-S33 has the heartwood/sapwood boundary ring date of AD 1526, giving an estimated felling date for the timber represented to within the range AD 1551–72. This allows for the sample having a last-measured ring date of AD 1550, with incomplete sapwood. The second sample, ASH-S49, has a *terminus post quem* for felling date of AD 1554.

Four of the timbers taken from the ground-floor ceiling/first-floor frame have been dated, three of which have the heartwood/sapwood boundary ring. The average heartwood/sapwood boundary ring date of the three samples represented is AD 1545, giving an estimated felling date for the timbers represented to within the range of AD 1555–91. The fourth sample has a *terminus post quem* for felling date of AD 1549.

Bottom barn

Three of the samples taken from timbers of this building have been dated, two of which have the heartwood/sapwood boundary ring. The combined heartwood/sapwood boundary ring date is AD 1540, giving an estimated felling date for the timbers represented to within the range of AD 1550–86.The fourth sample has a *terminus post quem* for felling date of AD 1534.

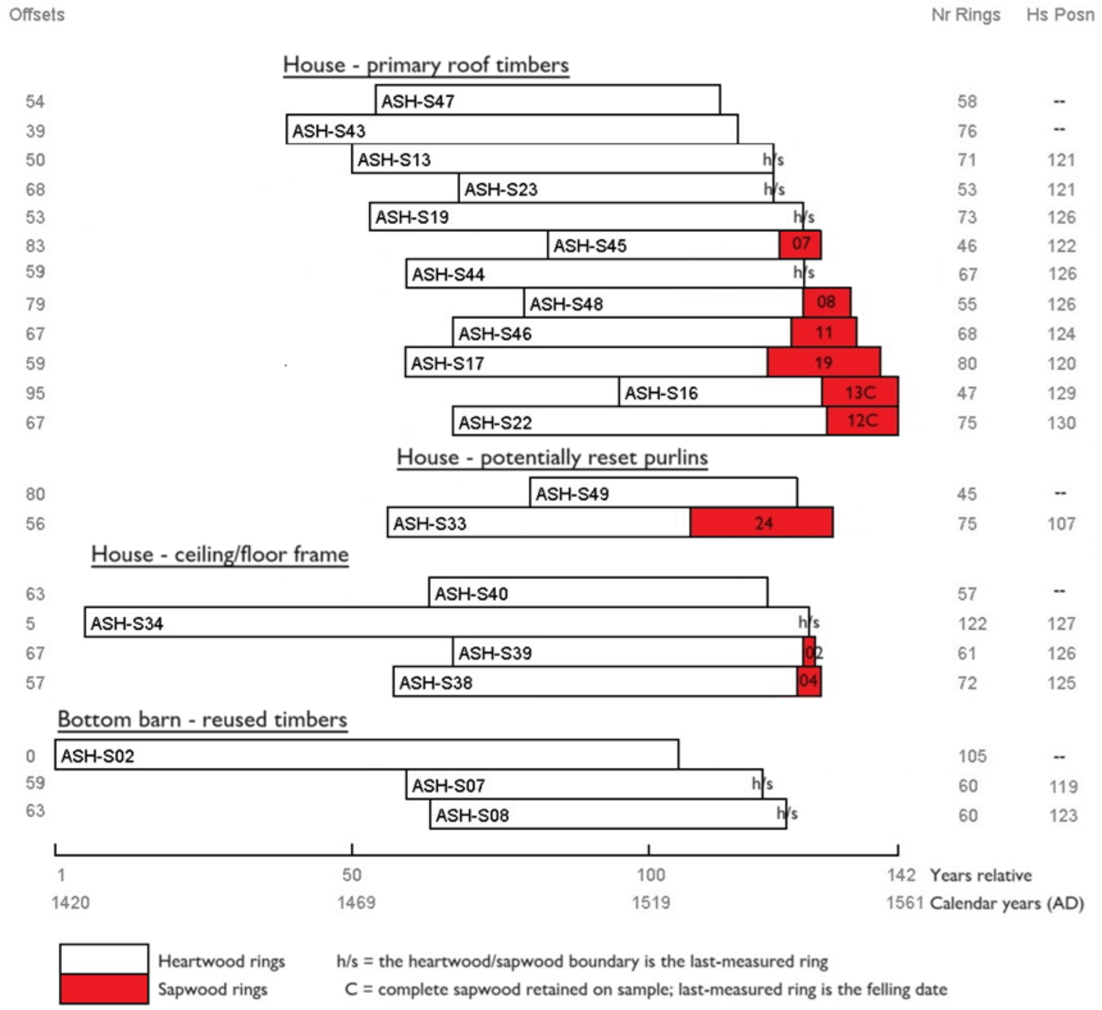

Figure 26: Bar diagram of all dated samples, sorted by area.

Discussion

Prior to the tree-ring dating being undertaken the primary phase of the house had been dated on stylistic grounds to the mid-sixteenth century. This has now been supported by the dendrochronology, which has shown that the roof over the earliest part of the house utilises timber felled in, or around the winter of AD 1561/2. Tree-ring analysis has also demonstrated that the ground-floor ceiling/first-floor frame for this part of the house is coeval, with a number of the timbers of this being dated to AD 1555–91, consistent with also being felled in, or around, AD 1561/2.

Two of the purlins of the modification to the roof have also been dated to the second half of the sixteenth century (AD 1551–72 and a *terminus post quem* for felling date of AD 1554) and it is likely that these are purlins from the primary phase reset in their current positions.

The two hip rafters and one of the principal rafters of the bottom barn roof have been dated to AD 1550–86 (two timbers) and a *terminus post quem* for felling date of AD 1534 (one timber). All three of these timbers displayed clear signs of reuse in the form of redundant mortices, and it would now appear that these were salvaged from a mid-sixteenth century building of broadly contemporary date with the main house, possibly from original service ranges/outbuildings.

It is unfortunate that three of the five site sequences from this building complex, along with 24 measured but ungrouped samples, are undated. Neither of the undated oak site sequences are particularly well replicated or long; site sequence ASHSSQ03 contains only three samples and is relatively short at 62 rings long, whereas site sequence ASHSSQ04 is longer at 90 rings but it only contains two samples. The two component samples in question (ASH-S36 and ASH-S37) match each other at a value of t = 12.7, so it is possible that the timbers represented were cut from the same tree. This means that, in effect, we are trying to securely date an individual sample, something which is generally more challenging.

Although we cannot say when the timbers represented by site sequence ASHSSQ03 were felled, we can say, by looking at the relative heartwood/sapwood boundary ring positions (Fig. 23), that all three timbers are likely to have been felled at the same time. This is also true for the two timbers, potentially derived from the same tree, in ASHSSQ04. The pine site sequence contains four samples and is of 100 rings but, due to the challenges of dating imported conifer timbers, a longer site sequence, which is better replicated (i.e. higher sample depth), is desirable for successful dating.

In addition to the potential same tree match identified above, samples ASH-S52 and ASH-S56, both pine tiebeams, also match each other at a value (t = 10.5) high enough to suggest both may have been cut from the same tree and hence, felled at the same time.

The rate of successful dating of oak samples seen at this complex is somewhat lower than might be expected. This is probably, in part, due to the short ring-width sequences within a large number of these samples. Of the 50 oak samples taken, about 16% had less than 35 rings and so were not measured, and another 20% had less than 50 rings. It is also possible that more than one source and phase of felling is represented amongst the timber, which would explain the large number of ungrouped samples and that four separate oak site sequences have been constructed. The lack of success with the pine timbers may reflect these likely imported timbers being multi-sourced. If they are associated with early-nineteenth century building works, then they may be imported from sources around the Baltic Sea, Fennoscandia, and around to the White Sea on the northwest coast of Russia, but also, at this time, from the eastern seaboard of America. If they are of the latter source, then this is an aspect of dendrochronological provenancing that, unlike European conifer imports, is in the very early stages of development.

An interesting point to note about the potential woodland source for the timber utilised at this site is that the reference chronologies against which the two dated site sequences match most strongly are noticeably different despite being from the same period in time. Site sequence ASHSSQ01 can be seen to match most highly against other sites in Cumbria or surrounding counties (Table 3) signifying a local woodland source as one might expect during this period. However, site sequence ASHSSQ02 has a much more diverse spread of reference chronologies ranging from the south, south-east and Wales (Table 4), although whether one can definitively say this suggests a source further afield, is debateable.

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Data of Measured Samples

Measurements in 0.01mm units

ASH-S01A 43
403 265 170 309 176 119 98 103 83 116 105 123 150 150 171 235 239 283 228 284
196 224 265 347 329 381 281 302 159 169 274 299 297 355 487 442 365 316 387 351
326 414 190

ASH-S01B 43
417 260 170 323 175 124 98 102 87 116 99 151 178 150 172 229 241 282 235 281
195 226 254 339 334 385 281 293 167 163 263 284 322 371 473 460 370 338 379 403
329 425 180

ASH-S02A 77
268 272 267 205 245 284 214 205 125 120 88 126 170 256 215 168 140 139 118 98
86 76 159 216 250 158 225 274 423 396 231 231 207 205 134 118 257 244 271 202
435 285 265 235 112 132 98 125 151 199 121 179 196 181 194 210 263 321 201 307
192 247 255 329 340 327 262 260 145 170 229 235 289 263 371 358 360

ASH-S02B 105
48 41 56 76 83 60 99 126 161 207 135 105 62 105 93 113 121 147 108 116
257 294 145 198 233 110 94 137 224 188 225 170 240 241 193 119 78 83 115 94
156 127 107 81 82 76 60 59 55 111 172 186 100 133 213 275 251 160 158 149
144 86 98 153 176 171 153 364 232 228 210 98 106 76 98 107 149 98 117 113
108 120 145 181 185 156 281 144 192 206 283 292 302 226 229 113 109 157 193 233
180 287 252 220 238

ASH-S07A 60
294 367 416 315 196 227 293 228 387 310 359 319 353 252 235 253 230 273 250 265
236 160 138 211 161 165 214 210 174 185 204 134 145 137 115 158 182 198 193 207
203 194 197 194 87 51 43 53 67 56 47 44 54 55 68 78 131 144 148 149

ASH-S07B 60
278 364 410 314 198 225 296 228 380 296 381 321 380 251 235 258 236 270 232 254
252 152 139 202 165 171 203 203 167 167 200 129 137 121 109 154 183 199 198 189
203 190 196 189 92 46 51 46 59 53 49 45 45 53 69 68 120 131 133 144

ASH-S08A 60
216 346 371 248 443 314 332 342 364 254 232 266 248 285 213 266 274 216 156 266
207 225 223 200 166 206 207 142 209 160 160 172 255 282 153 179 193 215 181 214
100 46 50 54 66 55 38 41 58 50 83 77 112 109 150 116 158 178 156 114

ASH-S08B 60
182 362 392 258 463 329 344 357 341 255 227 281 243 300 220 259 272 217 152 269
207 230 212 198 168 222 204 137 204 159 152 168 254 289 155 174 196 212 189 199
103 50 43 51 70 52 38 40 64 50 81 73 115 114 141 118 160 184 182 137

ASH-S09A 44
223 162 182 256 439 357 221 299 299 409 444 488 431 435 309 262 236 264 279 215

311 174 129 233 259 388 424 295 287 250 236 285 253 282 296 309 297 208 148 73
73 49 49 54

ASH-S09B 44
219 162 173 239 418 372 224 341 297 398 440 481 410 427 312 238 251 259 304 216
307 176 129 230 254 390 414 306 282 254 236 279 243 291 297 318 286 215 149 72
78 52 42 55

ASH-S10A 55
91 111 139 157 136 143 157 103 148 177 115 150 169 136 90 61 127 122 135 145
214 158 215 152 147 158 224 147 213 169 74 84 116 122 154 103 157 160 163 119
142 240 298 112 106 162 166 170 169 230 209 220 155 150 114

ASH-S10B 55
108 107 140 153 131 150 155 109 150 176 109 151 169 134 89 66 123 122 137 156
208 154 218 150 150 153 231 144 211 169 64 106 108 120 143 127 156 158 166 118
137 245 285 114 99 166 171 166 162 234 202 220 169 155 118

ASH-S11A 71
227 167 108 181 249 294 167 171 121 187 173 172 301 223 317 329 325 310 242 292
405 309 284 351 283 455 267 256 247 279 364 299 300 184 433 407 343 452 318 293
73 55 57 52 85 94 95 71 108 167 134 245 146 100 47 64 34 41 51 51
55 61 72 46 36 37 31 41 70 68 71

ASH-S11B 71
224 165 94 179 275 285 173 160 110 176 181 172 296 226 310 336 317 318 246 281
400 290 265 350 227 451 263 264 245 288 374 297 284 202 401 422 347 449 302 286
72 52 50 56 85 82 86 75 111 169 141 249 139 103 54 66 31 33 58 48
54 63 82 35 42 33 34 42 75 59 68

ASH-S12A 60
537 522 520 252 267 613 402 341 251 485 447 495 537 380 319 394 246 229 187 264
306 391 368 250 248 334 325 300 393 333 311 294 300 233 230 400 207 166 113 153
188 164 128 161 149 109 132 146 153 167 179 165 143 134 90 137 136 147 163 165

ASH-S12B 60
538 512 540 253 267 620 398 376 251 484 443 450 501 361 310 393 255 222 187 251
301 394 367 250 247 330 326 301 391 343 307 295 308 228 230 398 218 165 112 152
182 164 133 168 143 108 133 148 151 165 178 161 139 123 96 147 131 149 161 176

ASH-S13A 71
276 247 203 251 207 227 192 175 187 187 193 134 92 124 165 163 187 211 168 169
210 186 150 135 190 162 179 168 160 155 129 144 169 154 195 160 153 158 136 148
158 125 126 144 129 135 144 105 103 62 54 74 118 89 119 110 149 124 112 92
68 121 66 119 83 129 193 257 103 166 112

ASH-S13B 71
282 249 203 254 209 219 194 177 164 198 192 133 94 122 166 164 189 208 169 176
207 187 150 135 184 165 182 163 154 154 132 148 169 149 193 161 153 159 133 152
154 127 125 150 124 136 134 105 110 60 50 77 118 94 105 116 149 124 105 99

61 125 61 118 81 126 199 250 107 159 117

ASH-S14A 46
92 73 163 180 130 143 139 201 314 211 182 226 242 268 248 193 213 171 206 180
213 229 237 185 94 79 88 118 211 212 263 225 245 224 226 160 125 134 152 127
107 112 124 105 111 106

ASH-S14B 46
81 72 167 176 134 143 131 204 317 226 199 209 225 287 241 217 201 187 211 179
211 235 233 187 91 78 87 114 210 214 256 221 248 220 222 173 123 130 150 113
113 107 131 102 118 96

ASH-S15A 62
736 563 421 277 339 210 325 514 284 327 172 310 283 361 316 302 296 488 515 403
288 277 186 186 236 191 217 277 261 194 177 154 246 251 218 219 212 370 228 172
129 120 147 151 124 182 161 136 134 166 116 140 164 161 140 136 103 159 155 156
207 171

ASH-S15B 62
745 534 414 307 368 210 283 491 295 321 182 304 277 361 323 296 296 490 523 404
269 293 180 192 242 190 217 273 261 192 181 154 246 247 229 211 215 366 222 179
131 123 145 148 127 185 160 133 141 163 125 146 160 155 143 140 106 160 150 154
218 182

ASH-S16A 47
111 169 132 111 160 138 228 343 253 312 301 179 250 299 181 309 444 366 240 285
260 224 250 158 164 238 210 171 202 228 230 296 313 332 227 262 310 224 150 150
214 185 122 163 240 178 124

ASH-S16B 47
111 164 139 115 164 138 219 327 268 330 315 168 291 282 187 308 453 364 242 279
257 226 255 158 161 237 207 175 199 225 233 296 311 331 224 257 304 224 153 152
226 185 120 174 212 209 128

ASH-S17A 80
247 262 137 89 173 219 229 303 288 279 298 283 234 212 227 217 276 247 194 211
225 173 170 123 119 138 157 140 157 128 107 129 138 97 134 144 158 128 121 111
77 51 69 123 82 125 110 127 109 101 85 65 76 39 99 73 111 149 213 66
131 166 146 137 91 77 85 143 103 114 80 94 142 90 101 76 104 47 74 84

ASH-S17B 80
245 253 141 82 181 225 230 292 324 290 282 266 225 210 235 220 273 246 191 205
228 175 160 131 125 132 159 141 142 121 112 120 136 109 126 143 151 135 117 120
73 58 59 118 81 134 118 120 113 105 78 64 65 48 91 83 113 141 213 70
124 169 156 125 101 76 76 137 106 117 70 108 138 89 115 69 111 49 70 88

ASH-S18A 80
337 560 343 282 488 525 565 405 574 427 516 406 218 162 232 228 301 323 260 304
187 215 232 287 219 306 401 112 96 105 109 121 160 132 104 120 118 120 122 127
127 97 108 126 148 205 195 171 166 160 181 190 197 165 141 153 163 129 141 91

95 109 94 92 115 115 86 164 320 284 221 197 266 254 291 164 174 154 153 125

ASH-S18B 80
348 550 352 274 485 520 579 396 547 423 501 422 235 171 229 231 299 328 271 294
180 242 230 305 222 308 403 98 83 97 128 123 159 147 107 117 115 99 123 129
124 99 113 140 128 216 187 185 156 161 180 191 192 155 145 149 163 120 139 82
98 109 87 104 118 98 95 176 322 294 207 204 274 253 299 159 172 157 149 124

ASH-S19A 73
548 595 479 333 325 446 597 472 242 160 300 370 284 427 574 401 448 414 251 252
351 398 390 478 383 343 300 249 290 354 269 287 430 205 133 155 182 223 180 157
126 150 134 182 189 128 224 168 297 281 263 232 302 204 236 237 158 234 411 332
218 195 206 193 189 140 157 199 154 117 135 142 145

ASH-S19B 73
530 578 462 330 320 434 611 448 267 167 305 369 276 324 586 406 452 414 227 234
319 385 390 485 367 354 288 248 292 355 264 279 429 201 132 157 182 218 189 144
137 146 141 175 184 143 209 163 298 287 262 241 303 196 236 228 157 249 409 333
208 195 208 192 192 148 156 197 148 119 126 132 137
ASH-S20A 42
235 346 227 326 559 412 495 297 324 264 394 344 348 265 382 330 410 283 296 222
193 225 223 195 208 183 174 201 238 230 210 168 167 152 242 210 195 176 225 231
215 173

ASH-S20B 42
250 353 227 331 559 401 482 302 328 258 397 339 357 267 374 334 411 240 308 227
200 228 225 197 210 177 174 211 246 229 224 164 164 147 250 209 188 177 216 230
217 185

ASH-S21A 56
384 379 213 83 122 115 147 137 148 201 151 119 172 187 175 175 148 186 268 250
327 276 168 222 150 182 228 284 276 234 336 116 121 121 92 98 108 148 131 144
133 129 171 282 315 287 260 310 200 280 200 251 198 170 178 235

ASH-S21B 56
411 384 207 85 115 131 148 134 140 209 155 109 184 162 152 155 167 158 269 222
354 272 179 233 170 192 234 288 283 234 336 119 113 125 90 100 113 143 135 143
136 123 170 290 312 285 272 310 209 284 200 235 195 176 177 222

ASH-S22A 75
495 288 404 500 330 235 407 457 376 311 231 337 248 208 215 250 242 259 416 183
160 156 187 145 86 82 100 138 106 108 120 106 126 97 247 276 232 229 226 237
210 250 151 229 339 248 208 267 154 120 133 104 104 224 233 145 175 183 153 234
369 238 205 312 393 311 195 146 323 200 149 172 364 280 175

ASH-S22B 75
492 294 366 517 334 229 402 440 365 317 233 325 262 211 213 265 246 257 410 185
180 134 184 151 85 75 102 151 96 117 115 107 131 97 243 281 228 233 229 239
208 257 149 225 341 252 209 267 150 120 127 117 93 231 229 147 152 181 148 234
379 237 205 309 397 308 203 152 325 215 165 179 361 207 153

ASH-S23A 53
397 528 440 306 361 282 273 329 333 274 260 274 218 238 153 194 183 262 286 219
151 140 196 182 116 146 158 135 182 162 163 107 81 95 188 153 192 154 186 184
196 130 118 169 92 171 136 219 342 419 328 414 302

ASH-S23B 53
391 535 431 307 369 306 273 316 331 268 251 266 206 224 149 198 186 248 275 219
152 132 203 184 117 146 152 130 181 160 159 111 79 99 183 158 187 160 185 179
192 142 124 148 96 167 137 212 352 392 335 427 320

ASH-S25A 50
257 374 360 328 80 99 64 97 158 189 186 217 267 287 278 260 346 282 332 340
321 359 359 402 365 261 319 312 325 344 327 323 339 296 249 242 302 205 297 253
275 214 279 290 323 383 369 407 329 252

ASH-S25B 50
210 321 294 323 74 112 59 107 151 195 212 223 275 291 265 237 334 272 312 384
343 348 367 386 373 265 320 310 332 341 325 347 331 293 249 245 295 205 302 246
277 215 278 294 321 379 381 405 335 239

ASH-S26A 46
230 250 300 267 312 303 270 396 364 320 353 271 318 265 300 327 342 422 288 433
327 344 361 252 283 344 308 215 226 196 154 122 72 69 41 50 41 36 28 36
64 123 111 120 104 90

ASH-S26A 46
229 261 294 245 306 308 255 390 370 324 374 294 304 261 302 327 337 428 295 427
306 346 359 252 281 350 315 192 214 193 176 155 95 62 41 54 42 34 31 38
63 106 115 120 99 88

ASH-S27A 61
256 218 299 211 185 228 219 291 244 263 260 245 322 315 385 220 286 211 180 273
274 231 169 309 228 226 226 119 110 49 64 30 16 23 28 48 54 56 93 103
73 68 43 67 130 118 114 120 124 166 200 158 150 127 171 174 178 269 340 199
156

ASH-S27B 61
252 227 311 218 178 221 224 289 222 266 257 251 324 334 312 236 306 230 208 264
269 234 171 301 201 234 216 126 106 50 63 27 18 25 30 58 59 61 98 103
81 70 46 84 125 114 108 117 121 156 190 149 140 137 181 173 179 281 330 219
160

ASH-S28A 63
65 87 107 148 58 54 137 158 231 179 215 174 183 128 110 71 87 90 91 98
76 94 115 113 113 137 202 237 170 186 143 141 164 186 234 165 195 190 225 227
138 143 196 146 111 108 90 89 70 62 47 39 39 32 37 31 27 54 75 68
53 71 82

ASH-S28B 63
77 94 102 135 56 55 139 154 232 187 209 177 188 120 110 65 89 95 85 101
76 89 113 118 105 133 201 241 171 207 121 146 162 185 233 166 204 179 231 226

136 149 190 147 109 111 89 89 68 52 43 50 42 29 35 32 32 54 55 66
51 64 99

ASH-S30A 44
202 212 240 165 79 136 159 246 266 189 194 126 168 162 157 108 118 131 125 161
182 150 100 102 118 124 96 131 163 186 134 159 145 129 116 79 109 81 135 127
90 108 107 137

ASH-S30B 44
242 220 231 159 86 135 159 240 263 177 204 147 170 147 140 116 122 131 125 154
185 150 119 93 114 125 101 129 170 183 141 152 151 128 127 92 114 74 150 130
96 102 94 107

ASH-S31A 51
164 254 215 207 177 186 166 107 107 141 132 142 128 88 57 52 71 142 181 185
194 161 183 152 168 140 136 142 164 178 133 117 117 100 110 134 141 151 166 135
144 149 139 146 116 106 119 95 128 120 125

ASH-S31B 51
161 260 211 204 167 177 149 94 109 136 124 146 121 82 59 51 75 142 167 184
203 166 178 157 168 138 132 139 176 176 137 120 112 106 115 139 114 131 150 135
146 152 146 134 111 97 99 85 110 119 126

ASH-S32A 48
296 234 237 269 164 226 182 219 227 166 165 159 169 110 108 116 148 233 207 147
160 134 172 160 205 153 155 168 165 169 116 139 128 122 131 169 142 133 163 152
165 130 146 119 138 134 173 187

ASH-S32B 48
316 227 260 276 165 247 208 225 231 161 175 146 144 116 105 113 155 232 206 150
159 134 174 160 206 156 150 172 166 174 115 141 128 129 127 167 145 141 168 149
170 124 156 113 141 144 173 131

ASH-S33A 75
419 301 283 585 430 382 269 312 340 261 216 377 222 219 242 169 157 98 145 144
157 148 137 110 96 51 82 101 154 198 206 172 142 155 128 113 131 118 150 142
127 133 142 161 138 124 167 119 160 144 146 131 135 118 107 107 82 94 108 173
116 90 73 70 83 58 41 66 49 72 68 56 53 57 72

ASH-S33B 75
391 330 332 591 434 404 276 297 338 266 219 397 221 210 236 172 161 89 136 154
150 156 137 103 95 59 81 106 148 197 210 181 140 155 120 117 120 125 159 135
110 138 144 165 136 124 171 120 164 148 140 135 132 130 98 107 83 96 115 174
109 90 75 76 76 61 48 60 58 65 71 50 50 59 69

ASH-S34A 122
324 268 246 348 348 218 399 426 238 248 137 126 141 138 118 117 233 183 283 285
165 122 132 148 150 106 128 243 300 275 149 127 77 117 156 251 211 239 238 252
246 156 109 66 83 128 154 127 121 190 283 252 231 172 98 148 99 54 68 98
120 136 217 134 130 124 123 139 117 81 140 171 163 130 108 56 40 52 50 65
66 34 26 25 30 27 23 22 19 30 28 42 55 63 90 71 115 135 88 105

132 135 158 169 136 91 125 94 137 153 207 195 230 175 292 221 180 137 188 218
167 218

ASH-S34B 122
348 261 233 337 333 221 396 416 253 251 147 129 128 133 120 122 211 200 284 284
161 124 128 144 150 113 125 227 318 287 143 122 71 107 149 264 233 254 247 276
262 176 107 73 84 120 156 125 129 183 287 249 226 175 101 151 110 57 68 99
115 145 214 138 131 123 122 145 123 77 141 173 164 131 116 57 46 44 40 65
58 30 25 23 31 27 24 20 24 24 26 38 47 64 93 86 120 138 82 125
137 140 161 160 127 85 124 103 136 148 195 197 236 187 294 225 201 142 183 219
176 204

ASH-S35A 57
460 421 689 645 520 577 498 617 461 494 433 433 516 447 401 478 435 470 464 342
397 345 378 249 186 201 210 178 158 195 188 169 171 262 204 196 147 208 200 186
183 199 203 215 199 224 199 252 232 243 220 224 215 200 184 193 267

ASH-S35B 41
403 325 375 310 332 214 163 218 229 153 121 177 182 179 137 240 188 178 148 201
214 196 191 217 229 226 192 224 208 239 221 236 205 193 199 186 184 194 256 199
117

ASH-S36A 84
205 294 280 234 271 172 170 253 224 267 241 203 104 119 148 131 219 144 206 120
139 124 156 155 176 149 158 110 150 125 143 217 144 88 95 116 112 99 79 66
111 151 155 184 118 126 194 151 102 129 131 101 112 119 130 80 132 117 68 33
56 67 57 34 64 62 63 64 76 96 60 76 79 83 121 141 132 128 110 150
80 88 126 141

ASH-S36B 84
206 294 287 255 261 171 167 234 211 271 244 201 103 122 143 135 219 153 202 132
132 122 159 162 171 152 156 120 142 129 137 211 147 97 94 117 123 89 85 73
115 165 171 183 122 117 191 148 102 139 120 100 111 121 122 81 133 120 60 41
47 67 61 35 59 65 63 63 72 97 59 75 71 91 118 147 133 131 108 149
81 91 125 132

ASH-S37A 88
239 203 213 238 229 257 166 204 213 221 186 176 186 286 198 202 172 174 96 108
88 74 123 124 177 113 118 99 172 128 120 96 94 72 137 118 117 141 124 83
78 83 102 90 84 78 143 147 160 200 139 129 233 183 128 153 162 150 165 177
165 111 157 153 79 39 82 107 80 60 81 95 126 108 93 106 80 125 98 116
177 163 137 111 123 145 97 88

ASH-S37B 88
248 194 217 239 229 258 166 200 215 219 186 176 206 291 192 198 188 176 113 119
132 108 202 175 250 124 127 96 176 163 154 114 113 64 119 109 117 152 127 91
80 94 109 79 76 77 124 119 132 154 96 110 198 177 125 140 140 149 155 160
186 107 144 165 83 43 91 88 98 51 83 99 114 106 89 101 71 115 95 117
173 184 129 115 126 149 92 86

ASH-S38A 72
201 195 196 177 191 110 329 360 318 383 588 338 335 400 327 237 133 140 219 166
109 141 172 121 97 122 145 181 165 133 78 71 95 70 91 68 59 88 119 130
138 138 228 214 299 235 122 154 129 149 212 154 84 82 139 117 122 169 217 250
255 107 145 126 195 280 265 354 394 269 308 299

ASH-S38B 72
228 188 194 175 188 111 330 392 319 371 548 311 334 378 293 203 143 150 211 154
115 133 173 126 96 117 151 181 162 133 75 71 99 65 90 58 54 95 110 137
126 143 223 210 187 222 115 159 129 162 207 149 81 80 140 119 132 184 225 246
259 90 150 128 182 279 257 340 440 267 274 219

ASH-S39A 61
669 540 466 442 343 336 228 184 274 484 297 306 373 181 166 317 245 365 368 218
136 94 128 82 125 84 64 108 149 160 221 214 296 182 229 319 200 420 242 250
307 221 73 73 124 101 132 170 167 209 210 79 119 143 126 147 275 336 370 273
353

ASH-S39B 61
700 557 469 453 348 350 232 170 279 466 299 303 394 193 176 344 245 365 372 222
136 102 135 74 126 81 67 101 142 162 221 217 275 175 243 318 225 429 248 250
291 221 80 83 108 99 137 174 143 211 198 69 142 128 120 145 252 321 390 263
339

ASH-S40A 57
341 427 360 257 472 225 239 334 234 212 133 124 242 385 338 412 484 235 217 412
228 230 240 206 163 128 151 160 206 132 118 206 257 249 224 344 308 280 224 323
236 287 184 281 382 449 286 309 366 416 447 440 418 587 461 211 291

ASH-S40B 57
321 433 358 251 485 219 250 332 230 202 126 129 238 391 337 408 474 248 214 426
232 245 257 214 159 127 142 155 199 135 114 204 255 245 220 315 330 298 214 334
223 290 193 280 387 450 292 325 374 394 432 434 445 604 454 204 295

ASH-S42A 69
361 274 293 240 301 314 279 376 409 362 251 329 125 77 47 40 60 60 87 98
123 165 148 149 221 249 231 107 64 56 63 87 110 102 134 129 143 148 173 177
193 206 220 234 328 292 244 185 206 157 96 85 85 108 130 96 112 132 135 141
146 132 137 146 150 135 145 218 114

ASH-S42B 69
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121 178 151 163 233 246 207 117 65 50 67 86 116 105 130 127 149 155 179 171
182 220 228 244 326 276 243 187 224 191 90 87 82 128 138 111 115 143 125 152
194 133 130 163 137 126 166 217 131

ASH-S43A 76
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291 268 143 115 178 216 255 224 324 173 197 237 133 100 88 154 321 380 256 243
196 150 122 253 288 372 336 289 136 210 273 297 314 276 190 180 249 119 59 71

75 71 86 136 92 140 117 95 109 125 105 75 79 63 85 95

ASH-S43B 76
94 92 100 99 110 176 175 166 184 171 201 216 148 204 214 280 316 291 338 251
284 273 135 120 180 220 253 223 326 170 196 241 123 94 93 159 316 378 268 237
194 151 123 239 289 374 324 295 140 203 264 285 318 282 184 190 253 117 68 74
74 66 88 124 95 142 120 90 117 118 96 76 78 65 84 96

ASH-S44A 67
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266 159 138 242 225 288 229 208 129 165 206 158 253 185 197 305 329 289 260 299
332 310 316 264 286 284 266 262 235 249 98 54 115 159 174 217 274 219 228 226
351 349 248 92 128 232 221

ASH-S44B 67
249 270 338 261 168 174 296 220 387 344 340 348 347 220 112 151 211 200 157 187
262 159 142 236 236 277 235 202 127 160 203 164 263 181 198 309 326 281 265 301
342 312 318 269 279 281 264 268 227 254 103 52 113 153 184 192 280 206 225 233
353 350 240 94 111 245 177

ASH-S45A 46
132 193 185 191 224 202 177 226 168 188 216 169 184 191 158 153 86 79 122 162
94 160 160 205 157 166 131 85 148 101 185 151 204 273 314 157 228 229 172 152
135 76 164 153 129 189

ASH-S45B 46
107 189 192 189 225 206 194 242 166 200 217 174 176 199 159 158 85 78 122 164
92 162 157 206 157 177 133 99 147 98 183 157 209 284 310 158 235 232 170 155
136 68 173 155 125 176

ASH-S46A 68
527 385 405 515 324 417 489 400 490 565 582 683 633 563 378 312 306 252 364 392
478 425 340 391 367 240 283 286 225 243 228 206 170 120 140 216 230 246 225 251
264 288 196 156 172 86 174 155 221 288 389 281 288 303 258 221 203 139 202 240
226 207 143 181 268 207 164 151

ASH-S46B 68
524 359 394 599 321 406 491 384 487 552 591 664 618 565 387 314 298 255 365 393
475 420 342 391 376 245 269 280 212 241 237 201 179 120 147 222 222 266 228 247
269 276 201 155 183 101 173 162 214 288 384 283 286 309 257 226 209 127 201 240
227 207 141 192 255 208 165 162

ASH-S47A 58
315 295 295 282 304 331 285 180 129 200 166 225 268 382 345 353 332 290 341 315
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175 175 140 135 152 102 72 101 154 156 185 164 202 162 128 125 94 111

ASH-S47B 58
299 298 308 291 331 306 300 168 134 205 166 222 273 406 343 337 342 278 320 300
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ASH-S48A 55
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274 405 376 236 173 101 233 272 217 245 186 247 310 215 168

ASH-S48B 55
466 359 294 269 333 350 486 430 370 480 285 354 352 251 286 266 216 221 152 208
132 91 146 189 200 268 214 290 264 263 172 117 166 119 177 192 263 305 451 246
278 395 374 225 184 107 249 269 212 248 182 248 311 214 173

ASH-S49A 45
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333 317 298 236 261

ASH-S49B 45
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198 220 203 225 236 222 195 253 214 235 263 304 337 285 323 270 268 278 274 252
336 315 297 238 265

ASH-S51A 85
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83 77 62 86 58 108 94 112 84 71 78 75 73 99 100 112 106 69 63 46
61 61 74 72 40

ASH-S51B 85
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56 63 77 78 44

ASH-S52A 82
231 296 339 297 184 210 145 75 59 82 149 180 285 277 211 213 290 237 245 279
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263 261 175 131 160 185 219 172 163 228 206 231 168 112 93 104 124 138 166 154
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197 149

ASH-S52B 77
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ASH-S53A 47
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ASH-S53B 47
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277 362 346 290 245 263 230

ASH-S54A 68
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ASH-S54B 68
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172 158 159 131 132 139 140 202

ASH-S55A 87
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102 69 50 70 124 157 107

ASH-S55B 87
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66 69 102 110 105 104 80 73 137 158 91 74 126 110 102 89 75 121 108 76
103 68 51 71 125 156 106

ASH-S56A 93
278 339 285 281 304 251 208 188 128 83 30 47 121 220 254 226 208 273 443 405
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236 213 185 188 149 145 163 180 201 160 136 137 131 137 132 87 92 80 96 97
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112 83 126 128 114 161 167 156 206 132 85 109 87

ASH-S56B 93
278 343 287 279 307 252 202 191 125 77 35 39 130 219 258 223 207 276 443 402
395 403 354 247 199 254 239 282 231 252 213 192 216 275 285 221 217 194 198 204
239 211 188 186 152 148 154 181 204 162 133 137 132 135 134 88 93 79 96 97
115 163 132 184 203 173 171 149 125 128 137 128 114 126 87 62 68 67 97 94
113 84 127 129 63 161 163 155 209 130 85 111 83

ASH-S57A 90
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147 167 246 146 208 238 198 188 160 195 181 152 231 182 156 122 123 192 112 160

202 142 190 231 148 151 221 134 115 131 144 156 179 165 205 121 84 107 85 88
85 94 109 167 92 133 71 89 96 93 109 124 101 109 82 100 111 79 62 53
39 36 52 42 64 60 51 89 118 94

ASH-S57B 90
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85 97 118 175 91 135 69 90 96 96 107 123 100 109 81 100 112 78 64 52
38 37 52 42 64 60 52 89 117 93

ASH-S58A 50
116 113 110 175 185 212 182 158 174 187 146 167 177 143 141 160 159 171 151 127
132 92 121 126 128 133 165 186 146 118 88 92 118 53 66 87 127 107 142 141
70 107 99 96 59 135 168 136 172 152

ASH-S58B 50
91 119 108 168 203 209 156 160 175 180 151 143 183 146 143 143 162 164 148 115
135 90 116 122 126 133 165 181 143 125 89 99 112 55 78 101 120 98 138 145
67 108 108 97 59 137 164 138 171 147

ASH-S59A 44
100 141 136 120 186 159 140 171 120 133 120 112 91 85 97 116 82 78 119 61
97 71 63 84 62 65 69 85 89 105 203 186 85 112 127 134 96 70 65 64
62 113 152 140

ASH-S59B 44
106 150 125 124 194 164 144 167 131 121 121 117 94 87 103 120 79 62 115 68
94 70 72 79 63 63 71 85 88 105 199 185 87 111 128 134 96 69 65 64
65 113 148 146

ASH-S60A 49
113 120 154 129 173 174 201 177 80 67 83 59 123 146 189 196 103 88 101 127
154 222 254 146 64 99 122 161 121 104 118 132 127 159 171 179 112 110 108 161
130 96 101 148 126 51 66 84 109

ASH-S60B 49
95 128 173 148 176 161 206 173 95 71 86 63 118 145 207 197 96 80 95 119
151 220 246 150 58 97 122 169 108 113 116 132 121 173 158 172 114 107 111 161
126 97 104 134 132 47 68 85 106

ASH-S61A 77
218 202 179 239 221 153 178 181 236 224 206 204 156 148 184 73 95 123 146 116
184 178 238 194 210 166 181 228 121 115 84 115 112 153 103 100 134 125 127 153
121 178 190 96 113 107 100 135 111 99 132 143 146 124 97 103 67 60 87 88
82 64 75 65 57 58 51 69 92 67 102 101 80 48 40 64 71

ASH-S61B 79
224 193 181 241 224 149 178 190 235 223 208 203 157 149 181 75 93 108 148 117
186 181 245 189 185 160 182 233 120 114 76 110 117 158 101 110 128 121 125 157
117 168 200 85 109 110 97 139 105 104 137 125 138 126 95 103 70 60 88 90

83 65 78 60 56 63 51 64 94 70 100 97 86 46 40 69 66 52 54

ASH-S62A 47
212 277 380 418 357 405 344 363 331 367 295 313 289 220 276 311 317 187 200 159
143 146 141 101 108 145 166 174 122 90 104 101 77 103 104 138 119 87 104 82
87 102 141 125 145 171 169

ASH-S62B 47
214 255 365 351 366 407 344 360 325 366 301 313 287 226 275 319 319 188 195 159
139 148 141 108 103 154 172 167 115 96 104 101 79 104 105 129 114 92 107 75
90 103 140 123 143 171 170

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

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.

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.

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).

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 (i.e. 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).

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; e.g. 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).

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, 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.

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 (e.g. Baltic boards), then some allowance has to be made for this.

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.

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 AD 1810 is very apparent as is the smaller later growth from about AD 1900 onwards when the tree is maturing. A similar phenomenon can be observed in the lower sequence of (a) starting in AD 1835. In both the widths are also changing rapidly from year to year. The peaks are the wide rings and the troughs are the narrow rings corresponding to good and poor growing seasons, respectively. The two-corresponding sequence of Baillie-Pilcher indices are plotted in (b) where the differences in the immature and mature growths have been removed and only the rapidly changing peaks and troughs remain, that are associated with the common climatic signal. This makes cross-matching easier.

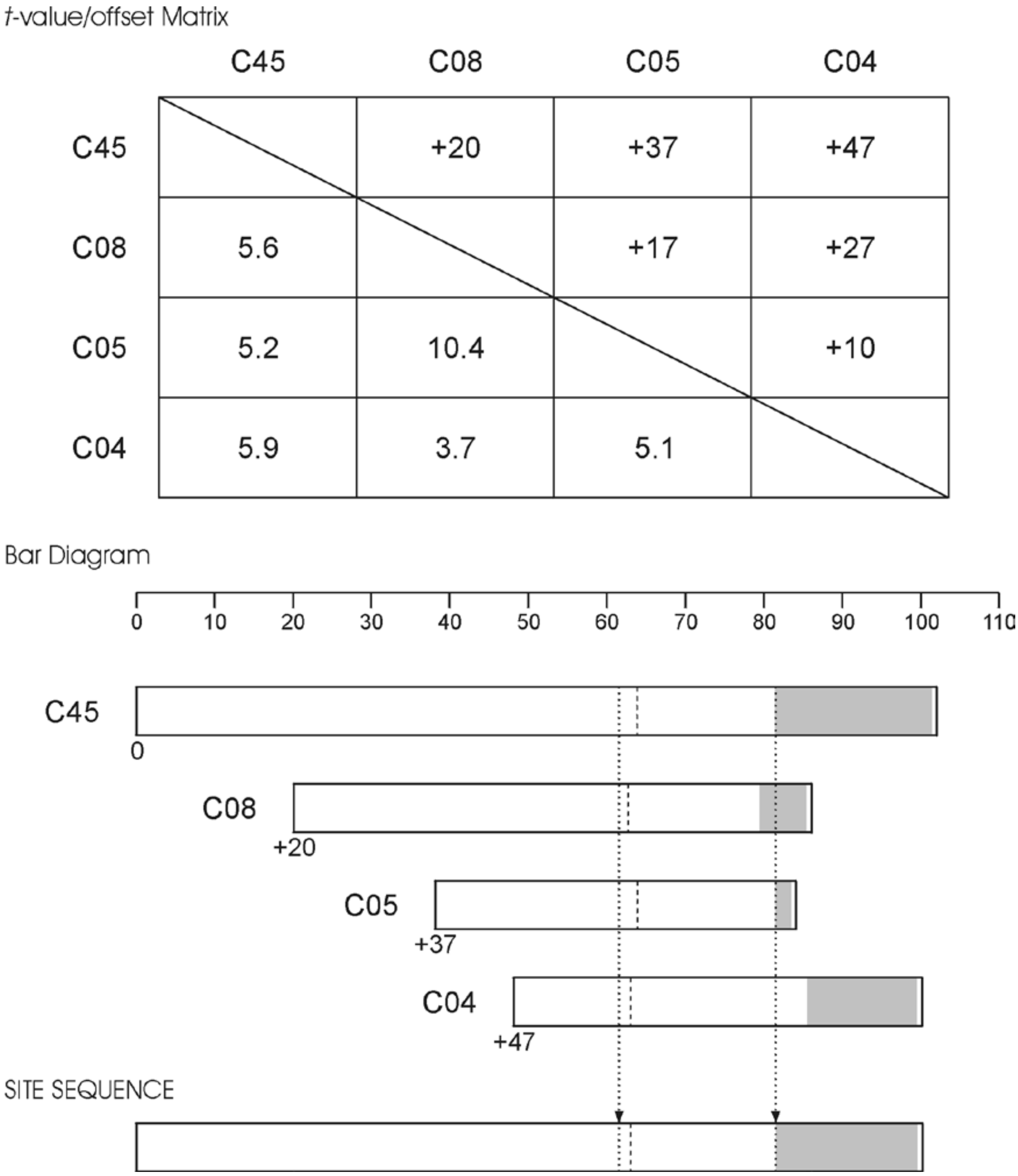


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them. The bar diagram represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set at relative positions (offsets) to each other at which they have maximum correlation as measured by the *t*-values. The *t*-value/offset matrix contains the maximum *t*-values below the diagonal and the offsets above it. Thus, the maximum *t*-value between C08 and C45 occurs at the offset of +20 rings and the *t*-value is then 5.6. The site sequence is composed of the average of the corresponding widths, as illustrated with one width.

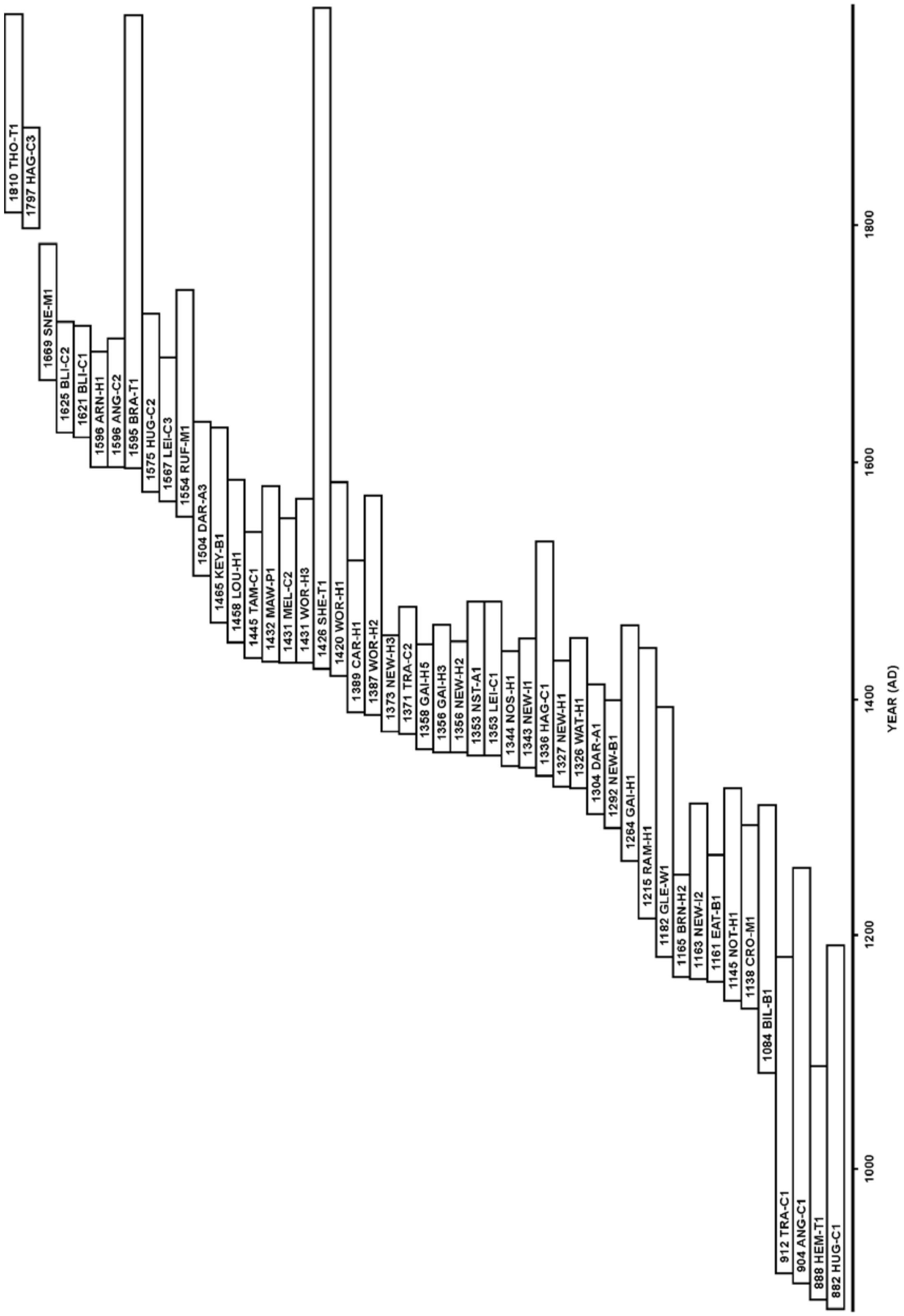
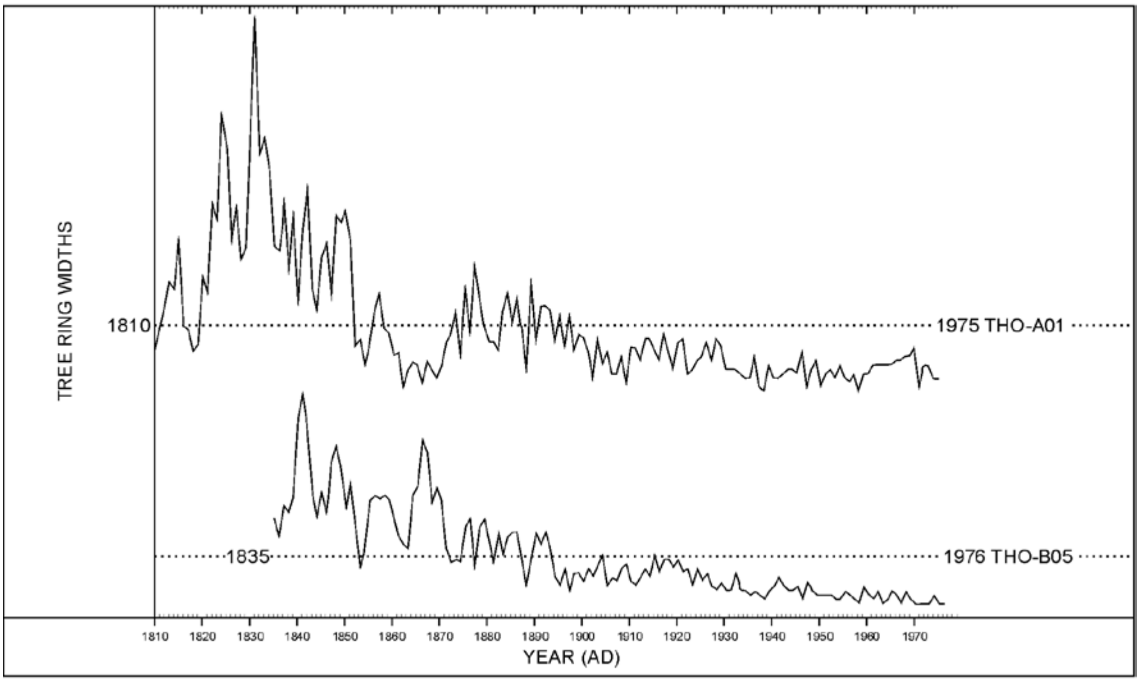


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

(a)



(b)

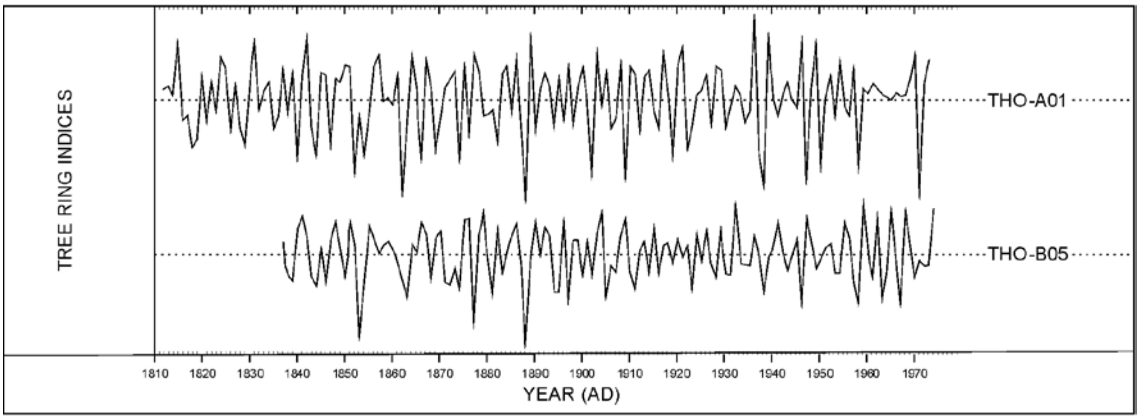


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young 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.

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