RESEARCH REPORT SERIES no. 40-2012

CHURCH OF ST PETER, WEST LISS, HAMPSHIRE
TREE-RING DATING OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

INTERVENTION
AND ANALYSIS

ENGLISH HERITAGE

Research Report Series 40-2012

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NGR: SU 77051 28679

ISSN 2046-9799 (Print)
ISSN 2046-9802 (Online)

SUMMARY

Tree-ring analysis was undertaken on samples from the roofs of the nave, south aisle, and porch at this church resulting in the dating of a single site sequence. Site sequence LSSASQ01 contains 14 samples and spans the period AD 1546–1614.

The five dated timbers from the nave roof comprise three rafters from the east end of the roof felled *c* AD 1616 and two reused collars, also from the east end, felled in the period AD 1581–1606. Eight dated timbers from the south aisle roof, including six rafters and two collars, were all probably felled during the period AD 1605–40. In addition the timber removed during repairs, which supported the valley gutter has an estimated felling date range of AD 1581–1606. Four other site sequences remain undated but one of these demonstrates that there are reused timbers from the nave and aisle roofs that are coeval with non-reused rafters from the nave, whilst another shows that at least five of the backing rafters in the nave roof represent a single felling episode.

CONTRIBUTORS

Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS

The Laboratory would like to thank Simon Goddard and Paul Taylor, both of The Goddard Partnership, for facilitating access and for their assistance whilst sampling was being undertaken. Thanks are also given to Dr John Crook for his on-site advice and for allowing us use of his drawings. Peter Marshall and Cathy Tyers of the Scientific Dating Team at English Heritage were, as always, extremely helpful throughout this study.

ARCHIVE LOCATION

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DATE OF INVESTIGATION

2012

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INTRODUCTION

The Church of St Peter, situated some 5km north-east of Petersfield and about 29km east of Winchester, in the village of West Liss (Figs 1–3), is a Grade II* listed building. It is believed that there has been a church on this site since sometime after AD 900. The foundations of the tower are Saxon though it is mainly of early thirteenth-century date, as are the nave and chancel. The south arcade, aisle and south door date from the late-thirteenth century, whilst the south porch was built in AD 1639. There is a seventeenth-century window at the west end of the south aisle. The chancel was restored in AD 1864 at the same time as the north organ chamber/vestry was added.

Nave

The roof consists of 19 frames of common rafters with collars, and arch braces. At some point 'backing rafters' have been attached to the rear of the common rafters on the south side, presumably for strengthening purposes (Fig 4). Some of the timbers are thought to be reused. This roof is thought to date from the early thirteenth century.

South Aisle

The construction of this roof is similar to that of the nave, with each of the 26 frames again consisting of common rafters, collars, and arch braces (Fig 5). Some of these rafters also have the strengthening 'backing rafters and higher 'modern' collars. Some of the rafters show signs of reuse in the form of empty mortices. This roof is believed to be late-thirteenth century in date.

Porch

This very simple roof has six frames of common rafters and collars. The seventh (most northernmost frame) also has a tiebeam with empty mortices from which arch braces may have once run to now removed posts (Fig 6). The south porch has an inscribed date of '1639' commemorating its gift by Henry James.

SAMPLING

The Church of St Peter was at the time of sampling being re-roofed with grant-aid from English Heritage under the Places of Worship Scheme. Dendrochronological analysis was requested by Robert Williams, English Heritage Historic Buildings Architect, to inform these repairs. The removal of the timbers supporting the valley gutter revealed a rare moulded stone valley gutter beneath (Fig 7). It was hoped that by providing dates for the nave and south aisle roofs, and hence elucidating their historical development, a date for this rare feature could be obtained by association. In addition it was hoped to provide support for the 1639 date ascribed to the Porch.

A total of 49 core samples and one sliced sample were obtained from timbers from these three roofs. Each sample was given the code LSS-A (for Liss, site 'A') and numbered 01–50. Twenty-three of these are from the nave roof (LSS-A01–23), 18 from the south aisle roof (LSS-A24–41), one from the *ex-situ* timber (LSS-A42), and eight from the porch roof (LSS-A43–50). The location of all cored samples was noted at the time of sampling and has been marked on Figures 8–43. The frames in the nave and south aisle were numbered from east to west, whilst those in the porch were numbered from north to south. Further details relating to the samples can be found in Table 1.

ANALYSIS AND RESULTS

Ten of the samples, three from the nave (all backing rafters) and seven from the south aisle roof (four rafters and three reused rafters), were found to have too few rings for secure dating and so were discarded prior to analysis. The remaining 40 samples were prepared by sanding and polishing and their growth ring-widths measured; the data of these measurements are given at the end of the report. These samples were then compared with each other by the Litton/Zainodin grouping procedure (see Appendix), resulting in 34 samples matching to form five groups.

Firstly, 14 samples matched each other and were combined at the relevant offset positions to form LSSASQ01, a site sequence of 151 rings (Fig 44). This site sequence was compared against a series of relevant reference chronologies where it was found to match consistently and securely at a first-ring date of AD 1464 and a last-measured ring date of AD 1614. The evidence for this dating is given in Table 2.

A further 11 samples matched each other and were combined at the relevant offset positions to form LSSASQ02, a site sequence of 99 rings (Fig 45). This site sequence was compared against a series of relevant reference chronologies for oak but no conclusive matching could be found and it therefore remains undated.

Five samples were grouped and combined to form LSSASQ03, a site sequence of 63 rings (Fig 46). Attempts to date this site sequence against the reference chronologies were unsuccessful and again the site sequence remains undated.

Two samples grouped and were combined to form LSSASQ04, a site sequence of 76 rings (Fig 47). This site sequence could not be matched and is undated.

Finally, two further samples matched and were combined to form LSSASQ05, a site sequence of 70 rings. This site sequence is also undated.

Attempts to date the remaining ungrouped samples by individually comparing them against the reference chronologies were unsuccessful and all are undated.

INTERPRETATION

The interpretation of the dated timbers from LSSASQ01 is presented below by roof area and all felling date ranges have been calculated using the estimate that mature oak trees from this region have between 15 and 40 sapwood rings.

However the undated site sequences also provide some potentially useful relative dating information. Site sequence LSSASQ02 comprises eight rafters from the nave roof, thought to be primary at the time of sampling, and one collar from the nave roof, thought to be reused, as well as two rafters from the south aisle also thought to be reused. These 11 timbers all appear likely to be broadly coeval. Site sequence LSSASQ03 comprises five backing rafters from the nave roof, four of which have bark edge and were clearly felled in the same year. The fifth backing rafter also appears likely to have been felled at the same time. Site sequence LSSASQ04 demonstrates that two collars from the porch roof are likely to be coeval, and LSSASQ05 that both rafters from frame 3 are clearly broadly coeval.

Nave

Five of the timbers sampled from the nave roof have been successfully dated.

Two collars, both thought to be reused at the time of sampling, have similar heartwood/sapwood boundary ring dates, the average of which is AD 1566. This allows an estimated felling date range to be calculated for the two timbers represented of AD 1581–1606

Three rafters, thought to be primary at the time of sampling, have slightly later heartwood/sapwood boundary ring dates, the average of which is AD 1600. This allows an estimated felling date range to be calculated for these timbers of AD 1615–40. However, two of these samples, LSS-A02 and LSS-A03 were taken from timbers which had complete sapwood but unfortunately, some of these softer outer rings were lost during the sampling process, about 3mm from LSS-A02 and 4mm from LSS-A03. This equates to about 3 rings and 4 rings, respectively, giving both timbers a felling date of *c* AD 1616, and hence it is likely that all three timbers were felled in *c* AD 1616.

South Aisle

Eight of the timbers sampled from this roof have been successfully dated, all of which were believed to be primary at the time of sampling.

Five rafters have the heartwood/sapwood boundary, the average of these is AD 1600, giving an estimated felling date range for the five timbers represented of AD 1615–40. The three rafters without the heartwood/sapwood boundary ring date have last-measured heartwood dates of AD 1531 (LSS-A31), AD 1545 (LSS-A33), and AD 1562 (LSS-A34) which would make it possible that they were also felled in AD 1615–40. In view of the fact that these three samples match extremely well against sample LSS-A28, at values of *t*=9.3, 9.5, and 10.1 respectively, it appears likely that they were felled at the same time as the other rafters in the first half of the seventeenth century.

Nave/South Aisle

The sample taken from the timber which once supported the valley gutter has a heartwood/sapwood boundary ring date of AD 1566, giving the timber represented the felling date range of AD 1581–1606.

DISCUSSION

Prior to tree-ring analysis being undertaken the nave roof was thought to date to the early thirteenth century with the south aisle roof dating to the late-thirteenth century. Unfortunately it has not been possible to positively identify any thirteenth-century timbers from either of these two roofs, though clearly many sampled timbers remain undated.

Two fellings have been identified from the five dated timbers of the nave roof. The earlier of these relates to two reused collars which are now known to have been felled in AD 1581–1606. The three dated rafters, thought to be primary when sampled, have been dated to *c* AD 1616. All five of these dated timbers are from frames 2, 3, and 4 at the east end of the roof. A detailed structural survey of the nave roof may be required in order to understand whether the felling date obtained for the apparently primary rafters is representative of a small scale repair to the east-end of the nave roof in the early seventeenth century using some reused timbers, or whether these few dated timbers are representative of a larger phase of building works.

The majority of the dated timbers of the south aisle roof, six rafters and two collars that appeared primary at the time of sampling, were felled in AD 1615–40. This encompasses the *c* AD 1616 date for the three dated rafters in the nave roof and it is therefore possible that these timbers also date to *c* AD 1616. The dating of all eight measured timbers from the south aisle roof suggests that this roof was constructed in the first half of the seventeenth century and potentially shortly after felling in *c* AD 1616.

The timber which supported the valley gutter between the nave and south aisle roofs has been dated to AD 1581–1606 and is hence clearly broadly coeval with reused collars from the nave roof.

By association with the south aisle roof the unusual stone valley gutter it is suggested that this is pre *c* AD 1616 but it is not possible to conjecture how much earlier this could have been due to the lack of significantly earlier timbers being identified in either the nave or south-aisle roofs.

Unfortunately, it has not been possible to provide any dating evidence for the insertion of the backing rafters in the nave roof, nor has it been possible to either confirm or refute the 1639 date ascribed to the porch roof.

It is disappointing that none of the other site sequences have been dated, especially in the case of LSSASQ02 and LSSASQ03 which are both quite well replicated and of a reasonable length. It may be that the trees used in the construction of these roofs experienced highly localised growing conditions, such as woodland management, disease, or other environmental factors which have affected the growth pattern, masking the climatic signal necessary for successful matching against the reference material. There is a noticeable dip in growth rate shown by all 11 samples towards the middle of site sequence LSSASQ02 but this is not so pronounced as to be expected to strongly adversely affect the chances of successful dating. Alternatively, it may be that the period to which these timbers belong is not well represented within the reference data in Hampshire.

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TABLES

Table 1: Details of tree-ring samples from the Church of St Peter, West Liss, Hampshire

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Nave: primary timbers						
LSS-A01	South rafter, frame 2	69	13	1546	1601	1614
LSS-A02	South rafter, frame 3	67	15c(+*c*3lost)	1547	1598	1613
LSS-A03	South rafter, frame 4	70	11c(+*c*4lost)	1543	1601	1612
LSS-A04	North rafter, frame 5	74	h/s	----	----	----
LSS-A05	South rafter, frame 5	80	h/s	----	----	----
LSS-A06	North rafter, frame 6	60	h/s	----	----	----
LSS-A07	North rafter, frame 12	71	h/s	----	----	----
LSS-A08	North rafter, frame 14	48	--	----	----	----
LSS-A09	North rafter, frame 15	70	h/s	----	----	----
LSS-A10	North rafter, frame 17	61	--	----	----	----
LSS-A11	North rafter, frame 18	49	08	----	----	----
LSS-A12	North rafter, frame 19	67	h/s	----	----	----
Nave: reused						
LSS-A13	Collar, frame 2	117	10	1464	1570	1580
LSS-A14	Collar, frame 3	86	h/s	1476	1561	1561
LSS-A15	Collar, frame 11	69	h/s	----	----	----
Nave: backing rafters						
LSS-A16	Frame 2	NM	--	----	----	----
LSS-A17	Frame 3	51	17C	----	----	---
LSS-A18	Frame 4	49	11	----	----	----
LSS-A19	Frame 5	NM	--	----	----	----
LSS-A20	Frame 6	57	12C	----	----	----
LSS-A21	Frame 7	63	20C	----	----	----
LSS-A22	Frame 8	NM	--	----	----	----
LSS-A23	Frame 9	52	17C	----	----	----

South aisle: original timbers						
LSS-A24	South rafter, frame 22	54	01	1545	1597	1598
LSS-A25	South rafter, frame 5	51	h/s	1556	1606	1606
LSS-A26	Collar, frame 5	NM	--	----	----	----
LSS-A27	South rafter, frame 6	55	h/s	1549	1603	1603
LSS-A28	North rafter, frame 18	79	h/s	1517	1595	1595
LSS-A29	North rafter, frame 8	NM	--	----	----	----
LSS-A30	South rafter, frame 9	NM	--	----	----	----
LSS-A31	Collar, frame 15	56	--	1476	----	1531
LSS-A32	South rafter, frame 17	NM	--	----	----	----
LSS-A33	North rafter, frame 21	70	--	1476	----	1545
LSS-A34	North rafter, frame 23	93	--	1470	----	1562
LSS-A35	Collar, frame 25	82	h/s	1517	1598	1598
South aisle: reused						
LSS-A36	North rafter, frame 3	90	h/s	----	----	----
LSS-A37	North rafter, frame 4	99	h/s	----	----	----
LSS-A38	North rafter, frame 5	NM	--	----	----	----
LSS-A39	North rafter, frame 6	52	h/s	----	----	----
LSS-A40	North rafter, frame 12	NM	--	----	----	----
LSS-A41	North rafter, frame 14	NM	--	----	----	----
Nave/South aisle						
LSS-A42	Timber supporting valley gutter	107	14	1474	1566	1580
Porch						
LSS-A43	Tiebeam, frame 1	76	--	----	----	----
LSS-A44	Collar, frame 2	66	h/s	----	----	----
LSS-A45	East rafter, frame 3	56	--	----	----	----
LSS-A46	West rafter, frame 3	68	--	----	----	----
LSS-A47	Collar, frame 3	62	h/s	----	----	----
LSS-A48	Collar, frame 4	53	h/s	----	----	----
LSS-A49	East rafter, frame 5	45	h/s	----	----	----
LSS-A50	Collar, frame 6	60	05	----	----	----

*NM = not measured.

**h/s = the heartwood/sapwood boundary is the last measured ring on the sample.

c(+xlost) = complete sapwood on timber, part lost during sampling with estimated number of missing sapwood rings in brackets

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

Table 2: Results of the cross-matching of site sequence LSSASQ01 and relevant reference chronologies when the first-ring date is AD 1464 and the last-measured ring date is AD 1614

Reference chronology	*t*-value	Span of chronology	Reference
Hampshire county chronology	12.2	AD 443–1972	Miles 2003
Avebury Manor, Avebury, Wiltshire	10.2	AD 1393–1596	Arnold and Howard 2011
Chawton House, Chawton, Hampshire	8.5	AD 1289–1589	Miles and Worthington 2002
Dog Kennel Farm, Clarendon, Wiltshire	8.4	AD 1351–1603	Miles *et al* 2004
Granary, Wellesbourne, Warwickshire	8.4	AD 1431–1639	Miles and Haddon-Reece 1996
Newnham Hall Farm House, near Wallingford, Oxfordshire	7.8	AD 1412–1614	Arnold and Howard 2006 unpubl
Danny House, Hurstpierpoint, West Sussex	7.7	AD 1389–1589	Miles *et al* 2010
Yarde Farmhouse, Malborough, South Hams, Devon	7.5	AD 1432–1603	Arnold and Howard 2009

FIGURES

Figure 1: Map to show the general location of West Liss, Hampshire, circled. © Crown Copyright. All rights reserved. English Heritage 100019088. 2012

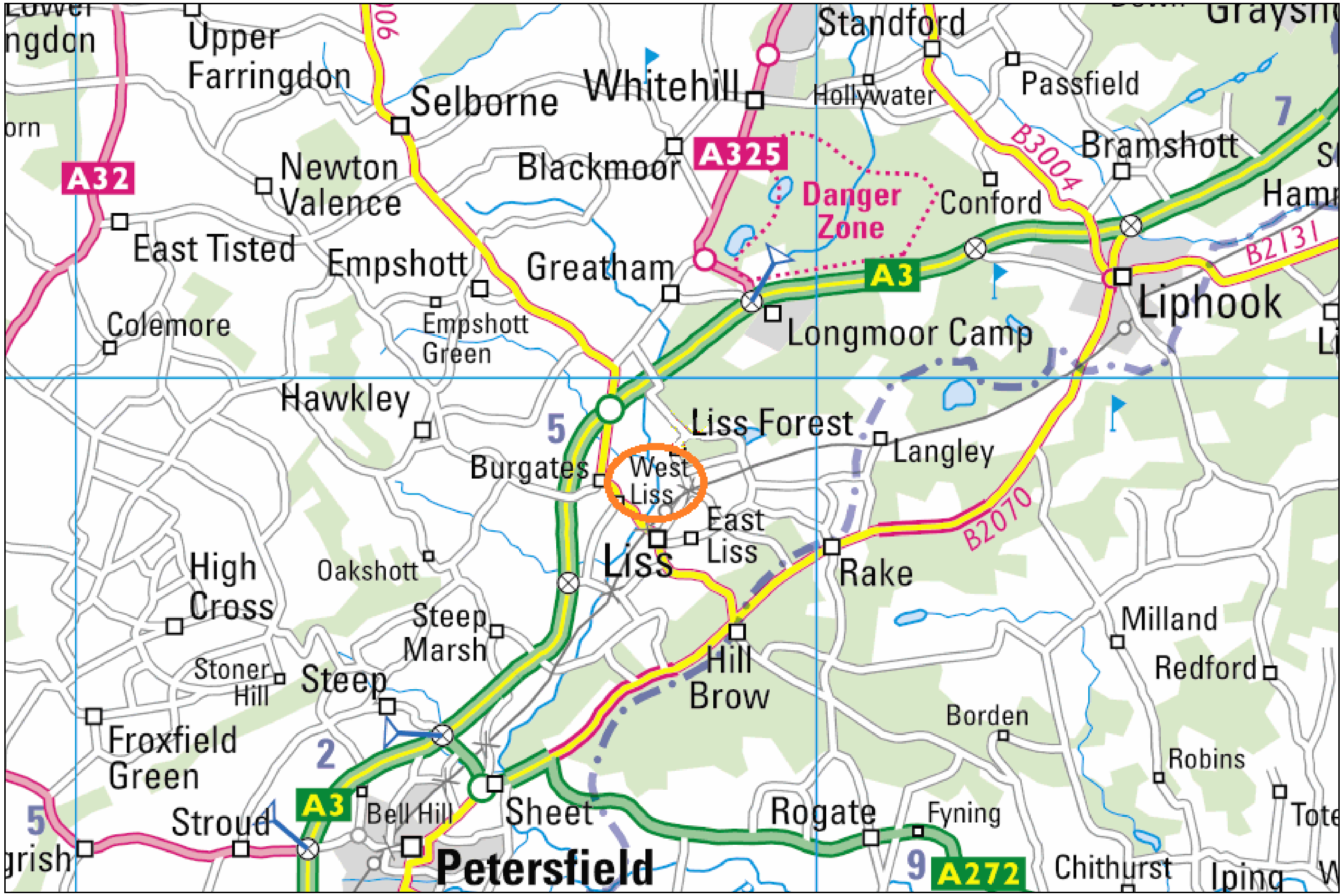

Figure 2: Map to show the location of West Liss, Hampshire, circled. © Crown Copyright. All rights reserved. English Heritage 100019088. 2012

Figure 3: Map to show the location of St Peter's Church, West Liss, hashed © Crown Copyright. All rights reserved. English Heritage 100019088. 2012

Figure 4: Nave roof showing the backing rafters (photograph taken from the south-east). Photograph Robert Howard

Figure 5: South aisle roof (photograph taken from the west). Photograph Robert Howard

Figure 6: Porch roof (photograph taken from the south). Photograph Robert Howard

Figure 7: Stone gulley between south aisle (to left) and nave (to right) roofs. Photograph Robert Howard

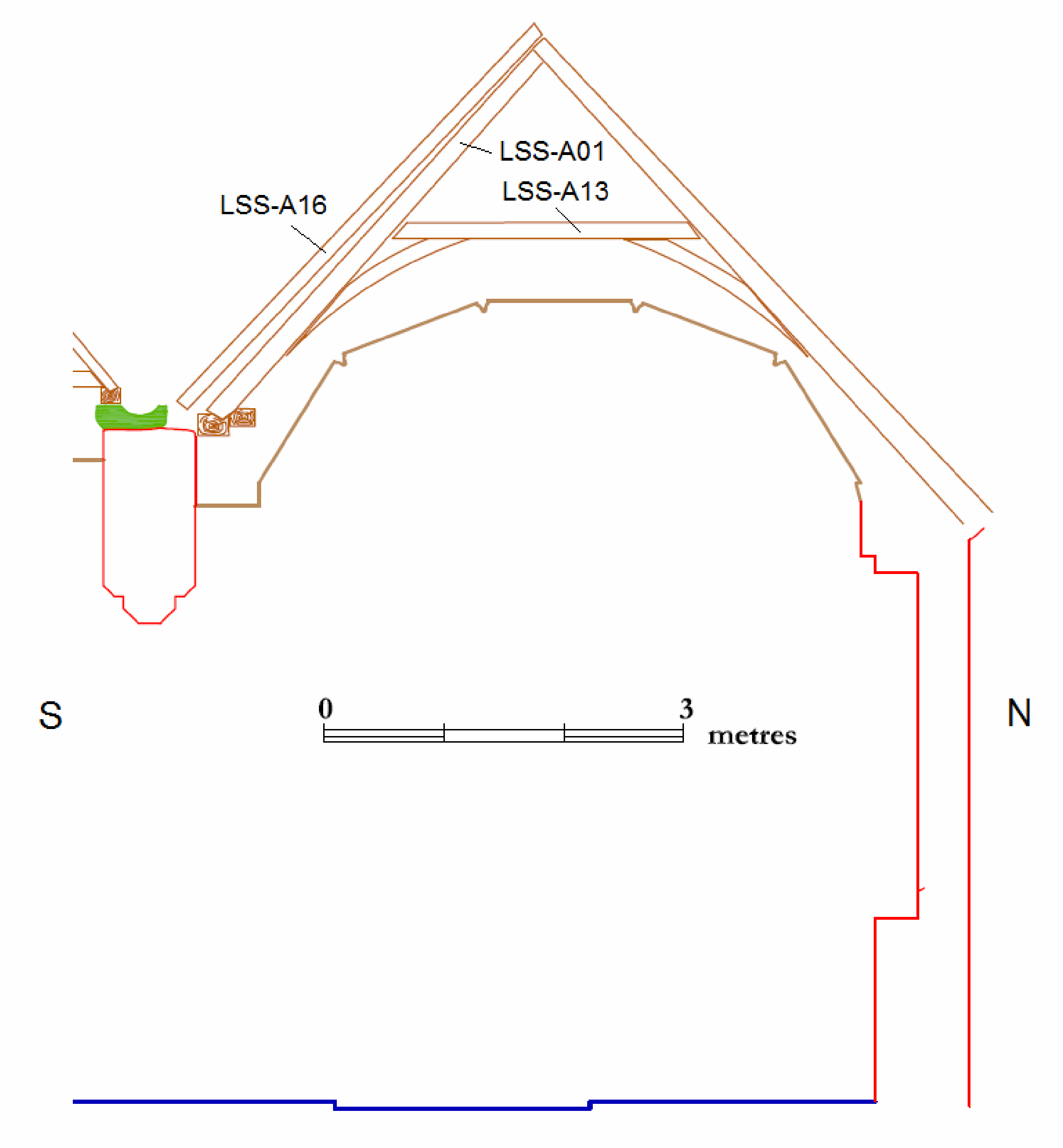

Figure 8: Nave; frame 2, showing the location of samples LSS-A01, LSS-A13, and LSS-A16 (John Crook)

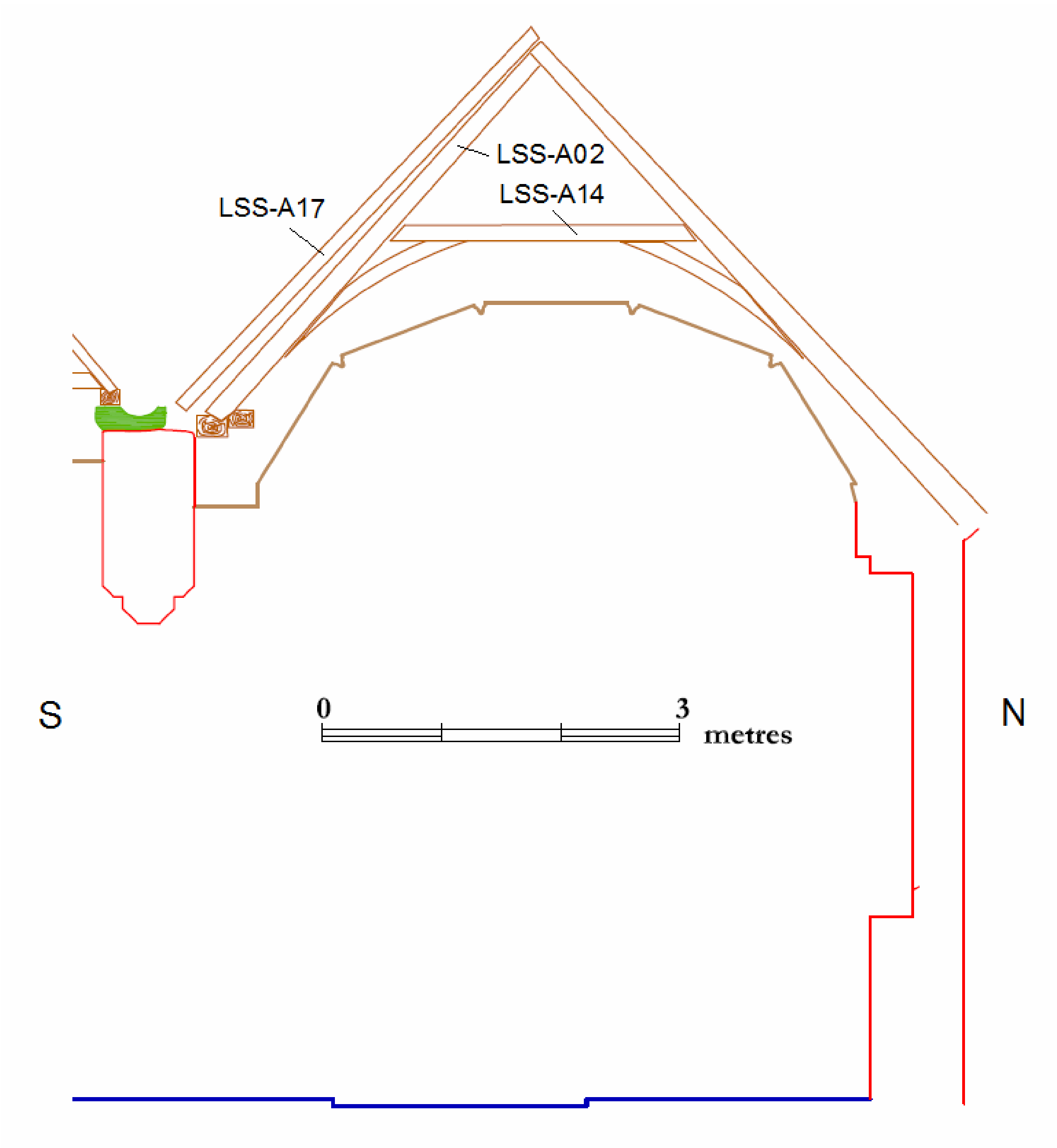

Figure 9: Nave; frame 3, showing the location of samples LSS-A02, LSS-A14, and LSS-A17 (John Crook)

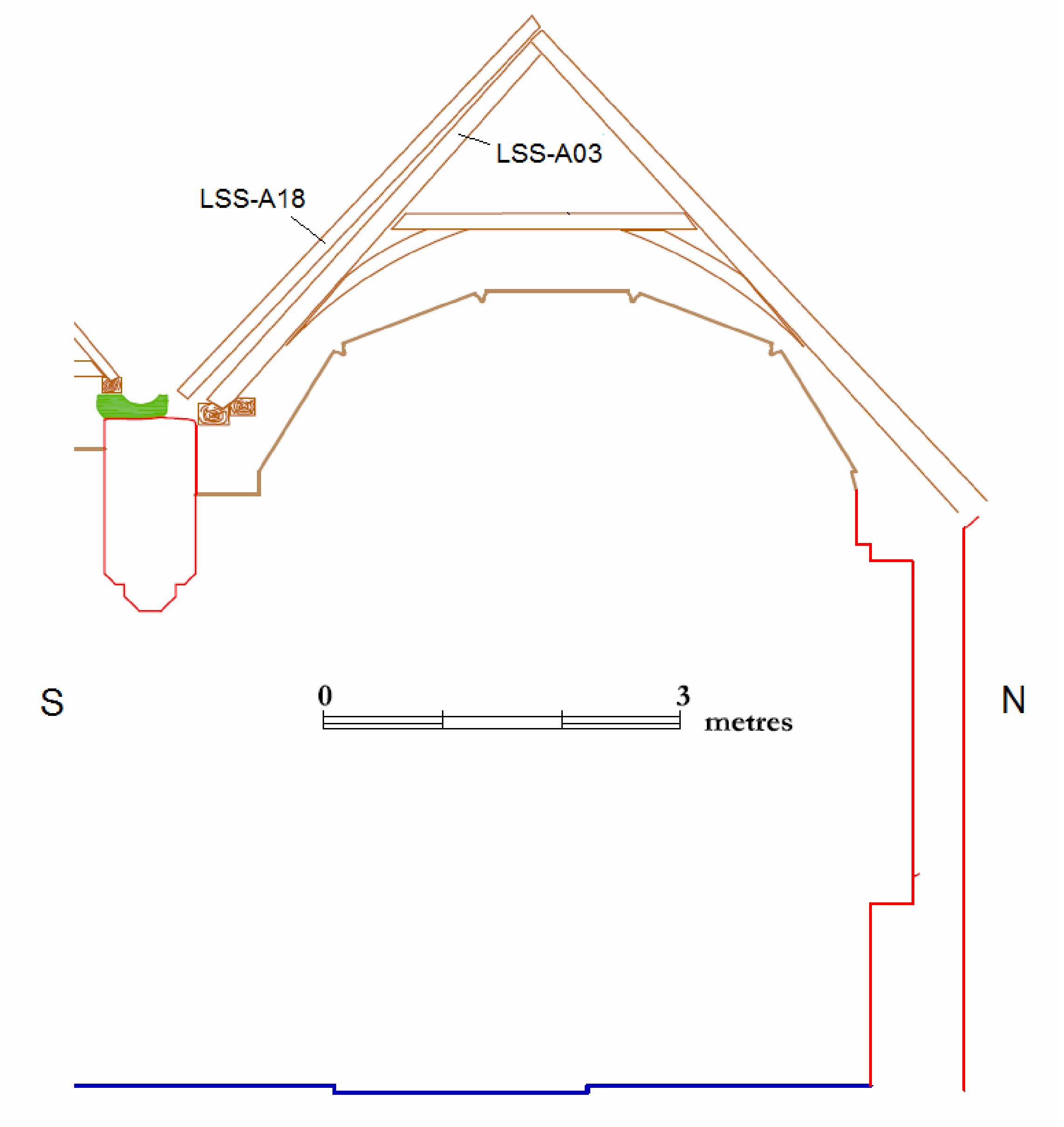

Figure 10: Nave; frame 4, showing the location of samples LSS-A03 and LSS-A18 (John Crook)

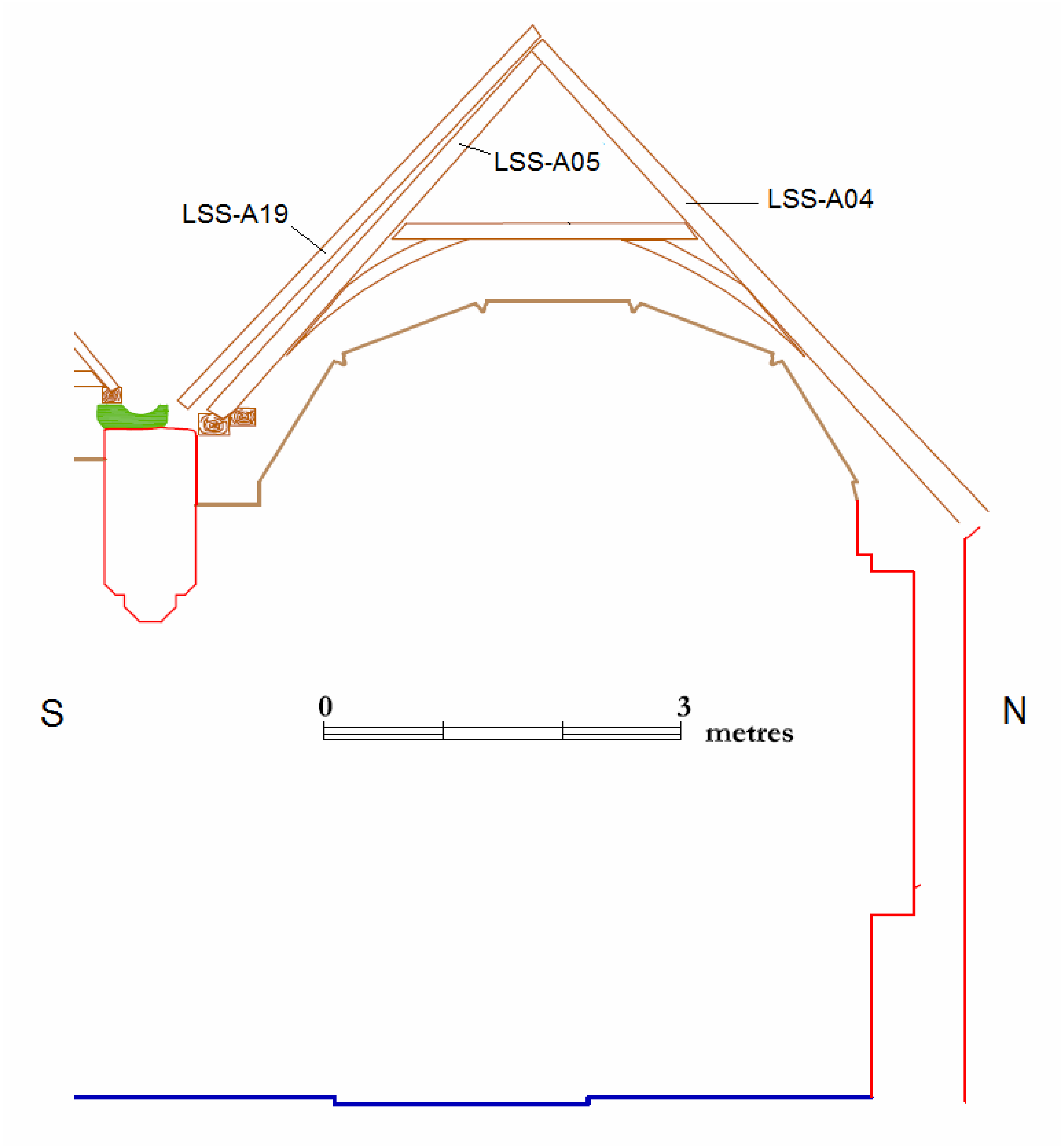

Figure 11: Nave; frame 5, showing the location of samples LSS-A04, LSS-A05, and LSS-A19 (John Crook)

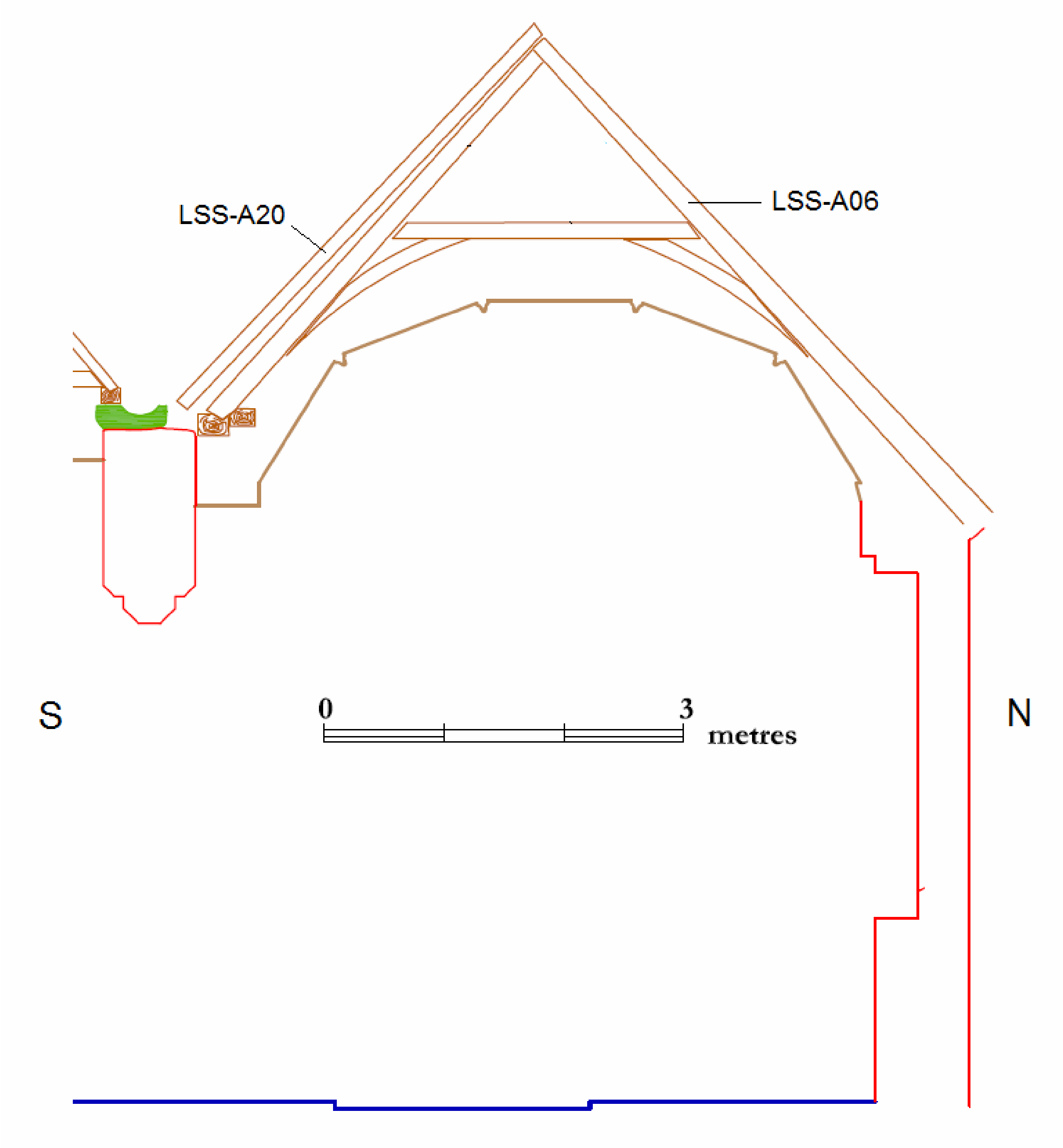

Figure 12: Nave; frame 6, showing the location of samples LSS-A05 and LSS-A20 (John Crook)

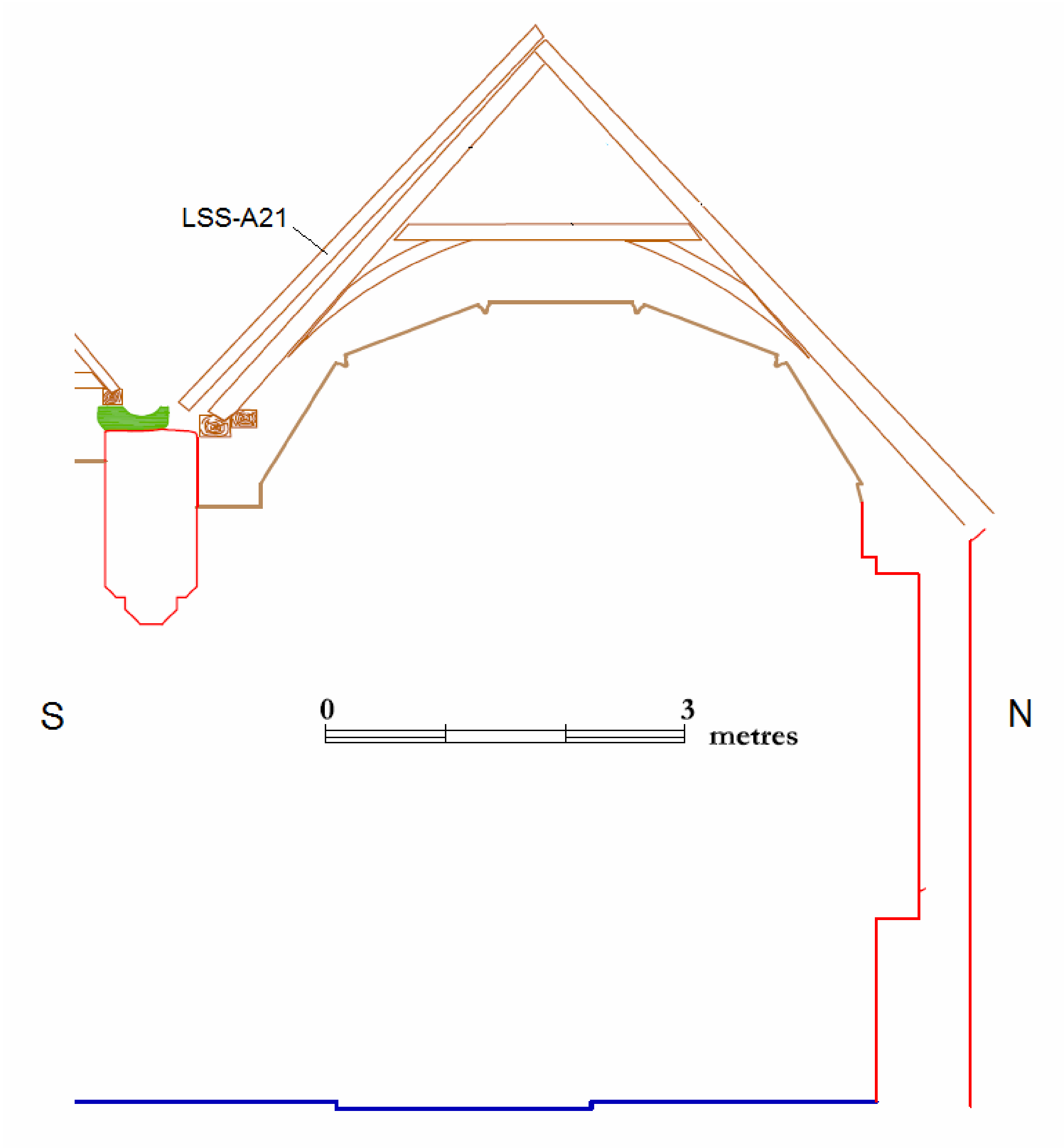

Figure 13: Nave; frame 7, showing the location of sample LSS-A21 (John Crook)

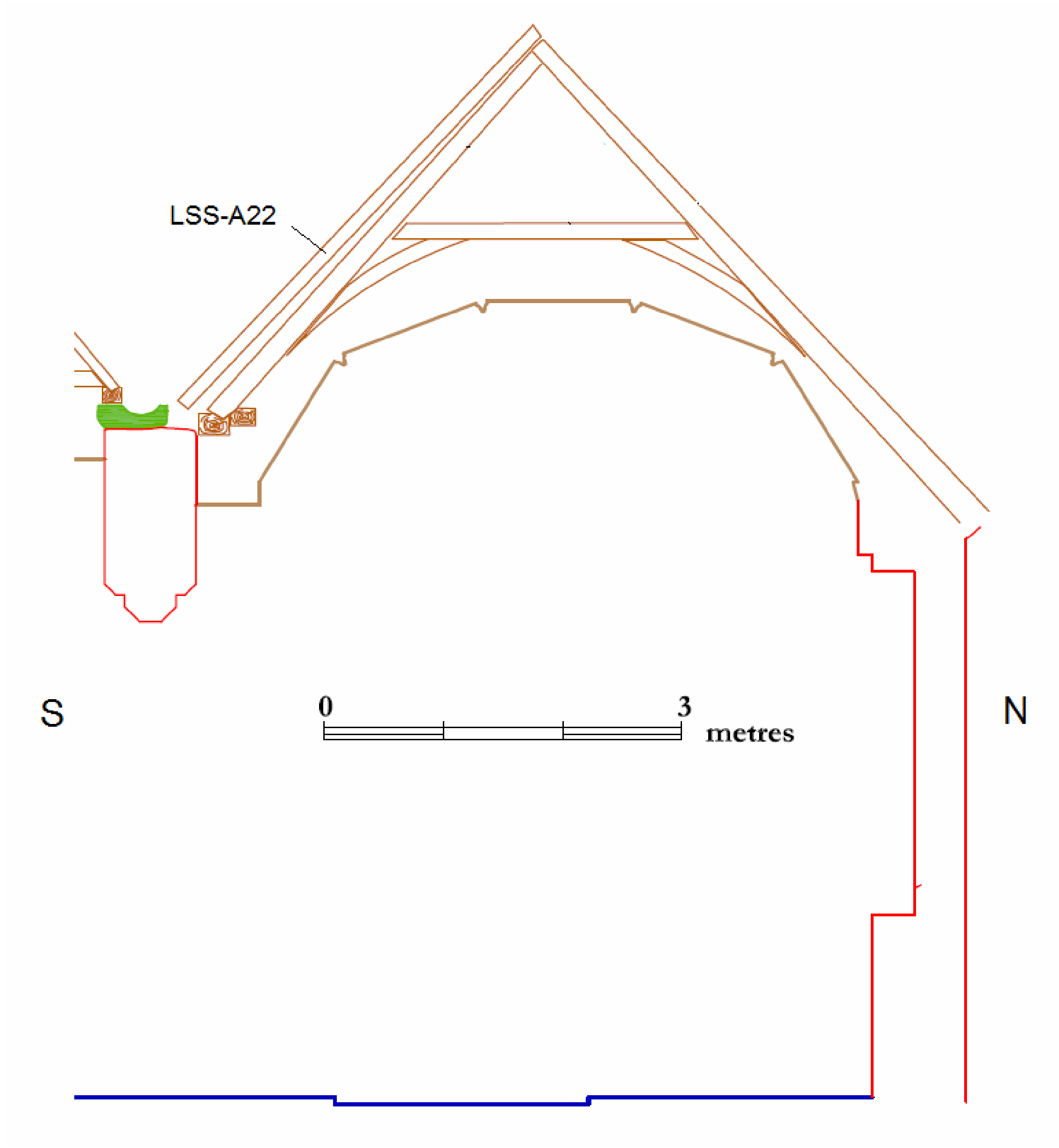

Figure 14: Nave; frame 8, showing the location of sample LSS-A22 (John Crook)

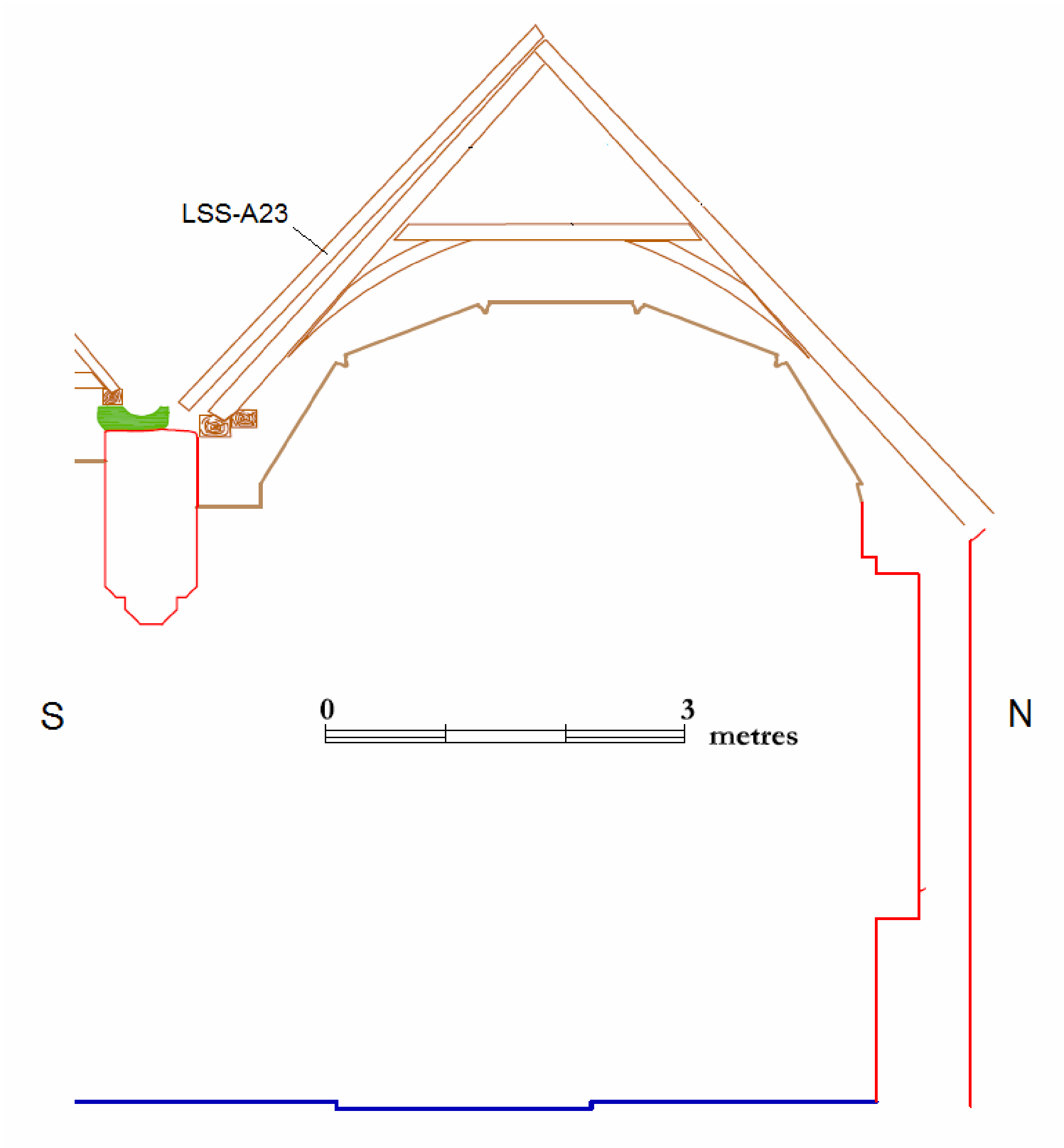

Figure 15: Nave; frame 9, showing the location of sample LSS-A23 (John Crook)

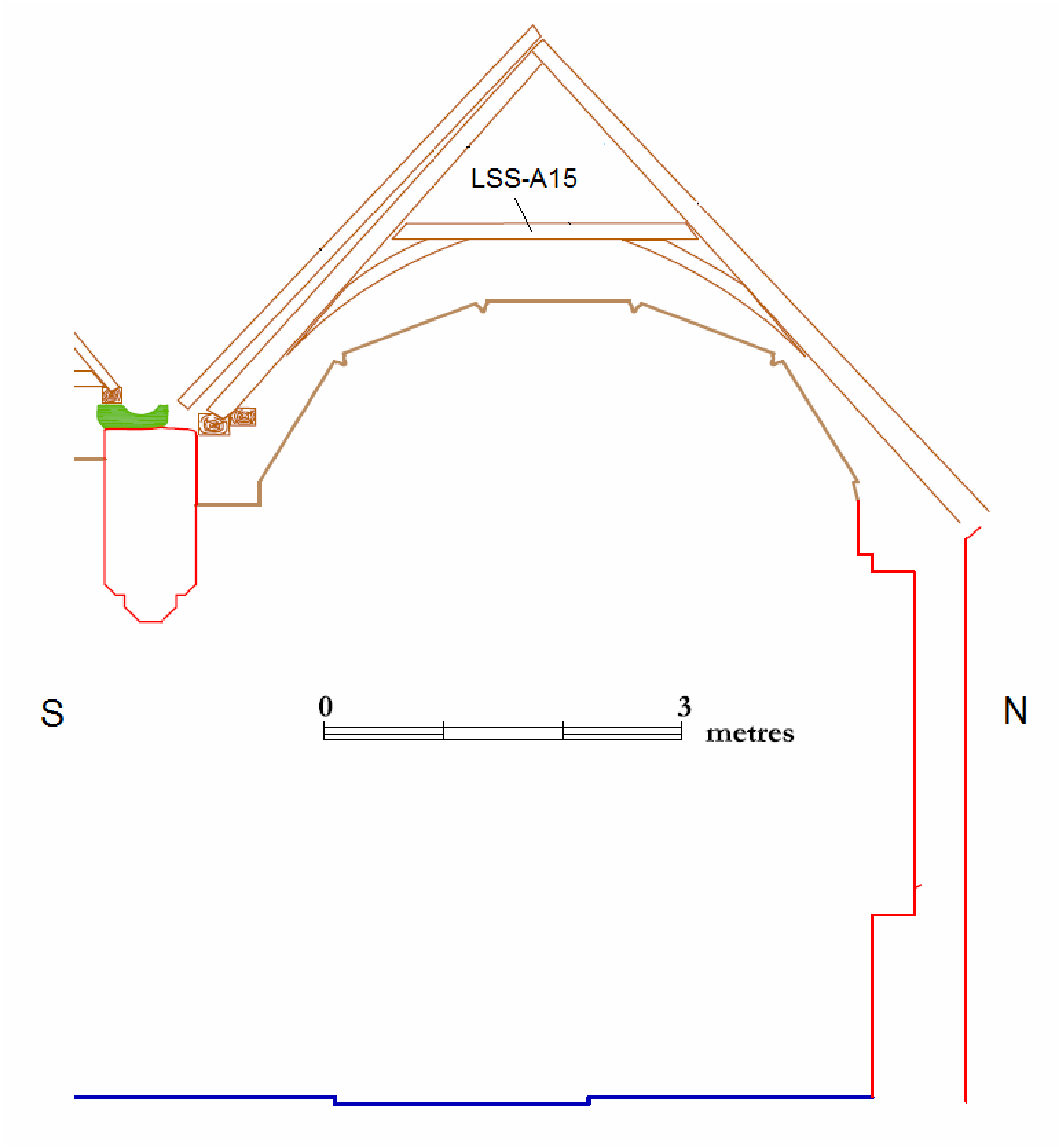

Figure 16: Nave; frame 11, showing the location of sample LSS-A15 (John Crook)

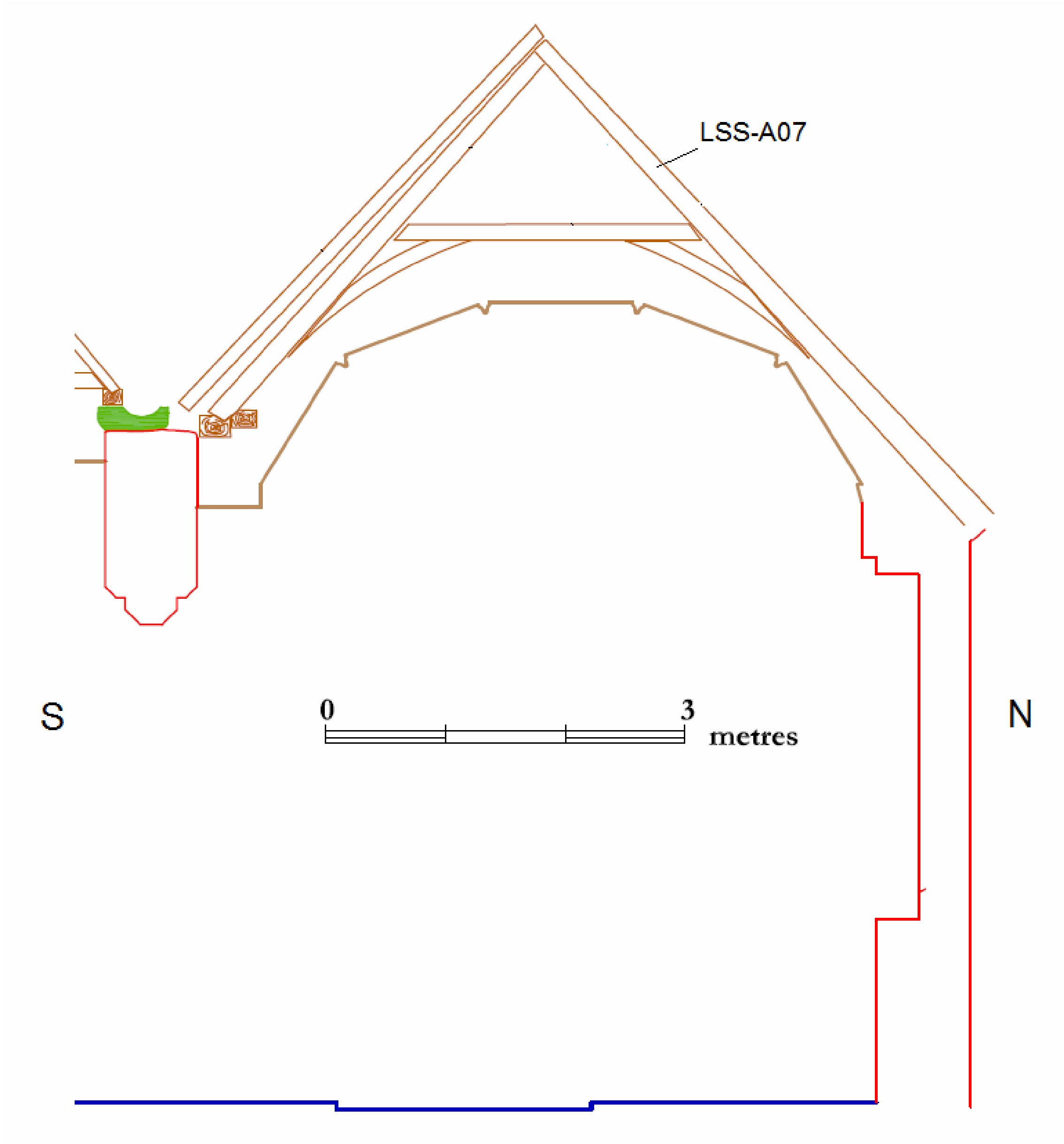

Figure 17: Nave; frame 12, showing the location of sample LSS-A07 (John Crook)

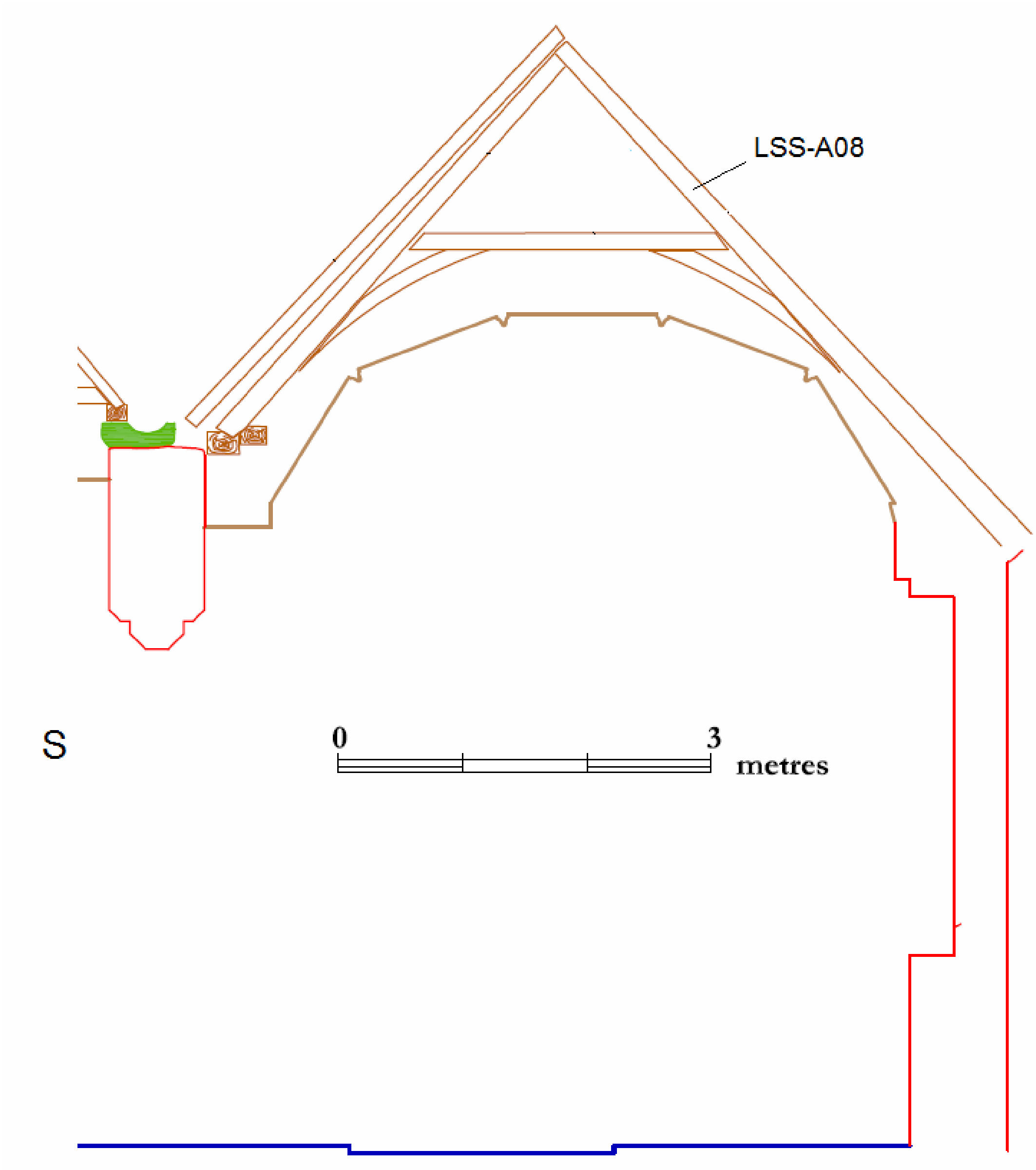

Figure 18: Nave; frame 14, showing the location of sample LSS-A08 (John Crook)

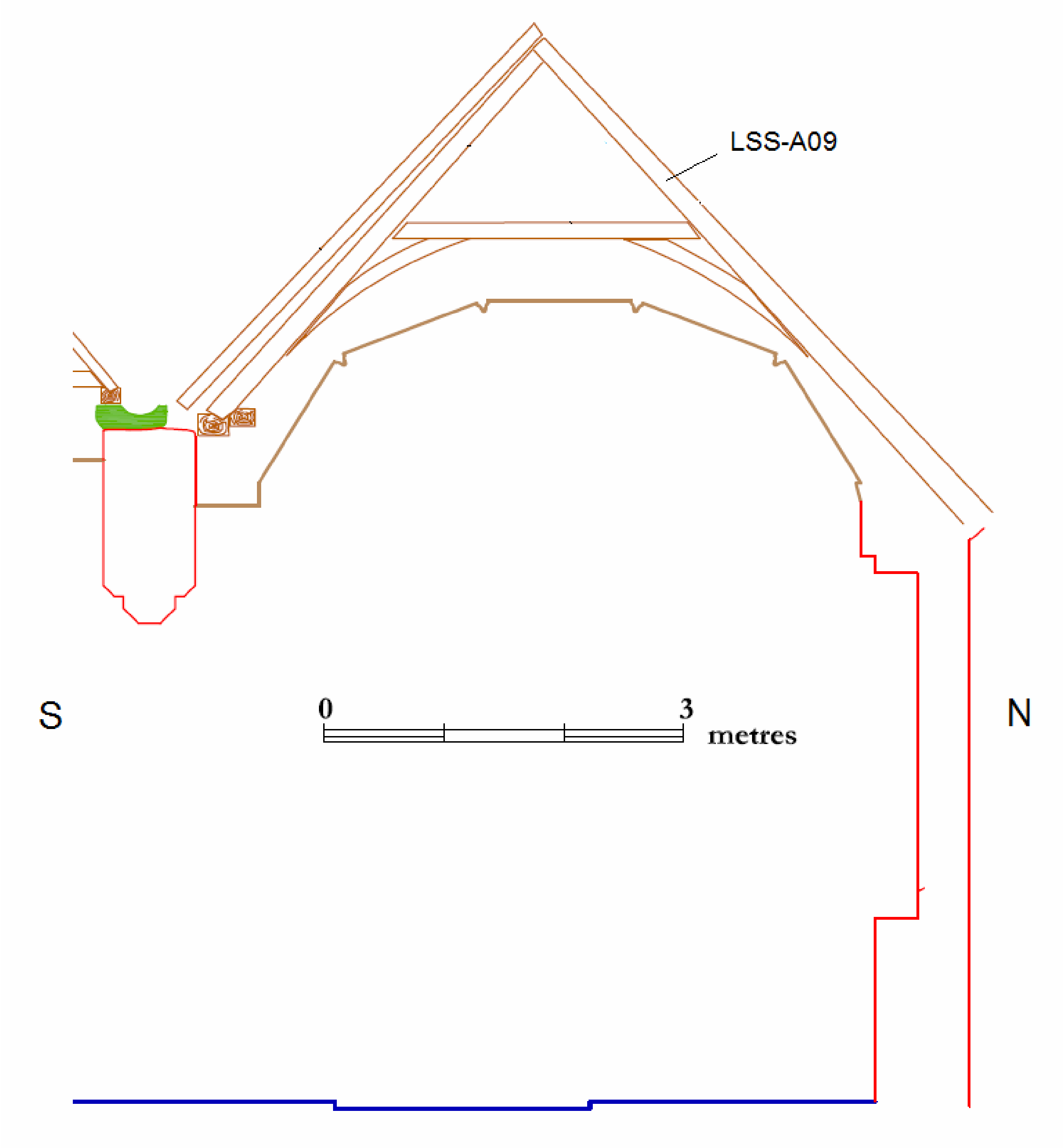

Figure 19: Nave; frame 15, showing the location of sample LSS-A09 (John Crook)

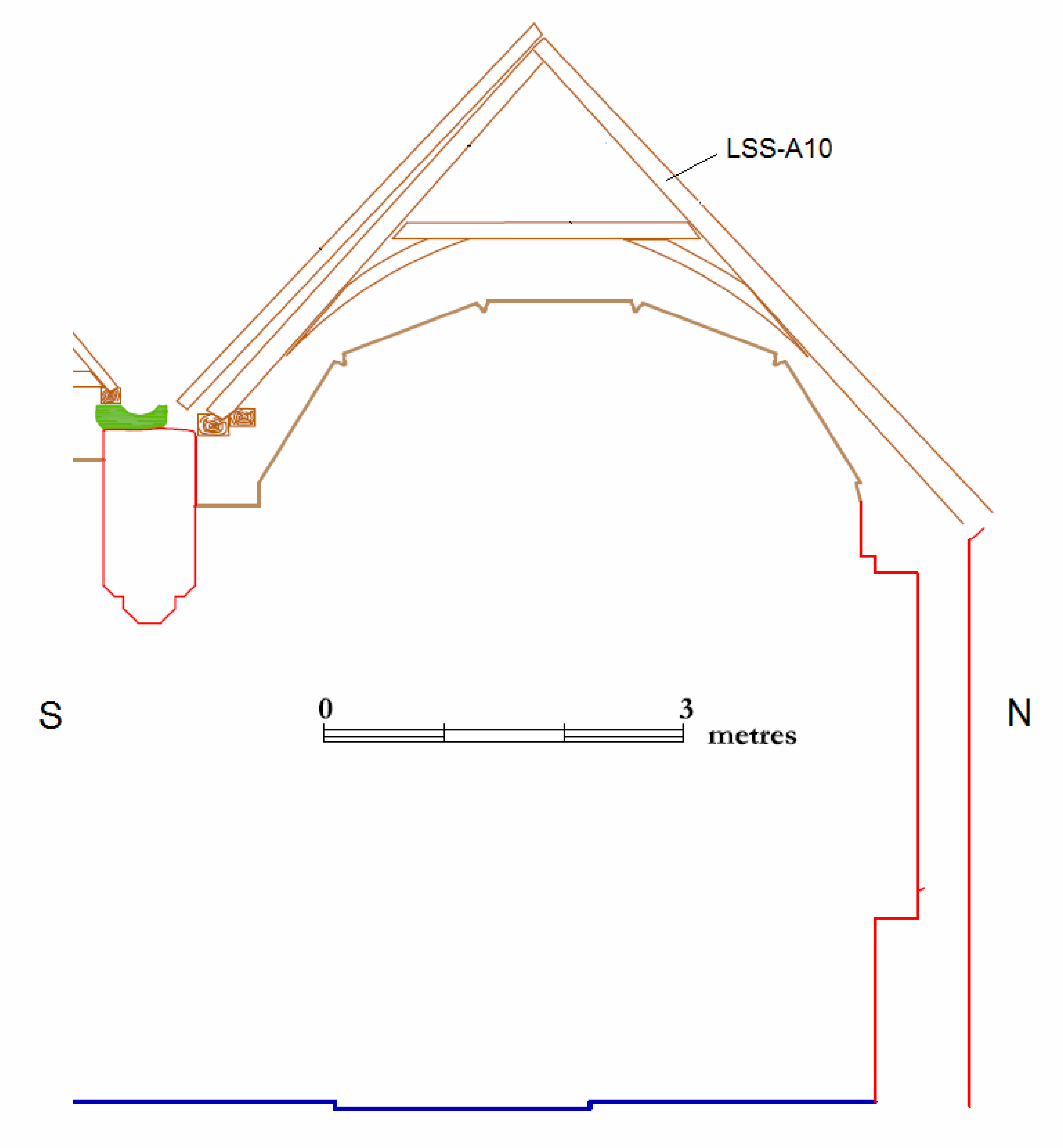

Figure 20: Nave; frame 17, showing the location of sample LSS-A10 (John Crook)

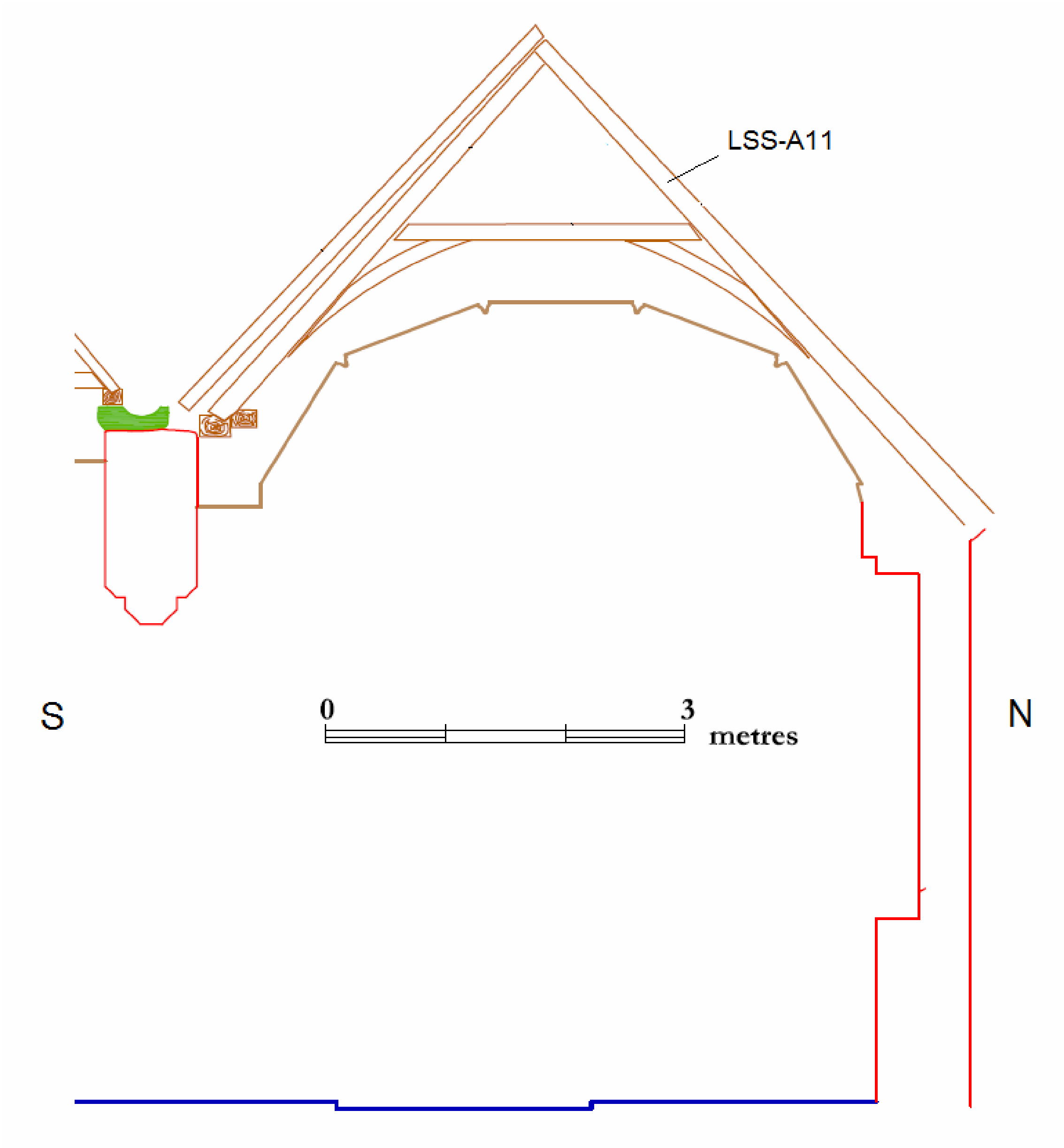

Figure 21: Nave; frame 18, showing the location of sample LSS-A11 (John Crook)

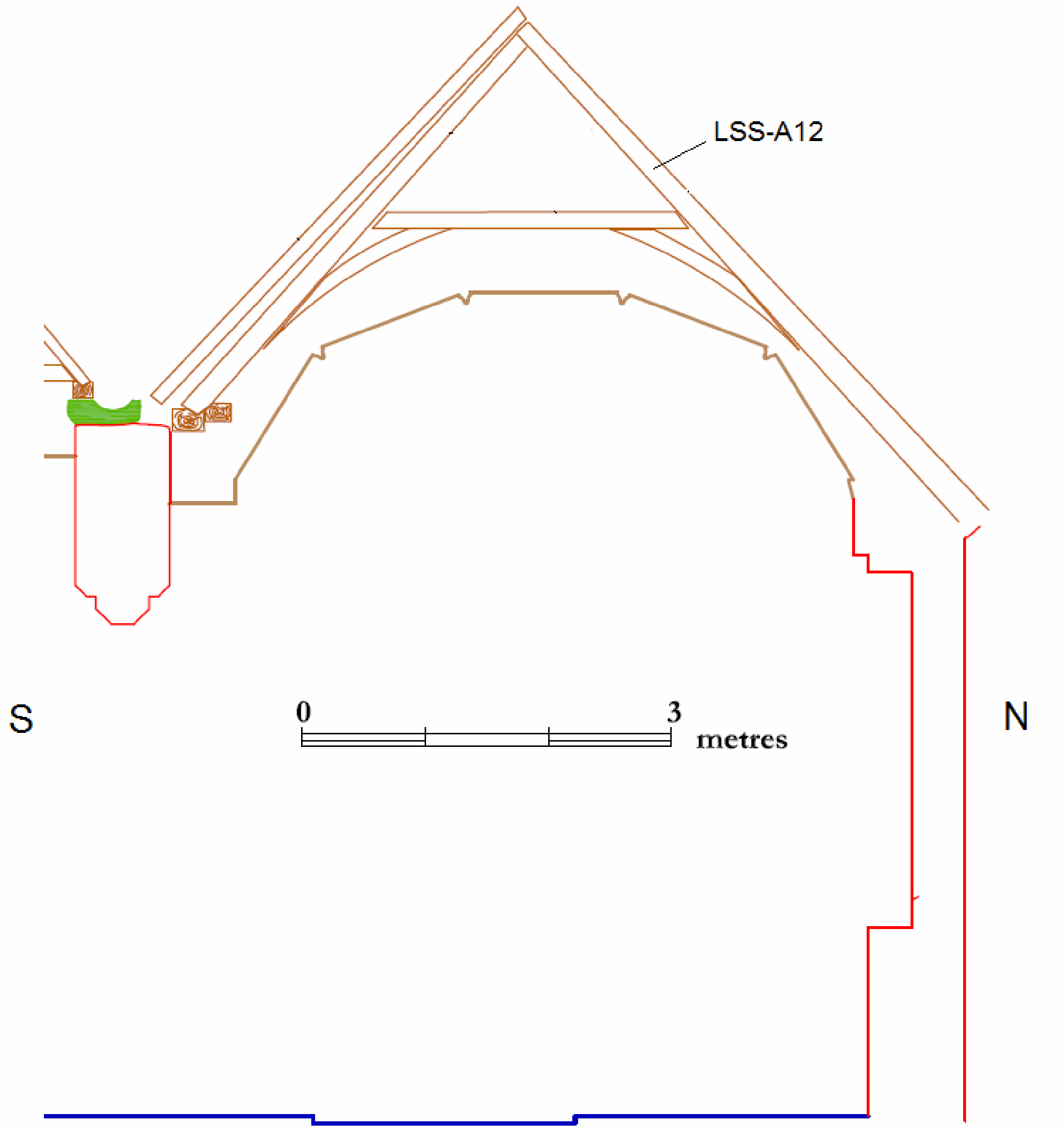

Figure 22: Nave; frame 19, showing the location of sample LSS-A12 (John Crook)

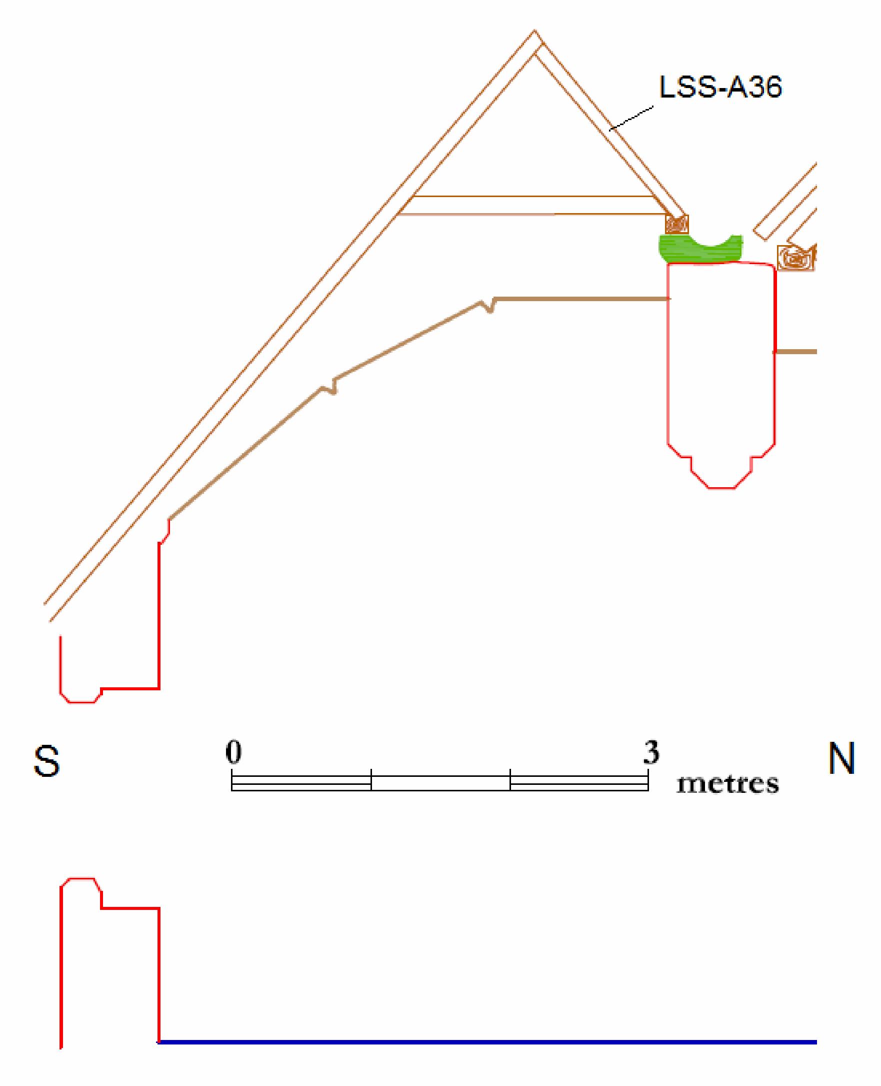

Figure 23: South aisle; frame 3, showing the location of sample LSS-A36 (John Crook)

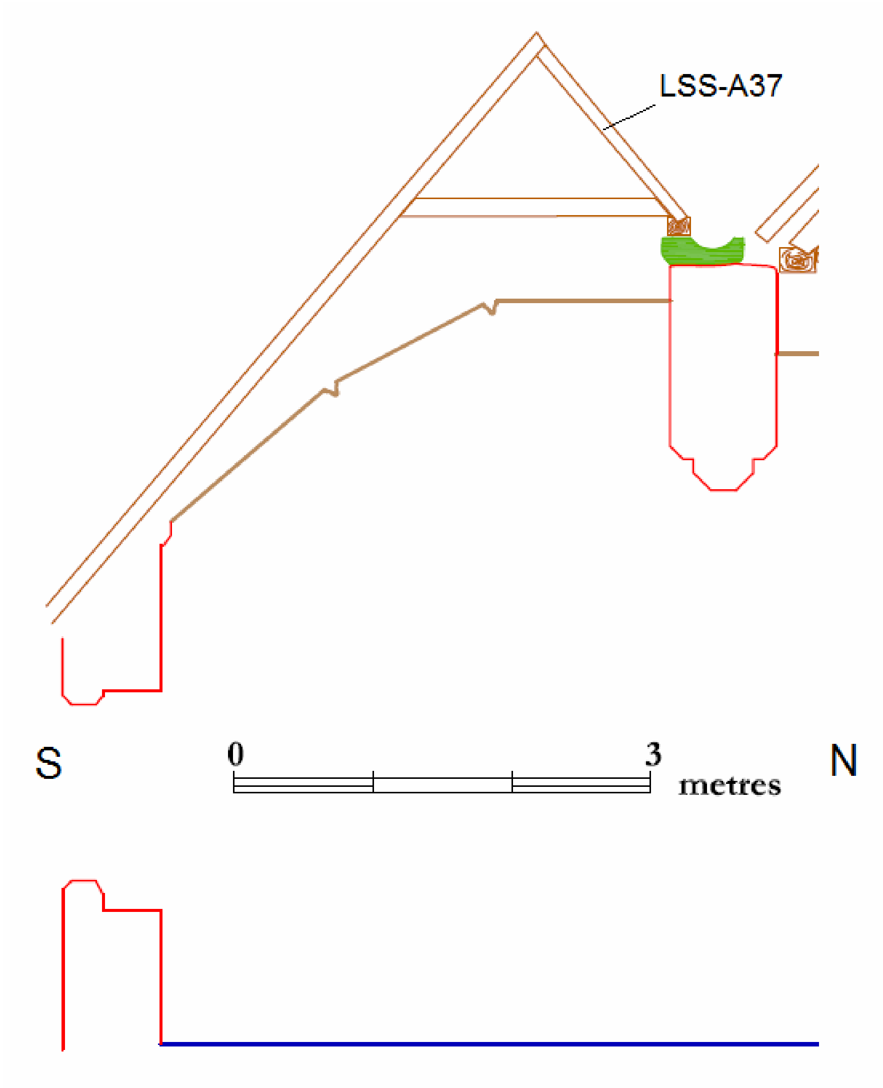

Figure 24: South aisle; frame 4, showing the location of sample LSS-A37 (John Crook)

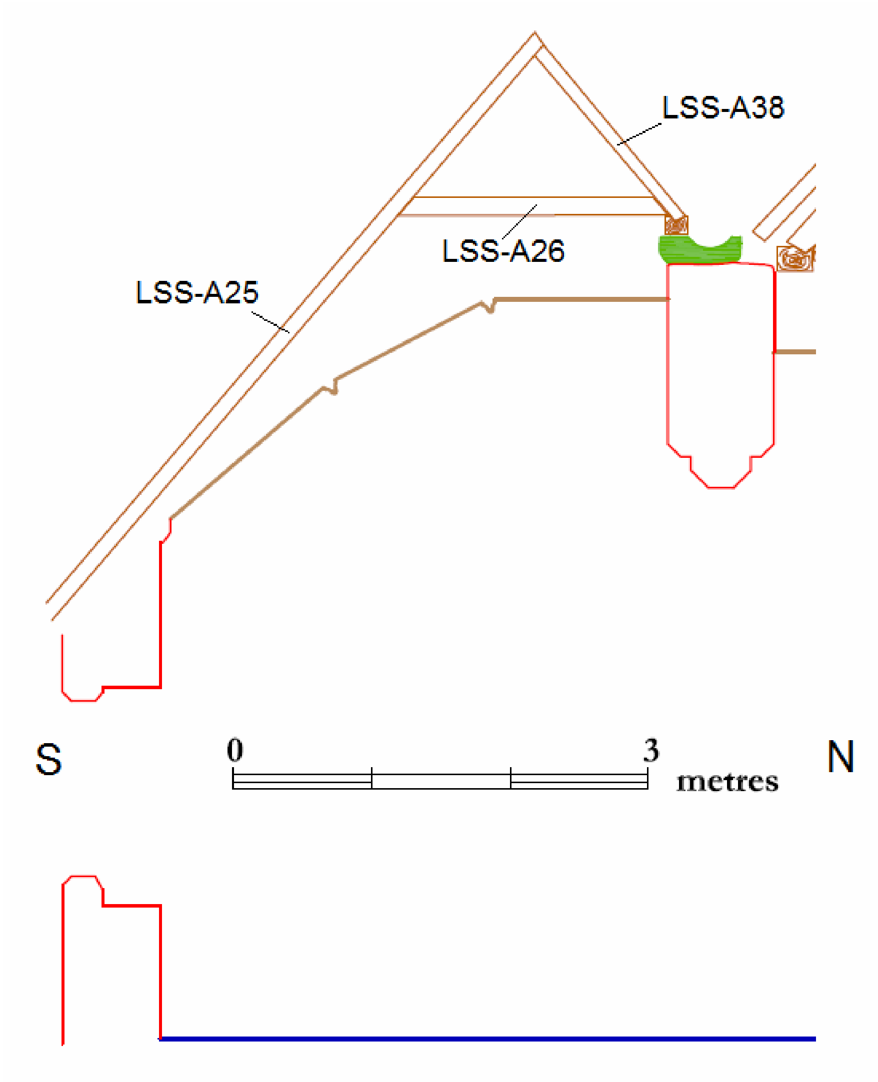

Figure 25: South aisle; frame 5, showing the location of samples LSS-A25, LSS-A26, and LSS-A38 (John Crook)

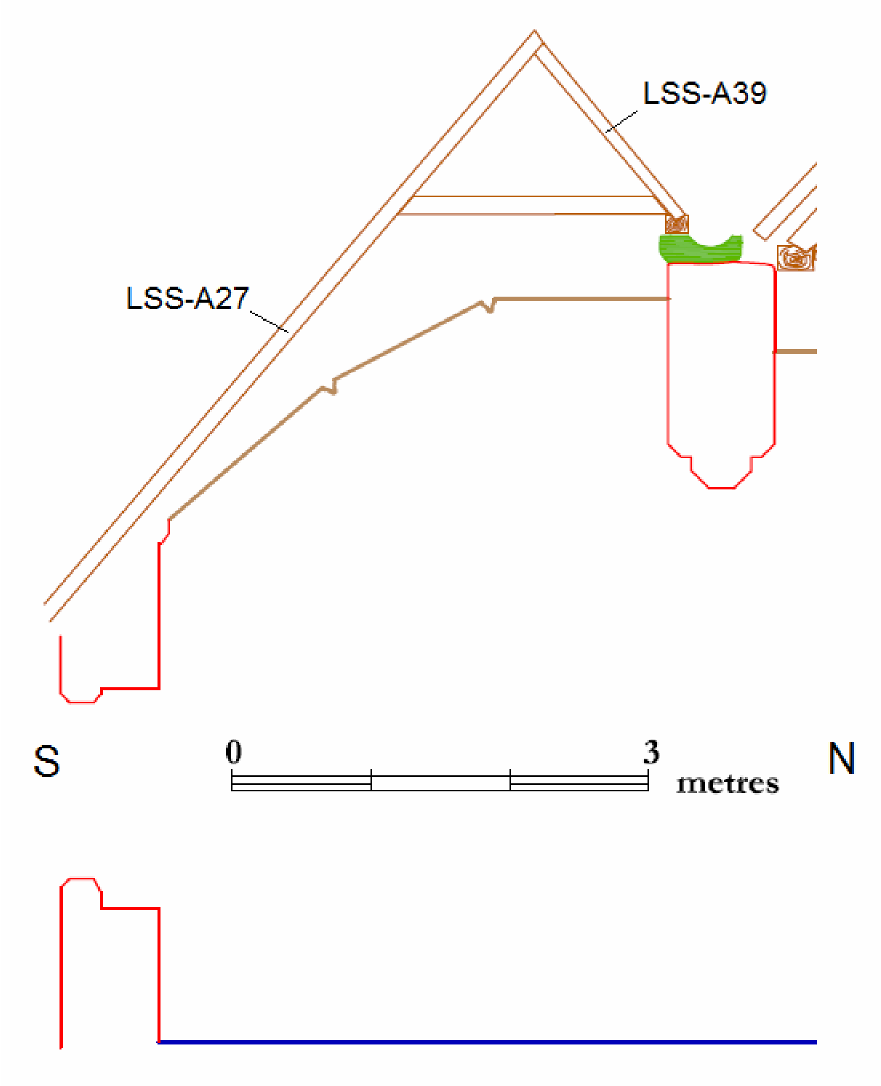

Figure 26: South aisle; frame 6, showing the location of samples LSS-A27 and LSS-A39 (John Crook)

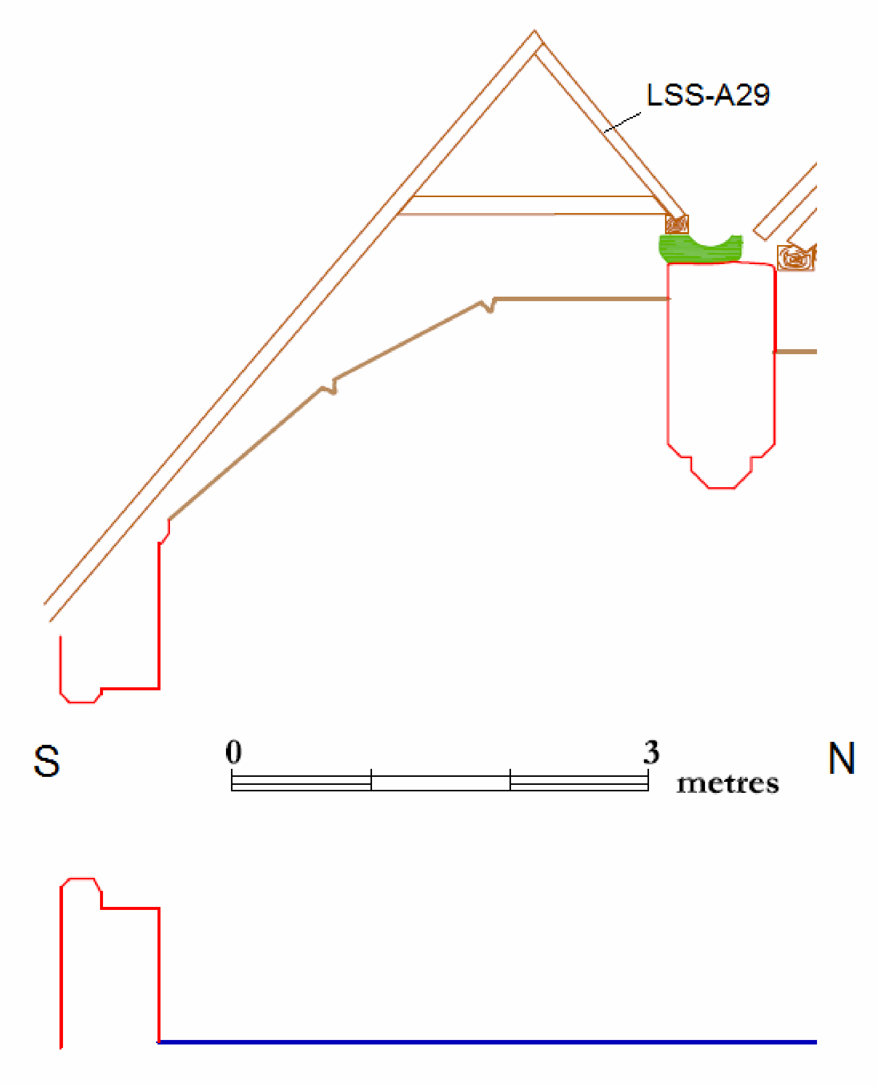

Figure 27: South aisle; frame 8, showing the location of sample LSS-A29 (John Crook)

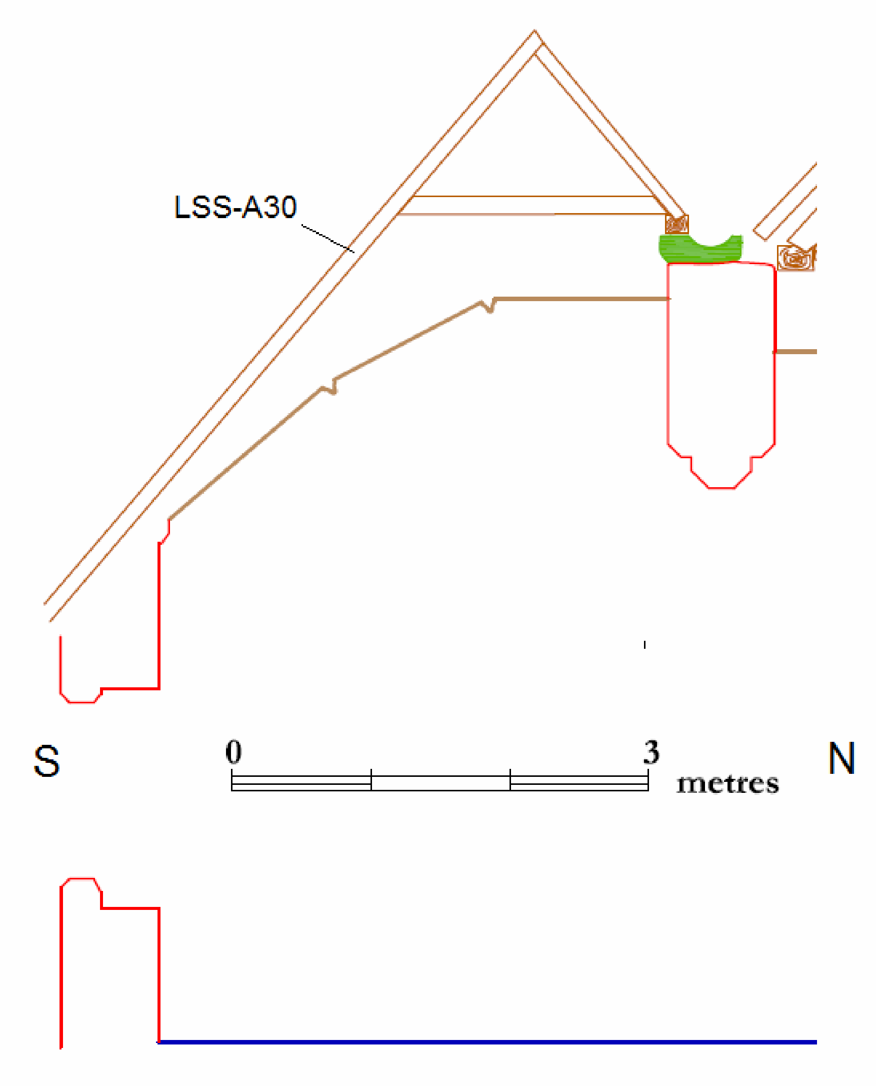

Figure 28: South aisle; frame 9, showing the location of sample LSS-A30 (John Crook)

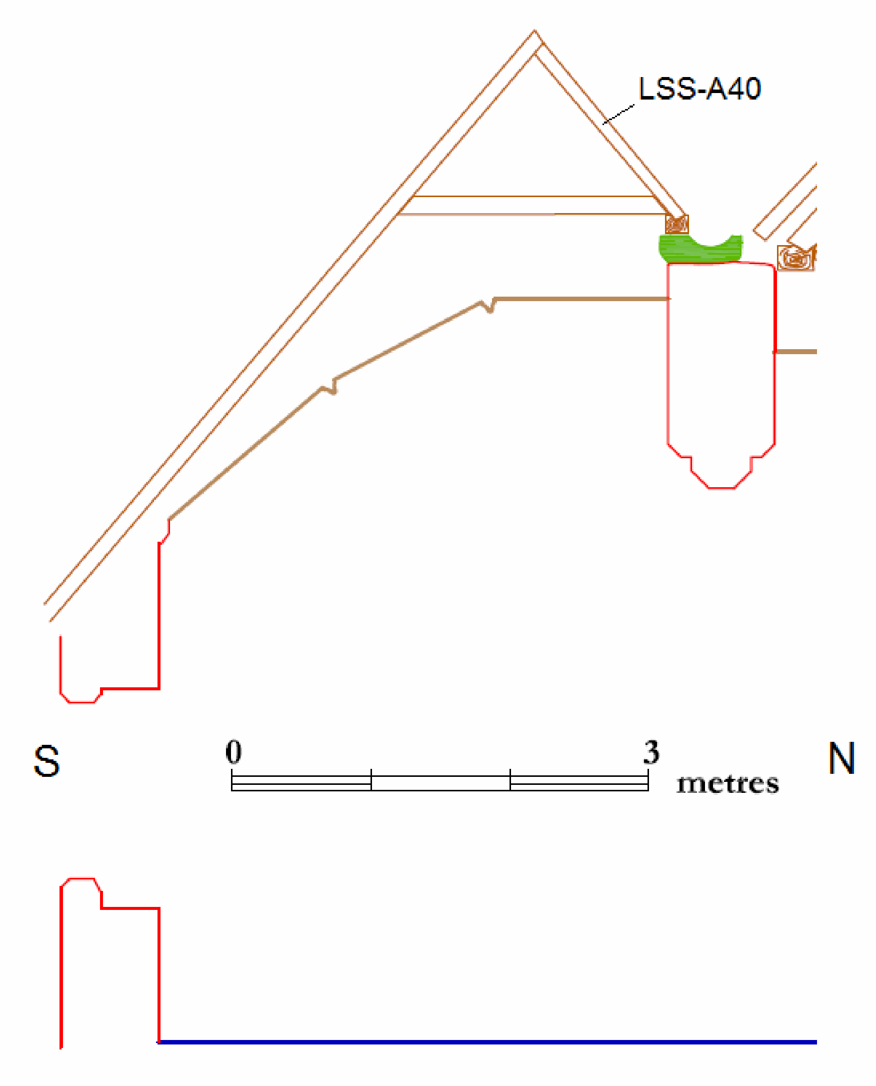

Figure 29: South aisle; frame 12, showing the location of sample LSS-A40 (John Crook)

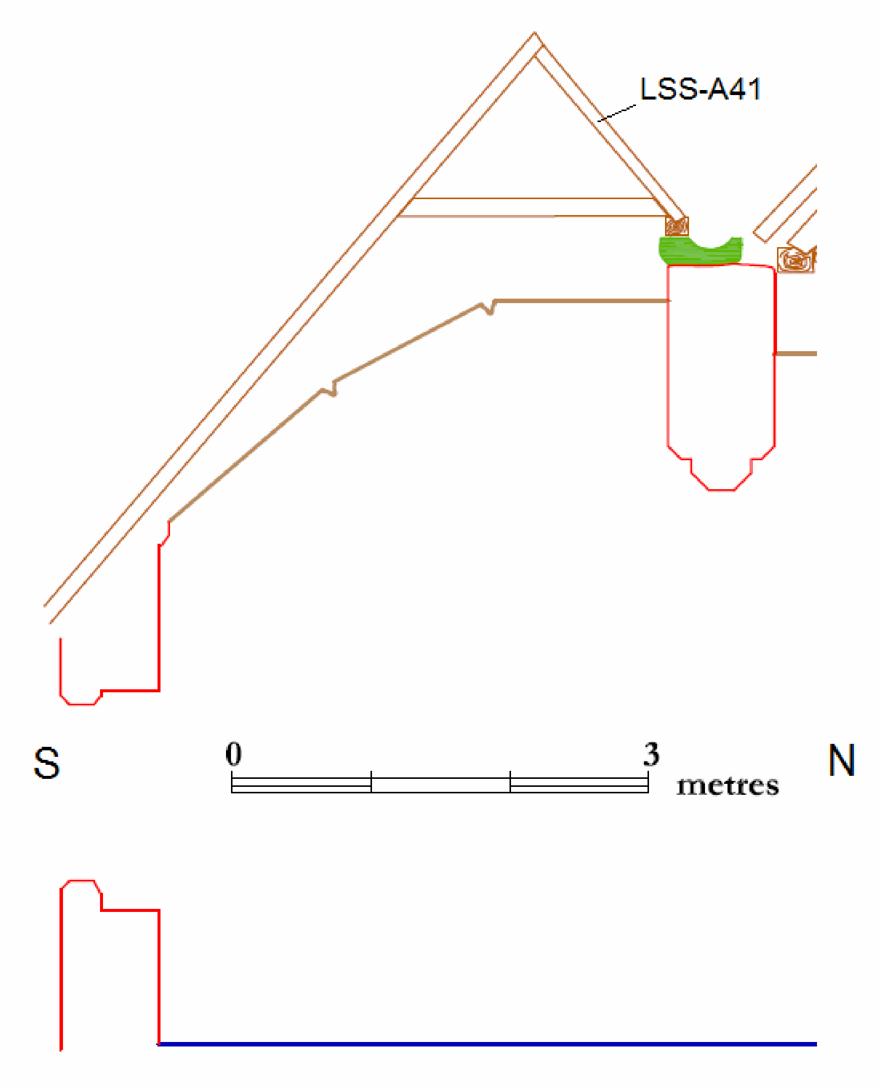

Figure 30: South aisle; frame 14, showing the location of sample LSS-A41 (John Crook)

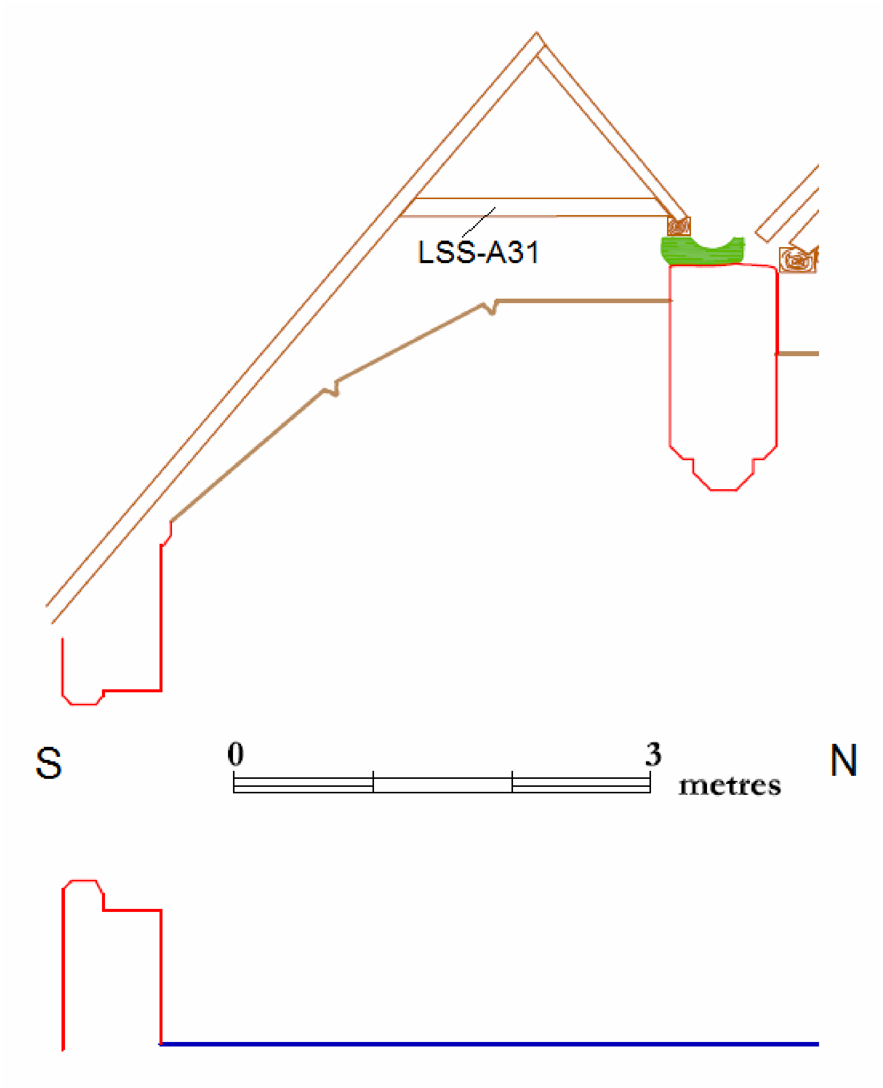

Figure 31: South aisle; frame 15, showing the location of sample LSS-A31 (John Crook)

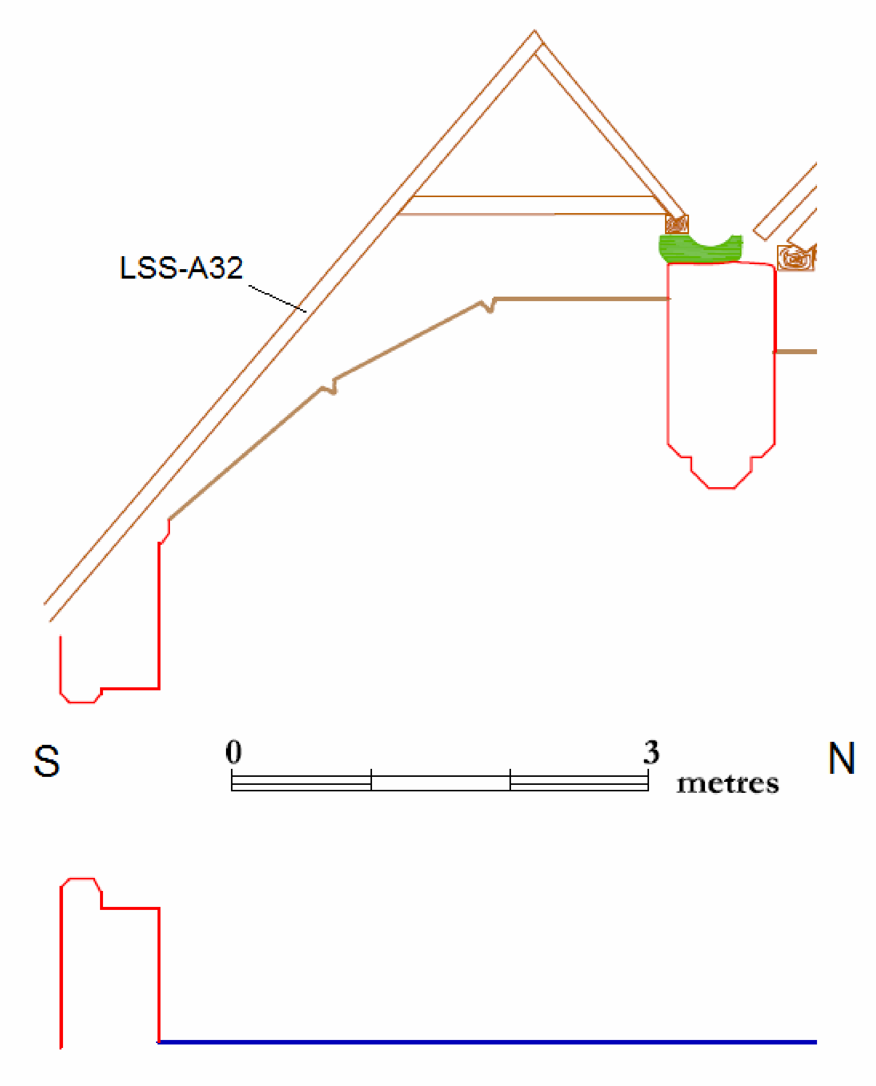

Figure 32: South aisle; frame 17, showing the location of sample LSS-A32 (John Crook)

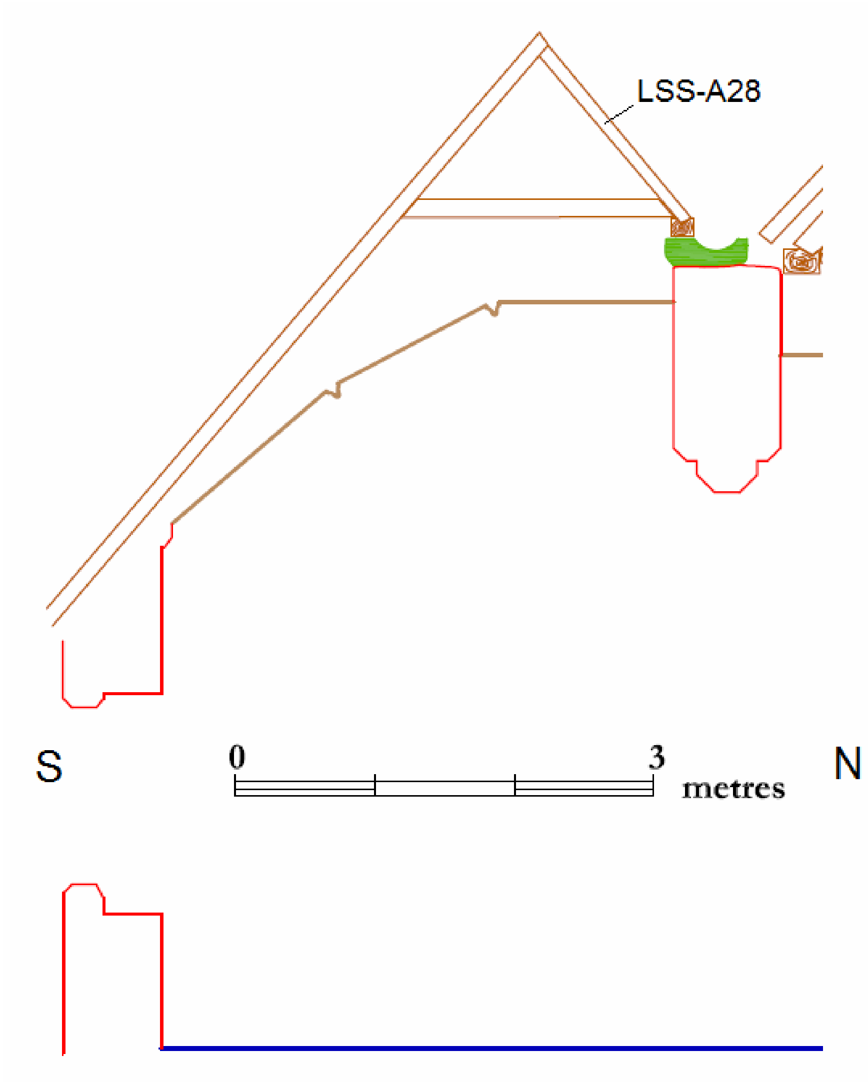

Figure 33: South aisle; frame 18, showing the location of sample LSS-A28 (John Crook)

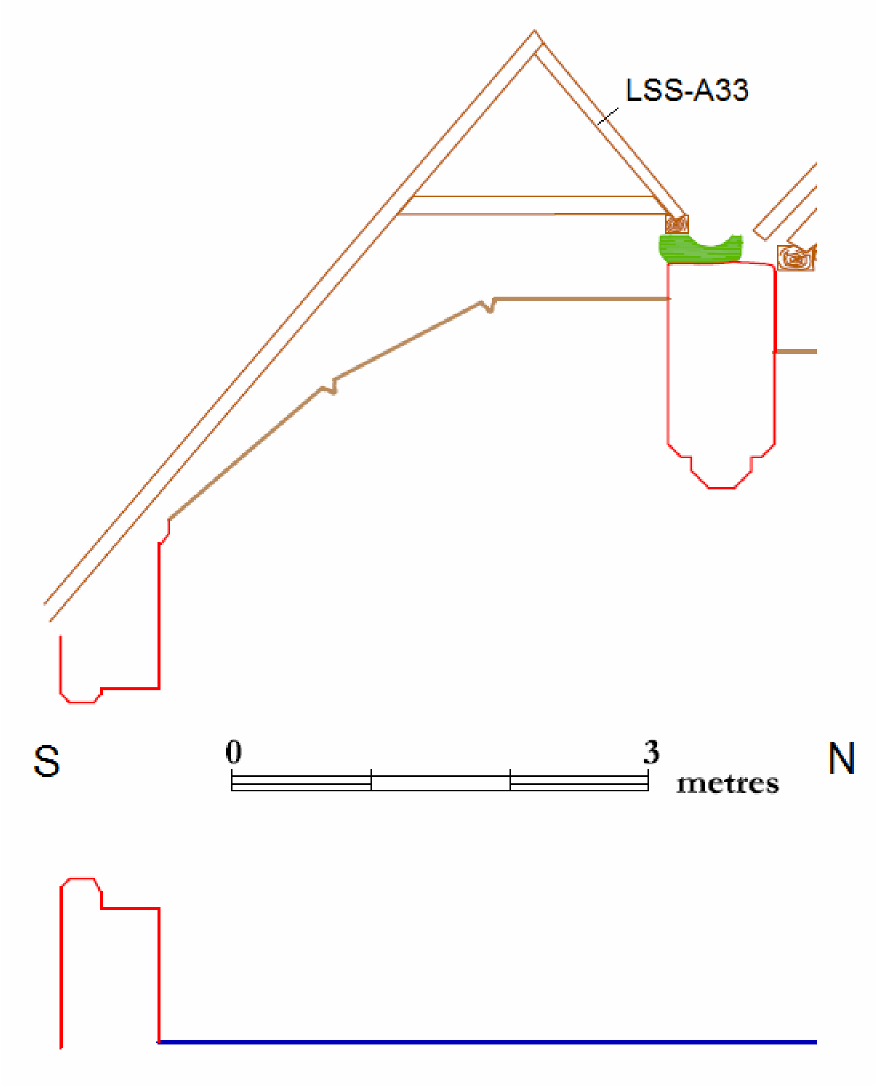

Figure 34: South aisle; frame 21, showing the location of sample LSS-A33 (John Crook)

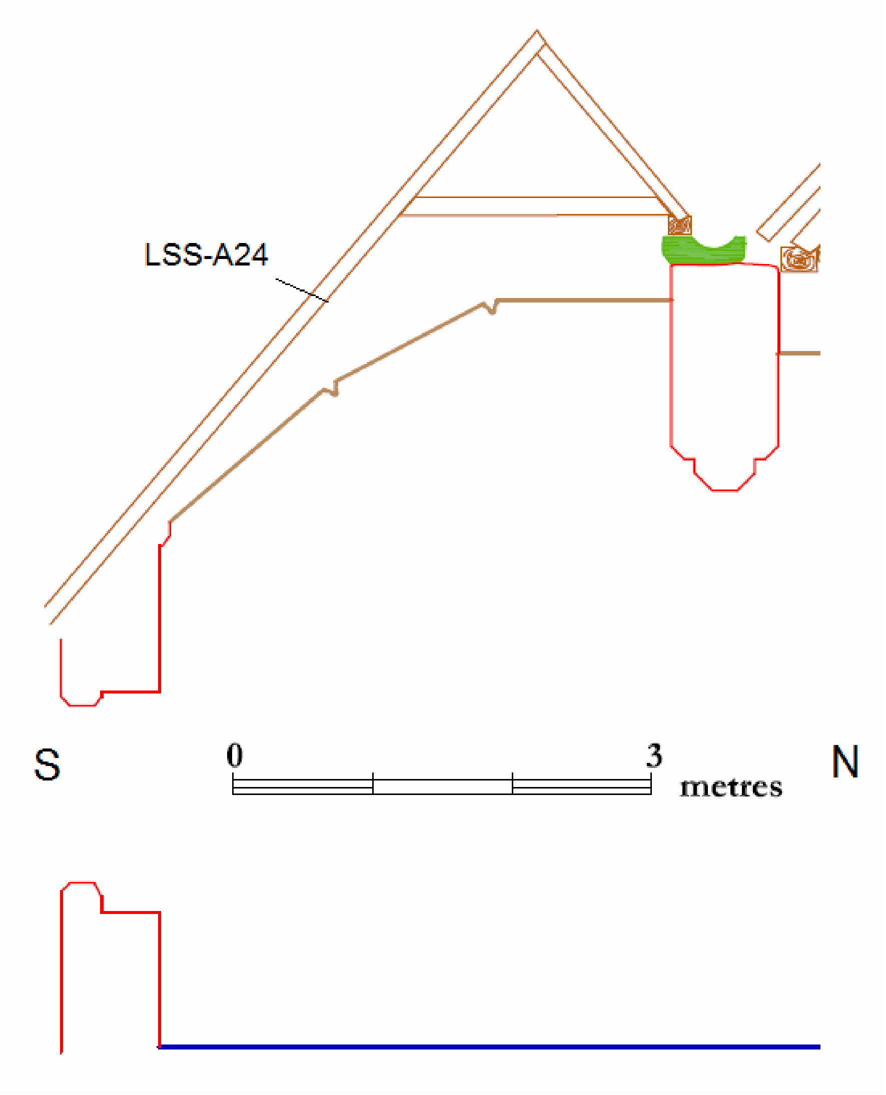

Figure 35: South aisle; frame 22, showing the location of sample LSS-A24 (John Crook)

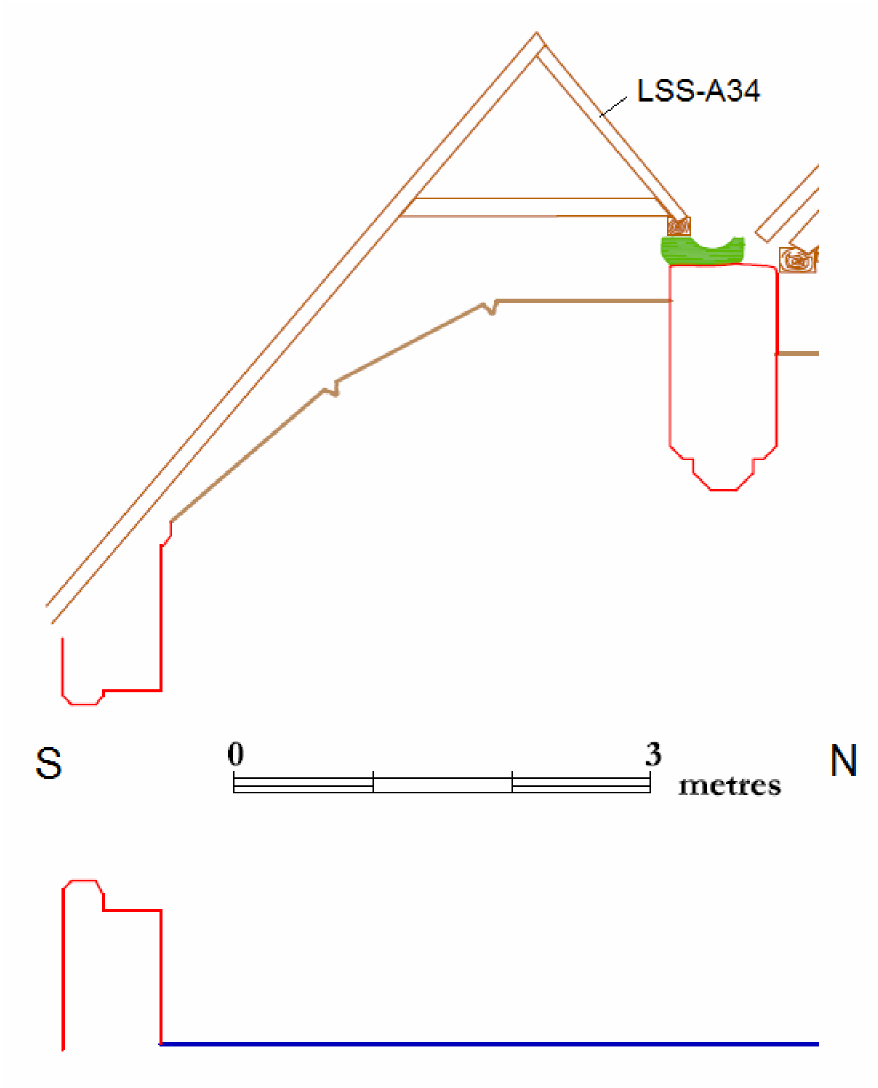

Figure 36: South aisle; frame 23, showing the location of sample LSS-A34 (John Crook)

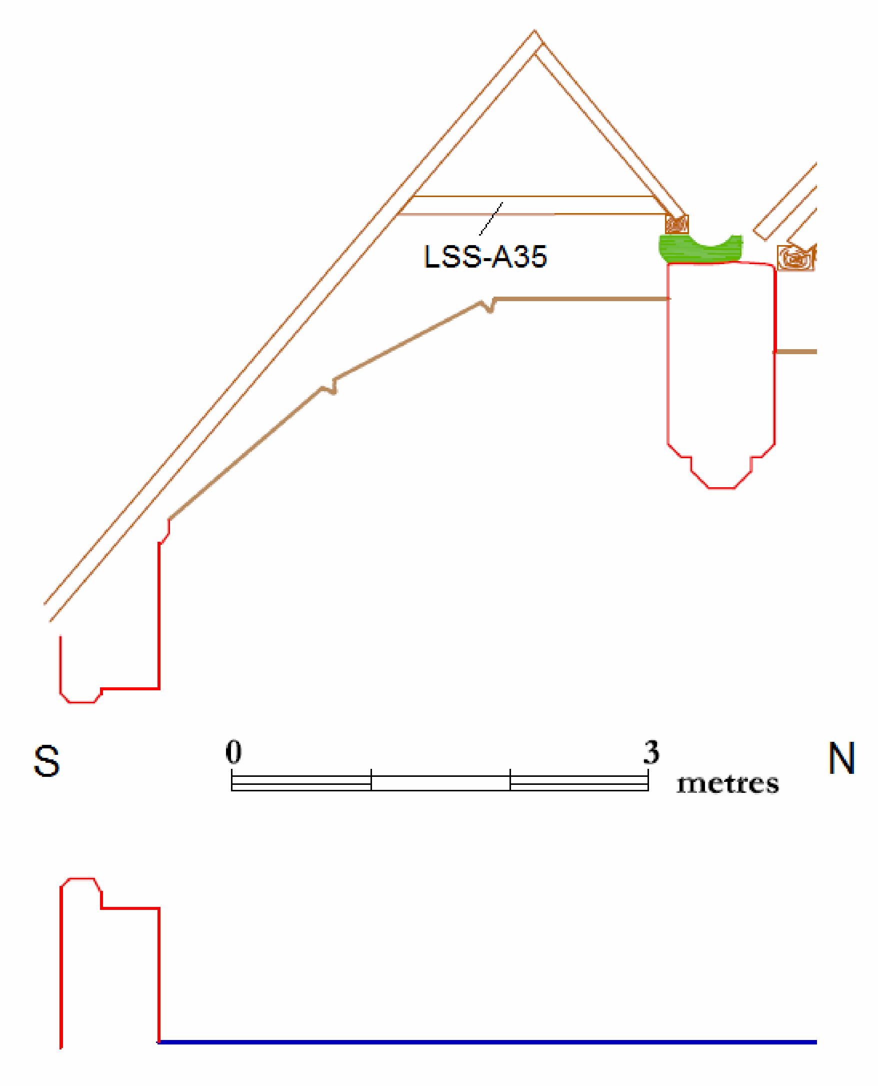

Figure 37: South aisle; frame 25, showing the location of sample LSS-A35 (John Crook)

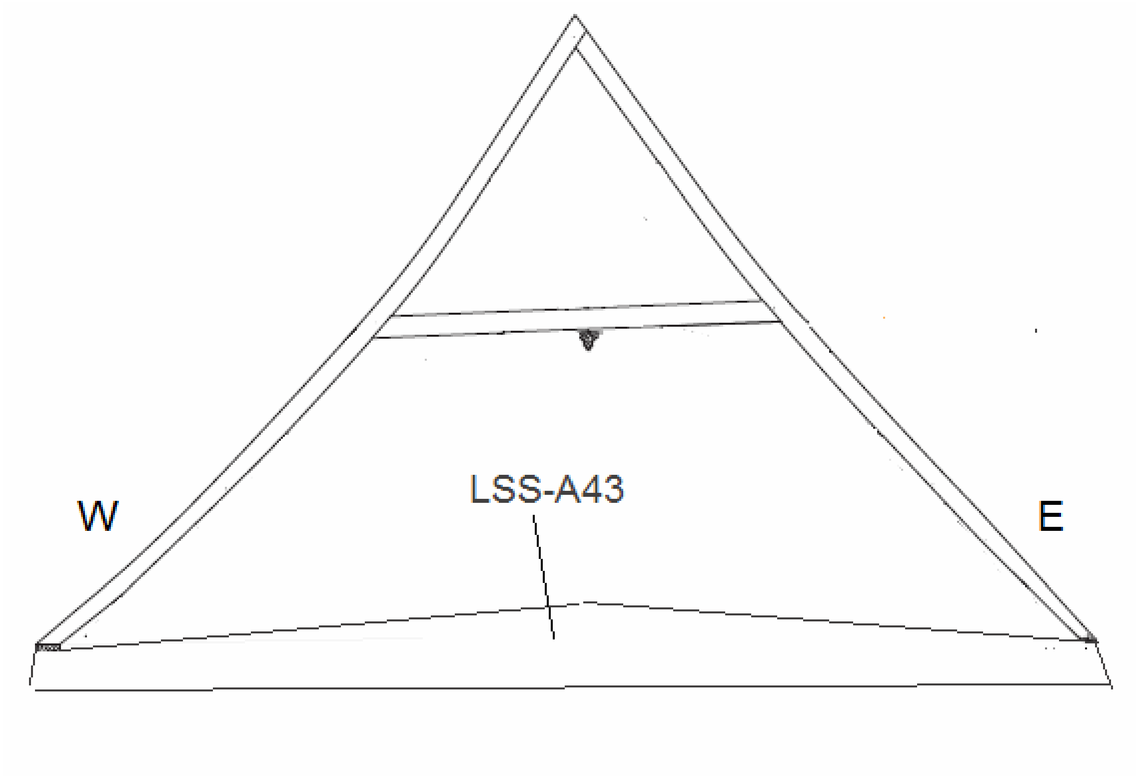

Figure 38: Porch; frame 1, showing the location of sample LSS-A43

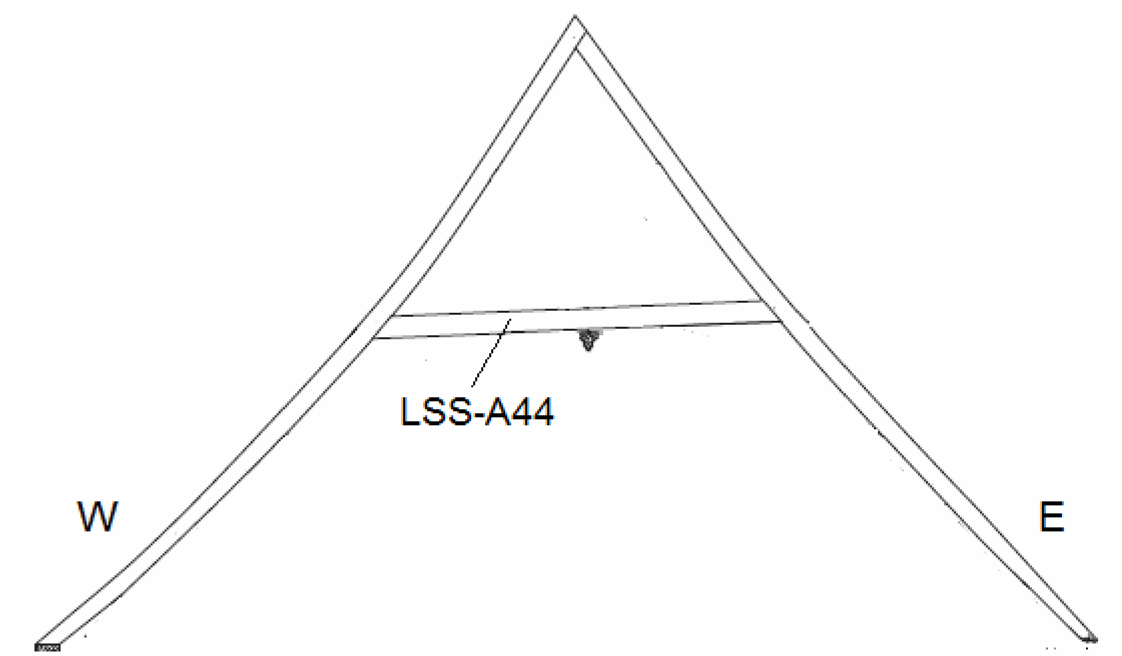

Figure 39: Porch; frame 2, showing the location of sample LSS-A44

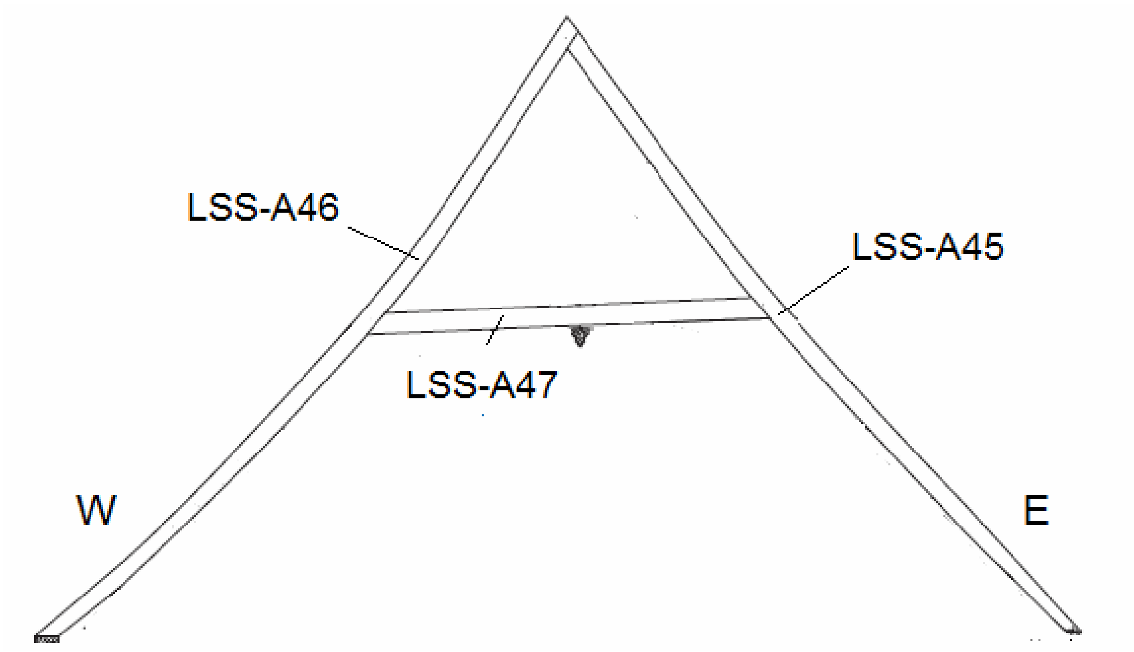

Figure 40: Porch; frame 3, showing the location of samples LSS-A45–7

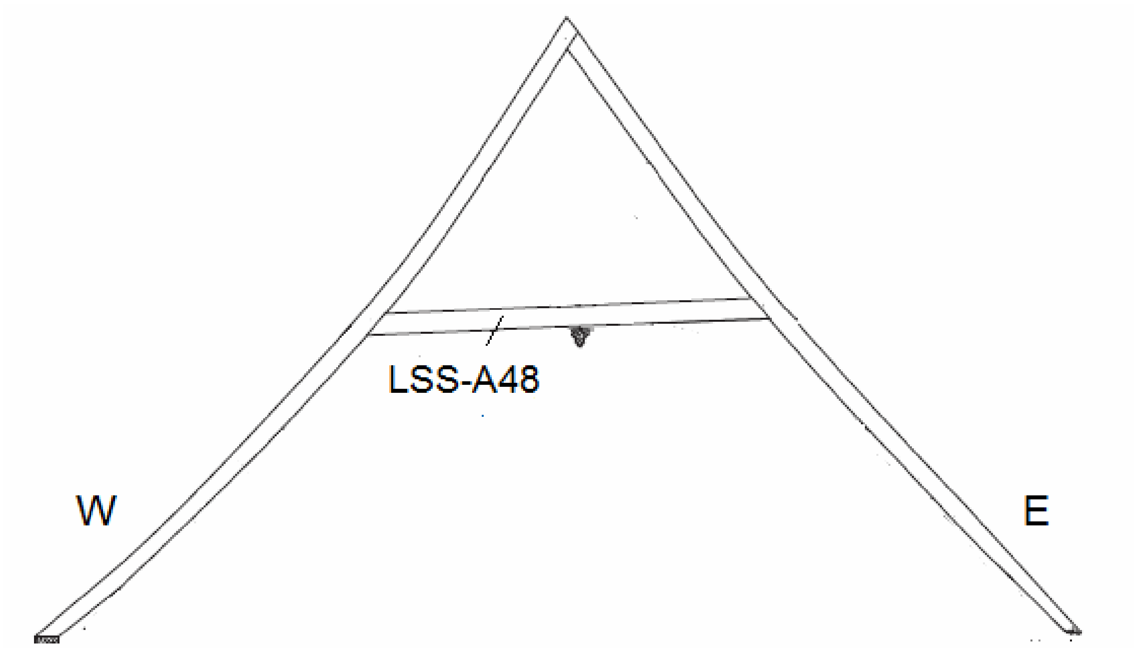

Figure 41: Porch; frame 4, showing the location of sample LSS-A48

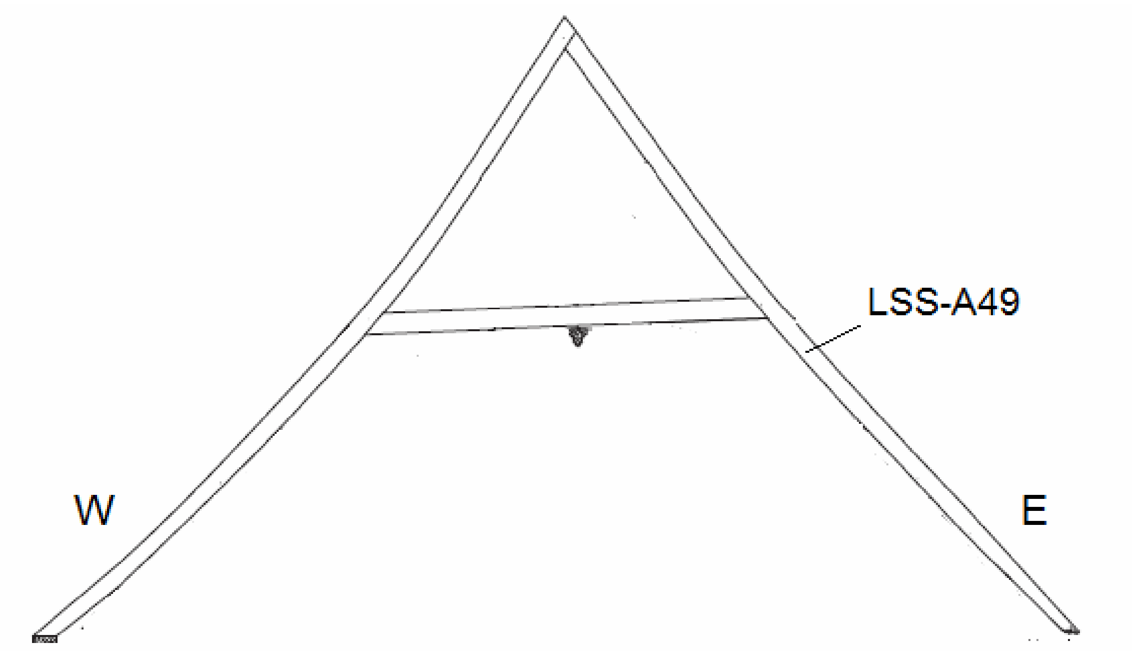

Figure 42: Porch; frame 5, showing the location of sample LSS-A49

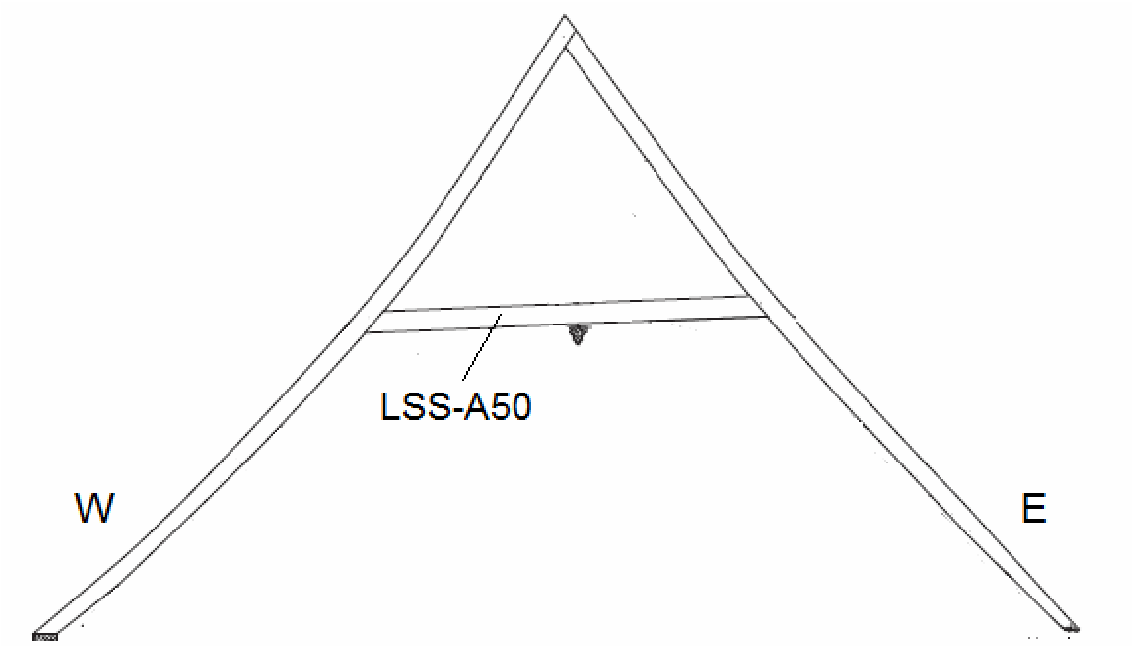

Figure 43: Porch; frame 6, showing the location of sample LSS-A50

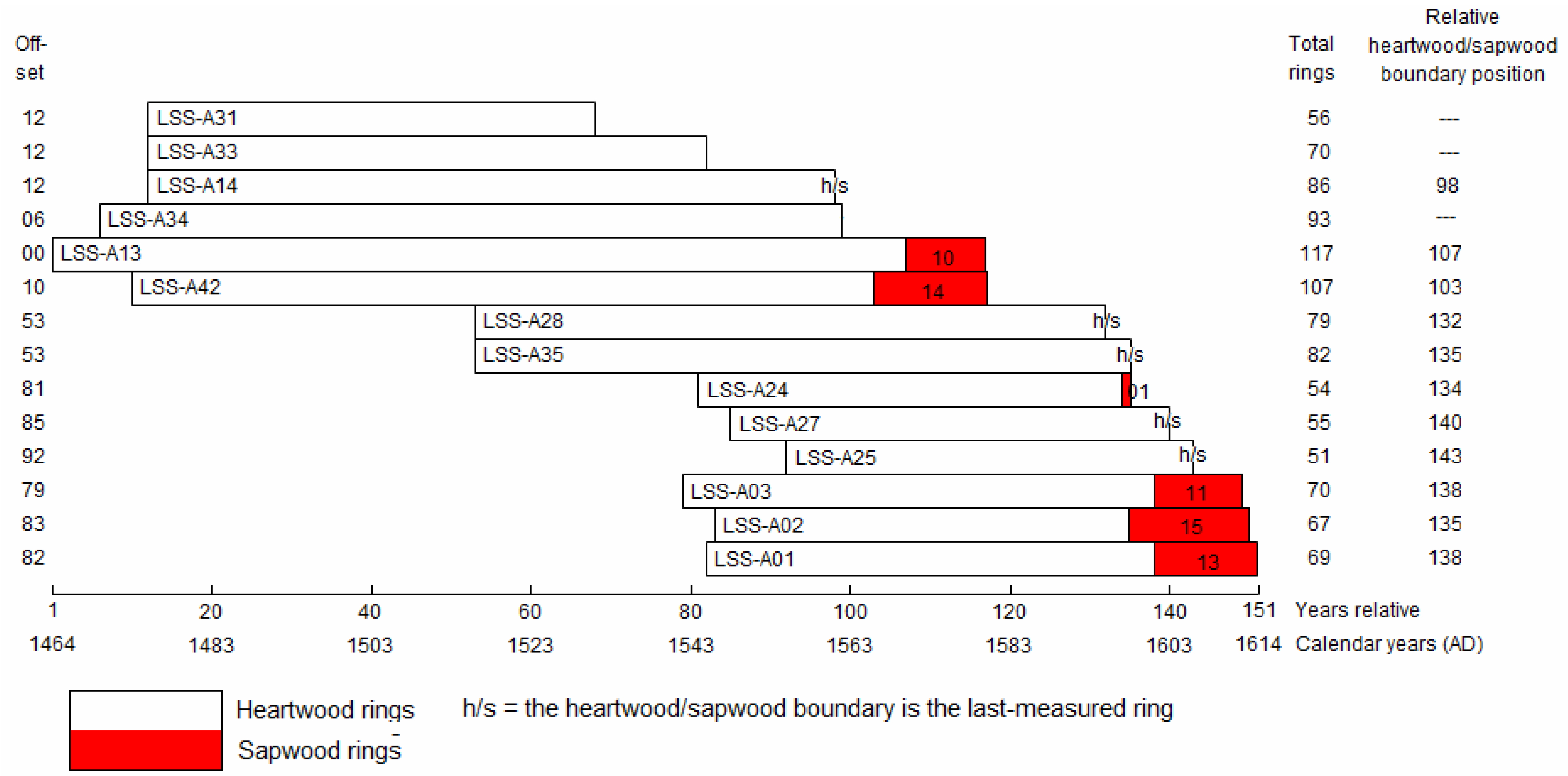

Figure 44: Bar diagram of samples in site sequence LSSASQ01

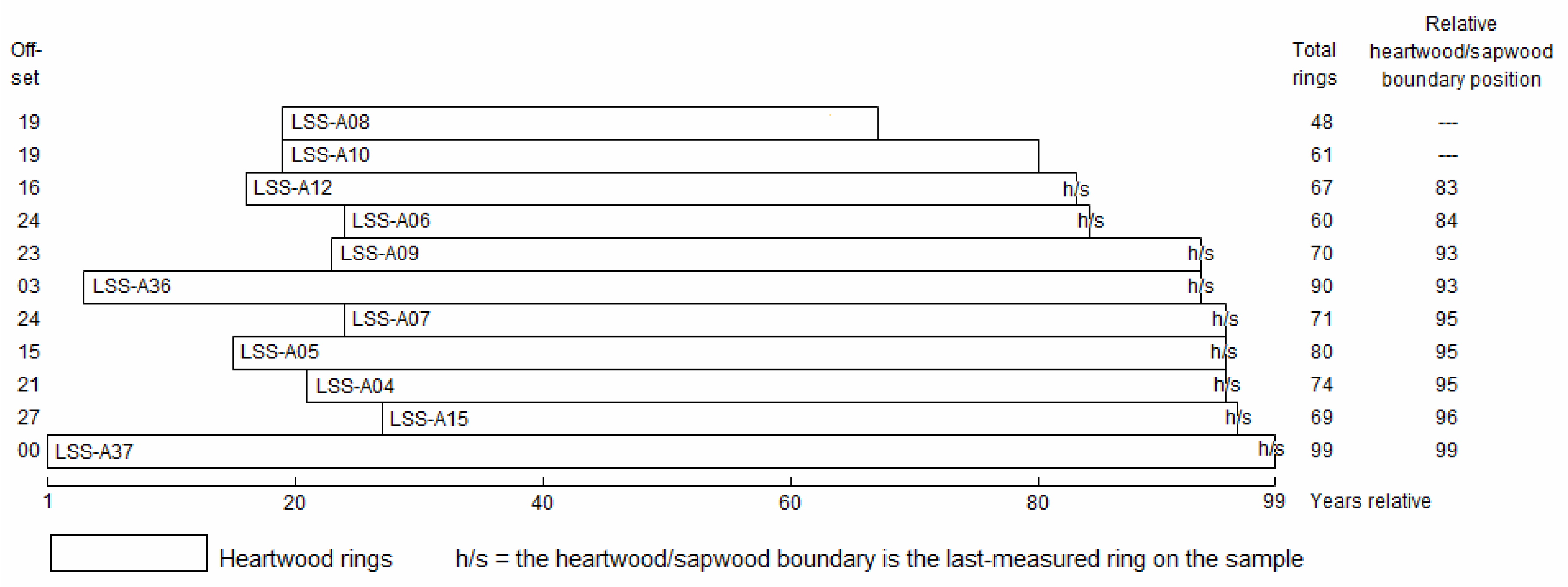

Figure 45: Bar diagram of samples in undated site sequence LSSASQ02

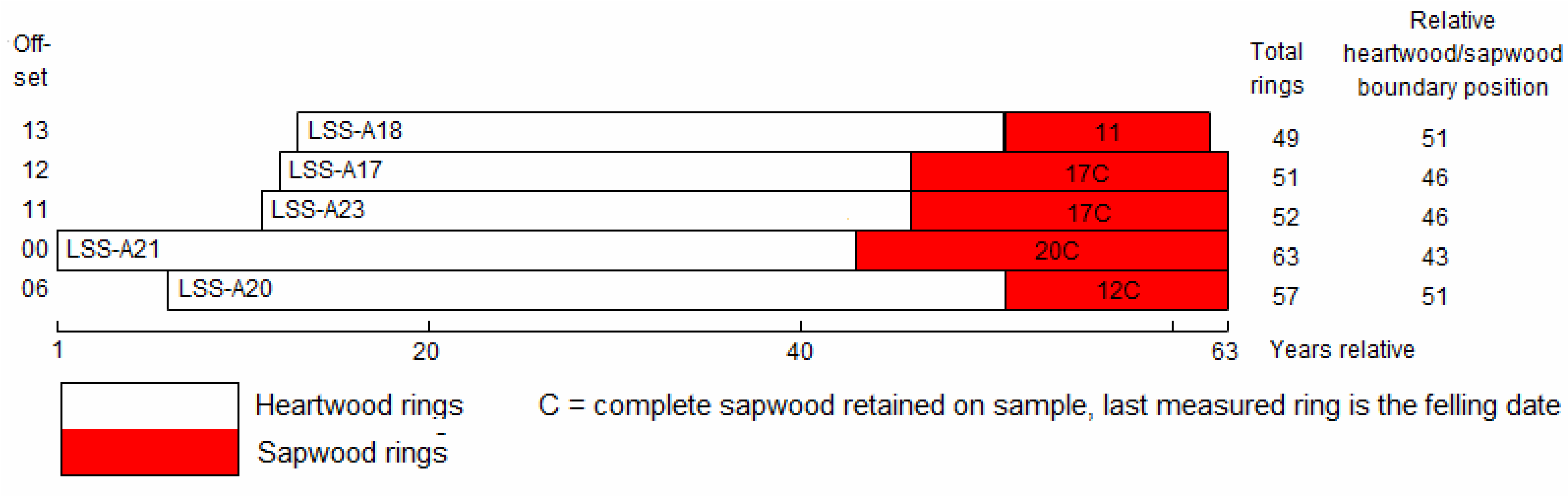

Figure 46: Bar diagram of samples in undated site sequence LSSASQ03

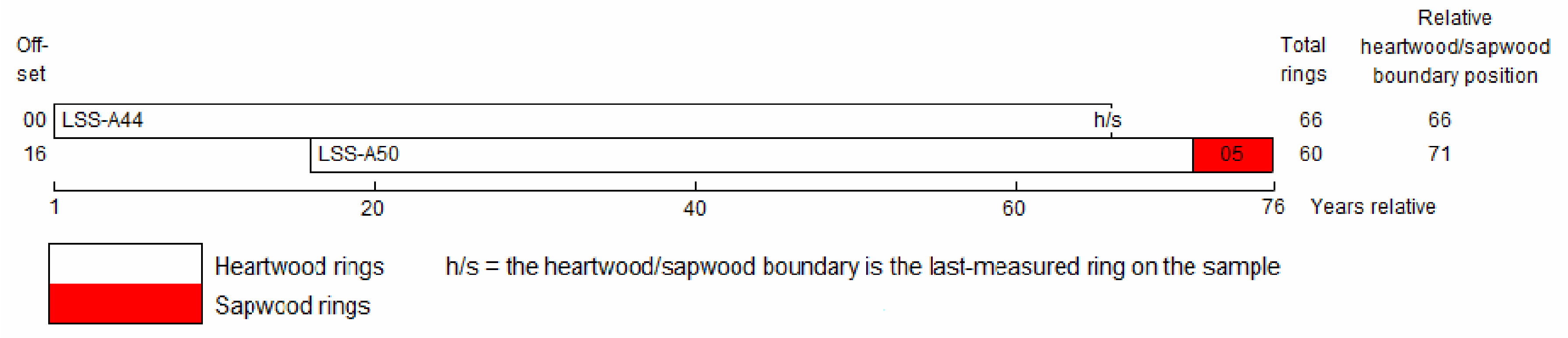

Figure 47: Bar diagram of samples in undated site sequence LSSASQ04

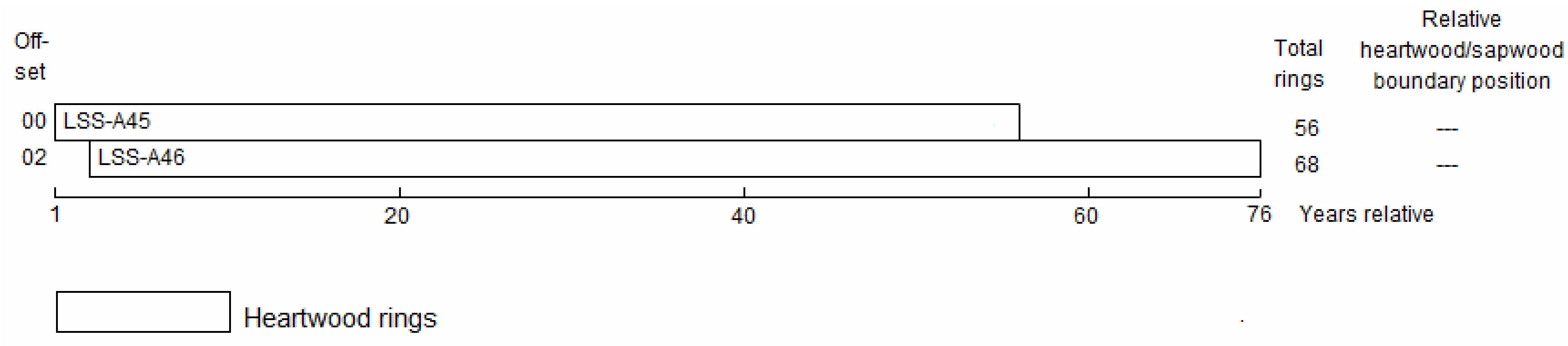

Figure 48: Bar diagram of samples in undated site sequence LSSASQ05

DATA OF MEASURED SAMPLES

Measurements in 0.01 mm units

LSS-A01A 69
406 377 439 451 316 353 263 216 254 389 228 198 207 239 322 251 405 225 331 343
292 261 234 206 185 174 261 230 209 192 171 198 113 132 188 147 99 117 169 242
176 189 163 229 126 132 171 152 233 160 142 217 210 136 146 224 236 190 246 181
221 128 193 118 110 83 157 214 100
LSS-A01B 69
418 367 444 454 321 353 262 230 243 389 224 199 213 233 322 247 401 220 333 346
300 261 236 216 188 174 249 238 201 190 170 198 115 129 187 147 102 120 168 238
173 178 162 225 126 136 168 151 237 165 150 214 213 138 153 222 232 195 244 176
224 137 159 140 113 104 151 215 90
LSS-A02A 67
247 350 170 363 439 220 218 319 424 225 205 195 184 251 140 214 124 165 215 131
129 160 175 149 114 134 141 116 145 132 126 80 108 87 81 68 89 102 151 126
173 123 169 111 140 188 128 175 141 136 150 146 76 117 141 197 154 175 135 114
124 139 99 104 120 129 142
LSS-A02B 67
225 359 169 367 452 216 217 323 423 227 209 192 175 258 142 206 130 159 223 128
140 162 180 141 126 140 139 129 139 122 127 84 113 92 77 77 76 108 155 122
167 137 140 121 139 191 133 172 141 127 154 147 90 114 149 201 166 161 136 125
127 133 107 108 122 148 135
LSS-A03A 70
415 387 550 442 372 411 421 347 376 297 260 357 561 290 258 260 299 304 151 227
146 241 264 171 171 158 140 176 215 204 236 336 204 171 167 135 110 132 101 129
140 146 160 205 172 151 289 205 190 252 187 231 208 212 174 224 236 203 249 249
145 119 99 152 180 209 142 132 118 137
LSS-A03B 70
507 407 559 446 372 394 402 352 379 298 255 351 557 285 246 248 295 303 146 227
144 250 266 164 175 163 144 165 231 234 236 334 215 151 172 139 111 130 105 128
137 141 167 192 182 159 304 204 205 239 191 219 215 208 197 219 240 193 254 244
150 120 93 148 186 190 153 124 116 118
LSS-A04A 74
253 209 139 89 79 146 121 169 196 196 126 124 61 82 98 67 54 53 78 57
68 44 34 42 33 83 76 136 104 128 163 123 113 143 192 153 168 219 123 124
134 122 129 146 139 156 153 138 142 115 84 92 87 98 95 79 87 78 66 56
58 60 71 95 88 70 76 82 82 84 125 131 99 113
LSS-A04B 74
263 209 134 93 83 140 139 156 193 190 127 116 63 85 98 74 59 49 72 58
63 46 36 33 44 90 65 134 103 128 158 120 109 138 191 152 173 228 128 126
137 117 127 150 138 162 154 130 141 121 76 94 90 92 100 80 89 75 64 60
55 63 71 90 92 68 81 82 75 81 129 133 100 99
LSS-A05A 80
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150 108 162 131 144 86 139 98 97 64 68 145 73 146 128 127 105 78 77 107
95 84 128 120 84 98 108 107 94 124 112 105 119 131 121 90 60 85 121 95
99 92 94 79 92 85 65 90 93 107 115 106 92 103 99 119 157 126 94 117
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154 107 151 132 139 102 144 107 84 69 59 159 76 134 127 138 113 75 67 115

89 69 124 107 100 97 123 111 80 124 108 108 127 119 121 99 71 84 106 106
100 98 95 74 99 73 63 92 89 119 111 84 109 111 92 95 179 130 94 122
LSS-A06A 60
186 173 185 132 127 120 122 127 134 100 114 110 132 119 124 119 170 182 120 91
52 80 151 98 141 146 147 160 134 121 143 149 98 117 143 92 88 93 112 108
96 108 92 120 103 101 89 63 95 92 91 76 85 79 70 72 49 55 88 79
LSS-A06B 60
189 176 190 139 132 119 122 140 136 94 123 111 134 122 125 115 171 185 133 110
52 78 142 104 153 145 147 157 141 114 131 149 104 119 150 92 98 86 108 99
103 99 95 124 102 95 83 71 88 98 82 86 83 88 67 68 64 59 87 93
LSS-A07A 71
315 286 245 245 189 201 202 170 215 180 165 183 173 185 192 162 148 129 78 66
65 84 140 88 145 128 164 180 148 145 167 182 129 159 207 120 106 114 125 94
75 74 84 82 92 112 103 71 67 85 74 63 69 67 57 64 55 59 54 59
52 53 54 67 72 75 61 102 85 94 93
LSS-A07B 71
321 291 252 242 197 202 211 172 212 180 165 179 175 185 195 164 152 122 85 68
56 86 146 91 144 129 162 177 157 144 173 182 126 158 211 117 107 106 125 99
75 77 82 80 101 129 96 67 59 86 72 59 70 67 53 72 56 62 60 53
64 48 54 70 75 75 75 91 96 84 100
LSS-A08A 48
71 187 292 221 233 185 92 141 137 107 105 97 118 127 138 139 116 138 212 136
138 142 184 53 31 19 58 111 103 205 167 219 235 169 170 175 165 158 165 200
118 124 131 152 116 157 124 94
LSS-A08B 48
76 192 281 232 225 182 107 131 134 115 114 88 122 138 114 131 125 140 218 133
147 157 165 42 40 28 46 141 108 211 170 224 229 177 167 156 183 156 165 211
120 123 132 152 115 160 122 106
LSS-A09A 70
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104 74 89 147 117 217 179 171 149 120 104 126 148 91 121 153 98 96 101 134
133 152 161 175 150 137 137 107 91 83 80 86 66 68 97 68 66 53 43 69
61 72 83 87 80 79 65 62 81 80
LSS-A09B 70
198 216 126 159 114 132 113 94 99 118 81 129 161 160 194 206 165 159 172 123
106 67 89 159 127 214 178 167 153 127 94 127 145 91 121 155 91 111 108 122
131 144 158 175 147 133 137 113 88 85 78 92 62 71 93 66 67 48 49 71
61 75 81 86 78 74 72 62 74 75
LSS-A10A 61
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176 139 87 126 111 107 94 83 101 104 112 84 93 88 95 100 67 67 59 47
65
LSS-A10B 61
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176 119 81 130 110 115 84 95 97 104 106 80 95 104 104 92 69 52 53 66
84
LSS-A11A 49
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263 243 233 267 214 148 174 192 181 144 240 193 137 115 174 170 187 179 135 149
150 150 202 234 222 234 249 277 187
LSS-A11B 49

247 272 268 390 479 334 292 242 254 182 181 255 253 177 194 179 169 158 201 235
265 241 225 268 216 144 176 186 177 141 233 191 148 111 187 167 192 182 124 153
154 152 190 254 223 230 254 298 169
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79 115 105 67 60 68 72 70 105 102 106 93 82 94 57 73 53 69 67 55
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84 108 101 85 54 67 79 67 97 96 113 83 90 93 63 63 59 71 58 66
60 57 54 62 37 41 71
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83 113 118 126 99 146 121 99 109 71 110 108 143 119 116 132 107 135 162 167
176 110 132 105 182 123 102 108 86 109 156 123 136 122 103 114 90 86 105 86
89 73 89 89 104 93 133 119 79 76 80 162 168 168 181 238 218 191 102 188
105 143 126 115 122 151 140 151 119 93 146 88 110 123 90 100 87 63 69 65
75 89 44 89 66 91 92 71 97 79 81 66 87 101 90 121 84
LSS-A13B 117
341 374 341 296 197 176 202 176 187 217 162 269 232 192 166 142 131 135 127 107
98 111 119 122 102 138 125 110 92 64 113 95 149 102 111 130 101 128 163 163
174 97 121 112 175 130 91 109 98 109 172 135 135 122 112 104 85 81 114 85
104 65 93 91 109 91 132 115 75 84 86 165 165 170 181 245 235 171 104 190
105 141 130 123 117 153 138 158 108 98 129 116 117 104 99 108 81 69 64 62
79 80 50 90 74 90 83 83 94 87 75 73 82 100 85 116 93
LSS-A14A 70
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109 94 88 121 117 130 110 135 126 119 78 126 83 76 78 83 108 115 104 103
80 86 112 81 74 73 65 82 54 64
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197 191 179 198 178 154 105 168 124 165 164 160
LSS-A15A 69
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121 132 136 113 142 175 301 195 126
LSS-A15B 69
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133 289 242 240 231 141 107 136 215 157 60 31 36 70 85 150 170 253 155 171
162 198 204 203 196 219 184 114 121 131 134 112 146 190 130 166 154 142 159 138
122 132 133 123 140 179 294 208 124
LSS-A17A 51
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238 144 234 197 185 136 202 293 282 322 347 266 307 310 277 275 210 265 226 334
321 289 335 293 176 257 256 157 114 133 122
LSS-A17B 51
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202 170 248 203 191 142 171 303 271 345 343 266 290 321 218 247 210 255 260 382
365 264 313 289 195 243 253 150 115 121 137
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137 229 172 160 189 221 307 194 188 245 173 186 233 238 254 260 338 294 248 353
190 346 284 309 221 219 254 217 346
LSS-A18B 49
338 489 326 323 334 411 273 302 387 360 258 366 354 252 222 134 182 350 331 199
139 249 178 155 191 236 305 196 190 266 176 186 203 222 257 271 326 298 242 354
182 347 296 303 223 186 282 322 355
LSS-A20A 57
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283 208 90 136 138 198 144 105 141 131 114 91 77 95 126 206 261 132 229 254
141 165 151 149 131 173 147 111 201 195 188 214 218 192 142 143 159
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156 157 137 151 134 175 147 105 203 203 181 205 221 162 129 148 154
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179 174 199 145 172 140 105 81 73 162 125 181 157 149 231 206 129 144 160 110
83 99 136
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226 223 273 205 217 220 241 191 156 253 233 214 252 219 249 266 236 161 204 177
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175 180 205 140 159 142 101 83 73 156 135 166 156 136 230 191 153 142 159 108
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237 236 225 202 232 195 220 242 194 153 130 143
LSS-A23B 52
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349 171 156 222 164 188 157 194 292 234 290 263 187 180 178 164 184 169 197 223
237 221 180 222 213 185 211 213 205 153 117 140
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121 195 138 116 140 123 153 196 140 215 201 133 117 92
LSS-A25A 51
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187 180 131 105 206 310 347 516 371 321 223
LSS-A25B 51
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129 170 140 194 272 208 173 302 236 335 364 272 239 265 161 197 252 239 310 241
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LSS-A27A 55

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392 185 286 295 265 415 257 232 252 192 184 308 362 402 347
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385 180 289 274 281 413 255 230 253 212 182 305 351 405 357
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127 116 156 169 168 181 173 179 242 109 159 165 180 165 236 156 148 136 93 72
115 118 119 141 99 108 156 142 111 167 147 129 127 107 157 179 175 208 132
LSS-A28B 79
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153 148 158 197 188 162 185 114 191 137 139 188 176 123 175 148 135 183 163 113
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113 115 124 128 88 109 161 149 110 146 150 132 135 86 167 167 168 219 120
LSS-A31A 56
469 354 427 386 303 381 369 245 314 232 242 282 313 244 253 213 200 213 218 202
241 251 149 134 102 171 168 174 183 166 178 128 120 148 170 178 211 191 257 169
144 226 213 169 117 104 158 120 169 123 172 151 185 149 173 199
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LSS-A33A 70
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181 177 184 194 210 195 186 227 109 204
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156 175 140 185 117 143 133 127 123 149 144 113 116 138 128 142 142 163 148 160
121 178 157 161 107 128 175 134 118 97 134 149 137 141 144 179 153 158 148 135
188 183 175 203 212 196 175 229 111 189
LSS-A34A 90
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159 158 138 116 143 132 136 111 109 161 132 125 96 139 143 161 128 152 194 159
158 170 158 193 195 165 197 210 198 145 192 115 213 165 163 172 210 133 191 161
157 184 180 111 105 93 151 168 146 190
LSS-A34B 65
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275 216 197 177 158 160 179 209 134 157 98 149 136 134 143 143 144 99 106 125
142 182 146 142 160 133 108 144 114 115 95 106 128 118 125 99 122 132 142 106
143 170 141 136 146
LSS-A35A 82
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171 151 182 173 181 91 142 102 124 139 168 140 155 128 224 144 131 173 160 96
115 91 135 152 131 166 162 210 196 91 119 134 161 129 194 139 108 137 85 57
93 98 138 180 117 123 175 173 160 174 195 145 162 113 155 148 206 215 240 210
172 134
LSS-A35B 82

257 259 178 121 130 206 154 194 154 183 188 207 176 202 238 206 212 200 282 313
178 149 176 159 178 88 140 100 128 139 169 140 153 122 212 161 140 175 168 105
113 89 139 161 132 170 156 217 190 100 115 126 158 130 182 141 119 133 78 64
96 97 132 185 116 122 179 181 162 176 197 134 165 113 155 151 193 222 232 211
178 161
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62 35 77 84 70 116 103 128 96 81 79 93 111 74 138 148 94 100 121 118
96 85 111 113 86 121 98 122 106 101 93 68 69 86 83 66 61 78 104 118
81 76 71 66 60 64 72 78 110 106
LSS-A36B 90
238 125 108 194 185 109 103 117 103 99 106 98 73 94 104 112 107 119 84 127
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60 31 78 77 82 110 107 128 93 91 75 94 106 78 131 151 94 98 118 115
96 86 120 107 81 127 112 108 89 104 95 65 72 84 82 64 66 80 96 118
84 75 69 72 52 68 70 81 111 108
LSS-A37A 99
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LSS-A48B 53
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200 247 134 192 194 240 185 203 198 156 187 174 223 376 471 297 193 238 236 163

229 176 175 261 283 181 204 207 263 307 186 203 155
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155 202 244 132 168 159 190 354 258 317 195 232 271 230 244 213 199 255 248 199
200 238 189 222 236
LSS-A49B 45
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LSS-A50B 60
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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 1998) and Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates (English Heritage 1998). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The width of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure A1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths for oaks, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of oak timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring.

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

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

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

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

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

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

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

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

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

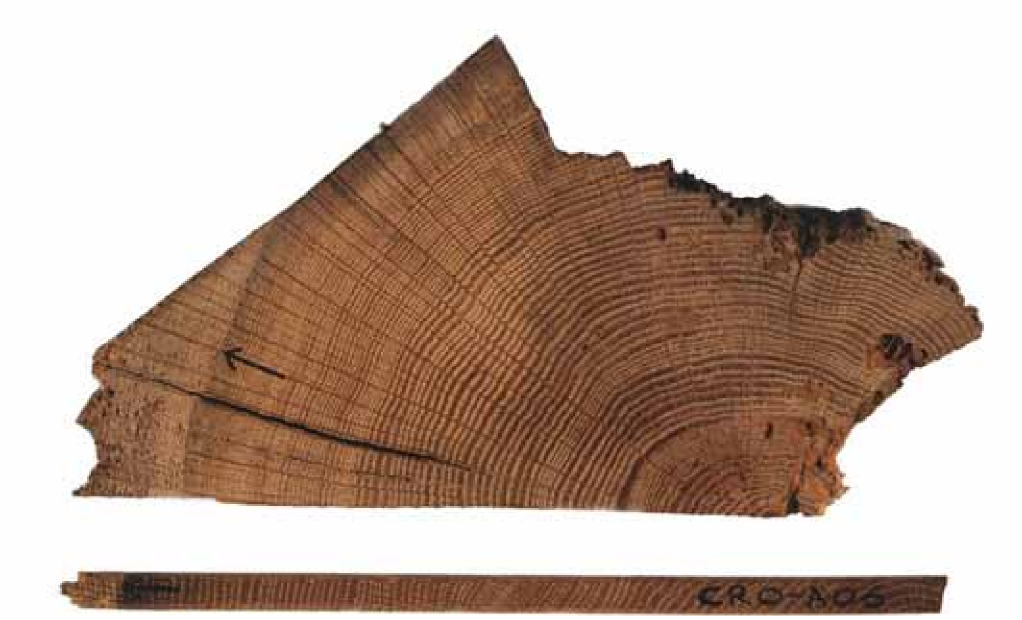


Figure A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

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

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

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

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

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

It is standard practice in our Laboratory first to cross-match as many as possible of the ring-width sequences of the samples in a building and then to form an average from them. This average is called a site sequence of the building being dated and is illustrated in Figure A5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences of the four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. Thus in Fig A5 if the widths shown are 0.8mm for C45, 0.2mm for C08, 0.7mm for C05, and 0.3mm for C04, then the corresponding width of the site sequence is the average of these, 0.55mm. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

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

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

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

Various estimates have been made and used for the average number of sapwood rings in mature oak trees (English Heritage 1998). A fairly conservative range is between 15 and 50 and that this holds for 95% of mature oaks. This means, of course, that in a small number of cases there could be fewer than 15 and more than 50 sapwood rings. For example, the core CRO-A06 has only 9 sapwood rings and some have obviously been lost over time – either they were removed originally by the carpenter and/or they rotted away in the building and/or they were lost in the coring. It is not known exactly how many sapwood rings are missing, but using the above range the Laboratory would estimate between a minimum of 6 (=15-9) and a maximum of 41 (=50-9). If the last ring of CRO-A06 has been dated to 1500, say, then the estimated felling-date range for the tree from which it came originally would be between 1506 and 1541. The Laboratory uses this estimate for sapwood in areas of England where it has no prior information. It also uses it when dealing with samples with very many rings, about 120 to the last heartwood ring. But in other areas of England where the Laboratory has accumulated a number of samples with complete sapwood, that is, no sapwood lost since felling, other estimates in place of the conservative range of 15 to 50 are used. In the East Midlands (Laxton et al 2001) and the east to the south down to Kent (Pearson 1995) where it has sampled extensively in the past, the Laboratory uses the shorter estimate of 15 to 35 sapwood rings in 95% of mature oaks growing in these parts. Since the sample CRO-A06 comes from a house in Cropwell Bishop in the East Midlands, a better estimate of sapwood rings lost since felling is between a minimum of 6 (=15-9) and 26 (=35-9) and the felling would be estimated to have taken place between 1506 and 1526, a shorter period than before. Oak boards quite often come from the Baltic region and in these cases the 95% confidence limits for sapwood are 9 to 36 (Howard *et al* 1992, 56).

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

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

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

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

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

t-value/offset Matrix

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

Bar Diagram

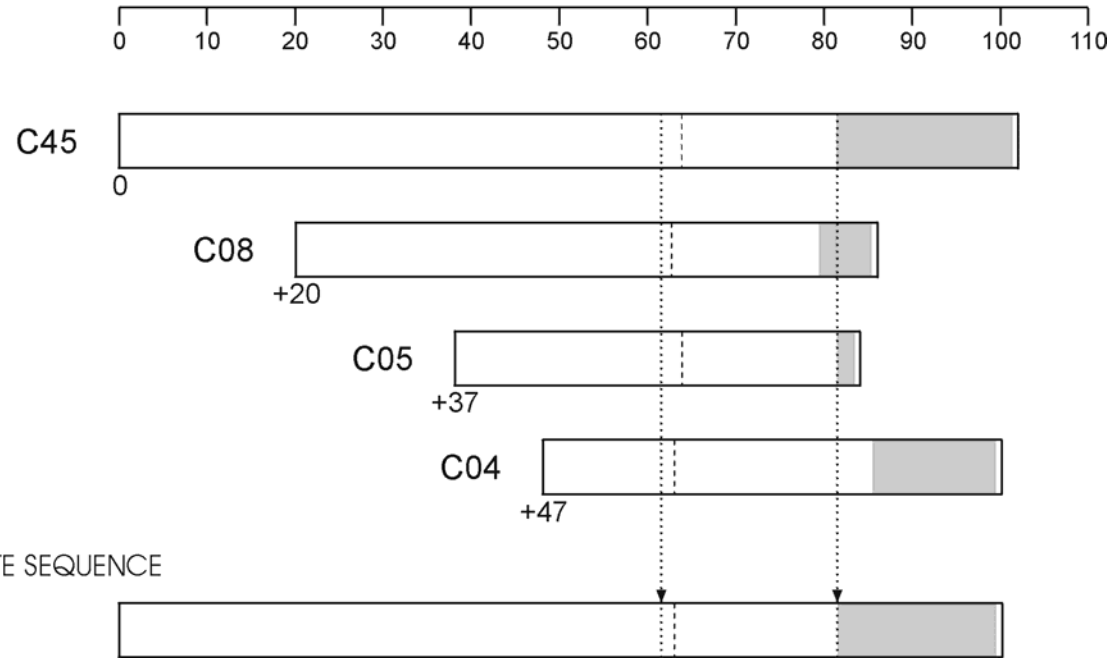


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

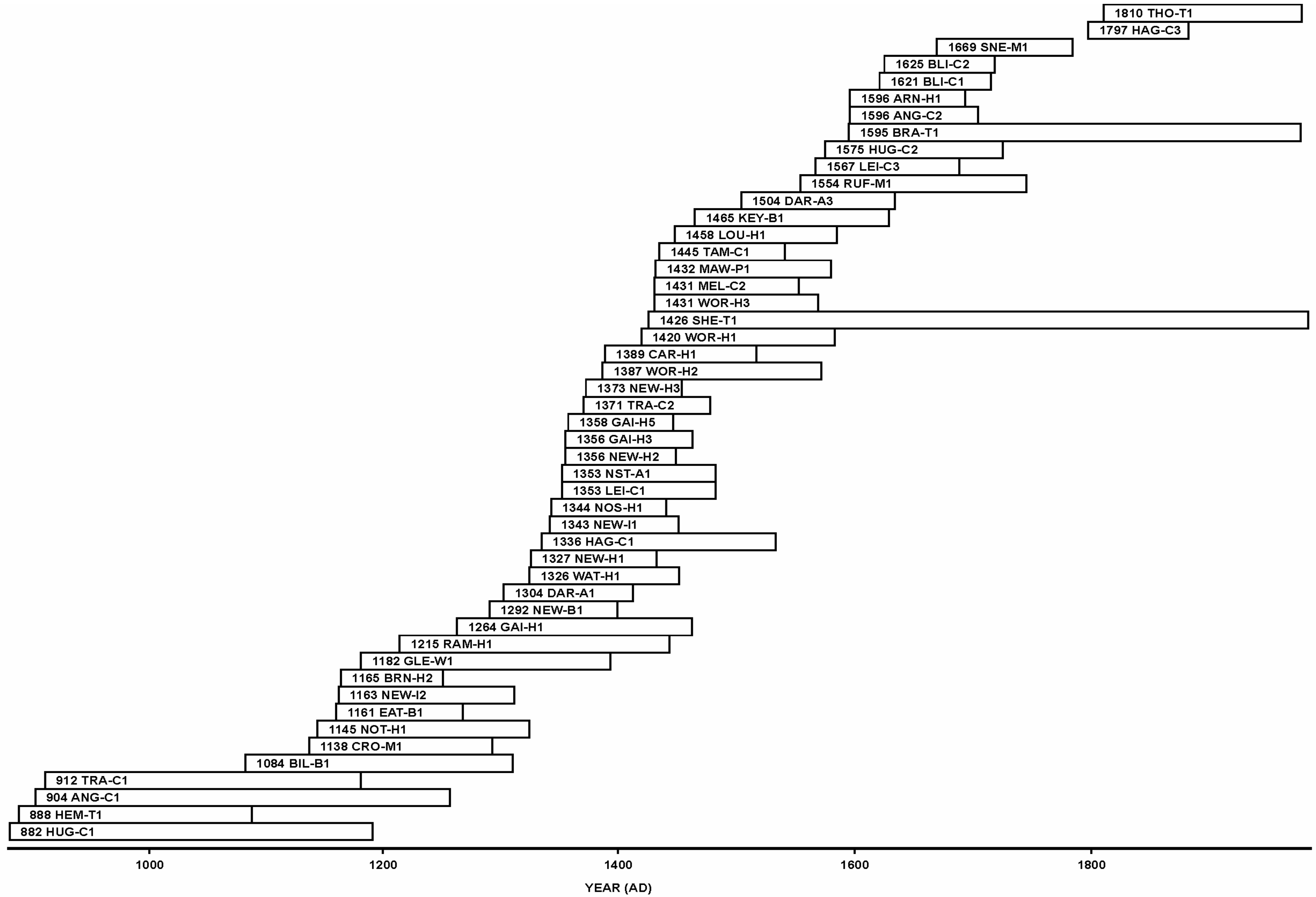
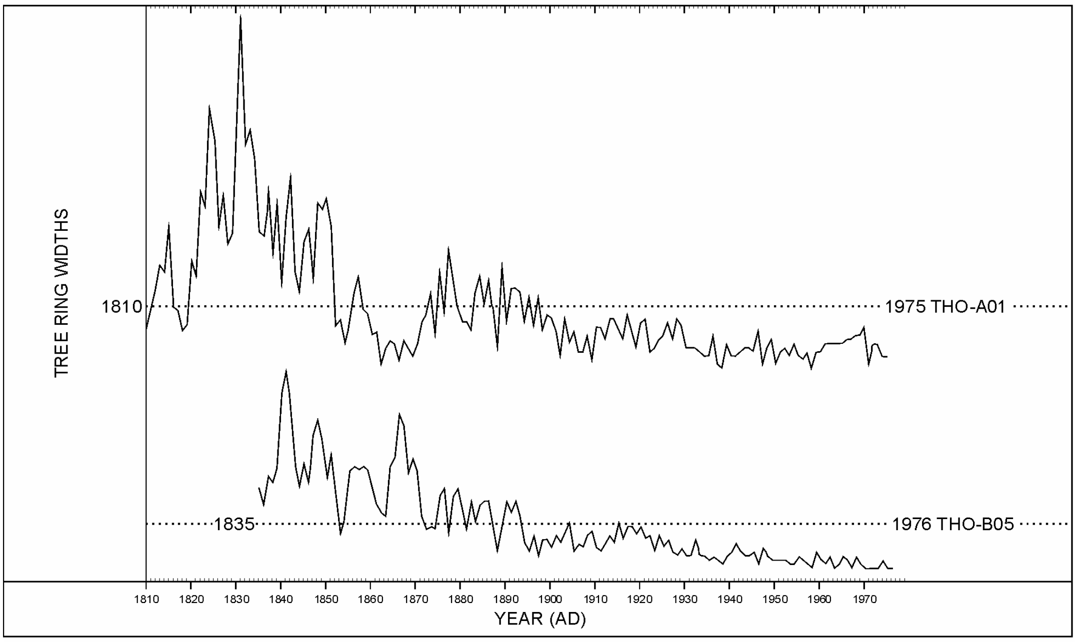


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

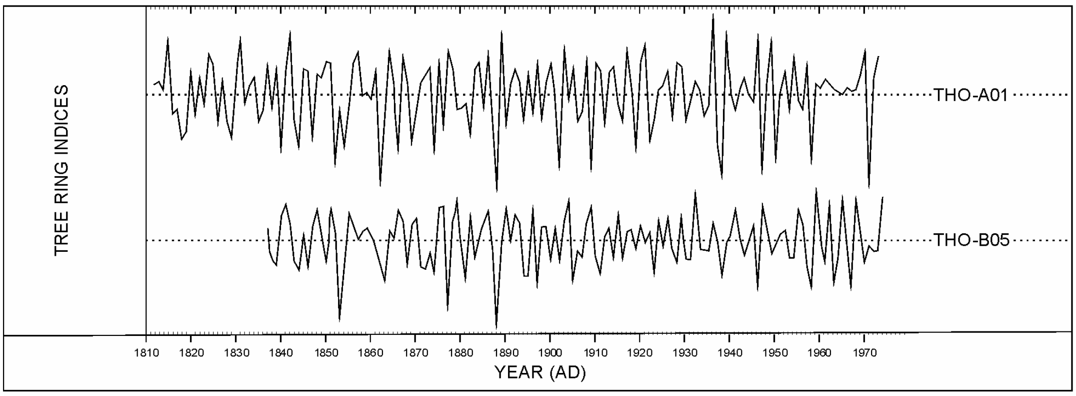


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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

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

The growth trends have been removed completely

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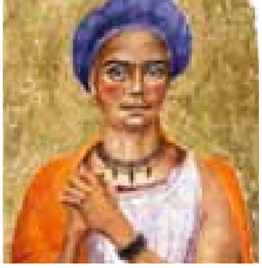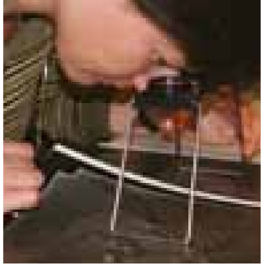

ENGLISH HERITAGE RESEARCH AND THE HISTORIC ENVIRONMENT

English Heritage undertakes and commissions research into the historic environment, and the issues that affect its condition and survival, in order to provide the understanding necessary for informed policy and decision making, for the protection and sustainable management of the resource, and to promote the widest access, appreciation and enjoyment of our heritage. Much of this work is conceived and implemented in the context of the National Heritage Protection Plan. For more information on the NHPP please go to http://www.english-heritage.org.uk/professional/protection/national-heritage-protection-plan/.

The Heritage Protection Department provides English Heritage with this capacity in the fields of building history, archaeology, archaeological science, imaging and visualisation, landscape history, and remote sensing. It brings together four teams with complementary investigative, analytical and technical skills to provide integrated applied research expertise across the range of the historic environment. These are:

- Intervention and Analysis (including Archaeology Projects, Archives, Environmental Studies, Archaeological Conservation and Technology, and Scientific Dating)
- Assessment (including Archaeological and Architectural Investigation, the Blue Plaques Team and the Survey of London)
- Imaging and Visualisation (including Technical Survey, Graphics and Photography)
- Remote Sensing (including Mapping, Photogrammetry and Geophysics)

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

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

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

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

ENGLISH HERITAGE

ISSN 2046-9799 (Print)
ISSN 2046-9802 (Online)