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Southwood Hall, South Field Court, Cottingham, East Riding of Yorkshire
Tree-ring analysis of oak timbers

Alison Arnold, Robert Howard and Cathy Tyers

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SOUTHWOOD HALL
SOUTH FIELD COURT
COTTINGHAM
EAST RIDING OF YORKSHIRE

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SUMMARY
Analysis of samples taken from the roof, the stairwell, and an *ex-situ* lintel from Southwood Hall, Cottingham, resulted in the construction of a single site sequence. Site sequence BEVISQ01 contains 14 samples and spans the period AD 1514–1662. Interpretation of the sapwood suggests felling of the roof and stairwell timbers occurred in the summer of AD 1662 or early AD 1663 whilst the lintel has a *terminus post quem* felling date of AD 1610 and so could also be coeval.

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INTRODUCTION

The Early Fabric in Historic Towns: Voluntary Group Projects, funded by Historic England, have been developed in the recognition and acknowledgement of the excellent work being undertaken by local vernacular groups in the study of local architectural trends and fabrics. The project's intention is to encourage this type of study through the provision of support and facilitate training of more people in building analysis and recording. The local projects were coordinated by Rebecca Lane (Historic England South West Region: Senior Architectural Investigation).

Early Fabric in Beverley Project

Whilst there is a corpus of research on form and age of the town of Beverley, it does not cover detailed examination of early fabric or aspects of typology, with analysis and interpretation of existing buildings until now not having benefited from dendrochronology, with the exception of some limited work on the Minster.

Initially, 13 properties were identified that were thought to be key to understanding the town's architectural development for a programme of comprehensive investigation. These properties were assessed for their suitability for tree-ring dating and those found to contain timbers potentially suitable for analysis were sampled. As the project progressed and some of the original buildings identified were rejected as unsuitable for tree-ring dating, further candidates for tree-ring analysis were assessed and sampled if appropriate.

It was hoped that successful dating of these buildings would extend the knowledge of early fabric and selected buildings in the historic town of Beverley in support of Historic England's responsibility to identify and understand the urban vernacular and historic environment of a market town. The reports produced on the buildings recorded as part of this project by the Yorkshire Vernacular Buildings Study Group, led by David Cook, will be held in the YVBSG archive and will be available through their website (www.yvbsg.org.uk), whilst a summary of the project is presented in Vernacular Architecture (Cook and Neave 2018).

SOUTHWOOD HALL

The grade II* listed Southwood Hall (List Entry Number 1310021) is located in the village of Cottingham, *c* 7.5 km to the south of Beverley (Figs 1–3). It has a main, two-storey plus attics, east-west range which faces south onto a walled garden, with a central two-storey porch. To the rear of this is the two-storey north wing. There is a barn attached to the east gable of the house, detached stables, and other buildings beyond the yard to the north. In addition, the house wing has an attached former cow house to the west and the barn has an outshut to the north, a store on the east gable, a wash house on the south elevation and a privy between the wash house, and the barn (Fig 4).

Main range roof

The roof structure is interrupted at collar level by the ceiling of the second-floor. Above this ceiling level are a series of common rafter couples, with every fourth pair having a collar, halved across the rafters with half-dovetail lap joints. A tier of purlins is set into 'V' trenches cut into the collars, clasped between common rafters and collars. There is a lower collar below the second-floor ceiling, for every couple, not halved across the rafters but butted up against a lower tier of purlins (Fig 5).

Stairwell

The central bay of the house is divided into two spaces through each storey. The front area contains the timber framed newel stairwell and associated landings with the rear containing an ante-room. The lowest level forms a small basement room with a heavy beamed ceiling and close studding (Fig 6).

Southwood Hall was thought to have been built by William Catlyn for the Bacchus family sometime between AD 1650 and AD 1661 and is believed to be the best-preserved example of its type and period in North Humberside.

SAMPLING

A total of 21 samples was taken from the timbers from the main range roof and the stairwell. Each sample was given the code BEV-I and numbered 01–21. Additionally, an *ex-situ* lintel was taken back to the laboratory for preparation and measurement; this sample is BEV-I22. The location of all core samples was noted at the time of sampling and has been marked on Figures 7 and 8. Further details relating to the samples can be found in Table 1. The timbers of the rear wing were also assessed for potential tree-ring dating but these were not sampled as they were found to be too fast grown and, therefore, unlikely to have sufficient growth rings for secure dating.

ANALYSIS AND RESULTS

Sample BEV-I06, taken from a purlin, had too few rings for secure dating and so was rejected prior to measurement. The remaining samples were prepared by sanding and polishing and their growth-ring width 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 programme (see Appendix), resulting in 14 samples matching to form a single group at a minimum *t*-value of 4.2.

These 14 samples were combined at the relevant offset positions to form BEVISQ01, a site sequence of 149 rings (Fig 9). This site sequence was compared against a series of relevant reference chronologies for oak where it was found to match securely and consistently at a first-ring date of AD 1514 and a last-measured ring date of AD 1662. The evidence for this dating is given in Table 2.

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

INTERPRETATION

Tree-ring analysis has resulted in the successful dating of 14 timbers (Fig 9). These have been dealt with according to area below. All felling date ranges have been calculated using the estimate that 95% of all mature oak trees in the region have 15–40 sapwood rings.

Ex-situ lintel

This single beam has a last-measured heartwood ring date of AD 1595. Unfortunately, it does not have the heartwood/sapwood boundary and without this ring it is not possible to calculate a felling date for this timber except to say that this would be estimated to be AD 1611 at the earliest.

Stairwell beams

Four of these have been successfully dated, three of which have complete sapwood and the last-measured ring date of AD 1662. When looked at under the microscope it is possible to see both the spring and summer growth cells of the final year on all three samples, giving a felling date in late AD 1662 or early AD 1663 for the timbers represented. The fourth dated beam does not have the heartwood/sapwood boundary and so a felling date range cannot be calculated for it, except to say that with a last-measured heartwood ring date of AD 1595, this would be estimated to be AD 1611 at the earliest.

Roof timbers

Nine of the samples taken from the roof have been dated. One of these, BEV-I09, has complete sapwood and the last-measured ring date of AD 1662. Again, the summer growth cells of the final ring of this sample can be seen, giving a felling date for the timber represented of late AD 1662 or early AD 1663. The other eight dated samples all have the heartwood/sapwood boundary, which is broadly contemporary and suggestive of a single felling. The average heartwood/sapwood ring date for these samples is AD 1632, giving an estimated felling date range for the timbers represented of AD 1647–72, consistent with these timbers also having been felled in AD 1662/63.

DISCUSSION

The tree-ring analysis has demonstrated that the roof and the stairwell are likely to be coeval, both structures utilising timbers felled in AD 1662/3. The *ex-situ* lintel has a *terminus post quem* felling of AD 1610 making it possible that this beam was also felled at this time and is contemporary with the rest of the timbers. Alternatively, and perhaps less likely, the lintel may represent a separate felling and signify the use of a reused timber or a later alteration or repair. On the basis of the tree-ring dating it would seem likely that the main range, including the stairwell, were built in or soon after felling of timbers in AD 1662/3.

It is known from documentary sources that John Bacchus purchased the land at Southwood sometime between AD 1650 and AD 1661 and that in his will of July

AD 1662 he referred to the house in which he currently resided as being ‘new built’. With the timbers utilised being felled in the summer of AD 1662 at the earliest it would seem unlikely that the house was completed by July of that year. It may be that the north wing was built first and that John Bacchus was living in that part of the house whilst waiting for the main range to be completed. Unfortunately, with the timbers of this wing being unsuitable for tree-ring dating this is not something that can be proven by dendrochronology. It is possible that detailed investigation of the relationship between the two parts of the house could clarify the sequence in which they were built. Alternatively, it may be that an error was made when writing the will or John Bacchus was simply anticipating being in shortly.

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YVBSG 2009 *Southwood Hall*, YVBSG rep 1753

TABLES

Table 1: Details of tree-ring samples from Southwood Hall, Cottingham, South Field Court, Yorkshire

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Main range roof						
BEV-I01	North common rafter, frame 6	112	22	--	----	----
BEV-I02	North common rafter, frame 7	117	h/s	1514	1630	1630
BEV-I03	South common rafter, frame 8	75	h/s	1564	1638	1638
BEV-I04	South common rafter, frame 12	101	16	1545	1629	1645
BEV-I05	South common rafter, frame 13	110	h/s	1523	1632	1632
BEV-I06	South purlin, frame 15	NM	--	----	----	----
BEV-I07	North common rafter, frame 26	66	06	----	----	----
BEV-I08	North common rafter, frame 30	85	h/s	1539	1623	1623
BEV-I09	South common rafter, frame 30	134	30C	1529	1632	1662
BEV-I10	South common rafter, frame 31	116	10	1526	1631	1641
BEV-I11	Collar, frame 31	110	--	----	----	----
BEV-I12	North common rafter, frame 33	70	01	1570	1638	1639
BEV-I13	South common rafter, frame 33	81	02	1558	1636	1638
BEV-I14	Collar, frame 35	113	h/s	----	----	----
BEV-I15	North common rafter, frame 36	58	h/s	----	----	----
Stairwell						
BEV-I16	Joist 2, north side	74	33C	----	----	----
BEV-I17	Joist 3, north side	56	h/s	----	----	----
BEV-I18	Joist 4, north side	60	--	1536	----	1595
BEV-I19	Joist 5, north side	88	23C	1575	1639	1662
BEV-I20	Main beam	116	27C	1547	1635	1662
BEV-I21	Joist 1, south side	102	27C	1561	1635	1662
Ex-situ timber						
BEV-I22	Lintel	52	--	1544	----	1595

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

Table 2: Results of the cross-matching of site sequence BEVISQ01 and the reference chronologies when the first-ring date is AD 1514 and the last-measured ring date is AD 1662

Reference chronology	*t*-value	Span of chronology	reference
Nun Appleton, Tadcaster, West Yorkshire	6.9	AD 1478–1657	Arnold *et al* 2008a
Upper Hall, Hartshorne, Derbyshire	6.9	AD 1448–1611	Arnold *et al* 2008b
Hipper Hall, Walton, Derbyshire	6.5	AD 1478–1632	Howard *et al* 1994a
Donnington-le-Heath Manor House, Leicestershire	6.5	AD 1411–1618	Esling *et al* 1989
St Peters Church, Saltby, Leicestershire	6.4	AD 1446–1625	Howard *et al* 1995
Moor Farm Cottage, Shardlow, Derbyshire	6.3	AD 1437–1616	Howard *et al* 1994b
101 Meeting Street, Quorn, Leicestershire	6.3	AD 1489–1658	Arnold *et al* 2008c
Manor House, Preston, Rutland	6.2	AD 1471–1631	Arnold and Howard 2013 unpubl
Bentley Hall, Hungry Bentley, Derbyshire	6.0	AD 1444–1675	Arnold and Howard 2009
Pontefract Castle, Pontefract, Yorkshire	5.8	AD 1507–1656	Arnold and Howard 2005

FIGURES

Figure 1: Map to show the general location of Cottingham, circled. © Crown Copyright and database right 2017. All rights reserved. Ordnance Survey Licence number 100024900

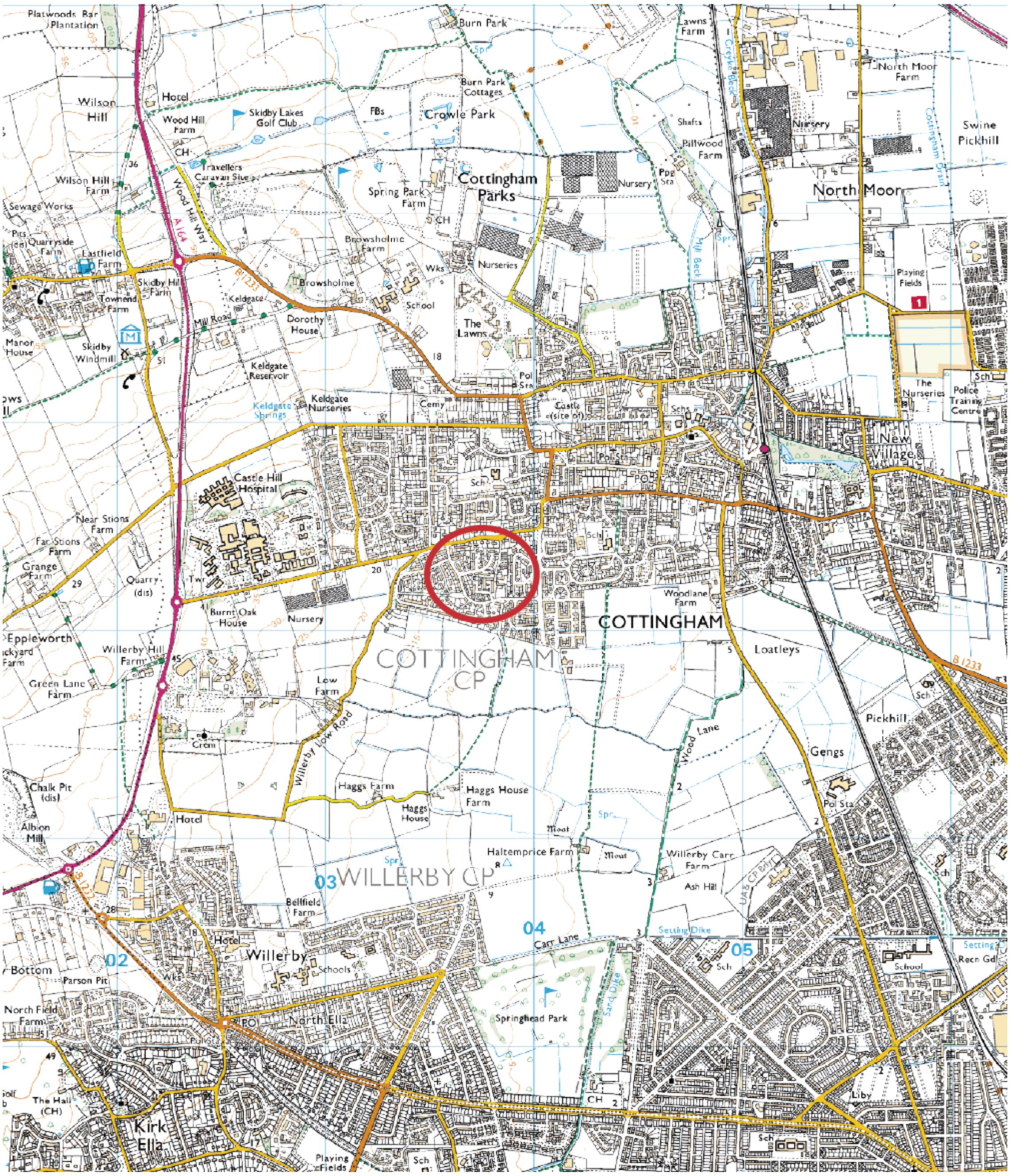

Figure 2: Map of Cottingham to show the general location of Southwood Hall, arrowed. © Crown Copyright and database right 2017. All rights reserved. Ordnance Survey Licence number 100024900.

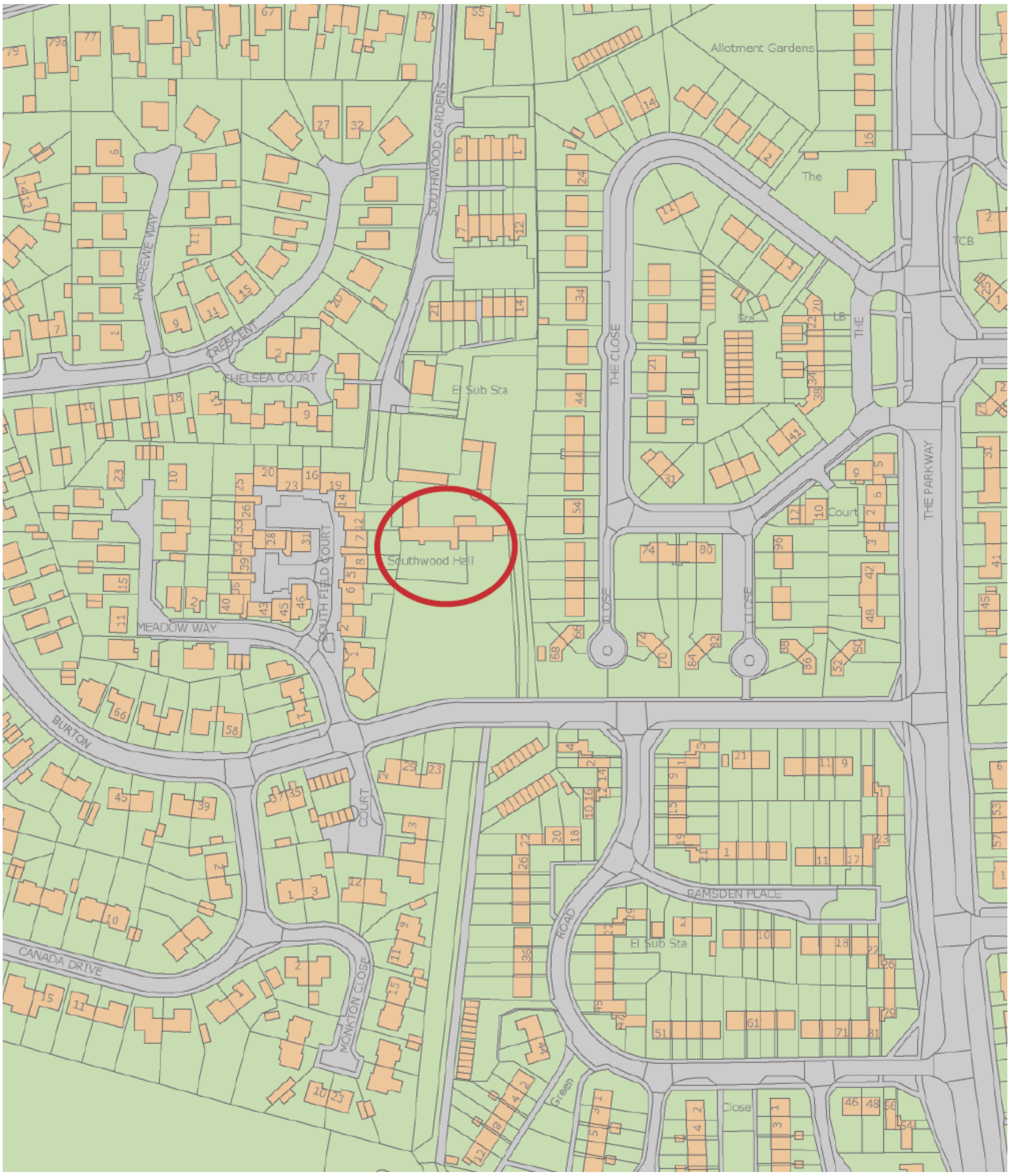

Figure 3: Map to show the location of Southwood Hall, circled. © Crown Copyright and database right 2017. All rights reserved. Ordnance Survey Licence number 100024900

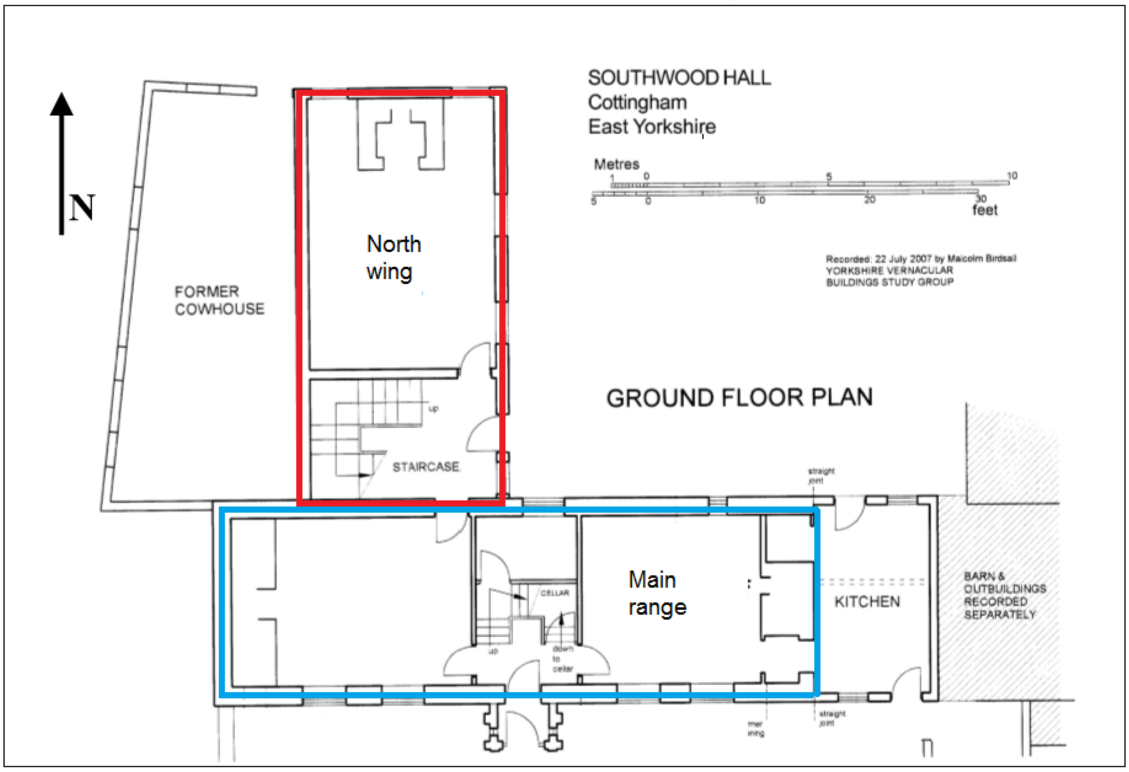

Figure 4: Ground-floor plan (YVBSG 2009)

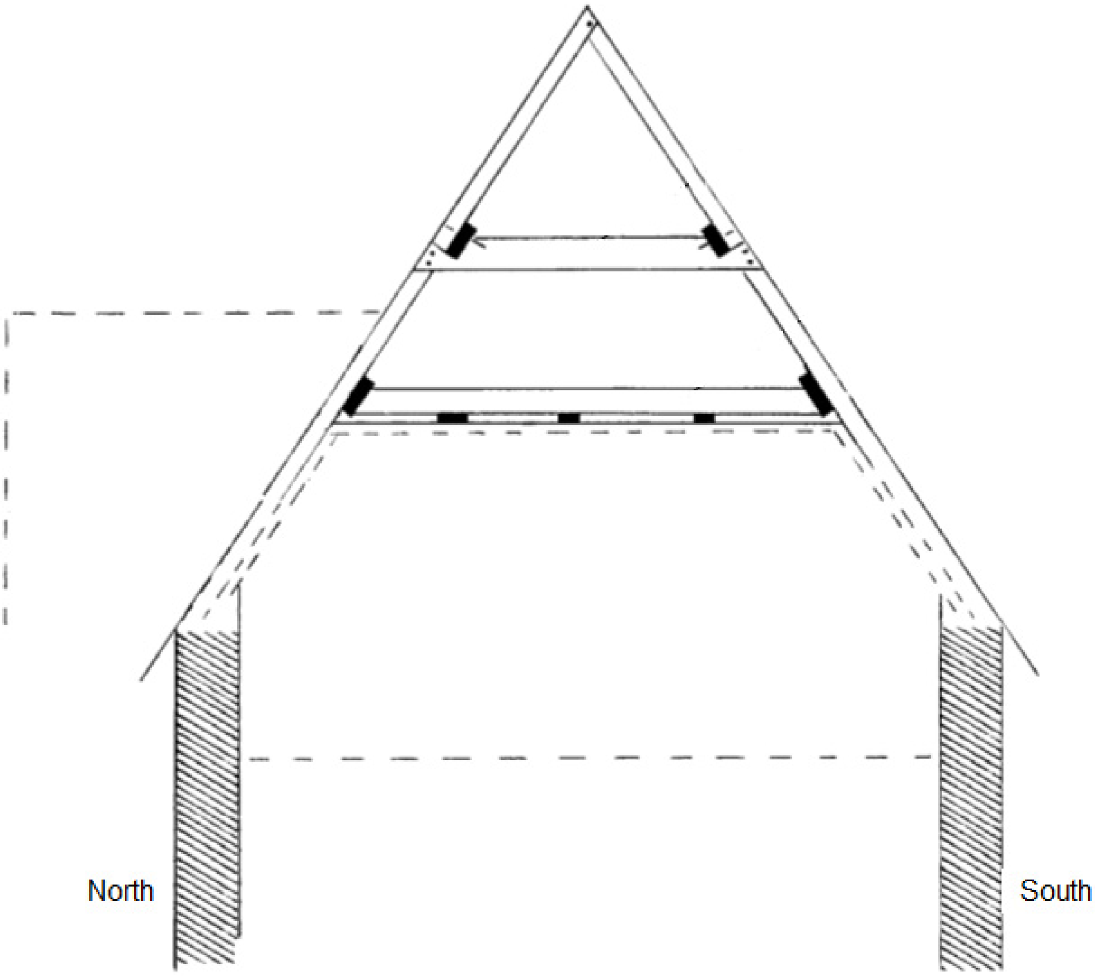

Figure 5: Representative truss (after YVBSG 2009)

Figure 6: Stairwell at cellar level

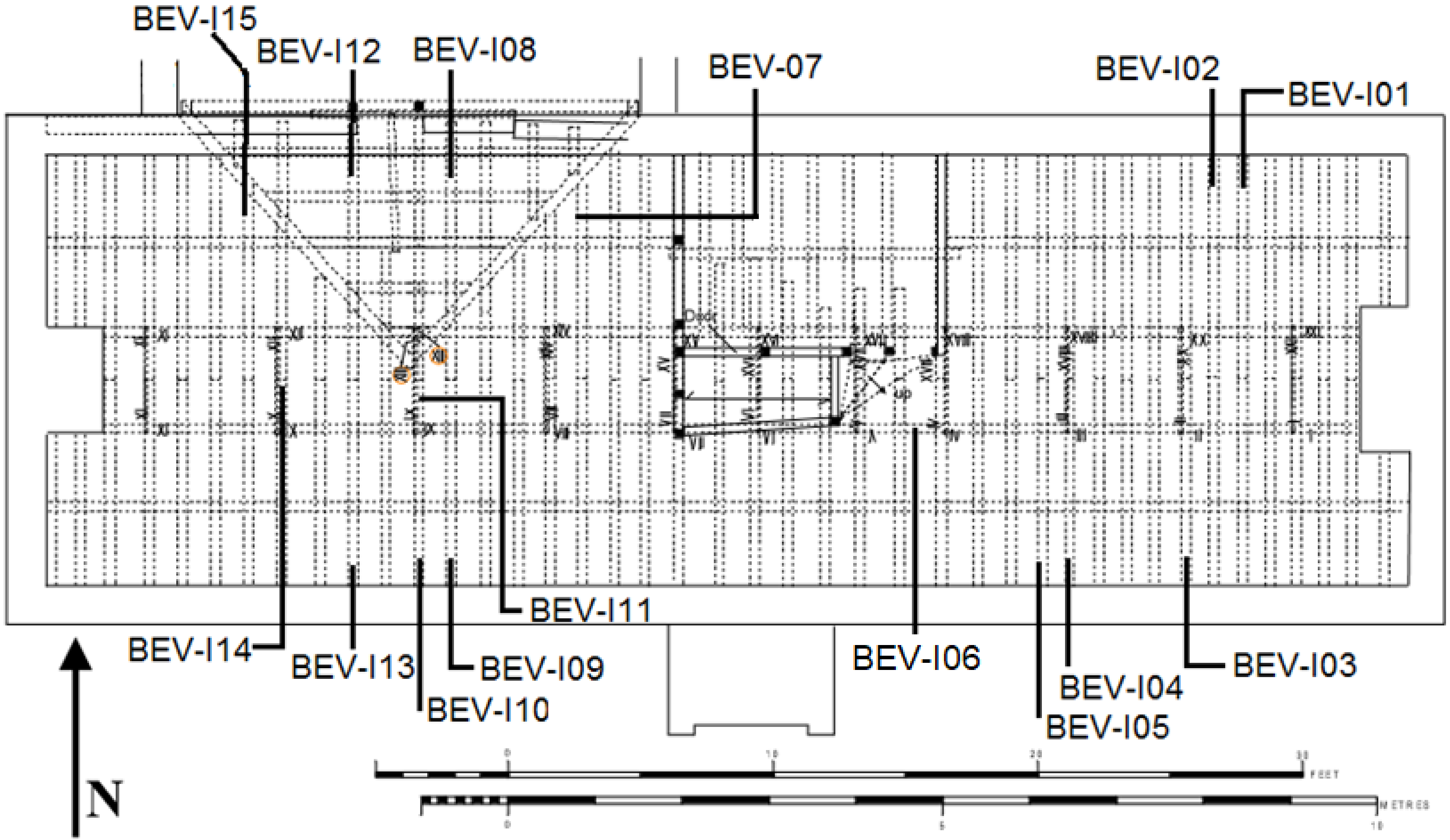

Figure 7: Plan at attic level, showing the location of samples BEV-I01–15 (after YVBSG 2009)

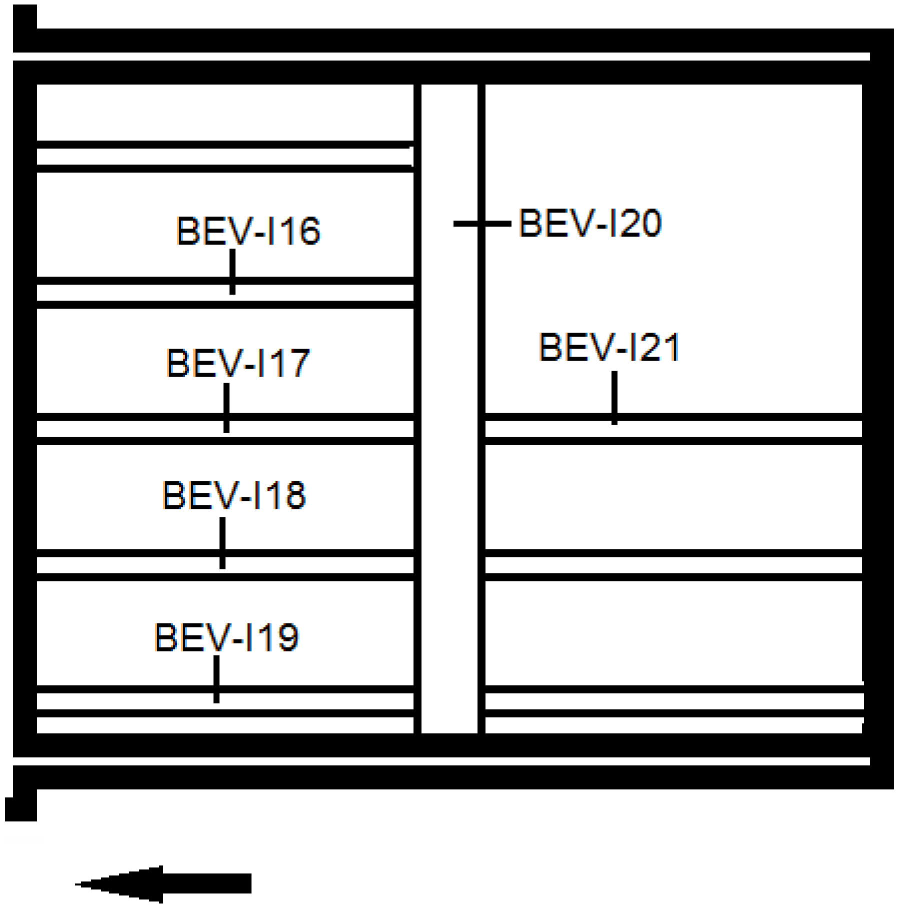

Figure 8: Sketch of basement ceiling, showing the location of samples BEV-I16–21

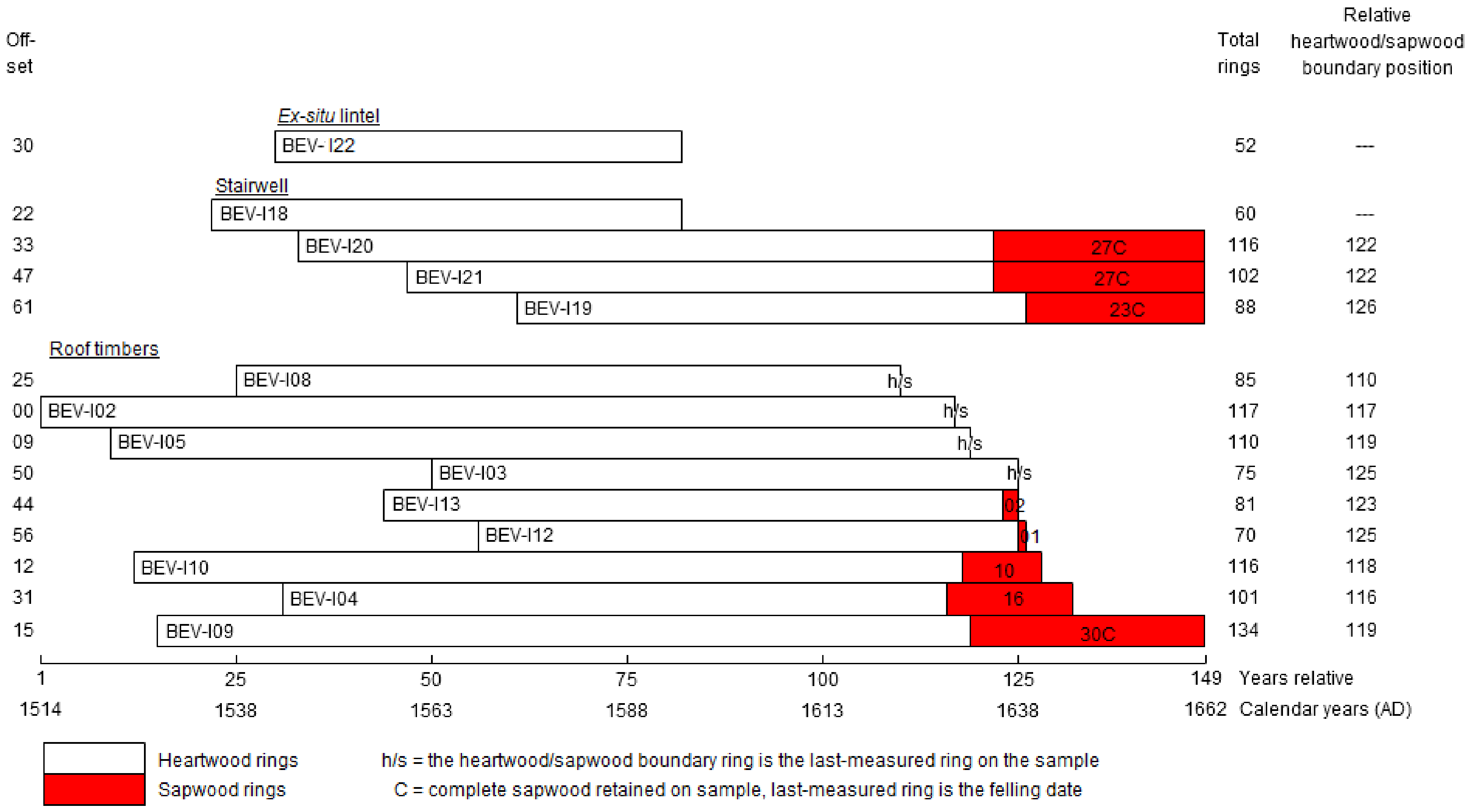

Figure 9: Bar diagram to show the position of samples in site sequence BEVISQ01, sorted by area

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units with the exception of sample BEV-I22 which is in 0.1mm

BEV-I01A 112
64 92 113 216 167 126 158 175 99 98 29 31 38 33 35 42 42 45 66 99
161 164 137 182 65 47 39 37 32 50 50 87 96 90 82 83 129 111 57 37
39 25 43 45 54 65 74 84 82 80 53 41 29 25 34 35 49 46 52 42
47 29 33 52 72 44 42 33 31 46 41 60 64 36 41 70 56 58 49 39
57 38 37 35 38 44 23 36 29 31 29 22 36 44 41 40 40 38 43 37
67 60 40 77 44 47 39 27 43 35 25 29

BEV-I01B 112
75 94 123 196 173 124 164 167 104 95 29 39 36 28 31 42 48 45 68 97
154 173 143 177 59 40 50 28 42 45 51 97 86 95 85 71 118 115 58 35
41 24 39 51 51 66 74 84 88 82 55 38 36 20 42 40 37 49 49 43
43 30 33 49 78 42 40 32 37 43 40 60 66 34 46 66 60 60 46 43
57 41 38 36 38 43 24 32 29 37 24 24 44 44 32 39 40 42 36 42
69 47 42 80 49 45 28 40 34 34 26 29

BEV-I02A 117
60 68 117 181 128 91 47 90 108 93 71 69 104 106 136 164 89 259 296 243
223 257 250 260 421 302 173 83 54 71 115 141 212 194 166 115 128 174 156 121
96 92 80 96 65 127 199 230 242 142 160 134 102 53 42 61 78 94 109 81
68 76 69 64 97 124 125 75 56 34 50 58 80 74 65 78 102 127 129 157
140 64 23 19 22 26 35 31 47 75 70 98 90 69 74 59 54 79 74 64
66 66 41 32 38 36 45 35 41 40 43 37 38 34 37 54 49

BEV-I02B 117
68 69 117 186 118 93 52 87 107 96 65 71 106 110 133 167 93 255 288 253
202 269 255 257 381 267 171 91 42 75 109 140 201 179 168 124 143 162 167 130
109 90 73 85 84 125 197 206 250 154 160 138 98 64 54 55 81 97 115 81
70 83 70 66 101 118 132 72 60 40 46 61 82 73 66 72 109 118 137 164
136 57 26 30 23 22 30 33 42 69 75 92 97 68 68 61 56 75 72 62
62 63 40 34 33 40 40 37 36 45 43 32 38 35 42 56 51

BEV-I03A 75
338 194 231 219 276 332 252 240 195 140 106 69 80 63 87 90 117 97 80 87
110 191 196 138 113 125 176 144 165 169 126 140 162 252 202 187 161 150 143 176
127 83 99 138 168 131 89 125 103 94 92 128 79 87 129 115 107 81 123 131
65 68 72 59 67 93 103 59 105 93 60 85 83 86 95

BEV-I03B 75
328 193 224 216 266 323 258 238 196 137 101 65 77 68 84 101 115 105 79 93
106 182 202 139 116 128 173 133 160 162 131 138 151 242 206 171 146 121 155 159
130 81 96 152 166 113 86 137 100 101 93 119 82 77 145 123 103 85 117 124
63 69 73 59 68 100 88 55 95 74 57 75 72 60 106

BEV-I04A 101
373 361 342 256 164 169 239 152 97 91 143 180 208 160 223 267 280 321 293 280

220 185 206 273 256 277 284 281 227 90 50 52 39 68 100 112 98 86 87 82
154 152 136 51 53 60 60 67 86 79 83 41 66 54 69 112 58 42 53 42
35 35 46 69 61 85 93 48 48 56 82 67 60 78 62 66 53 46 44 60
60 80 57 74 101 85 96 60 50 33 58 68 50 37 38 48 51 36 46 66
67

BEV-I04B 101
369 368 336 252 158 166 250 157 99 104 137 178 197 163 220 262 282 320 286 286
221 180 199 262 264 270 288 275 223 88 52 52 42 67 102 110 100 89 78 78
146 160 132 54 50 65 53 75 86 78 85 54 62 59 67 112 57 41 55 40
38 34 50 66 63 83 92 49 53 48 85 67 52 75 66 72 49 45 49 63
55 78 53 83 103 95 74 71 49 49 57 73 54 51 39 46 54 46 52 58
67

BEV-I05A 110
37 39 48 68 134 127 70 44 80 87 67 88 97 122 93 78 141 104 93 52
78 114 130 100 69 65 69 68 62 47 46 34 46 40 38 44 53 42 43 50
50 45 40 36 34 31 29 40 45 35 42 30 27 26 38 43 55 49 53 47
52 54 58 79 68 54 42 31 32 24 33 33 36 33 37 35 39 40 42 33
29 39 25 34 46 54 40 30 30 32 34 26 35 29 29 47 37 37 36 36
39 38 53 52 49 51 63 56 34 61

BEV-I05B 110
46 46 32 69 133 122 70 47 80 86 61 95 98 125 96 74 142 101 91 53
76 122 122 99 63 65 60 70 72 40 49 37 50 37 38 45 52 40 48 50
47 43 37 42 36 30 29 41 36 37 38 27 32 23 40 47 54 48 56 45
54 53 58 81 68 56 43 28 33 25 34 31 37 34 34 38 42 38 38 32
34 37 24 35 49 52 40 31 29 32 31 28 35 35 31 39 39 39 36 36
34 44 50 57 51 52 52 62 34 59

BEV-I07A 64
197 237 249 208 249 254 352 263 229 298 184 183 159 170 149 155 163 140 176 184
222 213 186 122 72 63 73 59 74 73 140 172 144 155 160 170 153 120 94 86
94 125 120 113 117 102 93 109 139 120 143 202 188 242 216 236 266 253 254 105
73 69 53 63

BEV-I07B 66
189 204 190 257 193 238 259 334 258 220 306 173 201 160 168 145 154 166 149 170
182 220 216 189 116 78 62 71 62 70 75 143 166 144 151 164 169 151 124 87
91 85 134 120 115 110 105 90 116 130 122 143 202 193 237 216 231 273 244 264
107 75 74 66 79 44

BEV-I08A 85
190 237 156 79 100 134 206 146 182 207 154 154 188 159 116 93 83 80 79 55
85 115 136 137 188 180 129 116 62 68 72 67 74 76 73 74 94 75 54 69
90 99 48 35 29 48 57 75 74 67 57 87 102 114 100 86 100 80 45 49
38 44 52 43 68 64 56 52 38 46 28 47 48 57 48 52 53 43 49 44
42 41 30 24 24

BEV-I08B 85
191 234 159 85 97 128 211 148 185 210 136 169 179 166 119 93 81 81 80 59
88 113 137 146 183 176 129 121 66 72 53 78 76 71 73 73 98 67 57 69
73 99 52 39 28 43 61 70 74 73 51 88 101 117 99 85 99 76 45 39

37 52 47 43 71 63 54 58 42 37 32 40 48 54 60 52 51 51 48 46
34 44 29 25 20

BEV-I09A 134
186 99 194 192 239 258 289 223 220 249 200 146 129 57 82 160 121 124 120 161
108 113 147 80 55 38 50 55 64 41 87 148 82 56 56 84 99 87 45 43
56 51 51 80 70 67 65 45 63 72 79 93 60 30 37 47 68 85 72 72
104 105 90 82 102 88 54 42 36 54 57 78 89 117 104 79 59 64 54 103
39 43 52 45 37 29 48 65 82 66 60 69 79 99 74 71 48 60 44 39
72 53 66 60 40 41 69 62 93 126 97 51 25 33 26 28 27 42 36 49
44 34 26 35 59 45 42 54 51 32 36 55 51 51

BEV-I09B 134
182 99 198 194 235 256 285 227 229 234 212 138 128 58 87 148 122 134 119 157
111 91 139 91 58 47 49 61 59 36 84 198 80 55 58 85 101 87 39 43
57 51 51 79 75 66 60 52 66 75 76 97 62 29 40 47 68 87 74 65
110 94 81 79 85 82 54 49 33 52 55 77 101 109 98 80 54 62 58 107
34 48 54 40 38 31 53 58 81 77 54 63 82 98 73 75 50 55 44 40
72 55 61 56 47 39 70 55 92 124 102 50 25 25 29 32 31 36 43 47
44 31 24 40 62 33 44 61 51 44 55 48 40 42

BEV-I10A 116
221 191 196 134 93 148 231 309 285 400 307 234 286 214 130 73 54 65 101 96
104 121 156 93 97 102 97 49 51 39 51 51 36 66 79 62 61 42 57 55
58 49 43 36 58 65 52 52 38 36 45 47 46 68 79 60 32 37 41 24
54 38 40 36 54 55 44 52 69 48 40 29 57 24 97 77 97 88 81 40
44 45 73 24 33 45 39 36 42 53 59 63 63 36 46 55 66 44 57 35
63 55 48 78 85 101 90 72 59 50 48 70 78 38 37 31

BEV-I10B 116
217 189 198 137 97 158 223 311 283 410 311 239 268 196 127 73 52 71 115 96
107 117 151 96 103 98 104 43 50 43 49 47 38 74 68 59 52 51 63 54
60 44 41 42 54 68 53 51 41 35 48 42 49 73 76 59 42 33 35 29
58 35 41 34 51 57 50 45 73 47 39 31 38 45 71 96 95 92 74 50
44 46 74 26 32 49 36 33 44 53 59 59 62 41 41 53 69 39 58 36
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BEV-I11A 110
119 129 150 178 215 168 231 121 121 78 131 149 172 90 126 92 108 244 149 224
183 276 162 92 81 74 104 135 118 80 82 142 136 125 79 79 84 132 127 121
100 127 89 66 38 48 49 57 47 45 55 67 63 53 66 98 118 43 31 25
36 56 46 61 55 44 43 65 99 116 97 145 111 112 133 87 75 89 54 59
41 61 35 64 48 65 64 79 72 77 113 74 56 50 41 60 81 73 71 36
31 40 32 42 36 64 46 132 84 67

BEV-I11B 110
124 124 145 176 223 175 241 133 124 91 138 137 179 92 112 79 115 244 146 214
180 280 160 94 84 72 106 130 122 85 78 141 144 125 77 96 82 131 118 121
103 124 95 61 45 39 50 58 51 43 48 74 54 57 71 94 121 44 39 31
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BEV-I12A 70
239 152 150 156 104 99 120 79 138 160 174 78 64 88 115 115 126 153 177 131
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49 36 65 48 33 38 54 82 100 86

BEV-I12B 70
228 151 159 150 105 109 121 97 132 176 172 77 63 89 118 117 140 150 180 134
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45 41 60 47 34 34 52 88 109 87

BEV-I13A 81
237 328 310 378 426 247 216 158 143 136 192 286 254 256 185 102 90 63 105 70
125 103 103 63 57 108 91 120 136 104 98 95 115 83 103 111 88 112 103 125
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85

BEV-I13B 81
200 328 325 354 438 229 197 160 143 140 186 272 253 242 169 118 86 62 90 82
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67 63 69 46 55 62 60 71 95 56 62 87 87 49 98 74 54 79 79 92
75

BEV-I14A 113
246 155 158 173 165 169 162 131 125 154 137 149 119 138 89 96 102 100 111 129
152 149 187 168 113 60 61 67 77 94 90 127 143 183 100 122 116 129 121 90
110 97 76 94 98 163 162 125 109 137 145 99 143 206 166 134 110 118 140 111
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74 55 43 34 43 53 57 55 70 64 55 50 47

BEV-I14B 113
248 154 156 176 168 171 165 137 119 154 134 154 119 133 96 103 103 94 113 128
152 158 181 174 102 62 57 75 77 91 86 122 137 173 101 133 115 129 125 93
115 110 76 93 98 153 155 129 104 140 138 104 149 196 170 136 112 122 130 113
92 68 86 101 82 82 101 94 64 68 85 95 109 106 65 54 47 41 75 93
120 113 103 93 92 101 108 89 60 52 50 43 55 58 56 60 51 57 53 59
59 62 42 42 38 55 57 63 56 58 62 47 46

BEV-I15A 58
159 124 55 130 212 192 152 199 187 144 101 89 127 82 105 89 99 131 157 176
123 139 127 104 76 130 120 79 60 89 158 112 89 64 83 75 86 122 201 123
79 64 55 60 58 86 60 83 92 84 61 65 42 46 63 101 98 142

BEV-I15B 58
150 133 57 135 225 175 180 161 154 132 102 101 119 101 104 104 111 146 166 175
132 148 142 95 67 132 108 73 60 93 165 123 87 63 87 69 92 115 211 116
82 53 58 59 56 85 65 75 98 80 70 57 42 55 66 100 102 113

BEV-I16A 73

368 265 214 175 239 282 227 301 339 286 239 266 238 200 224 204 90 158 156 153
141 220 283 271 182 167 155 198 162 164 187 176 129 134 117 134 124 65 60 82
106 84 89 92 75 71 68 91 136 139 118 131 96 49 88 78 146 132 165 144
82 59 57 46 95 132 100 166 100 139 142 211 146

BEV-I16B 74
413 276 221 173 204 274 274 294 339 288 240 269 232 200 229 207 85 154 155 152
157 212 298 251 185 173 151 198 160 164 188 180 114 139 109 136 125 55 62 85
104 83 90 93 75 76 65 88 133 141 121 140 99 56 83 74 144 143 163 145
78 65 46 54 80 130 98 167 107 142 128 201 157 83

BEV-I17A 56
382 388 339 340 392 236 200 173 250 272 171 271 330 245 130 171 123 125 215 120
76 95 91 63 41 106 114 98 146 101 134 120 93 108 108 54 58 95 115 92
92 121 99 134 172 124 67 52 53 50 49 44 53 65 58 54

BEV-I17B 56
395 387 343 344 390 252 200 171 250 274 172 276 330 246 148 194 128 133 215 123
74 96 87 60 43 107 117 120 154 112 147 131 116 116 118 73 59 87 122 95
94 121 94 130 170 125 71 49 45 48 49 54 47 60 65 54

BEV-I18A 58
143 124 137 118 115 123 217 192 184 103 83 72 55 77 65 76 84 137 110 86
100 113 198 133 123 94 114 124 139 152 120 120 163 113 138 118 119 102 106 101
167 164 176 173 68 62 64 86 98 129 97 77 101 101 97 152 94 131

BEV-I18A 60
284 218 181 163 166 121 101 136 236 215 189 108 85 71 55 74 60 63 81 144
108 89 102 112 202 127 125 97 112 128 148 145 114 121 175 116 136 118 119 101
100 105 170 168 186 169 64 56 60 76 100 165 113 76 105 96 99 150 96 126

BEV-I19A 88
135 206 135 170 192 243 202 240 250 237 259 331 285 166 245 208 185 187 233 256
243 87 65 60 74 91 100 86 114 104 60 87 126 163 169 78 51 57 49 35
41 44 26 63 62 62 63 88 113 54 45 29 33 27 32 28 26 33 28 24
31 67 65 139 130 150 166 117 93 46 38 44 50 84 46 51 47 68 115 132
94 93 96 81 129 103 71 65

BEV-I19B 88
139 220 142 177 204 247 225 249 263 246 258 344 308 175 230 212 188 190 235 252
257 99 50 66 75 102 95 84 127 101 55 88 131 162 175 76 55 51 44 33
44 34 38 61 66 63 74 92 110 45 47 35 26 29 36 23 26 31 29 28
34 68 69 135 123 147 177 122 86 59 39 44 51 77 41 59 42 69 112 137
97 99 96 78 131 119 69 68

BEV-I20A 116
399 439 302 194 235 164 182 256 321 179 90 147 271 319 512 355 304 176 121 76
80 174 401 404 292 175 121 75 61 61 67 126 202 183 133 138 141 106 146 205
191 103 63 98 96 92 85 75 78 62 60 67 48 64 51 35 39 54 48 41
49 45 38 40 64 74 86 49 47 49 36 36 37 41 33 31 35 31 35 40
37 34 57 35 33 46 38 33 50 58 75 63 48 34 40 36 34 33 35 95
63 119 57 42 25 27 31 51 31 57 54 51 41 43 33 46

BEV-I20B 116
371 346 308 187 241 162 183 267 321 180 77 145 296 307 485 365 297 169 123 77
81 173 397 396 280 189 141 77 65 67 86 123 199 195 142 147 122 108 141 197
166 106 59 104 86 96 79 79 72 58 66 62 55 61 47 34 43 50 49 41
49 51 32 42 67 68 89 54 44 49 39 35 44 33 36 38 35 26 35 45
36 29 58 35 31 52 34 36 45 54 74 61 48 42 45 39 31 36 33 95
65 117 54 39 32 20 31 48 35 62 50 58 48 35 40 48

BEV-I21A 102
464 352 228 148 116 140 108 199 249 324 270 179 134 107 132 163 182 198 214 159
111 132 124 109 143 161 115 98 133 111 80 112 105 119 104 90 55 76 131 109
106 60 64 47 53 80 79 98 47 29 47 46 38 32 26 36 30 61 54 62
42 47 72 58 88 71 73 62 96 62 52 54 53 52 61 66 68 47 39 37
63 52 45 40 58 71 49 57 33 26 33 33 37 41 44 54 63 58 46 38
37 31

BEV-I21B 102
454 355 226 145 118 136 123 202 249 331 265 159 133 97 135 154 199 191 211 161
114 127 125 108 143 158 116 99 132 113 84 109 107 110 110 76 84 80 128 124
98 64 57 45 56 76 83 93 50 30 53 40 34 35 31 35 39 49 52 58
44 44 73 58 85 73 73 58 99 63 51 56 51 48 64 68 64 46 40 38
58 52 51 40 44 80 49 53 33 32 36 32 32 44 48 46 67 62 45 39
31 35

BEV-I22A 52
12 12 21 23 26 22 25 27 19 19
25 30 21 12 11 15 25 43 42 30
22 13 12 9 14 17 22 20 23 20
25 35 23 22 25 30 38 34 18 11
16 17 17 13 8 10 16 15 14 22
22 25

BEV-I22B 52
11 13 21 23 27 22 25 26 20 20
23 31 21 11 11 18 25 43 40 29
20 11 12 9 15 18 22 20 22 22
23 31 22 19 21 24 34 39 19 15
16 20 18 14 8 13 19 16 15 20
21 25

APPENDIX: TREE-RING DATING

The Principles of Tree-Ring Dating

Tree-ring dating, or dendrochronology as it is known, is discussed in some detail in the Nottingham Tree-ring Dating Laboratory's Monograph, *An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Buildings* (Laxton and Litton 1988) and *Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates* (English Heritage 1998). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The width of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure A1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths for oaks, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of oak timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring.

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

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

1. Inspecting the Building and Sampling the Timbers.

Together with a building historian the timbers in a building are inspected to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can sample *in situ* timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer rings than this, 50 for example, sequences of widths become difficult to match to a unique position within a master sequence of ring widths and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure A2 has about 120 rings; about 20 of which are sapwood rings – the lighter rings on the outside. Similarly the core has just over 100 rings with a few sapwood rings.

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

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

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

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

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

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

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

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

2. *Measuring Ring Widths.*

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

3. *Cross-Matching and Dating the Samples.*

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

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

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

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

4. Estimating the Felling Date.

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

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

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

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

Even if all the sapwood rings are missing on a sample, but none of the heartwood rings are, then an estimate of the felling-date range is possible by adding on the full 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	

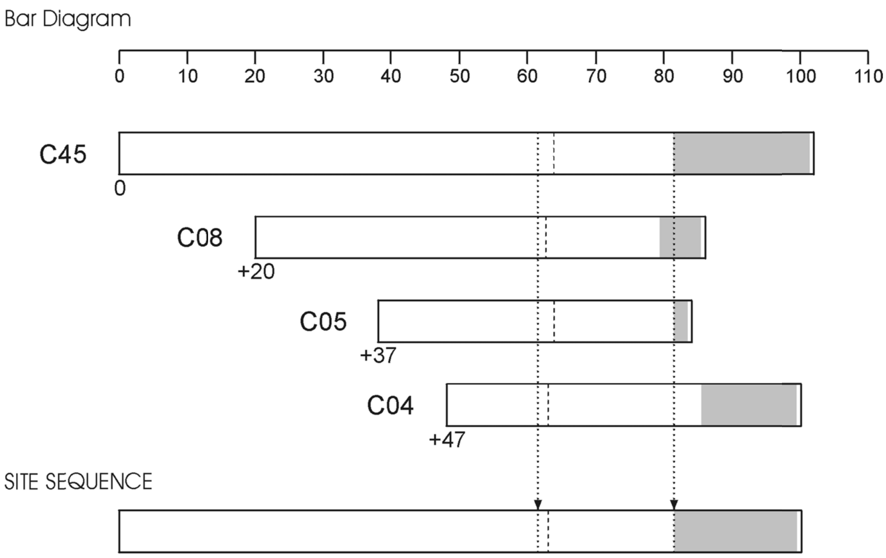


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

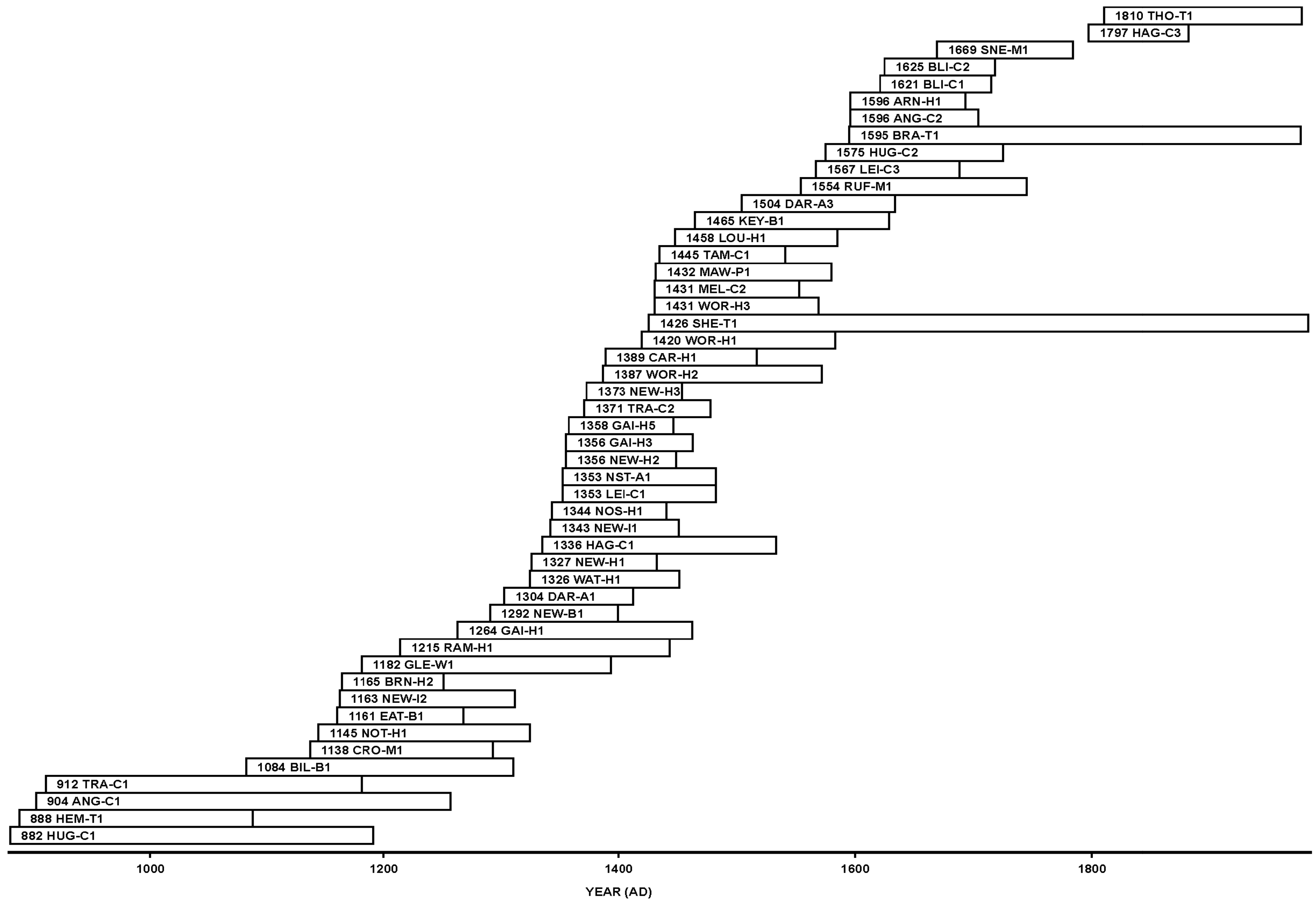
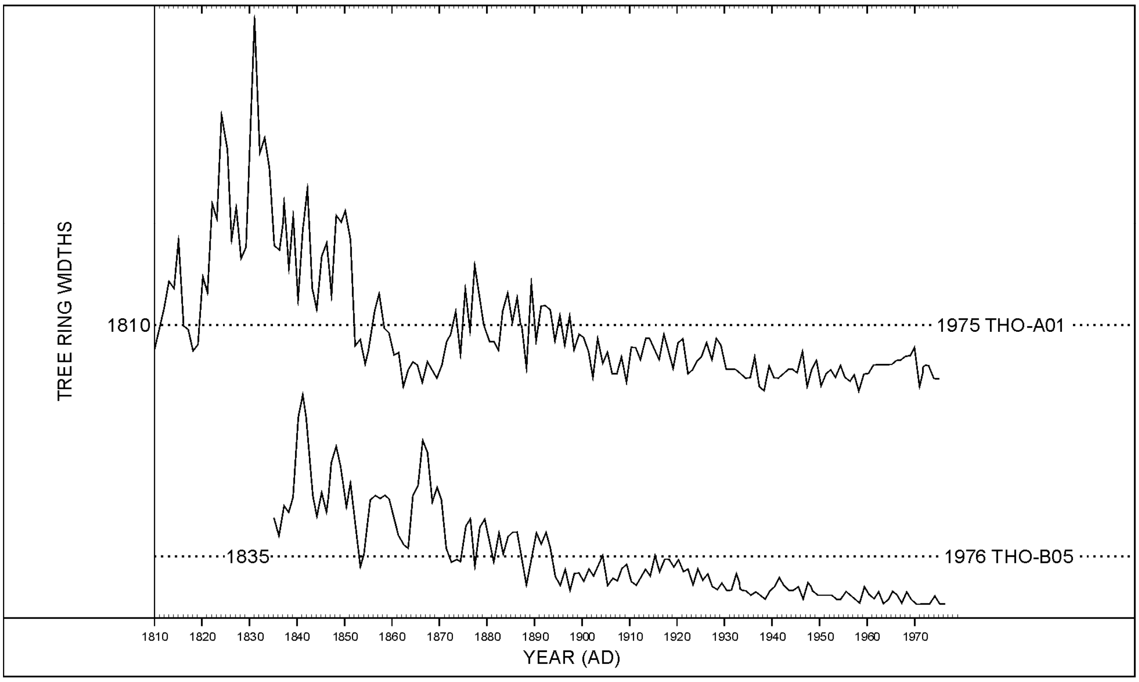


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

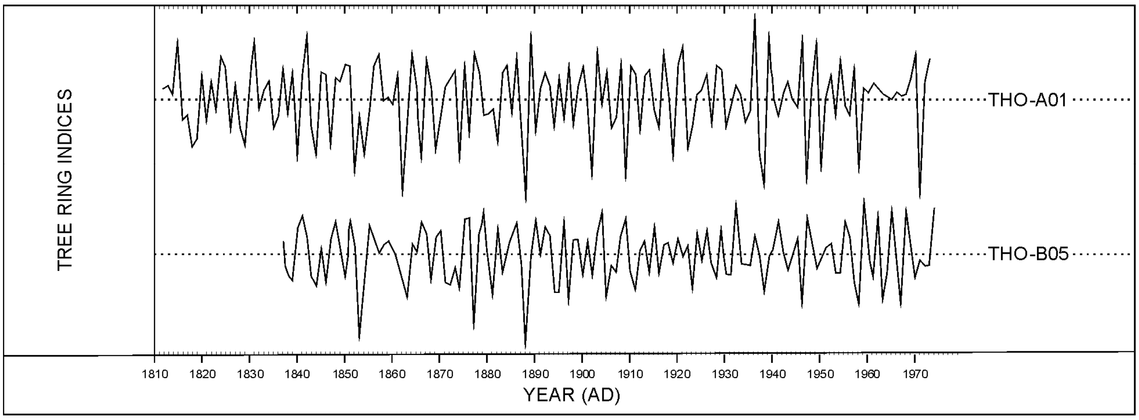


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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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