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The Thatched Barn, Burncliffe, Tow House, Northumberland Tree-ring Analysis of Timbers

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Summary

Dendrochronological analysis was undertaken on a series of samples from the roof structure of this building. No grouping between samples occurred and attempts to individually date them proved unsuccessful.

This barn has previously been dated stylistically to the seventeenth or eighteenth century but the dendrochronological analysis can neither support nor refute this.

Keywords

Dendrochronology
Standing Building

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Introduction

This Grade II* listed building is a heather-thatched barn, located at Tow House (NY76716433; Fig 1), north-west of Burncliffe, near Hexham. It is a single-storey structure of five bays with four pairs of full crucks, halved and crossed at the apex to carry the ridgepiece. It has the original upper collars which carry lapped purlins. The lower collars are thought to have been renewed (Fig 2). The building is likely to have been an all purpose agricultural or storage building which could be used for small scale domestic threshing. The roof type is of an archaic form of which we know little, and so dating on stylistic grounds cannot be more precise than to the seventeenth or eighteenth century (*pers comm* Martin Roberts). It is an extremely rare example in the county of this type of building.

Sampling and analysis by tree-ring dating was commissioned and funded by English Heritage. The barn is being placed on the English Heritage's Buildings at Risk register and tree-ring dating was requested by Martin Roberts, Historic Buildings Inspector at English Heritage's Newcastle office, to provide independent evidence for the date of its construction.

The Laboratory would like to thank Peter and Susan Clark, the owners of the property, for allowing sampling to be undertaken and for their assistance whilst this was carried out. Figures 3–6 were produced by Kevin Doonan. Thanks are also given to Martin Roberts for his helpful comments on an early draft of this report.

Sampling

Fifteen timbers were chosen for sampling with each sample being given the code TWH-A (for Tow House) and numbered 01–15. The position of samples was noted at the time of sampling and has been marked on Figure 3. Further details relating to the samples can be found in Table 1. Trusses were numbered from north to south.

Analysis and Results

At this stage it was noticed that four of the samples (TWH-A04, TWH-A05, TWH-A06, and TWH-A10) had too few rings to make secure dating a possibility and these samples was rejected prior to measurement. The remaining 11 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. All 11 samples were compared with each other by the Litton/Zainodin grouping procedure (see appendix).

No grouping occurred and attempts to individually date the samples by comparing each against a series of relevant reference chronologies proved unsuccessful.

Discussion

Previously, this building was thought to date to the seventeenth or eighteenth century. Unfortunately, in this case tree-ring dating has not been successful and its interpretation and dating must continue to rely on stylistic evidence only.

There are no obvious reasons as to why these samples do not date. The ring patterns are not overly complacent or compacted and whilst there are bands of narrower rings on some of the samples these do not appear to represent major growth disturbances which would reduce the dating potential by masking the overall climatic signal required for successful dating. It may be that this barn was constructed using a disparate set of trees, each growing in an area more strongly influenced by local conditions at the expense of the general climatic conditions, hence the lack of grouping within them and individual matching against the reference chronologies. Alternatively, it may be that, although no obvious signs of reuse were noted on the timbers sampled, they may be of different dates which again would preclude the grouping between them. Although not explaining the lack of intra-site cross-matching, a deficit in contemporary regional data may also have contributed to these samples not dating.

Table 1: Details of tree-ring samples from The Thatched Barn, Burncliffe, Tow House, Northumberland

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
TWH-A01	East blade, truss 1	60	--	----	----	----
TWH-A02	West blade, truss 1	156	h/s	----	----	----
TWH-A03	Collar, truss 1	90	15	----	----	----
TWH-A04	East blade, truss 2	NM	--	----	----	----
TWH-A05	West blade, truss 2	NM	--	----	----	----
TWH-A06	Collar, truss 2	NM	--	----	----	----
TWH-A07	East blade, truss 3	71	04	----	----	----
TWH-A08	West blade, truss 3	121	26C	----	----	----
TWH-A09	Collar, truss 3	88	18C	----	----	----
TWH-A10	West blade, truss 4	NM	--	----	----	----
TWH-A11	Collar, truss 4	88	24	----	----	----
TWH-A12	East purlin, trusses 1–2	55	h/s	----	----	----
TWH-A13	West purlin, trusses 3–4	55	h/s	----	----	----
TWH-A14	West rafter, bay 1	56	05	----	----	----
TWH-A15	West rafter, bay 4	99	07	----	----	----

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

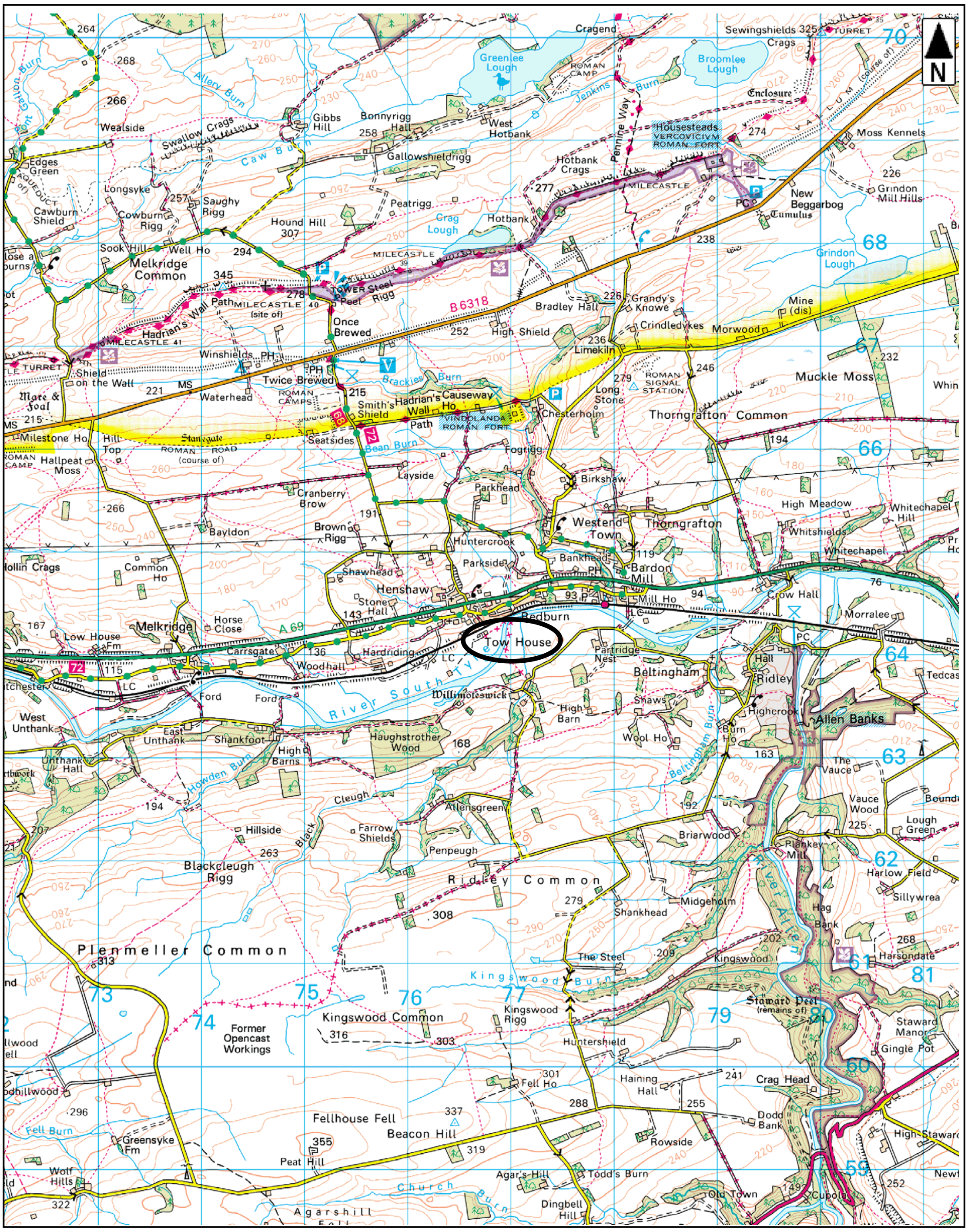


Figure 1: Map to show the location of the Thatched Barn, Burncliffe, Tow House, Northumberland

Figure 2: Truss 2, viewed from the south

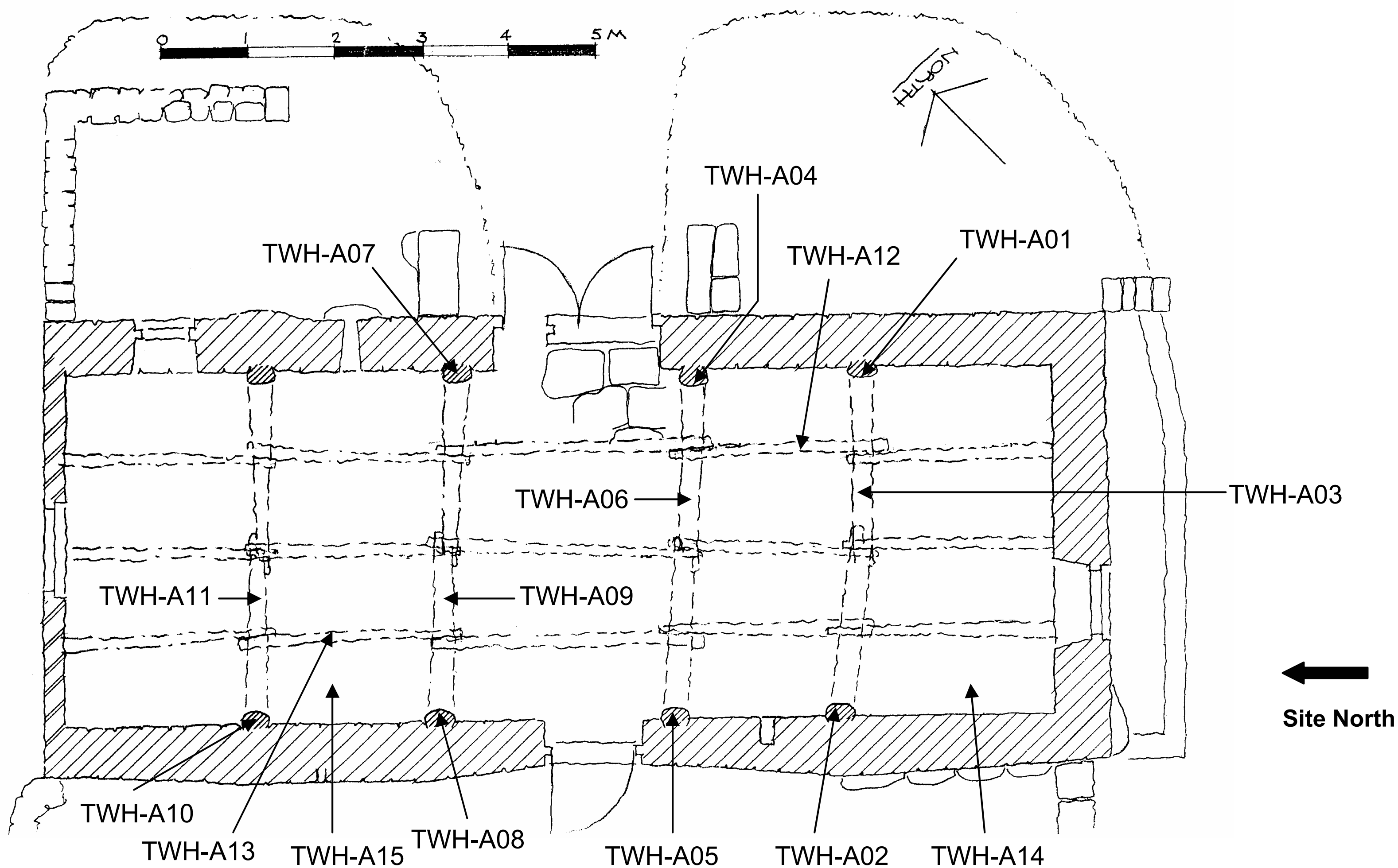


Figure 3: Ground plan (Kevin Doonan), showing the location of samples TWH-A01–15

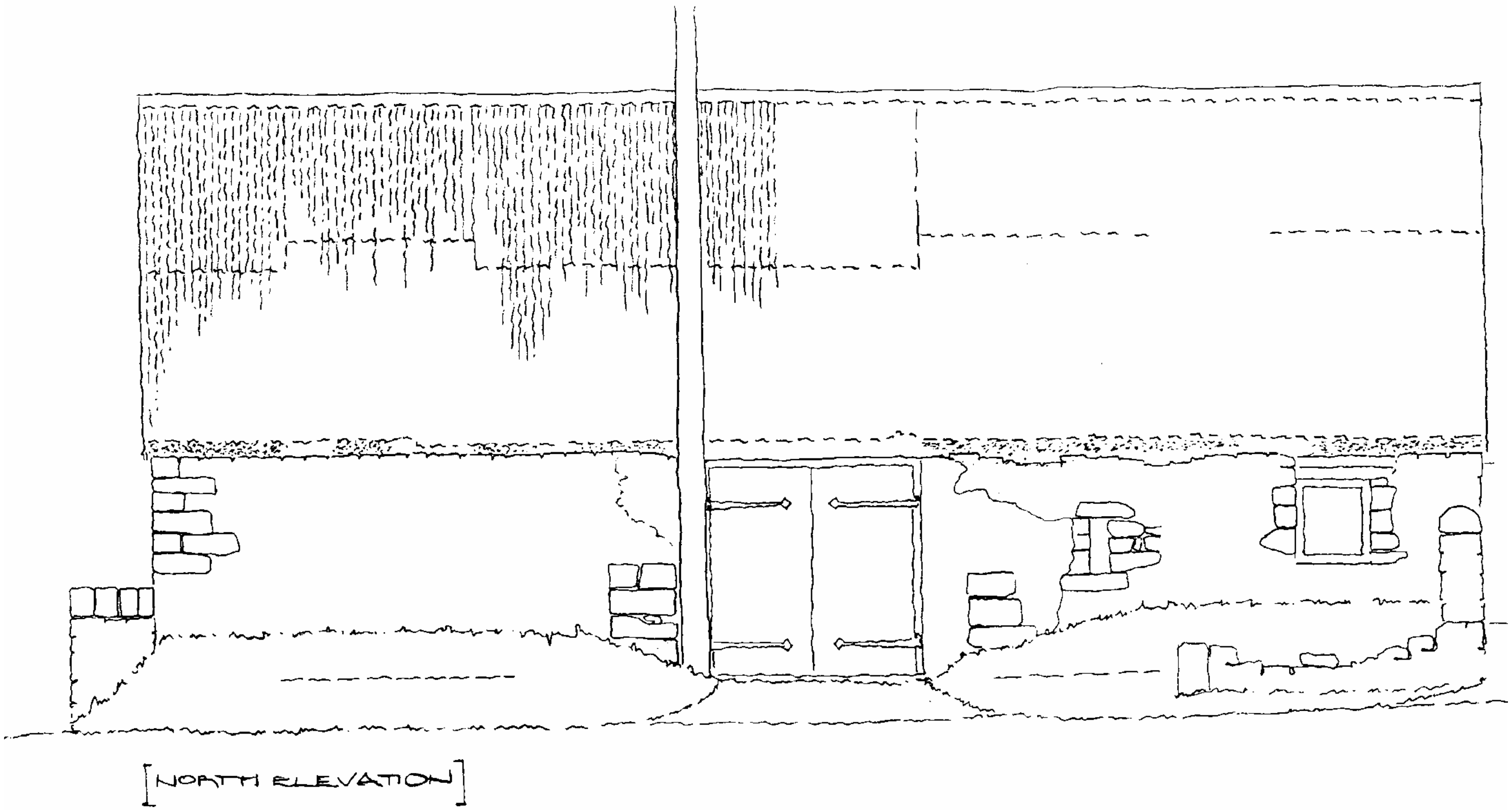


Figure 4: North elevation (Kevin Doonan)

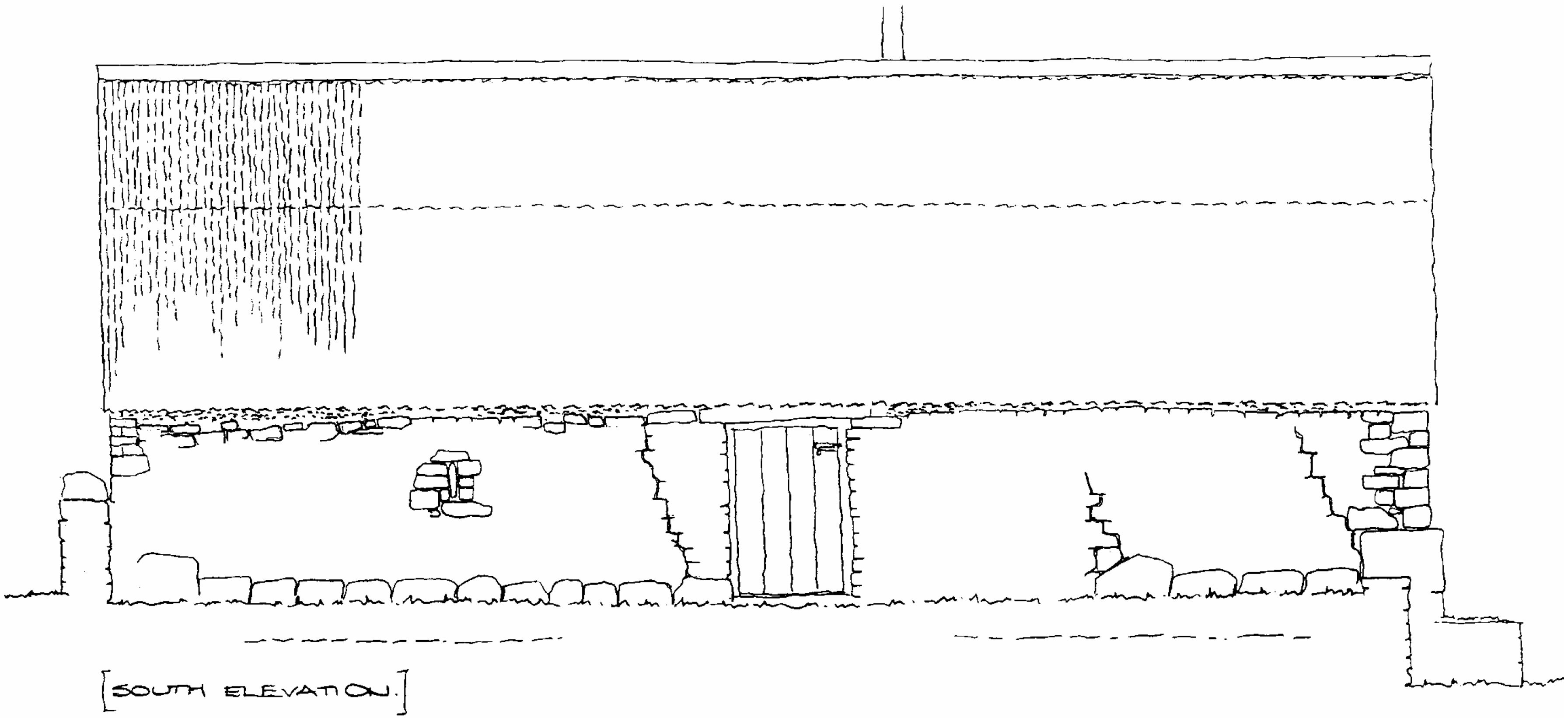


Figure 5: South elevation (Kevin Doonan)

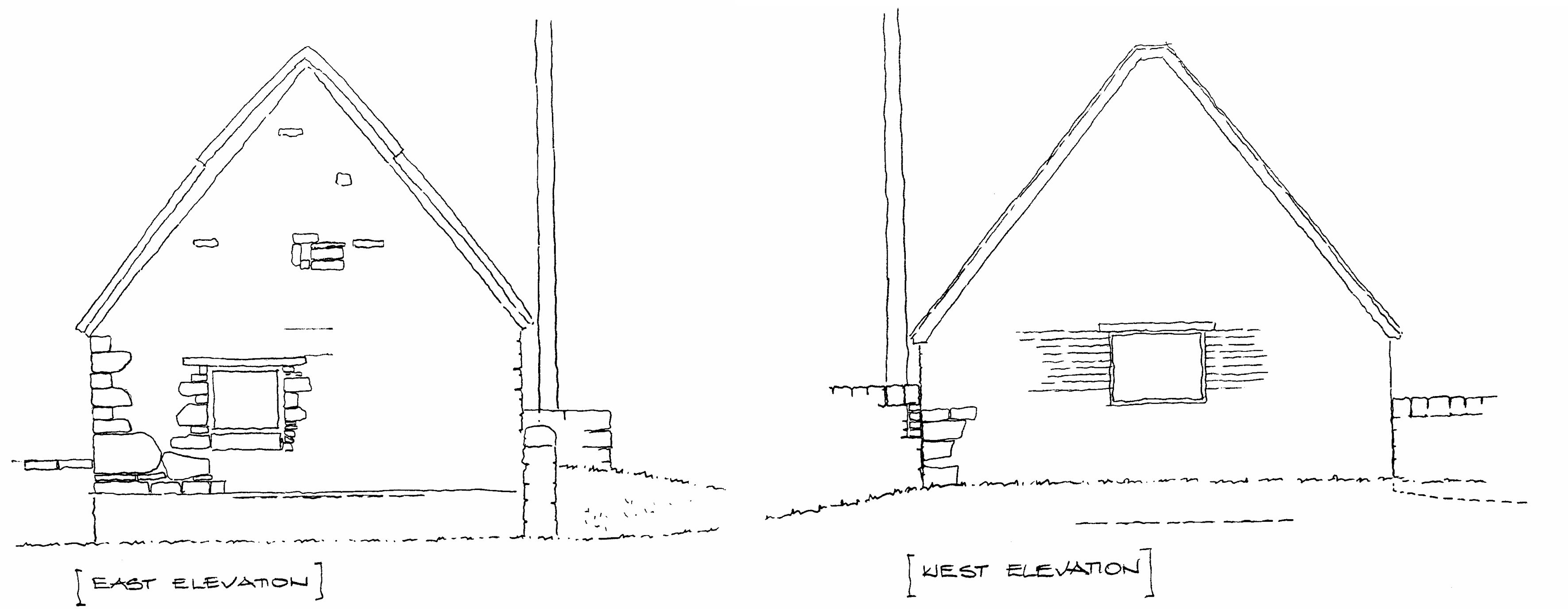


Figure 6: East and west elevations (Kevin Doonan)

Data of measured samples – measurements in 0.01mm units

TWH-A01A 60
266 455 312 453 275 381 380 442 397 400 453 309 213 90 107 168 217 197 179 272
293 377 393 325 303 234 224 342 233 199 134 74 78 87 54 89 180 281 284 130
132 110 124 133 168 228 208 296 345 442 388 384 182 154 166 175 93 135 123 85
TWH-A01B 60
259 464 313 460 326 367 398 447 392 379 417 301 203 97 100 166 222 193 183 271
298 381 393 324 294 245 233 354 244 185 138 75 81 84 59 86 169 294 286 127
139 108 117 133 173 228 207 295 343 436 394 384 186 158 172 158 97 127 120 79
TWH-A02A 156
143 180 173 165 174 144 180 119 131 131 159 127 108 111 104 71 79 75 119 85
73 70 77 109 99 121 61 71 76 98 117 94 78 91 76 87 88 85 92 102
72 98 73 68 63 110 82 99 88 76 84 83 111 71 75 49 78 75 105 59
56 66 65 95 72 110 101 113 129 106 103 84 90 60 90 52 71 90 70 66
54 52 66 49 81 71 82 87 84 66 98 98 74 72 47 80 87 84 65 64
92 102 81 65 96 116 87 89 94 89 80 73 75 69 71 86 84 97 94 93
73 71 74 73 46 84 65 90 79 76 99 100 88 106 113 107 76 70 52 78
106 63 81 51 68 68 78 77 78 72 40 53 78 82 92 88
TWH-A02B 156
151 172 172 173 171 148 160 112 127 141 152 130 98 106 99 61 80 72 115 90
71 72 82 97 105 122 57 73 81 97 119 90 74 94 69 89 87 84 99 110
71 95 78 67 63 112 86 89 88 76 74 95 108 68 71 57 65 84 89 66
62 64 62 93 71 113 108 120 135 110 103 90 95 66 82 52 74 84 77 64
49 53 65 56 80 67 82 86 82 68 100 93 75 63 50 76 86 83 66 85
83 98 78 72 90 105 85 96 84 92 77 68 81 63 73 86 85 92 98 83
79 71 70 80 46 82 61 95 77 74 97 101 89 108 104 103 85 63 58 72
108 57 85 50 70 65 74 81 78 78 44 50 81 78 93 85
TWH-A03A 90
270 347 372 318 412 212 198 230 232 259 126 132 208 268 258 231 223 155 123 103
122 127 174 204 154 181 159 158 118 86 96 84 92 68 60 78 73 42 47 67
44 61 83 108 110 85 89 70 52 50 77 71 123 162 162 124 131 189 165 183
222 193 164 190 76 112 89 87 98 77 96 78 58 69 96 90 127 113 139 180
135 127 104 83 94 153 138 124 174 166
TWH-A03B 90
258 351 365 321 404 209 200 231 230 266 119 133 194 272 260 237 233 140 122 100
94 128 173 224 158 176 152 147 125 84 99 82 100 62 65 74 63 54 49 66
43 64 91 104 114 72 97 66 54 51 69 74 122 161 168 124 123 200 168 183
217 192 164 191 84 107 96 74 100 85 95 67 77 61 93 89 130 101 137 186
140 131 100 84 92 156 144 184 147 177
TWH-A07A 71
266 503 333 312 316 263 237 245 309 280 292 221 218 197 157 178 183 212 239 145
126 103 97 99 111 125 141 159 146 138 184 155 193 173 152 171 58 43 38 28
32 28 32 50 55 74 66 37 36 42 47 34 54 55 33 51 43 58 38 30
64 65 70 46 51 45 45 90 58 59 64
TWH-A07B 71
179 440 474 276 276 270 286 261 272 248 265 231 205 187 165 172 176 214 247 150
125 104 94 93 107 131 141 158 160 126 186 162 190 177 144 179 59 51 36 28
33 25 35 49 52 74 71 35 41 41 43 40 53 45 48 43 39 53 49 32
69 71 65 51 51 45 48 85 52 77 68

TWH-A08A 121
242 276 287 168 151 178 236 202 206 237 198 236 209 208 279 236 258 284 302 314
147 87 107 118 135 132 98 73 97 110 120 70 45 45 37 37 86 113 87 69
87 67 87 87 99 132 119 114 53 64 66 77 115 69 90 83 91 90 85 84
89 111 129 100 100 88 74 87 85 100 75 97 85 102 78 91 86 107 103 78
75 126 136 66 61 48 32 31 55 53 45 68 62 52 73 58 55 59 50 40
75 38 38 29 26 23 19 25 24 26 13 26 31 29 23 22 16 24 21 22
33
TWH-A08B 121
232 270 273 164 154 184 228 178 208 245 208 241 217 203 272 245 259 292 297 299
149 87 108 119 133 131 99 76 90 115 108 68 43 45 39 46 80 112 75 78
88 58 89 90 94 139 117 106 62 51 68 79 118 63 89 95 99 80 79 87
85 110 120 94 105 81 73 96 81 103 72 75 96 100 83 92 83 103 92 91
69 139 130 70 58 50 40 24 51 54 54 57 66 55 73 66 56 66 50 43
62 36 41 32 29 26 20 17 35 24 24 27 29 23 23 19 20 21 14 21
45
TWH-A09A 88
82 147 207 143 189 219 214 273 224 195 210 177 112 103 104 138 103 88 76 41
78 91 72 80 94 139 148 116 95 96 52 86 114 140 199 189 150 175 223 134
119 72 99 128 114 128 148 145 133 158 130 138 98 115 84 120 85 81 94 100
169 89 70 69 65 55 53 65 93 151 72 140 96 45 41 63 65 106 90 68
66 63 82 65 127 117 100 77
TWH-A09B 88
58 174 215 151 194 198 210 274 220 193 215 182 127 127 127 169 108 88 78 34
87 84 82 68 101 132 141 130 95 100 44 94 107 142 199 170 162 177 219 136
117 63 110 135 108 134 160 148 128 159 119 146 99 113 86 113 94 75 100 94
165 98 56 85 53 45 73 49 106 188 82 129 108 60 35 55 76 84 90 60
73 68 82 70 122 117 91 68
TWH-A11A 88
538 735 407 468 359 236 257 233 224 177 201 172 221 244 194 151 103 135 143 119
126 144 138 163 163 178 260 359 377 207 208 212 185 155 129 109 89 56 55 92
106 109 70 95 161 62 75 78 57 74 55 43 45 67 60 57 66 66 83 77
84 67 36 59 58 87 91 60 42 38 40 46 62 61 55 59 75 111 87 51
93 95 101 134 82 35 49 51
TWH-A11B 88
516 734 406 459 360 246 252 229 224 180 195 175 214 245 197 145 99 128 151 118
121 145 132 139 155 185 261 356 380 207 211 210 184 160 126 78 72 50 65 96
132 116 95 108 171 78 81 71 58 53 42 43 38 54 50 49 62 56 79 70
63 76 45 51 68 95 83 63 42 43 43 52 50 65 55 60 76 108 91 53
90 90 106 135 80 28 41 47
TWH-A12A 55
100 46 89 143 197 303 106 211 224 228 184 166 178 154 171 185 135 91 103 158
143 123 185 149 154 199 128 181 187 120 151 189 171 198 209 199 115 109 157 178
169 188 157 145 204 162 150 99 113 87 77 131 193 206 122
TWH-A12B 55
110 52 77 138 200 309 103 245 226 231 185 152 181 153 178 183 136 88 96 163
147 127 176 142 153 190 133 175 195 130 150 193 166 213 215 192 107 101 141 166
175 182 156 143 203 162 150 98 119 92 84 122 188 213 151
TWH-A13A 55
155 101 87 121 132 92 81 94 121 113 111 84 75 81 111 123 144 156 168 237
227 228 217 145 115 94 101 71 154 143 156 120 114 97 61 102 76 59 52 44
30 37 28 31 32 36 29 27 23 26 16 21 22 30 37
TWH-A13B 55
157 107 92 122 130 93 70 96 117 110 114 78 77 79 117 117 141 155 152 228
208 240 221 150 106 101 100 74 159 138 137 136 125 81 74 90 87 55 48 49
32 31 27 29 35 37 33 24 20 23 19 24 31 32 43

TWH-A14A 53
194 138 212 259 248 231 146 139 145 148 154 155 91 132 181 233 220 181 174 108
135 99 97 106 117 141 72 83 147 97 118 95 90 48 52 48 46 54 49 60
71 48 45 50 60 53 101 101 110 91 116 132 89
TWH-A14B 51
232 123 190 183 129 189 276 260 217 138 109 129 110 144 152 98 101 181 172 173
163 159 110 130 90 83 86 104 117 84 70 151 104 111 93 107 50 47 50 57
52 56 71 67 55 65 58 49 62 88 116
TWH-A15A 99
155 146 113 97 88 116 150 186 77 72 93 120 123 149 102 122 137 139 172 98
79 78 115 91 109 114 91 88 72 87 84 100 93 75 84 83 116 70 88 81
83 64 75 75 58 75 72 70 59 58 64 80 98 149 120 84 138 164 153 150
148 133 95 82 75 86 73 71 55 44 62 71 42 35 32 51 50 51 39 59
40 54 77 57 59 70 34 53 104 90 81 66 86 67 73 42 47 35 54
TWH-A15B 99
156 147 118 87 94 118 147 181 88 57 100 119 122 152 109 117 129 149 166 100
81 77 109 86 111 120 86 95 63 97 76 105 89 79 76 93 105 87 75 92
72 71 71 78 65 67 76 64 59 59 60 80 104 150 113 81 141 152 142 137
138 134 93 64 69 91 68 68 59 36 55 83 35 32 37 47 49 57 43 42
36 55 80 61 66 72 31 53 103 102 76 75 82 74 72 40 48 33 59

APPENDIX

Tree-Ring Dating

The Principles of Tree-Ring Dating

Tree-ring dating, or *dendrochronology* as it is known, is discussed in some detail in the Laboratory's Monograph, '*An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Building'* (Laxton and Litton 1988) and*, Dendrochronology; Guidelines on Producing and Interpreting Dendrochronological Dates* (English Heritage 1988). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The *width* of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure 1 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 1, 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 2 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 to 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 2; it is about 15cm long and 1cm 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 1: 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 2: Cross-section of a rafter showing the presence of sapwood rings in the left hand corner, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

Figure 3: Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measure 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 4: 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 2. 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 3).

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 4). 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 5 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 5. 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 5 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 straight forward 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. Actually it could be the year after if it had been felled in the first three months 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 2, 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 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 2 was taken still had complete sapwood but that none of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 2 cm, 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 and Miles 1997, 50-55). Hence provided 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, figure 8 and pages 34-5 where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storing 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 Fig 6 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 Fig 6. 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 Fig 7. 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

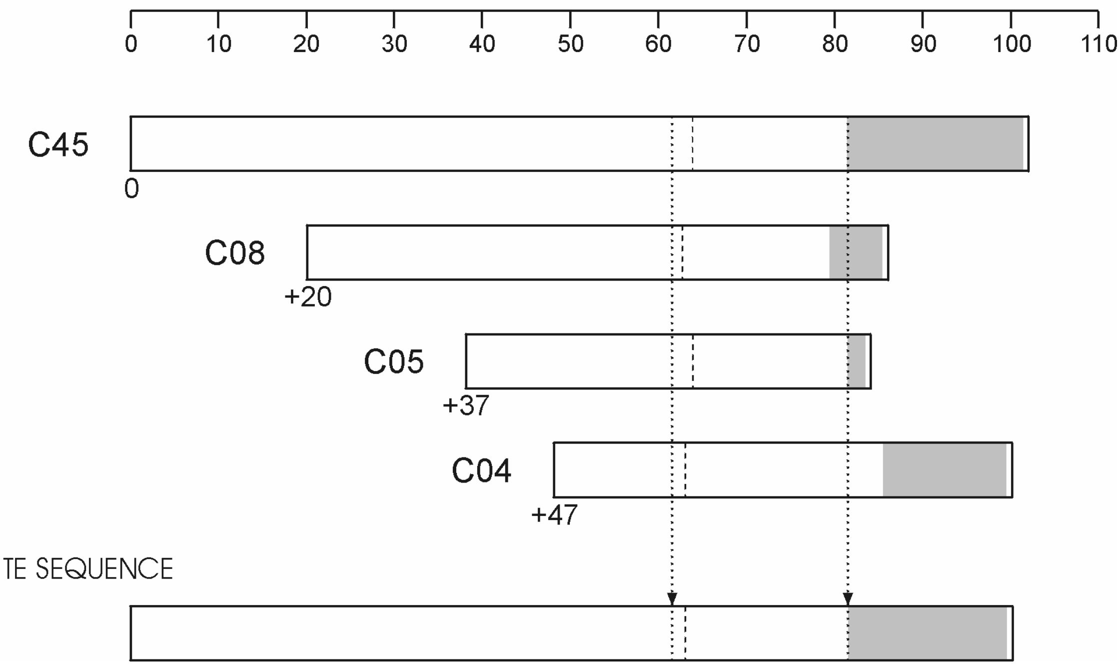


Figure 5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

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.

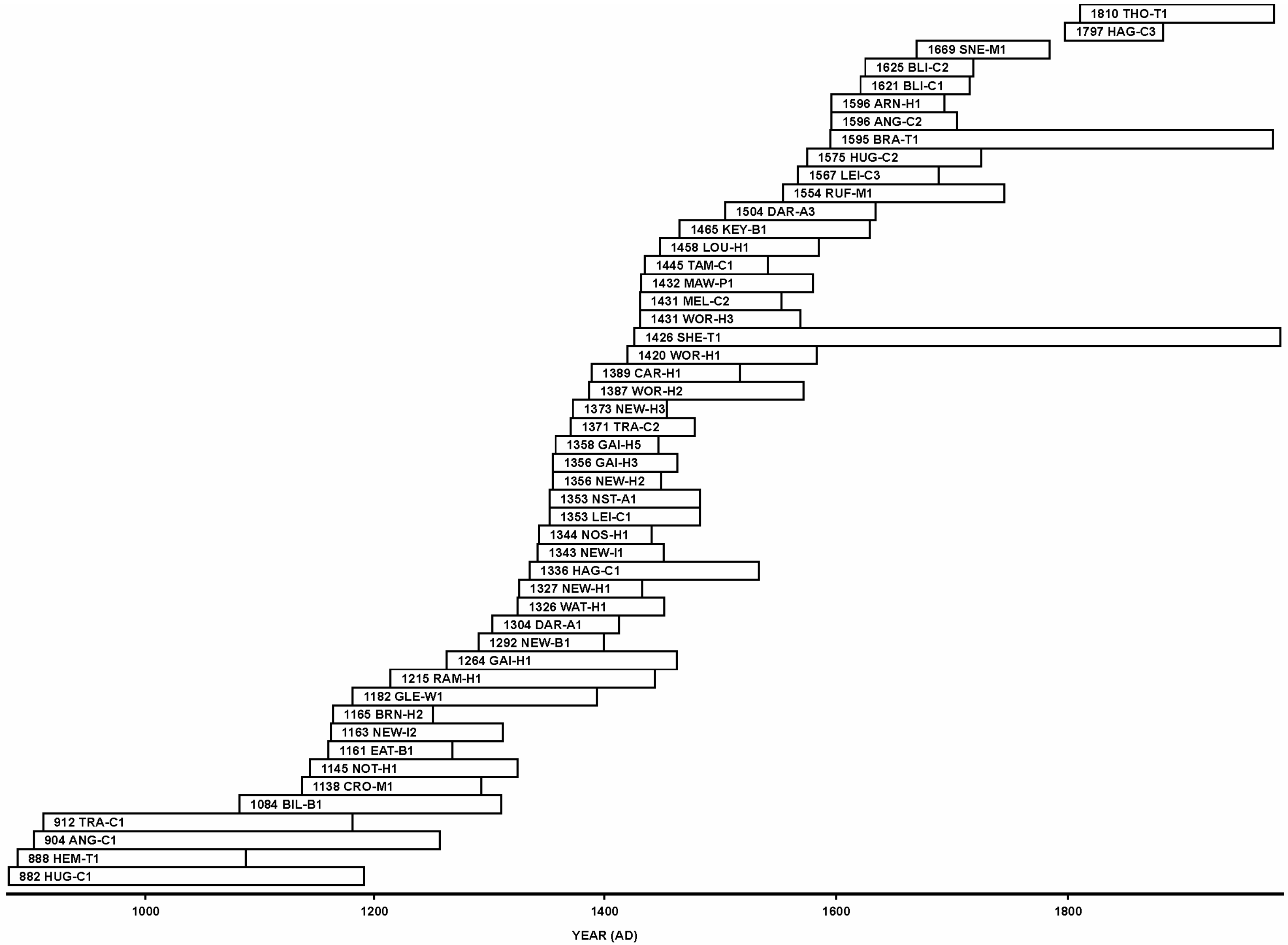
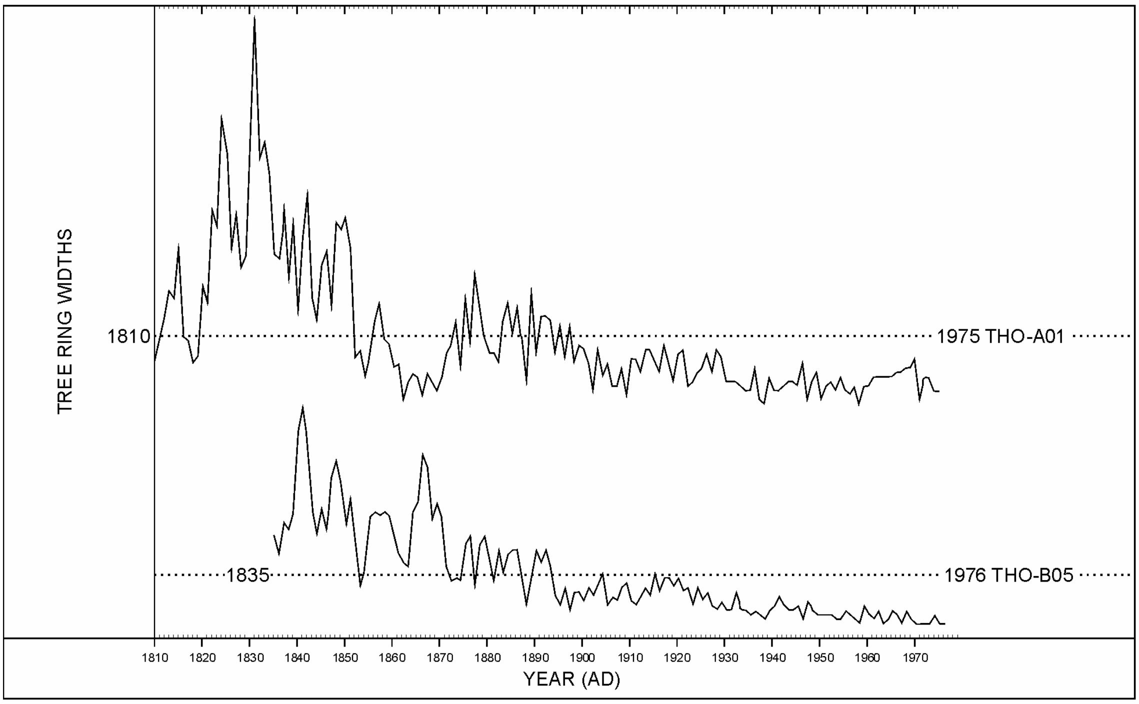


Figure 6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

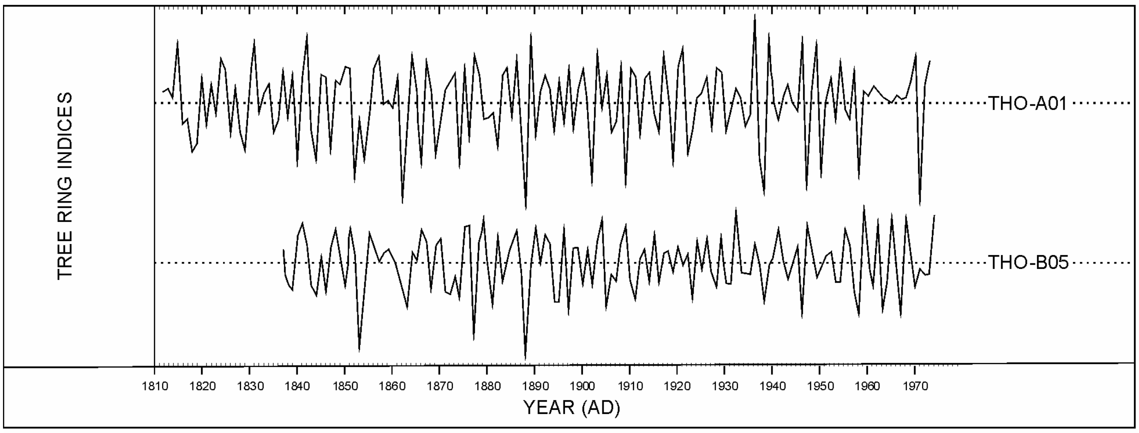


Figure 7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree are wider than the later ones of the older tree in both sequences.

Figure 7 (b): The *Baillie-Pilcher* indices of the above widths. The growth-trends have been removed completely.

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