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# Tree-Ring Analysis of Timbers from Dilston Castle, Dilston Hall, Corbridge, Northumberland

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**Summary**

Twenty-five samples were obtained from a number of elements of the Chapel and tower house at Dilston Castle. Analysis of these produced a single site chronology comprising twenty-one samples with a combined overall length of 210 rings. This site chronology was dated as spanning the years AD 1402 to AD 1611.

Interpretation of the sapwood indicates that probably all the dated timbers represented were felled in AD 1611 and relate to documented remodelling in AD 1616. There is no confirmed tree-ring evidence for any earlier or later material.

**Keywords**

Dendrochronology
Standing Building

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## Introduction

Dilston Castle stands about a kilometre south-west of Corbridge, near Hexham in Northumberland (NY 962533; Figs 1 and 2). Being originally built *c* AD 1400 as a tower house on the site of an earlier structure, it was extensively modified in the fifteenth and sixteenth centuries. It was further altered in AD 1620 and became part of Dilston Hall. Later still, in AD 1710-15, it became part of a large mansion built by the 3rd Earl of Derwentwater. Unfortunately the third Earl was executed in AD 1716 for his part in the Jacobite rebellion. The property then passed to his son and upon his death, in AD 1731, the Derwentwater estates were seized by the Government and passed to the Greenwich Hospital Trustees. They demolished most of the buildings in AD 1765 leaving only the tower house standing.

Adjacent to the castle a small chapel survives. The date for its original construction is not known, but documentary sources indicate that remodeling was completed in AD 1616. However it was believed that parts of it may be older than this, possibly dating to an undocumented Tudor phase. A new roof was put on to the chapel in the AD 1730s (completely covering and protecting the earlier one), but later removed. Observation and recording of the interior plaster shows that there was once a large first-floor gallery at the west end of the chapel. It is not known when this was removed.

The castle and chapel site are grade I listed and a Scheduled Ancient Monument. It is listed as category B on the English Heritage Building's at Risk Register.

## Sampling

Sampling and analysis by tree-ring dating were commissioned by English Heritage on behalf of the owners of the buildings, North Pennines Heritage Trust. The purpose of this was to provide a precise date for a number of elements of the castle and chapel as part of a larger programme of repairs, recording, and research.

In particular the Laboratory was asked to sample three elements of the chapel. The first of these was the timbers of present chapel roof. This comprises five trusses of cambered tiebeams (giving a very shallow pitch roof), with ridge beams and purlins. A ground-floor plan of the chapel is provided in Figure 3 and the roof is illustrated in Figure 4.

Secondly the Laboratory was asked to sample what appeared to be the original joists of the first-floor gallery, sited at the west end of the chapel. The remains of these joists were found as cut-off beam-ends buried in sockets in the walls beneath the plaster. They were only discovered when the plaster was removed during renovation as part of a programme to reinstate the gallery.

The third element of the chapel to be sampled was a timber lintel over a doorway to the stairs which would have lead up to the gallery. This door is shown in Figure 4.This lintel was so badly decayed and rotted that it was uncertain if it was one timber or two.

The importance of these timbers lay in determining whether or not they belonged to some early undocumented, possibly Tudor, phase or if they belonged to the early seventeenth century or later remodeling phase.

A number of single timbers from the castle were also to be sampled. These consisted of lintels over doors and windows. On the basis of their architectural style and positioning they were deemed to date to various phases of the castle's developmental sequence in the fifteenth, sixteenth, and eighteenth centuries. It was hoped that by dating the timber the date of the opening, and thus the phasing of elements of the castle, might be determined.

Thus, from the available timbers a total of twenty-five samples was obtained. Each sample was given the code DST-A (for Dilston, site "A") and numbered 01 - 25. Timbers were selected on the basis of their having sufficient rings for suitable analysis and for having sapwood, or at least the heartwood/sapwood boundary.

Fifteen samples, DST-A01 - A15, were obtained as cores from the roof of the chapel. A further four samples, DST-A16 - A19, were obtained as slices from the beam ends of the joists of the former gallery. These beam ends had been removed from their sockets due to decay and were not required for reuse or reincorporation into the building. Two slices, DST-A20 and A21, were obtained from the lintel of the door to the gallery stairs in the chapel. This timber was also removed due to severe decay and was again not required.

In the castle slices were obtained from two lintels removed from the south window in the south tower, samples DST-A22 and A23. Finally, cores were obtained from a lintel over what was believed on stylistic grounds to be an early eighteenth-century window (DST-A24) and a doorway into the stair tower on the second floor (DST-A25).

Where possible the locations of the cores and slices were recorded at the time of sampling on drawings provided, these being reproduced here as Figures 5 and 6. The most notable absence is a plan of the roof or the drawing of a typical truss. However, for Laboratory purposes, a sketch was made and the positions of the samples recorded on this. This sketch is not shown in this preliminary draft in the hope that a suitable illustration may be found.

Given that some timbers had been removed prior to sampling as a consequence of building works the Laboratory is reliant on information provided about these. Details of the samples are given in Table 1. In this table, where possible, the trusses are numbered from east to west with members described on a north - south basis as appropriate. Other timbers are listed by the locations and descriptions provided.

The Laboratory would to take this opportunity to thank Frank Geicco of the North Pennines Heritage Trust for assisting during sampling, and for providing photographs and drawings, and for providing information about the timbers.

## Analysis

Each of the twenty-five samples was prepared by sanding and polishing and the width of their annual growth-rings measured. The data of these measurements are given at the end of this report. The samples were then compared with each other by the Litton/Zainodin grouping procedure (see appendix). At a minimum value of $t$=4.5 a groups of twenty-one samples cross-match with each other at relative positions as shown in the bar diagram Figure 7.

These twenty-one samples were combined with each other at their relative offset positions to form DSTASQ01, a site chronology with a combined overall length of 210 rings. Site chronology DSTASQ01 was compared with a full series of relevant reference chronologies for oak, giving it a first ring date of AD 1402 and a last measured ring date of AD 1611. Evidence for this dating is given in the $t$-values of Table 2.

Site chronology DSTASQ01 was compared with the four remaining ungrouped samples but there was no satisfactory cross-matching. These four ungrouped samples were then compared individually with a full range of reference chronologies but again there was no further satisfactory cross-matching. These samples must, therefore, remain undated.

## Interpretation

Seven of the dated samples, DST-A04, A05, A09, A10, A13, A16, and A17, from the gallery floor in site chronology DSTASQ01 retain complete sapwood and thus have the last ring produced by the trees they represent before they were felled. In each case the last measured ring date is the same, AD 1611 and this is thus the felling date of the trees. The relative position of the heartwood/sapwood boundary on the other dated samples, where it exists, indicates that the majority of the timbers were likely to have been felled in AD 1611 too.

The timber represented by a further sample in site chronology DSTASQ01, sample DST-A24, a window lintel, is also from the castle. Although it is believed on structural and stylistic grounds that the window opening is of eighteenth-century date, it is more likely that the timber was felled in the early seventeenth century rather than the eighteenth. Sample DST-A24 cross-matches with the main group very well at its given date, with a value of $t=5.9$, and no eighteenth-century date is indicated when it is compared individually with the reference chronologies. It is likely that this early seventeenth-century timber was reused in a later remodeling of the castle.

A lesser degree of certainty could be expressed about the felling date of the timbers represented by samples DST-A20 and A21, and samples DST-A22 and A23. These are the two samples from the lintel of the doorway to the chapel gallery stairs, and the two samples from lintels of the south window in the south tower of the castle respectively. Due to decay none of these samples retains a measurable certain heartwood/sapwood boundary ring, they have become damp and they have rotted to such an extent that the outer rings cannot be prepared for measurement. However, estimating the number of unmeasured rings would put what is probably the heartwood/sapwood boundary at a relative position consistent with a felling of AD 1611 for these timbers also. However, it is possible that some of these timbers could have a slightly different felling date.

## Conclusions

Analysis by tree-ring dating has produced a single site chronology, DSTASQ01, of twenty-one samples with a combined overall length of 210 rings. This chronology has been dated as spanning the years AD 1402 to AD 1611. Interpretation of the sapwood indicates that probably all the dated timbers were cut in a single phase of felling in AD 1611.

Such a date is closely correlated with the documentary evidence for the completion of remodeling work on the chapel in AD 1616. The analysis shows that there are only a few years between felling and use. Of equal note is the fact that the dated timbers of the castle were felled at this time too. Although it was expected that some material of the fifteenth, sixteenth, and eighteenth centuries might be found, this has not been the case. It would appear that timber cut in the early seventeenth century was later reused.

The samples from four other timbers could not be dated. There is no obvious reason why these four samples should not cross-match and date. There is no indication of narrow or complacent rings which might make dating difficult.

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Table 1: Details of samples from Dilston Chapel and castle, Dilston Hall, Corbridge, Northumberland

| Sample no | Sample location | Total rings | *Sapwood rings | First measured ring date | Last heartwood ring date | Last measured ring date |
|---|---|---|---|---|---|---|
| | Chapel timbers | | | | | |
| DST-A01 | Tiebeam, truss 1 | 144 | no h/s | AD 1414 | ------ | AD 1557 |
| DST-A02 | Ridge beam, truss 1 - 2 | 135 | 11 | AD 1458 | AD 1581 | AD 1592 |
| DST-A03 | North purlin, truss 1 - 2 | 55 | 5 | ------ | ------ | ------ |
| DST-A04 | Tiebeam, truss 2 | 91 | 26C | AD 1521 | AD 1585 | AD 1611 |
| DST-A05 | Ridge beam, truss 2 - 3 | 172 | 39C | AD 1440 | AD 1572 | AD 1611 |
| DST-A06 | South purlin, truss 1 - 2 | 54 | h/s | ------ | ------ | ------ |
| DST-A07 | Tiebeam, truss 3 | 188 | 30 | AD 1421 | AD 1578 | AD 1608 |
| DST-A08 | North purlin, truss 3 - 4 | 122 | no h/s | AD 1428 | ------ | AD 1549 |
| DST-A09 | South purlin, truss 3 - 4 | 166 | 30C | AD 1446 | AD 1581 | AD 1611 |
| DST-A10 | Tiebeam, truss 4 | 111 | 20C | AD 1501 | AD 1591 | AD 1611 |
| DST-A11 | Ridge beam, truss 4 - 5 | 54 | no h/s | AD 1425 | ------ | AD 1478 |
| DST-A12 | North purlin, truss 4 - 5 | 129 | 20 | AD 1475 | AD 1583 | AD 1603 |
| DST-A13 | South purlin, truss 4 - 5 | 210 | 26C | AD 1402 | AD 1585 | AD 1611 |
| DST-A14 | Tiebeam, truss 5 | 140 | h/s | AD 1436 | AD 1575 | AD 1575 |
| DST-A15 | Ridge beam, truss 3 - 4 | 62 | no h/s | ------ | ------ | ------ |
| DST-A16 | Gallery floor joist | 206 | 33C | AD 1406 | AD 1578 | AD 1611 |
| DST-A17 | Gallery floor joist | 175 | 30C | AD 1437 | AD 1581 | AD 1611 |
| DST-A18 | Gallery floor joist | 90 | 8 | AD 1499 | AD 1580 | AD 1588 |
| DST-A19 | Gallery floor joist | 98 | no h/s | AD 1426 | ------ | AD 1523 |
| DST-A20 | Lintel, chapel door to gallery stairway | 90 | no h/s | AD 1456 | ------ | AD 1545 |
| DST-A21 | Lintel, chapel door to gallery stairway | 58 | no h/s | AD 1490 | ------ | AD 1547 |

Table 1: continued

| Sample no | Sample location | Total rings | *Sapwood rings | First measured ring date | Last heartwood ring date | Last measured ring date |
| --- | --- | --- | --- | --- | --- | --- |
| | Castle timbers | | | | | |
| DST-A22 | Lintel 1, south window, south tower | 104 | no h/s | AD 1457 | ------ | AD 1560 |
| DST-A23 | Lintel 2, south window, south tower | 91 | no h/s | AD 1477 | ------ | AD 1567 |
| DST-A24 | Lintel over eighteenth-century window | 57 | h/s | AD 1519 | AD 1575 | AD 1575 |
| DST-A25 | Lintel to second floor door in stair tower | 78 | h/s | ------ | ------ | ------ |

*h/s = the heartwood/sapwood boundary is the last ring on the sample
C = complete sapwood retained on sample; last measured ring date is felling date of timber

Table 2: Results of the cross-matching of site chronology DSTASQ01 and relevant reference chronologies when first ring date is AD 1402 and last ring date is AD 1611

| Reference chronology | Span of chronology | *t*-value | |
|---|---|---|---|
| Ingleby Manor, Ingleby Greenhow, N Yorks | AD 1429 – 1563 | 7.4 | ( Howard *et al* 1993 ) |
| Manor House, Sutton in Ashfield, Notts | AD 1441 – 1656 | 6.5 | ( Howard *et al* 1996 ) |
| England | AD 401 – 1981 | 6.3 | ( Baillie and Pilcher 1982 unpubl ) |
| Old Durham Farm, Durham | AD 1390 – 1619 | 6.2 | ( Howard *et al* 1995 ) |
| Ford Green Hall, Stoke on Trent, Staffs | AD 1436 – 1623 | 6.1 | ( Howard *et al* 1992a ) |
| North Lees Hall, Outseats, Derbys | AD 1468 – 1578 | 6.1 | ( Howard *et al* 1994 ) |
| 1-2 The College, Durham Cathedral | AD 1364 – 1531 | 5.1 | ( Howard *et al* 1992b ) |
| East Midlands | AD 882 – 1981 | 5.0 | ( Laxton and Litton 1988 ) |

**Figure 1: Map to show general location of Dilston Castle**

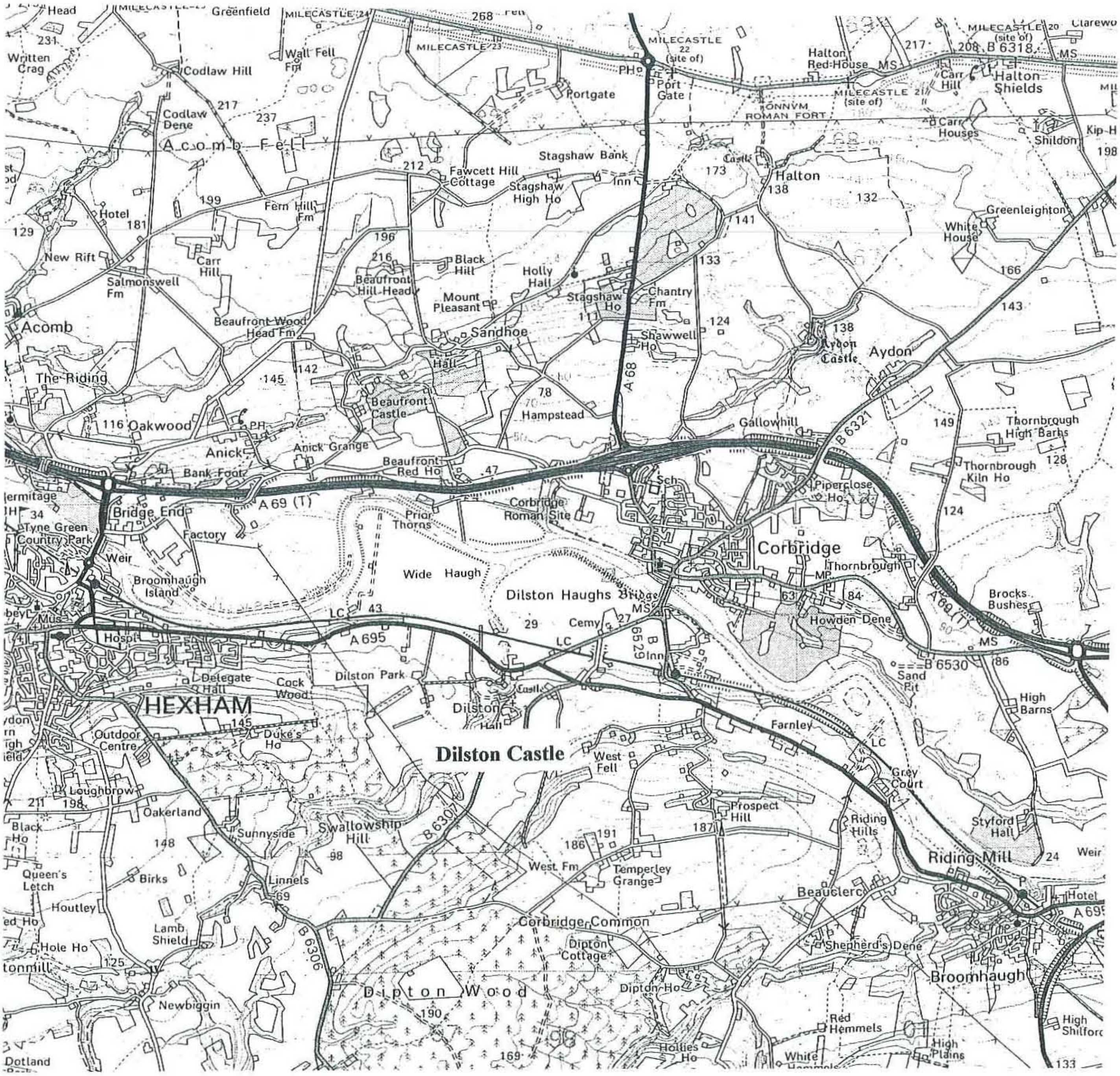


**Figure 2: Map to show specific location of Dilston Castle**

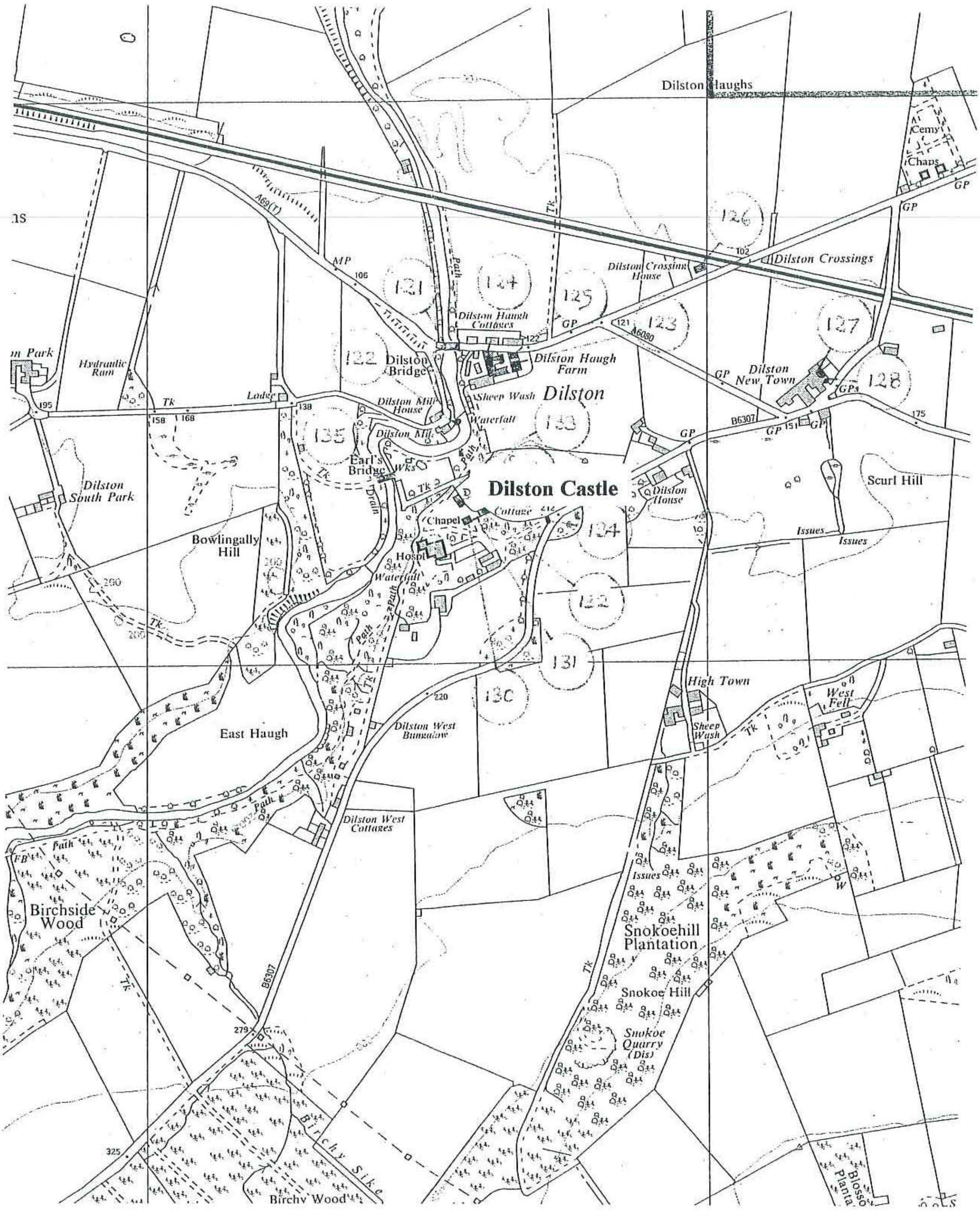


**Figure 3: Ground-floor plan of the chapel at Dilston Castle**

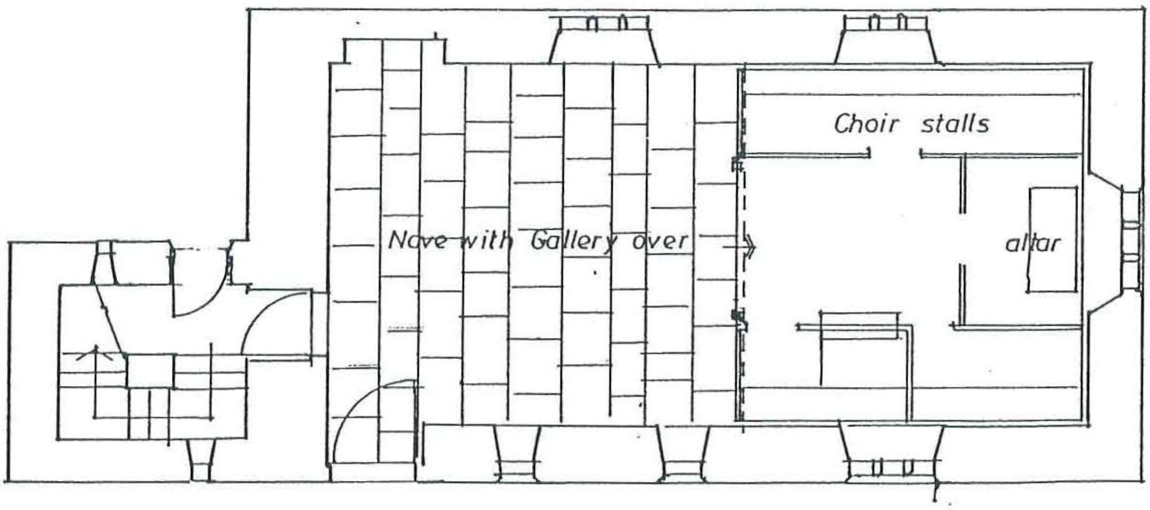


**Figure 4: The Chapel at Dilston viewed looking west (trusses 3 and 4 (west- most) in view**

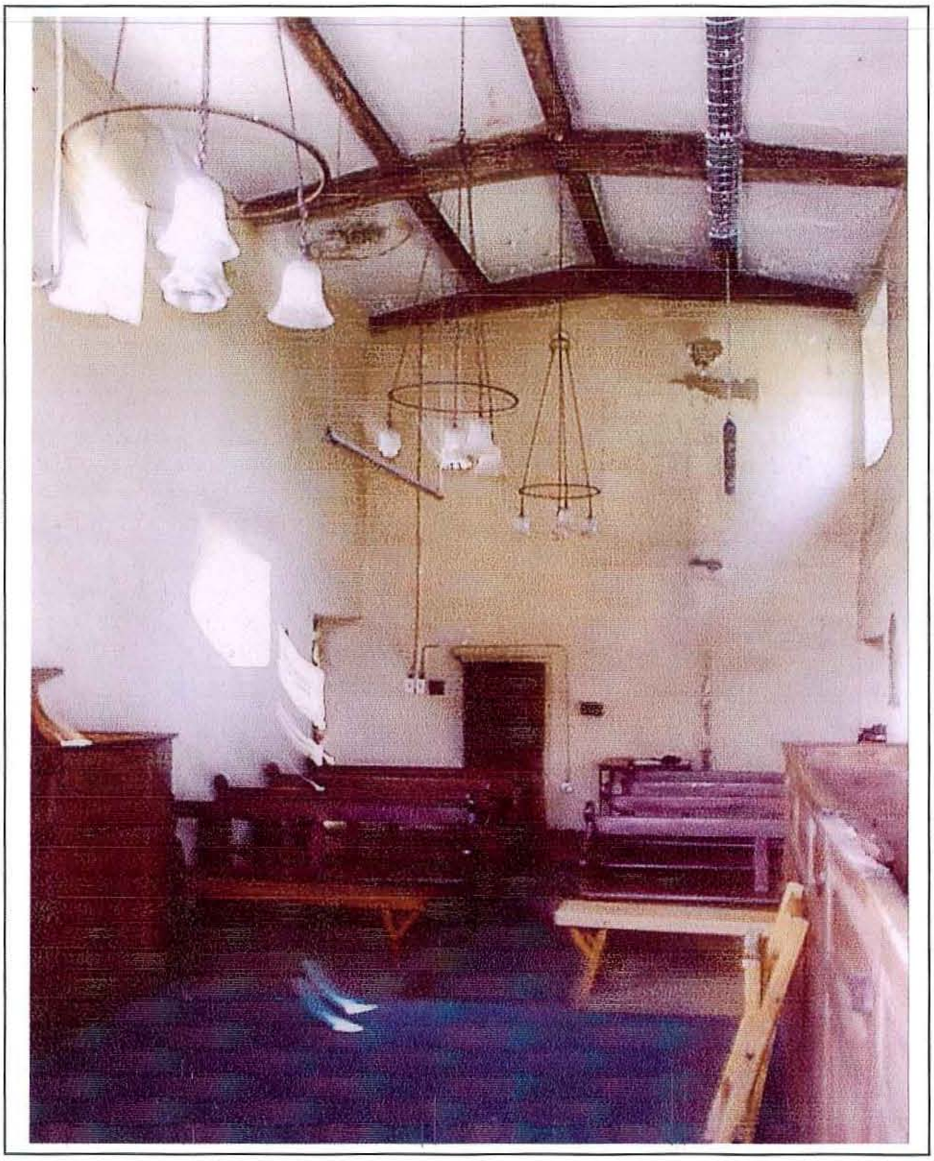


**Figure 5: Drawing to show location of samples**

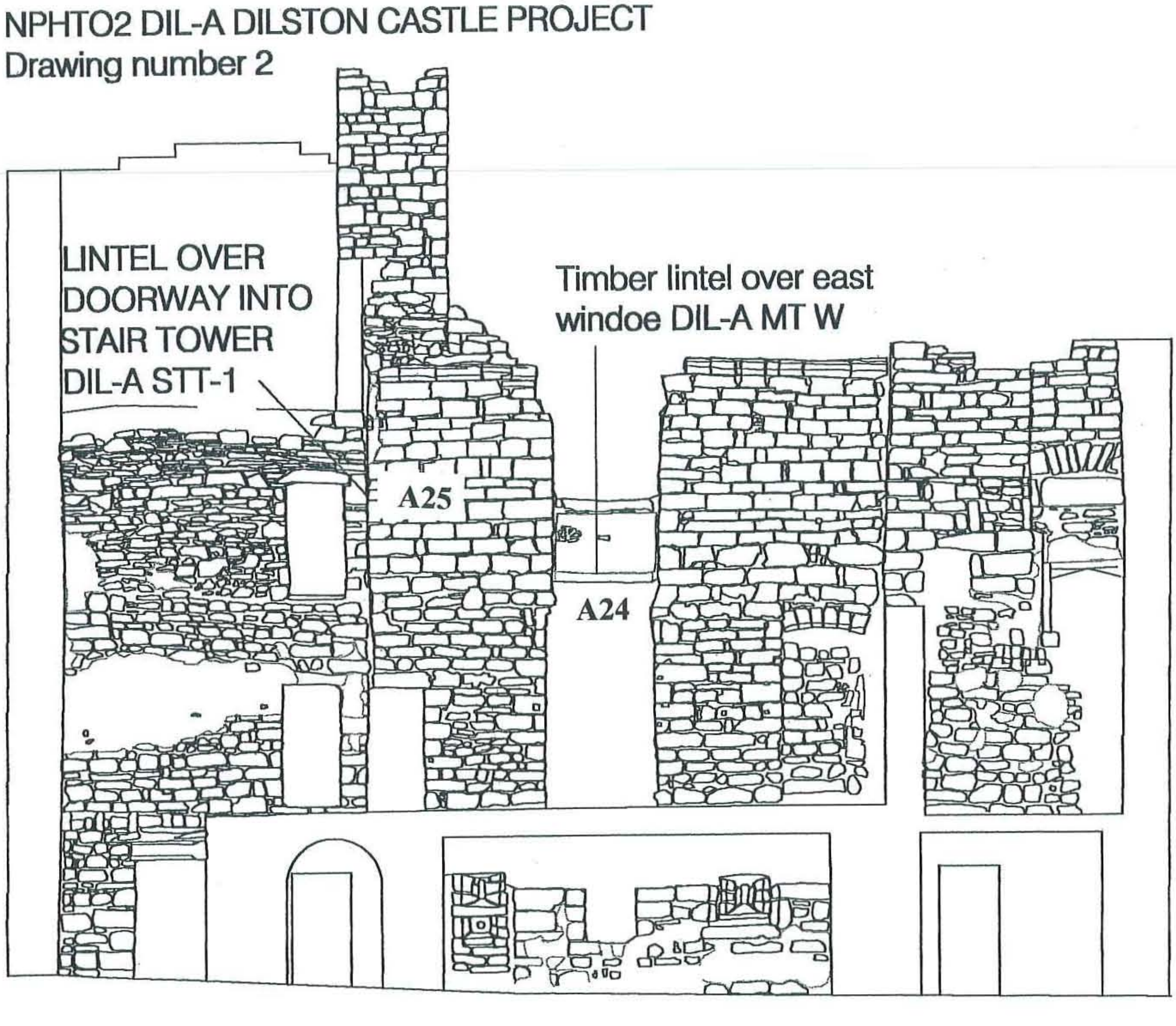


**Figure 6: Drawing to show location of samples**

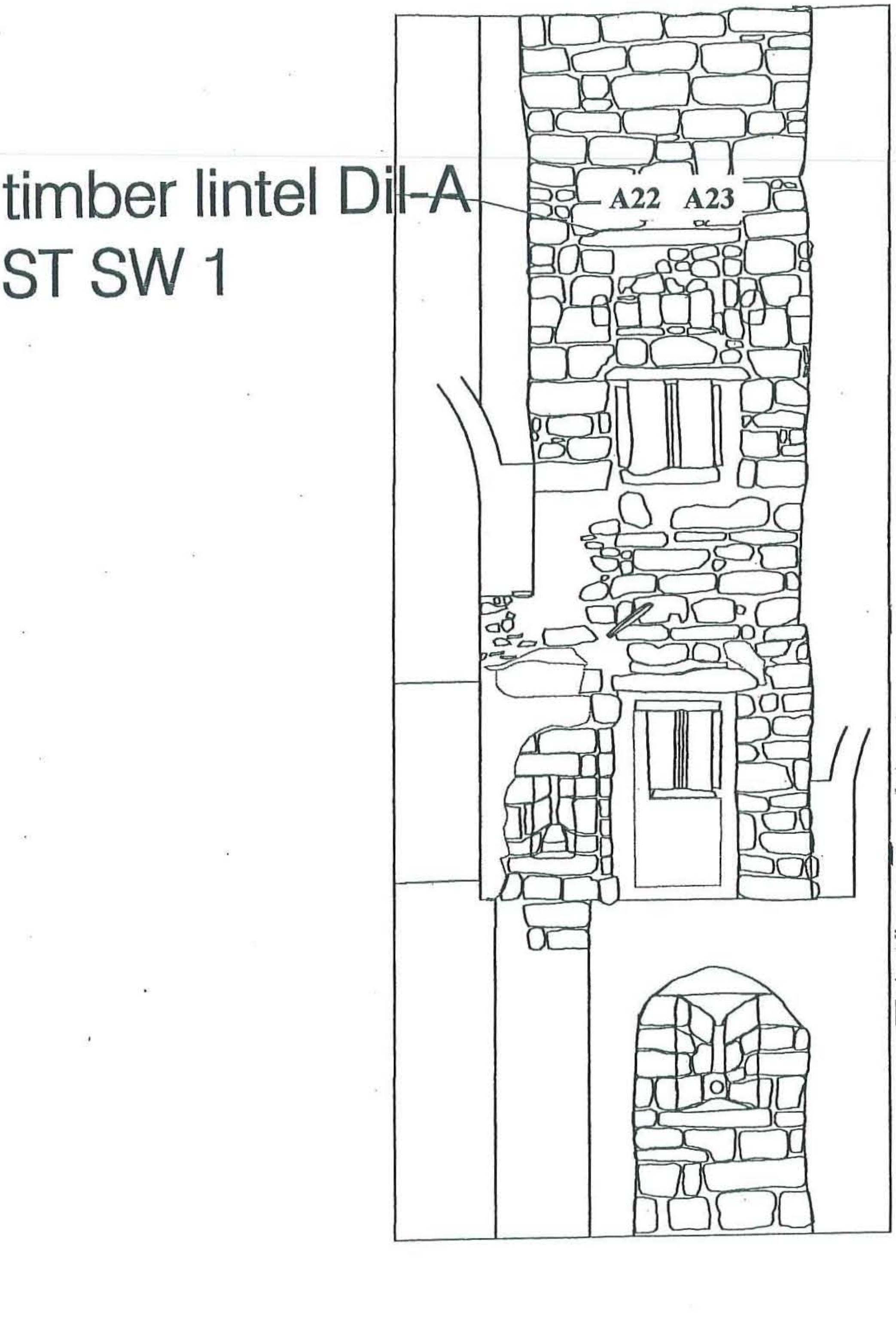
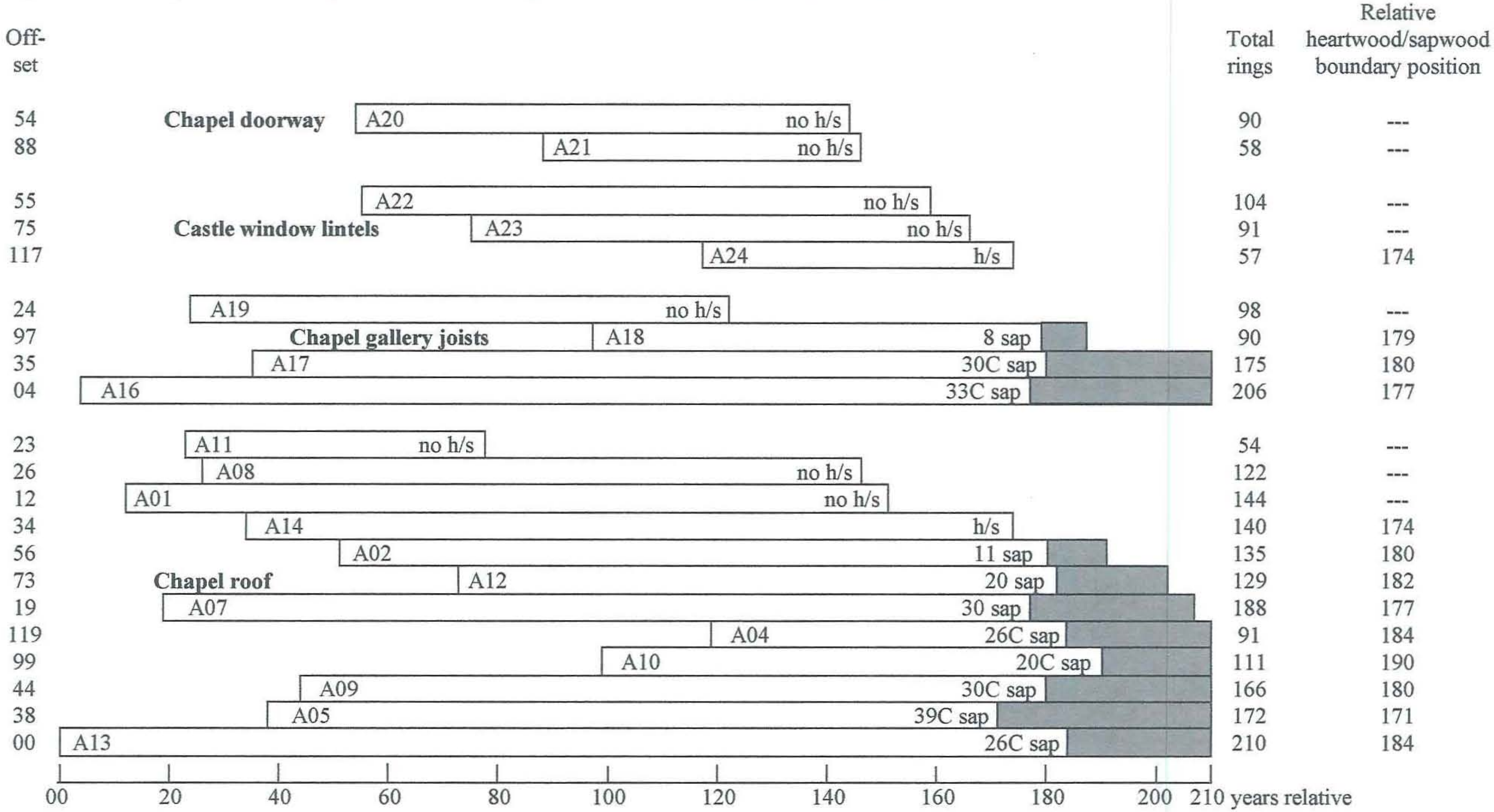


**Figure 7: Bar diagram of the samples in site chronology DSTASQ01 sorted by sample location**




white bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample
C = complete sapwood retained on sample, last measured ring date is the felling date of the tree

Data of measured samples – measurements in 0.01 mm units

DST-A01A 144
135 197 201 176 147 98 249 174 185 137 199 214 160 244 251 287 202 276 312 249
293 223 207 189 192 165 158 206 172 207 191 160 228 220 178 169 160 149 207 189
179 116 161 134 103 112 106 108 113 107 100 103 92 109 95 78 98 75 50 70
51 89 91 85 64 82 68 89 82 82 75 67 75 109 69 94 112 87 97 101
103 84 97 96 106 127 106 115 84 87 157 145 180 142 191 201 156 155 167 282
203 213 189 144 152 153 133 129 119 109 133 135 154 120 103 105 137 123 146 150
144 166 125 100 78 113 134 93 80 83 80 91 84 66 76 82 98 116 97 103
74 79 75 81
DST-A01B 144
159 207 201 206 137 102 258 161 204 162 212 214 155 248 246 284 201 273 309 256
285 232 200 176 169 147 158 199 163 233 259 239 215 224 171 171 153 154 210 182
162 129 153 140 104 106 100 112 106 113 99 99 84 103 94 71 92 85 54 62
50 94 96 75 67 80 72 92 82 81 72 73 78 97 79 104 101 93 96 98
94 87 96 97 113 118 105 107 81 85 149 143 181 140 180 214 157 144 158 277
212 216 183 146 144 156 140 121 118 115 137 130 157 124 91 106 140 131 149 148
155 160 128 89 84 112 138 91 84 85 77 91 92 65 78 58 95 111 102 101
67 71 76 93
DST-A02A 135
180 236 223 192 220 220 189 244 259 305 283 212 224 230 153 152 163 230 193 246
204 154 146 152 172 158 160 179 203 210 150 160 125 101 124 72 44 36 51 47
61 66 61 47 52 68 78 93 98 82 96 94 108 116 120 122 122 103 101 125
72 122 115 100 73 72 82 80 114 84 79 79 97 91 87 95 86 90 103 89
78 91 109 101 63 73 71 77 79 85 87 100 104 122 91 96 99 90 74 97
72 73 62 67 77 78 68 57 57 51 46 61 72 76 103 93 91 81 79 69
54 100 67 99 86 98 76 74 88 81 73 64 70 69 85
DST-A02B 135
169 223 222 198 231 216 202 250 244 303 279 170 226 222 164 142 182 195 195 260
198 150 155 143 174 152 165 185 205 203 154 156 121 110 129 74 38 46 47 52
59 65 59 48 51 69 81 78 105 88 103 98 114 117 107 130 121 104 105 122
82 115 106 91 82 70 83 85 100 92 86 78 96 98 87 95 90 85 109 86
82 88 108 106 57 75 71 75 89 79 87 98 107 125 93 108 97 71 79 91
70 72 66 67 79 69 74 55 62 58 38 67 73 76 108 85 97 77 87 53
62 99 72 86 89 91 84 78 97 77 72 65 73 74 75
DST-A03A 55
144 271 277 161 171 178 158 209 219 235 208 247 231 170 151 169 139 155 257 203
186 255 160 171 153 132 125 146 144 136 122 132 130 127 168 236 169 181 106 94
65 63 123 158 169 153 139 116 128 141 158 161 134 160 157
DST-A03B 55
156 267 275 153 171 183 159 199 203 229 224 266 230 143 152 159 148 174 252 204
160 237 154 172 161 120 131 152 155 139 118 130 123 133 171 235 148 180 104 96
63 70 128 152 171 163 132 117 126 148 175 153 142 163 160

DST-A04A 91
181 192 154 199 196 173 121 162 176 154 111 96 119 112 125 212 160 121 202 206
145 141 120 120 130 129 89 131 130 159 208 166 124 152 119 90 129 127 189 162
135 153 132 169 127 141 107 94 154 172 146 128 200 164 158 149 108 108 151 102
116 110 92 119 88 115 68 53 71 78 66 65 95 108 90 55 57 48 54 64
76 30 43 42 44 39 46 36 35 59 55
DST-A04B 91
169 198 145 195 216 176 137 179 127 151 116 95 117 105 111 212 150 132 202 203
147 135 126 109 137 128 98 126 143 146 205 162 134 122 123 99 128 130 184 151
126 151 146 156 132 152 112 95 140 153 146 135 200 157 160 140 111 109 156 101
125 106 86 124 88 113 73 49 74 78 67 73 93 102 90 62 50 53 55 61
76 38 40 45 35 45 43 36 36 59 54
DST-A05A 172
164 159 154 174 249 209 192 170 190 241 204 179 221 217 265 196 262 186 162 166
147 184 153 152 152 165 167 229 207 194 260 186 153 158 162 241 198 292 238 209
194 181 184 155 181 180 197 197 153 161 130 98 105 72 104 76 69 80 56 58
62 48 46 42 63 72 88 97 89 96 86 93 107 93 127 79 98 103 119 124
95 91 86 77 87 79 106 80 85 84 96 107 85 100 89 95 83 79 67 83
100 97 79 79 87 88 85 97 83 108 104 106 83 94 98 82 73 84 69 81
81 73 82 73 100 72 76 55 46 56 84 83 92 92 88 75 83 56 65 79
75 73 76 67 88 68 72 67 42 58 66 69 81 81 102 84 67 61 67 56
67 80 74 81 112 83 67 67 86 83 101 113
DST-A05B 172
160 161 163 177 249 213 159 196 184 237 181 180 216 229 253 196 272 178 147 181
150 187 162 143 151 163 170 217 122 117 174 177 148 155 161 240 202 278 244 212
172 178 179 163 189 153 200 204 158 155 135 94 125 77 100 73 59 48 56 59
77 43 45 36 59 60 90 100 85 101 84 90 98 106 120 82 94 102 130 123
97 85 84 76 83 86 106 87 81 81 88 104 90 100 90 97 84 78 65 80
100 96 83 79 92 74 90 90 90 108 100 104 84 92 95 58 73 79 73 74
71 89 78 68 100 75 73 48 51 61 78 85 89 98 76 86 67 57 46 84
80 60 78 57 77 66 80 60 44 64 66 73 77 84 100 83 69 56 68 53
75 79 72 85 109 79 75 57 93 81 104 107
DST-A06A 54
239 168 255 284 261 301 274 343 250 286 267 233 285 184 213 210 232 188 152 247
212 187 188 190 150 144 174 158 183 163 137 157 155 192 178 138 217 177 191 201
202 285 200 272 244 265 123 163 197 178 269 276 238 229
DST-A06B 54
215 168 241 297 261 308 265 352 242 270 279 230 290 191 220 205 241 147 162 249
167 201 187 181 165 143 180 162 182 166 140 150 161 187 183 132 214 176 193 201
202 282 202 266 259 263 121 157 205 169 273 266 279 211
DST-A07A 188
210 175 213 112 162 123 126 118 141 114 143 145 112 130 120 92 115 79 60 62
62 64 126 109 95 65 82 99 124 166 238 248 201 196 129 106 145 118 99 131
134 169 138 125 119 119 121 123 82 85 67 67 78 80 92 90 81 79 72 82
111 109 104 102 97 96 113 89 105 85 87 116 74 79 102 107 83 65 73 103
65 96 92 127 96 113 124 143 131 157 177 116 86 89 93 96 99 101 95 72
56 67 50 41 39 49 63 70 57 57 46 47 80 68 65 55 57 45 62 74
79 51 61 64 55 50 45 49 41 68 63 51 67 51 54 49 48 58 54 57
56 49 40 37 39 41 43 43 53 65 60 59 54 54 60 59 50 52 64 62
57 59 39 55 67 50 62 45 51 56 62 69 41 68 80 61 79 45 48 69
51 60 63 59 47 54 57 85

DST-A07B 188
189 175 217 114 160 114 128 127 130 123 132 159 106 126 120 101 111 79 65 61
59 70 115 116 92 67 78 102 127 164 213 253 201 199 125 112 147 112 84 116
136 166 137 133 109 126 126 105 101 80 61 63 79 76 89 94 87 74 76 75
111 105 103 106 102 94 118 92 86 87 98 108 74 73 89 126 74 62 67 103
73 92 96 123 98 114 113 140 144 145 175 105 101 74 97 92 97 100 96 72
52 64 50 44 37 49 65 72 53 56 44 49 78 66 66 55 56 46 61 81
79 53 65 56 53 52 46 47 47 62 63 57 58 50 59 52 45 53 61 55
47 58 36 40 39 43 40 41 53 60 66 56 61 53 58 60 53 50 71 62
58 42 46 56 55 59 60 49 56 57 53 61 50 93 53 61 57 45 48 64
59 62 62 59 54 47 48 81
DST-A08A 122
261 251 242 205 187 137 166 157 179 132 76 86 84 119 95 118 150 122 76 107
96 114 87 109 67 91 82 71 70 46 65 53 58 66 56 67 58 72 79 118
99 65 67 92 77 71 67 74 72 87 66 67 89 97 55 72 84 84 96 99
89 87 99 71 75 78 86 111 96 91 92 113 118 92 98 90 138 129 110 98
101 104 72 88 73 69 67 79 76 66 60 68 46 43 45 46 37 34 43 48
42 46 38 40 35 45 49 51 52 60 47 52 43 48 38 52 44 50 41 42
39 62
DST-A08B 122
243 229 240 187 190 143 171 143 170 140 73 97 101 116 93 135 140 118 98 113
98 92 94 93 79 87 80 70 62 66 64 57 61 75 66 48 70 58 77 110
105 71 73 94 79 64 74 71 61 98 70 79 85 93 59 65 75 88 102 101
87 88 100 75 73 70 84 105 107 94 96 113 127 82 100 87 139 138 112 89
114 102 79 82 78 68 62 80 72 76 68 63 48 46 40 45 34 36 50 42
44 46 39 39 32 44 52 58 45 64 44 50 46 49 40 46 51 42 41 42
42 54
DST-A09A 166
68 135 130 134 130 135 139 142 101 93 108 124 113 110 92 72 74 76 79 85
118 113 127 111 92 128 135 121 123 144 119 169 109 141 129 125 82 87 105 122
131 164 122 111 140 134 173 170 161 203 225 209 194 185 244 163 162 126 220 140
149 169 238 209 175 180 148 102 93 89 87 97 106 89 63 63 60 51 44 52
56 57 61 51 63 58 45 68 80 62 46 44 52 58 73 70 56 62 78 66
63 60 63 79 82 82 89 65 67 76 53 53 58 64 68 69 79 89 65 75
60 56 72 87 108 114 86 89 87 93 81 79 82 117 104 77 84 68 93 71
65 53 40 62 55 55 59 78 77 71 45 49 39 58 45 59 45 48 61 72
59 55 58 46 63 72
DST-A09B 166
104 160 131 138 128 138 127 150 100 91 101 105 111 113 84 66 65 80 73 106
117 117 127 105 106 127 137 114 116 156 121 152 145 140 126 137 76 91 109 126
132 165 126 118 132 140 206 157 163 197 225 204 199 185 244 158 163 129 217 153
148 167 228 214 174 185 146 110 90 96 98 95 95 88 70 65 58 43 44 54
48 60 64 49 58 56 49 68 75 61 56 45 50 57 70 69 56 65 84 69
67 58 69 77 78 81 81 65 72 70 53 59 53 67 63 69 88 82 74 67
58 61 64 98 102 109 89 95 89 96 93 74 83 117 110 80 73 74 93 72
73 48 43 57 51 33 60 73 78 69 51 41 49 51 54 45 51 51 60 66
64 52 58 46 62 66
DST-A10A 111
396 539 334 517 318 372 271 456 409 320 359 258 313 266 267 232 269 379 292 330
204 189 148 190 218 242 133 161 122 105 90 77 92 92 123 137 153 150 217 299
271 165 133 158 149 136 107 129 161 217 210 170 122 123 146 101 93 131 161 170

170 178 210 274 184 182 118 148 200 239 245 206 215 193 214 273 153 176 197 187
175 162 149 166 145 148 137 88 116 117 121 121 148 174 166 109 93 93 82 111
95 82 116 120 127 122 116 112 111 154 155
DST-A10B 111
395 524 339 514 323 359 295 443 417 318 364 252 319 261 270 232 276 376 294 335
200 186 151 182 239 233 132 145 131 107 90 75 87 101 118 150 149 143 221 327
268 166 125 162 150 133 112 122 165 205 203 166 117 130 132 104 86 124 179 173
161 173 225 266 164 180 128 153 189 239 266 199 215 196 207 280 153 173 197 191
185 166 144 176 136 158 131 95 113 117 118 129 143 174 169 121 92 88 83 109
111 81 118 131 113 127 114 117 115 151 163
DST-A11A 54
116 128 129 165 224 357 241 264 247 318 286 302 234 169 111 125 138 165 166 182
124 108 111 100 132 103 121 130 145 145 121 153 152 109 130 130 126 109 121 109
128 131 177 188 149 184 137 117 116 120 188 170 157 243
DST-A11A 54
114 136 135 165 231 356 261 272 248 322 305 298 226 174 116 128 139 156 163 180
135 109 111 128 123 121 108 116 145 125 118 150 139 112 134 128 111 88 91 107
120 117 172 162 141 166 134 109 116 125 174 189 166 207
DST-A12A 129
127 101 126 120 117 108 107 81 105 112 138 166 143 115 112 145 132 178 146 133
132 134 118 133 118 140 106 105 103 145 124 148 155 125 134 126 116 99 85 96
90 78 85 79 78 62 40 48 39 34 45 49 46 37 49 46 40 37 49 54
54 51 52 44 50 75 66 46 35 37 57 64 47 56 62 60 71 62 63 57
61 52 49 47 66 57 67 62 72 71 47 58 52 52 68 78 91 82 100 76
82 78 67 71 94 92 97 84 74 80 87 76 63 64 78 77 66 108 111 116
81 80 66 66 56 76 74 80 86
DST-A12B 129
126 100 123 129 114 111 106 84 106 116 135 157 144 125 113 133 134 175 139 139
140 129 127 130 116 150 110 105 98 147 128 152 136 128 136 123 107 101 86 81
93 72 88 83 78 55 57 44 37 31 43 51 43 43 52 48 46 38 49 53
52 55 49 44 50 73 68 46 59 66 61 66 46 65 68 63 78 74 61 55
61 50 51 44 62 58 71 64 68 68 55 58 51 45 70 75 95 84 100 81
85 85 67 72 92 93 97 84 68 86 82 76 65 59 78 74 75 103 113 114
92 67 64 67 65 70 89 71 87
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53 53 54 72 95 104 100 59 50 49 57 55 62 81 63 70 68 92 91 80
60 65 86 112 80 117 93 73 101 100 110 91 93 118 111 79 87 102 102 91
71 79 102 75 84 95 83 75 72 83 52 43 61 55 67 62 53 58 36 37
32 29 21 24 22 20 34 35 26 32 21 35 34 29 28 30 24 35 36 41
25 37 38 41 38 35 36 36 41 46 39 48 31 37 32 39 33 44 43 47
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36 41 43 44 36 27 31 46 31 33 37 37 42 32 43 33 37 35 34 32
34 29 34 31 25 29 24 30 27 31
DST-A13B 210
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50 55 56 72 96 101 109 53 46 54 53 58 57 80 75 65 68 88 89 84

67 66 80 105 93 111 93 74 94 110 107 90 102 113 110 85 90 94 104 92
70 78 100 80 80 90 85 75 83 82 53 50 61 56 65 64 51 58 38 36
35 25 25 17 26 21 38 32 28 28 27 31 34 28 27 33 28 36 38 35
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53 44 44 39 32 30 38 41 51 49 43 52 49 48 44 39 40 54 41 46
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99 88 82 80 87 111 88 108 87 95 90 120 101 105 111 88 91 98 113 100
130 115 103 147 120 110 67 94 145 152 138 126 174 168 151 121 161 245 186 205
152 128 138 138 121 110 116 125 149 116 159 140 126 112 128 129 141 137 138 150
104 84 63 92 107 77 73 76 65 128 84 87 101 104 139 128 115 101 79 99
71 81 59 90 65 77 105 97 107 79 103 70 66 94 107 111 103 108 90 127
DST-A14B 140
167 138 128 115 128 126 133 114 143 147 123 133 141 150 148 143 143 139 147 120
120 122 87 80 88 97 102 83 98 106 105 100 99 81 103 93 69 82 62 103
99 85 84 78 82 119 88 106 83 88 90 126 103 112 111 86 90 98 114 100
137 108 115 148 124 100 67 94 136 160 139 143 177 164 153 122 144 229 191 207
147 127 145 135 118 114 114 128 138 136 167 139 119 112 139 137 127 142 140 137
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65 74 64 81 66 77 102 101 104 87 103 60 77 93 103 109 100 109 88 111
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111 116 128 123 116 124 102 101 100 111 120 100 98 112 101 114 89 71 103 72
84 85 95 113 109 108 82 87 64 63 88 91 71 104 106 116 79 81 115 84
119 174
DST-A15B 62
116 112 138 129 108 87 83 109 124 115 129 104 132 118 109 111 106 69 70 92
119 110 131 126 119 137 101 111 101 111 120 101 92 114 102 110 97 74 100 95
75 82 99 110 120 105 80 88 72 62 86 95 77 109 115 117 77 84 105 91
123 178
DST-A16A 206
281 164 179 164 141 129 147 136 119 137 116 152 128 95 162 126 121 83 80 77
41 43 63 101 71 73 90 69 104 113 87 86 70 59 73 83 70 91 116 119
64 84 58 55 53 84 84 100 114 125 139 110 101 88 75 85 81 70 61 44
60 77 66 61 69 56 67 48 54 71 83 82 78 75 69 75 65 87 66 69
76 102 95 75 107 78 86 98 87 86 93 96 101 80 76 69 54 60 80 71
93 85 96 91 70 53 63 66 64 61 62 74 56 65 66 68 61 41 64 66
76 56 57 53 63 63 56 66 66 70 68 70 63 70 78 65 73 71 52 60
54 59 48 67 41 67 72 57 60 85 56 57 61 57 57 57 58 59 68 63
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26 55 43 49 54 80
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187 145 165 156 107 151 150 148 118 133 116 150 125 102 156 117 109 92 74 82
38 36 75 88 79 76 84 72 110 101 96 76 77 60 69 89 67 97 116 119
72 77 66 57 47 85 85 103 118 115 131 116 97 93 66 87 77 73 62 50
54 80 63 63 74 52 69 40 56 74 72 79 85 73 69 82 60 90 63 70
77 104 94 78 105 78 82 105 84 85 102 89 97 82 80 74 55 61 66 74

104 88 102 88 69 56 60 71 62 52 69 64 60 73 66 66 59 38 63 67
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51 55 53 58 50 65 66 62 61 85 58 57 53 61 61 55 55 62 69 58
62 46 51 41 54 51 63 58 55 60 55 63 56 60 76 66 52 53 60 67
45 54 67 56 55 47 51 47 59 60 50 44 47 57 55 45 38 41 57 44
29 57 42 62 52 74
DST-A17A 175
266 222 197 245 256 191 313 250 227 225 222 152 186 165 177 201 182 182 180 212
129 128 144 136 133 123 119 108 139 113 133 119 90 100 113 91 82 96 123 109
130 99 92 70 61 50 62 61 63 76 84 82 98 101 92 92 96 104 105 111
90 81 83 86 75 86 91 136 139 141 127 125 143 130 140 127 103 95 116 107
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113 99 103 105 99 95 86 99 95 106 107 88 102 86 118 69 97 102 105 79
72 77 76 90 104 66 81 85 84 94 76 72 72 75 94
DST-A17B 175
247 222 205 222 270 260 284 271 225 208 245 185 207 172 202 203 179 192 178 205
147 128 143 118 129 109 109 100 133 103 120 115 91 88 112 66 75 92 138 113
118 100 101 72 59 51 59 59 62 72 102 107 92 111 92 93 101 112 106 107
83 81 84 80 72 90 90 127 129 130 126 129 128 107 131 109 96 92 81 79
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99 107 108 101 95 100 85 90 107 105 96 111 82 80 102 92 96 96 107 86
70 75 76 95 87 74 88 80 89 98 67 78 68 77 87
DST-A18A 90
90 112 109 86 105 154 184 180 203 187 166 91 105 111 124 128 132 120 120 114
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111 94 104 112 111 137 102 108 50 60 99 110 126 84 109 103 107 111 123 111
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DST-A18B 90
101 133 103 71 80 119 176 159 177 170 138 102 110 108 124 109 114 102 111 112
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160 165 84 109 113 102 108 81 72 100 82 107 162 123 85 83 97 75 79 77
93 86 88 104 94 118 103 107 46 58 98 95 130 82 106 116 97 118 109 116
136 138 122 123 120 100 100 127 134 143
DST-A19A 98
341 286 206 388 320 338 377 240 443 404 318 249 244 138 187 194 179 278 365 309
246 271 282 251 223 310 291 235 243 227 194 215 173 141 164 107 129 149 144 194
208 270 276 275 255 183 142 169 159 240 238 265 336 391 226 331 280 209 170 151
213 275 280 243 277 195 246 152 106 119 167 121 91 108 117 93 76 93 131 128
111 147 170 124 121 120 122 152 138 186 217 209 304 312 296 235 159 203
DST-A19B 98
332 286 211 384 305 343 400 228 453 393 296 254 233 150 191 188 181 287 366 309
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225 262 279 271 254 199 140 163 133 261 250 271 319 358 239 327 275 190 153 160
224 293 266 264 231 200 262 122 111 140 214 93 89 103 122 90 80 90 130 128
111 143 161 123 139 124 113 154 133 194 187 257 301 290 288 223 171 215

DST-A20A 90
119 79 62 66 54 55 42 51 78 99 95 106 62 47 64 61 52 55 67 64
80 85 91 78 70 85 63 65 93 85 120 115 98 108 182 170 125 124 127 153
138 119 136 152 161 115 118 113 151 158 131 127 140 114 127 165 116 123 88 117
96 84 89 118 89 113 117 105 105 79 135 67 63 86 78 88 112 108 85 101
96 110 80 99 102 74 69 58 54 94
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139 95 67 66 61 48 43 56 74 90 96 105 63 52 69 61 46 74 52 69
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99 90 88 109 103 112 123 101 112 97 135 60 59 87 80 85 106 107 76 87
66 110 76 87 105 71 67 94 50 84
DST-A21A 58
137 160 181 149 172 176 172 150 154 225 182 184 147 123 189 168 182 151 123 159
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135 121 135 108 116 110 107 99 91 105 116 126 104 115 99 119 107 110
DST-A21B 58
112 150 166 144 170 191 161 164 157 212 190 167 140 134 183 174 188 146 145 165
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124 130 127 123 110 113 102 89 101 93 131 117 112 96 104 121 114 109
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178 137 172 209 236 181 149 156 134 120 138 183 144 161 210 133 120 77 131 177
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172 154 194 209 141 130 116 122 168 138 138 144 98 129 119 119 126 119 138 170
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DST-A23B 91
206 213 174 150 176 214 206 187 165 241 244 202 153 142 130 121 101 96 78 105
91 91 85 85 54 41 57 96 125 165 137 121 119 107 82 99 126 94 109 121
127 110 98 97 96 103 103 127 155 155 140 121 114 158 128 130 135 142 201 167
185 156 191 215 134 120 127 132 154 137 136 140 96 127 118 122 114 123 133 183
110 119 155 156 235 154 181 210 133 107 78
DST-A24A 57
420 350 245 208 89 169 263 317 257 347 329 417 334 285 270 320 459 379 347 256
349 403 328 275 308 279 282 266 236 268 366 346 376 273 259 340 341 273 177 113
126 202 315 270 231 250 178 179 79 91 173 191 267 190 203 171 168

DST-A24B 57
397 353 240 202 98 188 254 317 266 315 362 413 305 314 276 334 365 403 323 262
335 423 316 268 332 284 265 282 252 257 385 318 357 282 252 354 349 282 147 109
170 184 304 272 228 270 174 178 89 90 158 185 262 186 210 175 173
DST-A25A 78
212 284 293 264 248 291 246 287 216 193 222 198 109 121 82 161 162 102 89 79
57 91 101 107 123 103 99 81 68 53 76 101 128 105 90 79 96 86 114 154
131 157 145 163 91 120 103 211 184 187 176 177 248 203 83 95 117 126 208 202
207 214 104 97 89 92 119 164 129 126 157 156 152 72 62 100 114 138
DST-A25B 78
183 277 281 262 250 313 252 280 216 194 218 201 103 124 81 172 148 117 82 71
64 90 97 114 114 109 97 88 62 55 74 97 128 98 103 87 97 99 109 129
126 189 172 141 100 143 101 202 196 181 179 181 225 195 93 98 130 116 208 206
202 219 95 107 93 103 111 164 127 123 161 158 139 78 74 97 103 129

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 *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

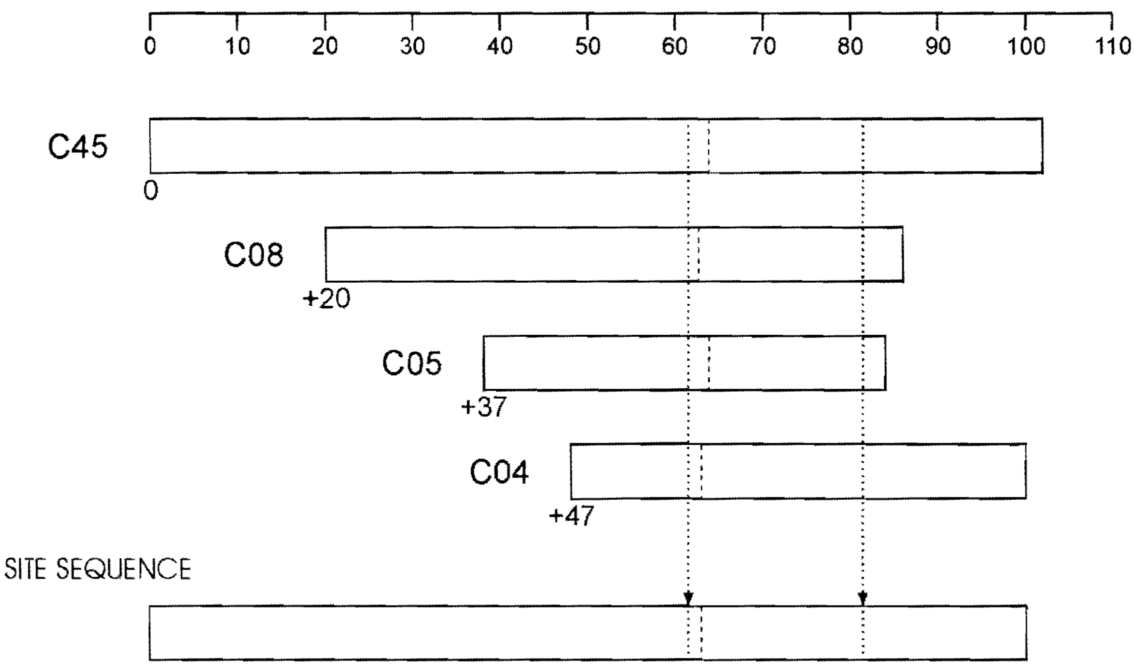



Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

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.

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 phenomena 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.

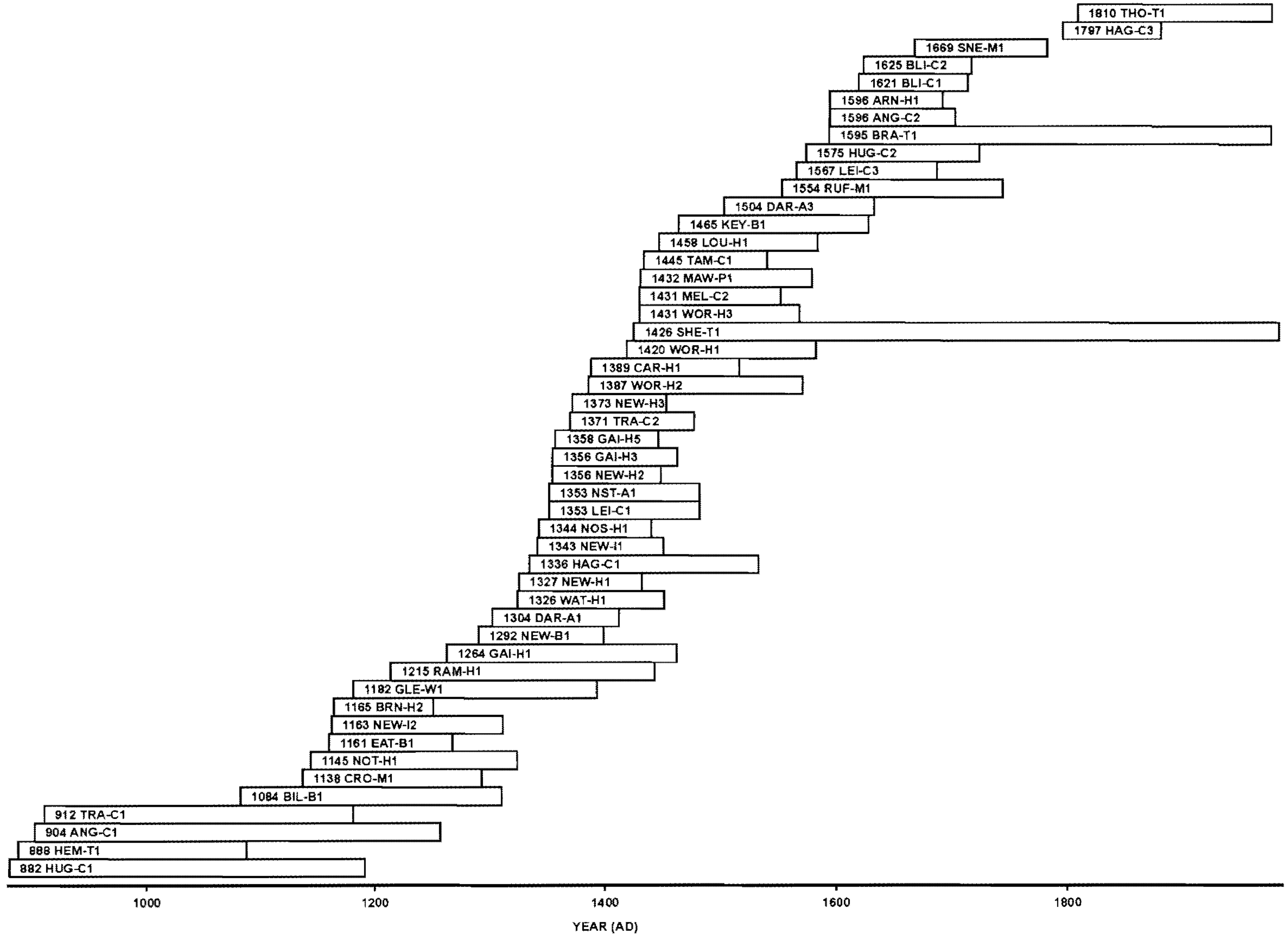
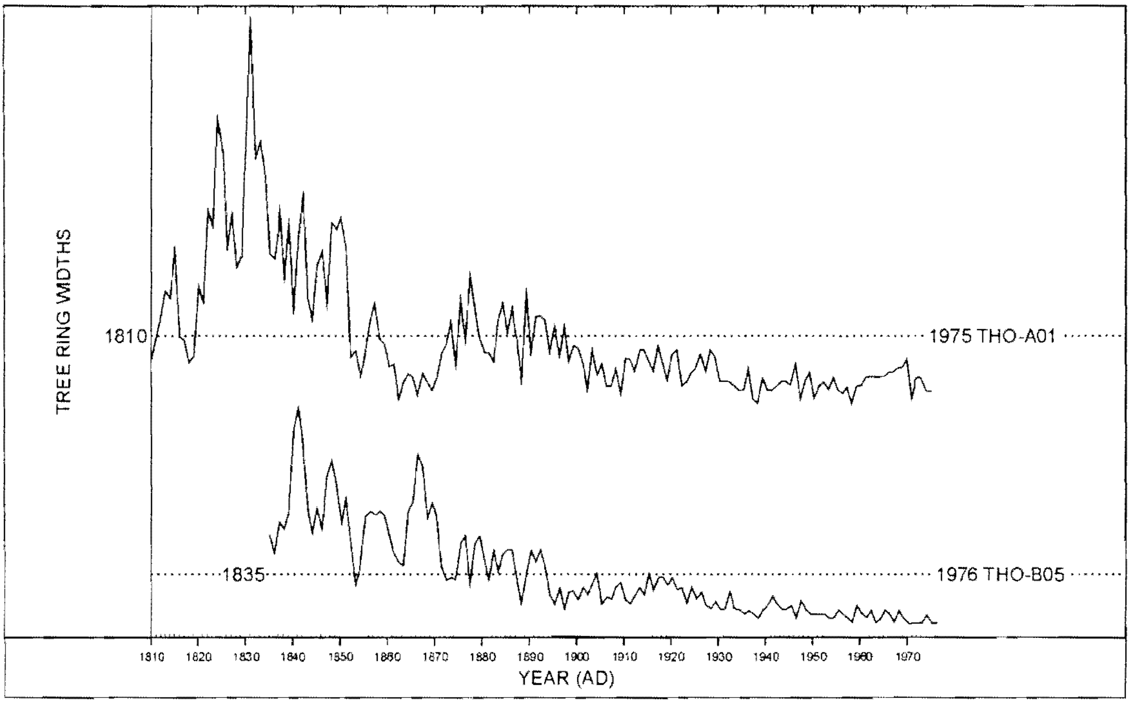



Fig. 6 Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)




(b)

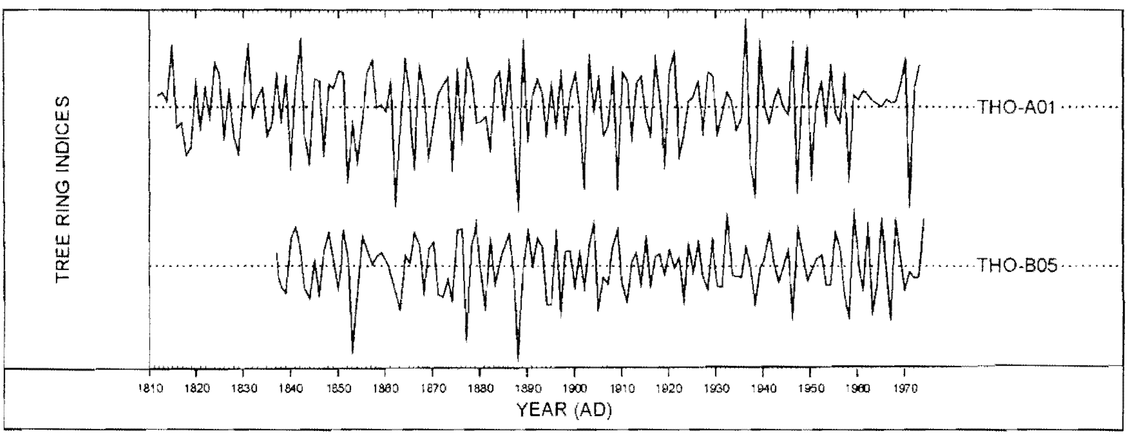



Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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

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

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