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Summary

Analysis undertaken on 22 samples from timbers of the ground and first-floor ceilings of this building resulted in the construction of two site sequences.

Site sequence DUROSQ01, of 145 rings, containing seven samples, all from reused timbers, spans the period AD 975-1119. Four of the samples are from timbers estimated to have been felled within the range AD 1129-64 with the last measured ring dates of the other three making it possible they were also felled at this time.

Site sequence DUROSQ02, of 140 rings, contains 11 samples, and spans the period AD 1402-1541. One sample, DUR-O14, from a reused main beam, is from a timber felled in AD 1516. Another five samples are from timbers all felled in AD 1541, with the estimated felling date range of a further five samples also consistent with this felling.

Sample DUR-O10 was dated individually to the period AD 1355-1445, with the timber represented estimated to have been felled in AD 1446-63.

The first-floor ceiling contains reused joists of AD 1129-64 and at least one other joist felled in AD 1446-63. The ground-floor ceiling is constructed from joists and main beams felled in AD 1541, but incorporates a reused timber of AD 1516.

Keywords

Dendrochronology
Standing Building

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Introduction

This Grade II listed building, currently known as the Timber Loft, is a late medieval/early post-medieval barn or service building situated within the outer court of Durham Cathedral Priory (now The College; Fig 1; NZ 273420).

The gable end of an adjacent building, the plumbers/electricians shop, forms part of the north wall of the timber loft (Fig 2). It is this section that is thought to be the earliest phase of construction within the timber loft. Incorporated into the earliest section of wall is a substantial post which has evidence, in the form of a cut-off piece of timber still in a mortice, for a brace which is thought would have risen to a now absent wall plate. A vertical indent and a base pad located in the main western section of the north wall of the timber loft, which butts the earliest section of wall, suggests the position of another post. These posts are neither integral to the timber loft nor the earliest section of the wall associated with the plumbers/electricians shop. It has previously been suggested that they represent another earlier building but this is currently under discussion.

In the eighteenth or nineteenth century the roof of the timber loft was raised to create a new upper floor. The tiebeams of the original roof are however thought to be retained in the first-floor ceiling structure. This structure also contains a series of joists that are clearly reused timbers. The east gable wall includes a timber framed screen (Fig 3) facing the road that runs into the masons yard. This is also thought to be potentially associated with the primary construction of the timber loft and hence contemporary with the tiebeams currently located within the first-floor ceiling structure.

At ground-floor level there appears to be two or possibly three phases of stonework in the south wall, though at the time of sampling this was largely concealed by scaffolding and ladders. The ceiling beams are set within these various phases and it is therefore possible that they represent an inserted floor. These timbers generally show no evidence of reuse but the main north-south beam at the west end, truss 5 (Fig 5), appears likely to be reused.

Similar to this building is Number 4, The College, the roof of which has previously been dated by this Laboratory to *c* AD 1445 (Howard *et al* 1995). This building is of rubble sandstone with surviving triangular vents and the vestigial remains of opposed cart door openings indicating it was probably also a small barn. Additionally, timbers from 1-2 The College, have been dated to a felling of AD 1531 (Howard *et al* 1992).

Sampling and analysis by tree-ring dating was commissioned and funded by English Heritage. Dating of the potentially early post located within the north wall of the timber loft was hoped to inform the growing evidence of the early monastic buildings. These survive in fragments within or below the standing buildings, which, if pre-Dissolution, are predominantly later medieval (fifteenth to sixteenth century). It was hoped that dating of the principal building would help inform imminent repairs of the west gable, develop a more comprehensive understanding of the medieval monastic buildings, and inform the Durham World Heritage Management plan, currently in preparation.

The Laboratory would like to thank Norman Emery, the Cathedral Archaeologist, for arranging access to the building and for providing the drawings used to illustrate this report (Figs 2-5). Mr Emery also provided much of the information included in the introduction and his comments were very helpful in interpreting the dates gained.

Sampling

The brief provided requested sampling of the potentially early post embedded into the north wall of the timber loft and the surviving elements of the primary construction of the building. Unfortunately, the timbers in the timber framed screen in the east wall of the timber loft were unsuitable for tree-ring analysis. These had insufficient numbers of rings for successful dating and so no samples were taken from these. However, following on-site discussions it was agreed that the brief could be extended to include the reused joists in the first-floor ceiling and the reused main beam in the ground-floor ceiling. It was thought these may have been reused from the original roof of the timber loft or may aid the understanding of the medieval monastic buildings within the Priory complex.

Samples were taken from the post located in the north wall, the ground-floor ceiling, and the first-floor ceiling. In all 24 core samples were taken from a variety of other timbers at this building. Each sample was given the code DUR-O (for Durham, site O) and numbered 01-24. The position of all samples was noted at the time of sampling and has been marked on Figures 4 and 5. Further details relating to the samples are recorded in Table 1.

Analysis and Results

At this point it was seen that the sample taken from the post (DUR-O24) had too few rings to make secure dating a possibility. Additionally, the sample taken from one of the main joists on the first floor (DUR-O02) had a distorted ring pattern, and so both of these samples were discarded prior to measurement. The remaining 22 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. The growth-ring widths of the samples were compared with each other by the Litton/Zainodin grouping procedure (see appendix).

At a least value of t=4.5, 18 samples formed two groups. Firstly, seven samples matched each other and site sequence DUROSQ01, of 145 rings, was constructed containing these samples at the offsets shown in the bar diagram (Fig 6). This site sequence was successfully matched against the relevant reference chronologies for oak at a first-ring date of AD 975 and a last-ring date of AD 1119. The evidence for this dating is given by the t-values in Table 2.

Eleven samples matched each other and site sequence DUROSQ02, of 140 rings, was constructed containing these samples at the offsets shown in the bar diagram (Fig 7). This site sequence was successfully matched against the reference chronologies at a first-ring date of AD 1402 and a last-ring date of AD 1541. The evidence for this dating is given by the *t*-values in Table 3.

Attempts were then made to date the remaining four samples individually by comparing them with the reference chronologies. This resulted in sample DUR-O10 being matched at a first-ring date of AD 1355 and a last-ring date of AD 1445. The evidence for this dating is given by the *t*-values in Table 4.

Interpretation

Analysis of samples from the timbers of this building has resulted in the production of two dated site sequences and one individually dated sample.

Site sequence DUROSQ01 contains seven samples and spans the period AD 975-1119. Four of these samples have the heartwood/sapwood boundary ring. The average of this is AD 1114 which allows an estimated felling date range to be calculated for the timbers represented of AD 1129-64. The other three samples do not have this boundary ring and so a felling date cannot be calculated for them. However, they are clearly broadly contemporary with last measured ring dates of AD 1077 (DUR-O08), AD 1100 (DUR-O09), and AD 1108 (DUR-O04) making it possible that they were also felled at the same time as the others. All of these samples are from first-floor ceiling joists which show signs of reuse.

Site sequence DUROSQ02 contains 11 samples and spans the period AD 1402-1541. Contained within this site sequence are six samples with complete sapwood. One of these, DUR-O14, has the last-ring date of AD 1516, the felling date of the timber represented. This timber has signs of reuse. The other five all have the last-ring date of AD 1541, the felling date of the five timbers represented. The average heartwood/sapwood boundary ring of the remaining five samples is AD 1518, which allows an estimated felling date to be calculated for the five timbers represented to within the range AD 1533-68, entirely consistent with these having also been felled in AD 1541. These 11 samples are taken from three main beams and eight ceiling joists from the ground floor.

Sample DUR-O10 was dated individually to the period AD 1355-1445. The heartwood/sapwood boundary ring of this sample is AD 1413 which, taking account of a last measured ring date of AD 1445, gives an estimated felling date for the timber represented to within the range AD 1446-63. This sample is taken from a first-floor ceiling joist which did not have empty mortices like the others but did show signs of reuse in the way it had been trimmed to fit.

All felling date ranges have been calculated using the estimate that 95% of mature oak trees in this area have between 15-50 sapwood rings.

Discussion

It is unfortunate that timbers thought to be associated with the primary construction of the timber loft have proved undateable in the case of the first-floor main beams (tiebeams from the original roof) or unsuitable in the case of the timber framed screen in the east wall. It has also not been possible to date the post located in the north wall of the timber loft. However, four felling phases have been identified by the dendrochronological analysis. These relate to the ground-floor ceiling and the joists of the first-floor ceiling.

Four of the reused first-floor ceiling joists are now known to have been felled some time between AD 1129-64, with it likely that at least another three were also felled at this time. From the evidence of carpenter's marks and the appearance of the timbers themselves it is thought probable that a large number of them are reused from the same building. A detailed survey of these timbers may make it possible to reconstruct the roof for which they were originally cut. An eighth ceiling joist from the first floor was felled some time between AD 1446-63. Although this timber did not have the empty mortices of the other joists it had been trimmed and shaped to sit over the main beam which could suggest that it is also reused. The inability to date the main beams (tiebeams from the original roof) prevents any relationship between these and the reused joists being established.

Dendrochronological analysis has shown that the first-floor ceiling is constructed from reused timbers, the majority of which are thought to date from the mid-twelfth century, but also at least one timber from the mid-fifteenth century. The felling dates of the recycled common joists, AD 1129-64, is of interest. The Cathedral nave was vaulted around AD 1133, and was probably completed by the AD 1150s. Work on the cloistral buildings started in the AD 1070s, and a new chapter house (or upgrading of the existing one) was completed by *c* AD 1141. Therefore, it is possible that the timbers used in the timber loft came from upgraded cloistral buildings, or from the buildings of the outer court of which little is known of their earlier structural history).

Eleven timbers from the ground-floor ceiling were successfully dated. One of the main beams, the only one that showed signs of reuse, is now known to have been felled in AD 1516 with a second main beam and four common joists being felled a little later in AD 1541. A third main beam and four more common joists have a felling date range of AD 1533-68 which is entirely consistent with a felling of AD 1541. One of the main beams thought to have been felled in AD 1541 (DUR-O23) appears to support the gable framing, originally thought to be part of the primary phase of the building. However, this does not necessarily mean that the gable framing is contemporary or later than AD 1541 as the construction makes it possible that this beam was inserted beneath it with brick packing around it.

As mentioned above a number of different phases of stonework were seen in the south wall at ground-floor level, with the ceiling beams being set into all of these. The majority of timbers were felled in AD 1541, with the exception of the reused beam felled in AD 1516. Therefore, this ceiling may represent a modification to a monastic structure immediately post-dissolution.

It has not been possible to provide a dendrochronological date for the initial construction of the timber loft. However, if the ground-floor ceiling was inserted shortly after felling in AD 1541 this would suggest that the primary construction of the timber loft pre-dates this. The dendrochronological analysis has identified four different phase of felling, though two of these are represented by only a single timber. The timbers from the AD 1541 felling show no evidence of reuse but those timbers from the earliest major felling phase in the mid-twelfth century and the two timbers felled in the mid-fifteenth and early sixteenth century all show evidence of reuse. The results indicate that this is a potentially more complex structure than initially thought. Further survey work would help elucidate the rather confusing results from the dendrochronological analysis and may identify areas in which further dendrochronological sampling may be of use in aiding the overall understanding of the building.

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Table 1: Details of tree-ring samples from the Timber loft, The College, Durham

Sample number	Sample location	Total rings	Sapwood rings*	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
First-floor beams						
DUR-O01	North-south main joist, truss 3	91	20c	----	----	----
DUR-O02	North-south main joist, truss 1	NM	--	----	----	----
DUR-O03	®Common joist, no 8, bay 4	99	h/s	1019	1117	1117
DUR-O04	®Common joist, no 12, bay 2	91	--	1018	----	1108
DUR-O05	®Common joist, no 10, bay 4	145	h/s	975	1119	1119
DUR-O06	®Common joist, no 5, bay 1	102	h/s	1009	1110	1110
DUR-O07	®Common joist, no 7, bay 4	131	h/s	980	1110	1110
DUR-O08	®Common joist, no 7, bay 1	74	--	1004	----	1077
DUR-O09	®Common joist, no 9, bay 4	103	--	998	----	1100
DUR-O10	®?Common joist, no 3, bay 1	91	32c	1355	1413	1445
Ground-floor beams						
DUR-O11	North-south main beam, truss 2	104	20C	----	----	----
DUR-O12	North-south main beam, truss 4	108	26C	1434	1515	1541
DUR-O13	North-south main beam, truss 3	106	36C	----	----	----
DUR-O14	®North-south main beam, truss 5	80	23C	1437	1493	1516
DUR-O15	Common joist, no 9, bay 2	110	20C	1432	1521	1541
DUR-O16	Common joist, no 5, bay 3	97	21c	1441	1516	1537
DUR-O17	Common joist, no 6, bay 1	94	21C	1448	1520	1541
DUR-O18	Common joist, 4, bay 3	99	23c	1440	1515	1538
DUR-O19	Common joist, 5, bay 2	62	20C	1480	1521	1541
DUR-O20	Common joist 6, bay 3	98	15	1440	1522	1537
DUR-O21	Common joist, no 2, bay 2	111	15C	1431	1526	1541
DUR-O22	Common joist, no 9, bay 3	83	17c	1455	1520	1537
DUR-O23	North-south main beam, truss 1	135	21c	1402	1515	1536

Sample number	Sample location	Total rings	Sapwood rings*	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
DUR-O24	Post	NM	--	----	----	-----

* NM = not measured
h/s = the heartwood/sapwood boundary is the last ring on the sample
C = complete sapwood retained on sample, last measured ring is the felling date
c = complete sapwood on timber, all or part lost in sampling

® = timber shows signs of reuse

Table 2: Results of the cross-matching of site sequence DUROSQ01 and relevant reference chronologies when the first-ring date is AD 975 and the last-ring date is AD 1119

Reference chronology	*t*-value	Span of chronology	Reference
East Midlands	8.0	AD 882-1982	Laxton and Litton 1988
England	6.0	AD 404-1981	Baillie and Pilcher 1982 unpubl
Trinity House (Rigging loft), Newcastle-upon-Tyne	8.8	AD 950-1181	Howard *et al* 2002
Carlisle Cathedral/Castle	7.2	AD 961-1446	Howard *et al* 2003 unpubl
Lincoln Cathedral (St Hughs Choir), Lincs	6.8	AD 882-1191	Laxton and Litton 1988
Brecon Cathedral (Chapter House), Powys	5.5	AD 996-1227	Howard *et al* 1994a
Hemington timbers, Notts	5.3	AD 888-1087	Laxton and Litton 1988
Lincoln Cathedral (Angel Choir), Lincs	5.2	AD 912-1248	Laxton and Litton 1988
Guildhall (East range), Market Place, Carlisle, Cumbria	4.9	AD 976-1382	Howard *et al* 1994b

Table 3: Results of the cross-matching of site sequence DUROSQ02 and relevant reference chronologies when the first-ring date is AD 1402 and the last ring date is AD 1541

Reference chronology	*t*-value	Span of chronology	Reference
Western England and Wales	6.0	AD 1341-1636	Siebenlist-Kerner 1978
England	6.0	AD 404-1981	Baillie and Pilcher 1982 unpubl
East Midlands	5.5	AD 882-1982	Laxton and Litton 1988
1-2 The College, Cathedral Precinct, Durham	14.1	AD 1364-1531	Howard *et al* 1992
Bull Hole Byre, Bearpark, Durham	10.4	AD 1452-1620	Arnold *et al* 2002a
Aydon Castle (Kitchen range), Corbridge, Northumberland	9.4	AD 1424-1543	Hillam and Groves 1991
Aydon Castle (Latrine block), Corbridge, Northumberland	8.4	AD 1406-1545	Arnold *et al* 2002b
Seaton Holme, Easington, Durham	7.3	AD 1375-1489	Howard *et al* 1988 unpubl
35 The Close, Newcastle-upon-Tyne	7.0	AD 1365-1513	Howard *et al* 1991

Table 4: Results of the cross-matching of sample DUR-O10 and relevant reference chronologies when the first-ring date is AD 1355 and the last ring date is AD 1445

Reference chronology	t-value	Span of chronology	Reference
Hergest Court, Kingston, Herefordshire	6.4	AD 1406-1665	Miles 2001
Cottage Farm, Easthope, Shropshire	6.0	AD 1308-1454	Miles *et al* 1994
Black Ladies, near Brewood, Staffordshire	5.9	AD 1372-1671	Tyers 1999
Ightfield Hall Barn, Shropshire	5.7	AD 1341-1566	Groves 1997
Crook Hall, Sidegate, Durham	5.3	AD 1354-1467	Howard *et al* 1992
Redroofs, Sawbridge, Warwicks	5.2	AD 1355-1448	Howard *et al* 1995b
Durham Cathedral (Choir roof), Durham	5.1	AD 1346-1458	Howard *et al* 1992
Witton Hall (barn), Witton Gilbert, Tyne & Wear	4.9	AD 1342-1441	Howard *et al* 1996
Hallgarth Manor Cottages, Hallgarth, Pittington, Co Durham	4.7	AD 1336-1624	Howad *et al* 2001

Figure 1: Map to show the location of Durham Cathedral

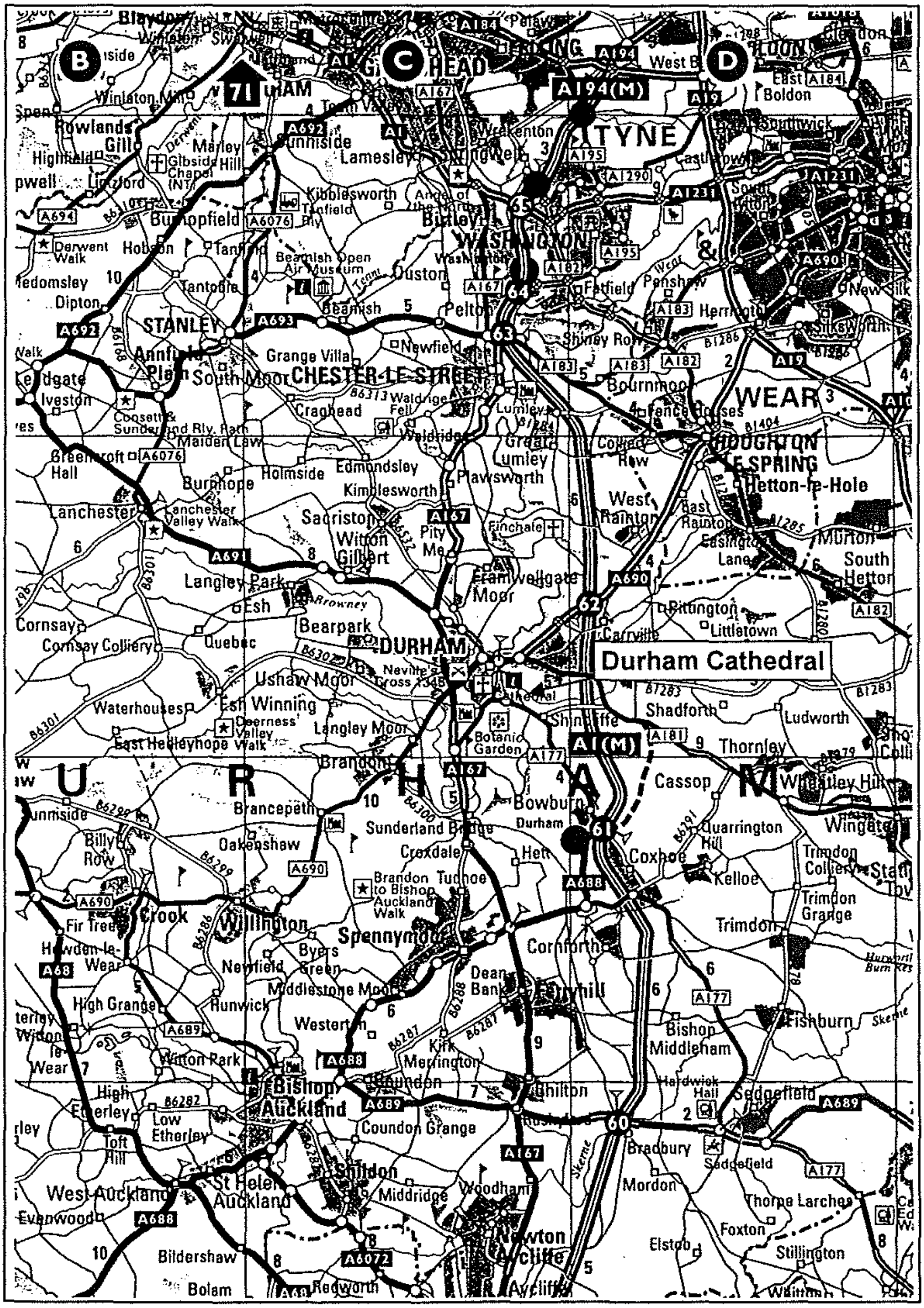


Figure 2: Sketch plan of the ground-floor showing the earliest phase, based on a sketch by Norman Emery

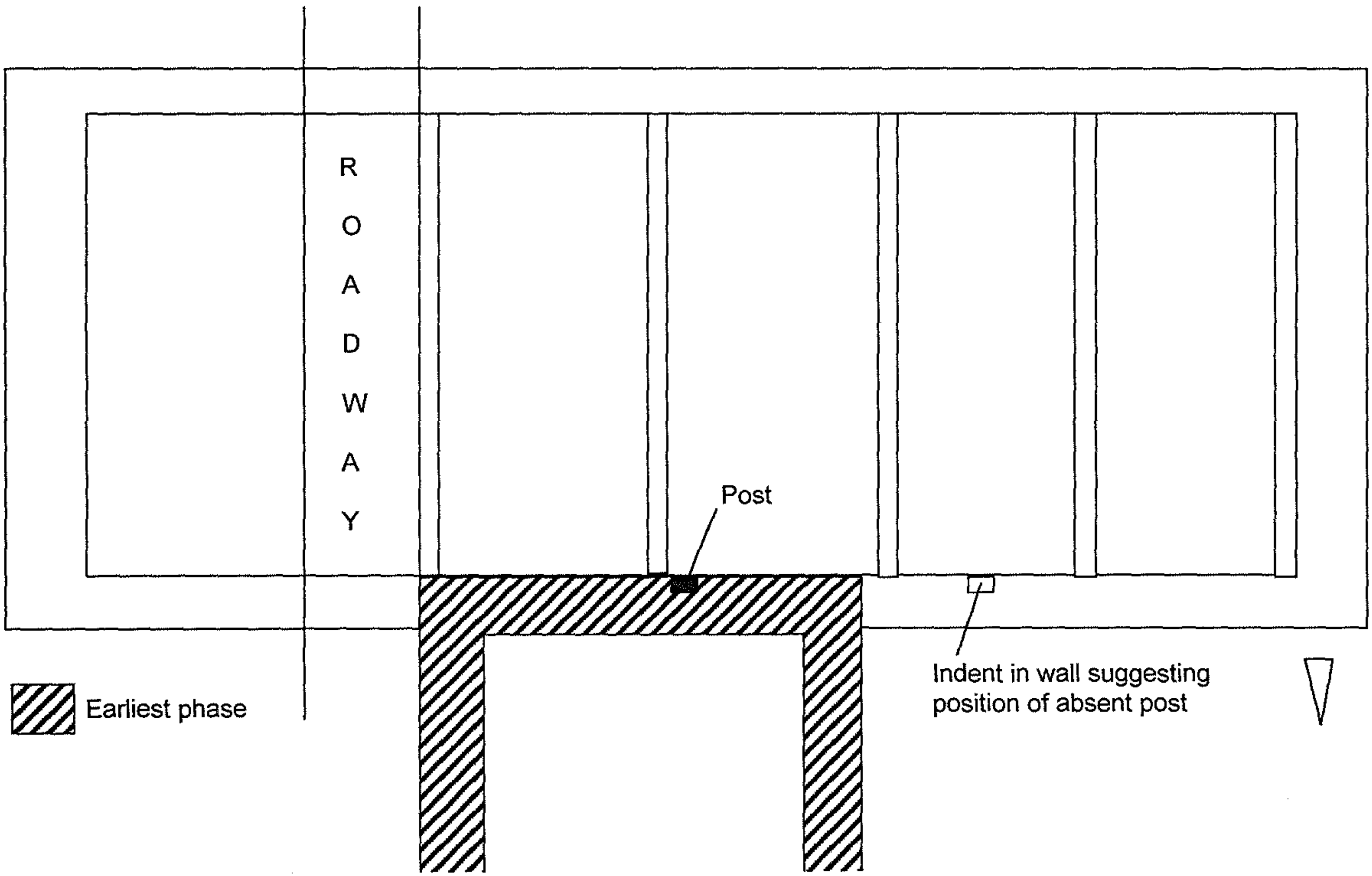


Figure 3: East gable end, drawn by Norman Emery

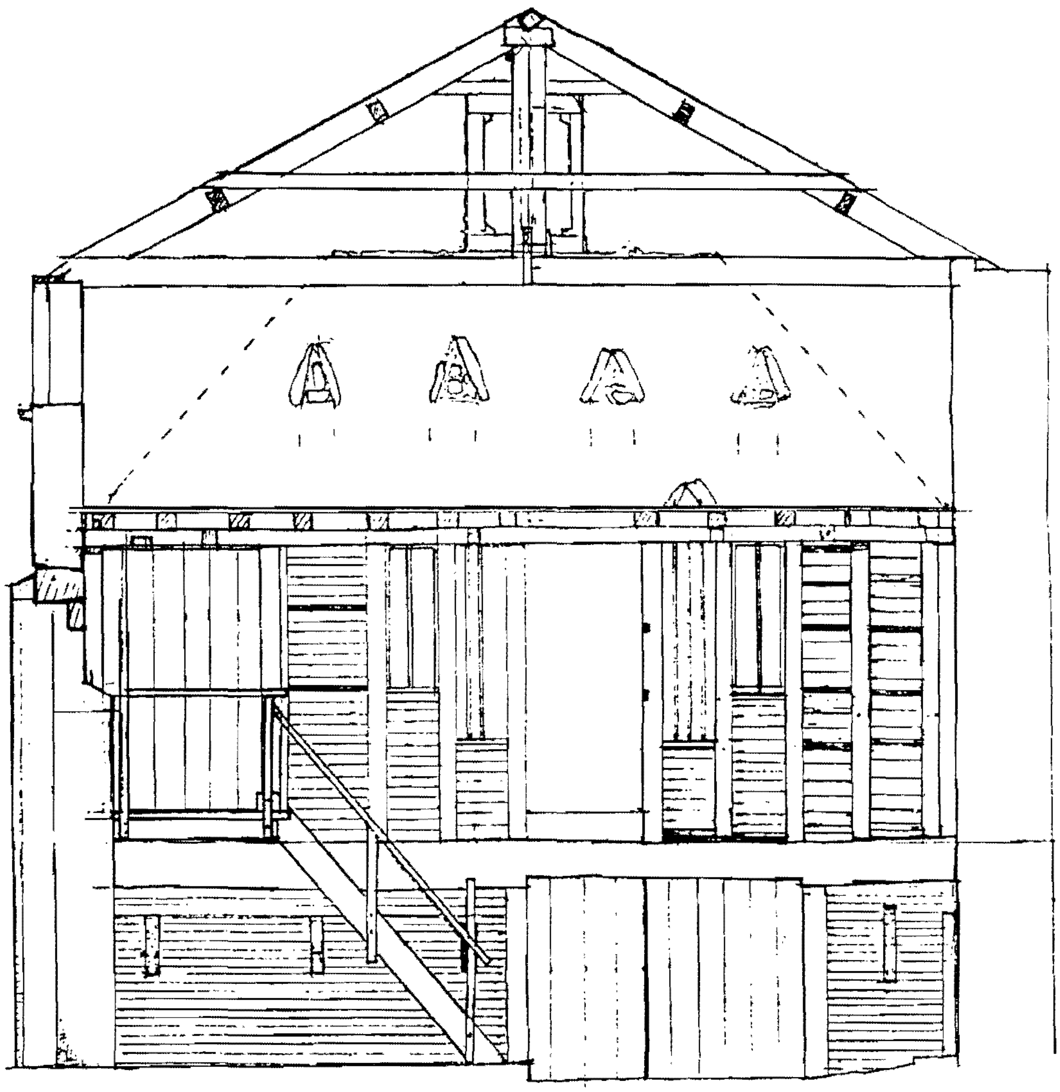


Figure 4: First-floor plan, showing the location of samples DUR-O01-10, based on a drawing by Norman Emery

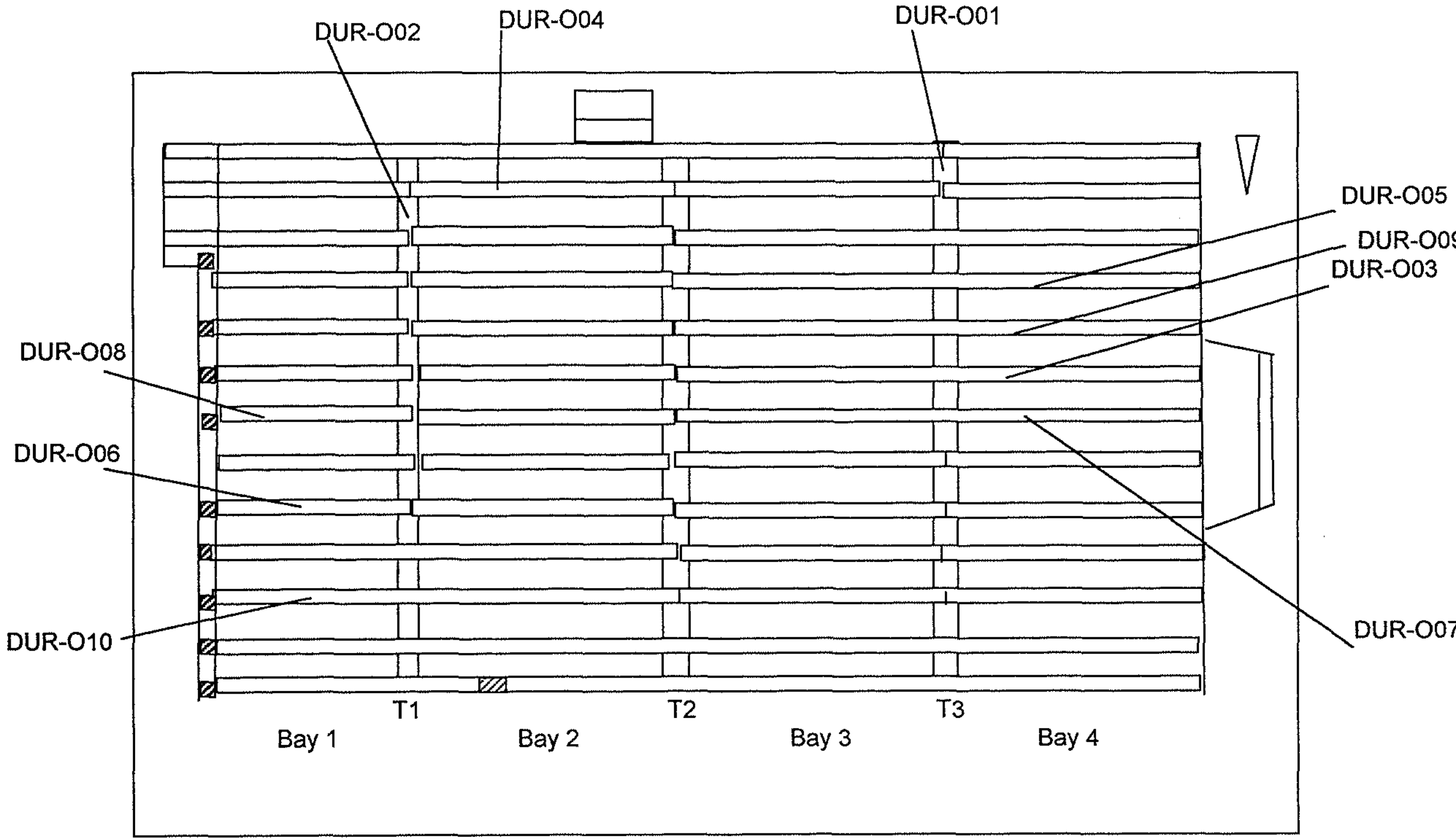


Figure 5: Ground-floor plan, showing the location of samples DUR-O11-24, drawn by Norman Emery

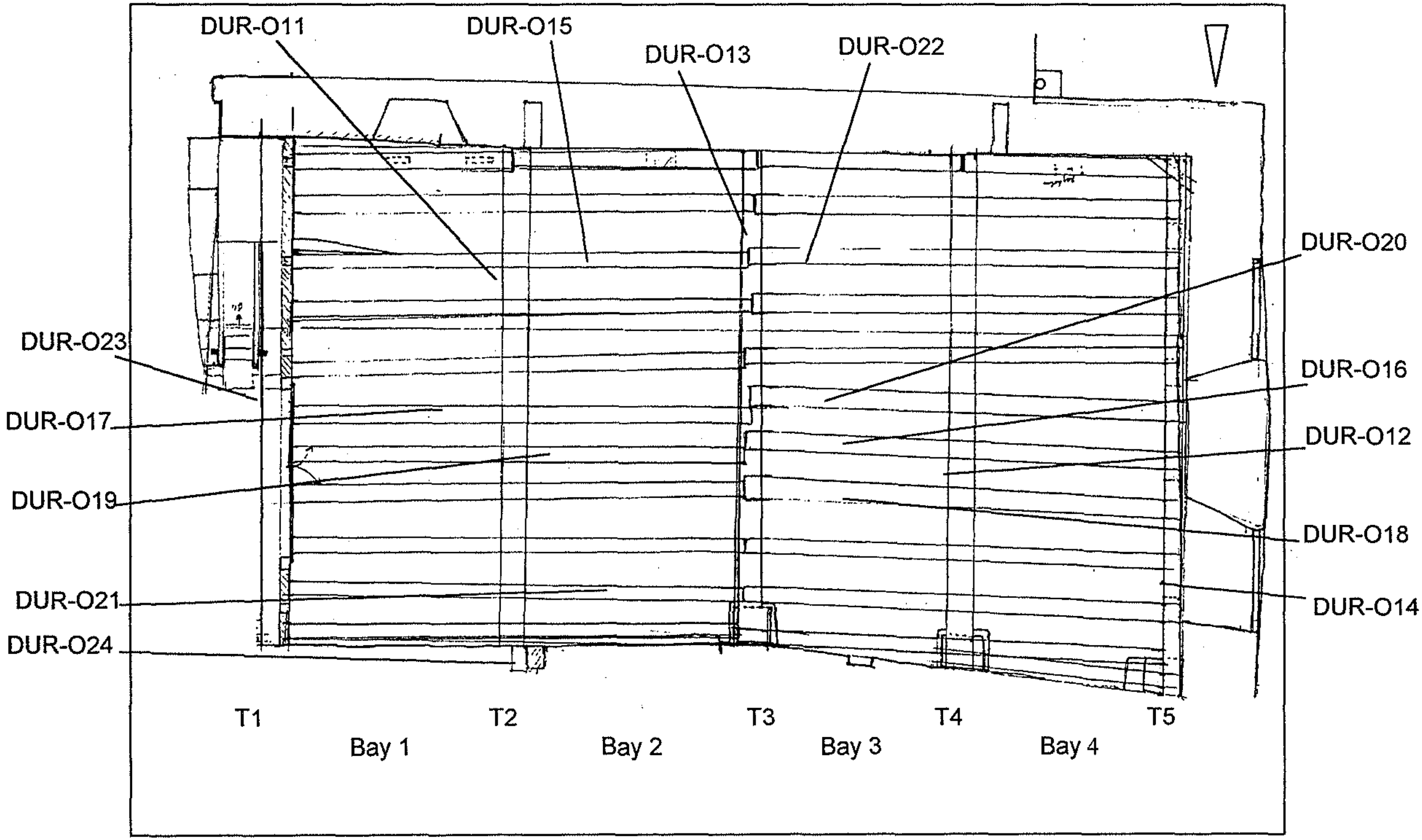


Figure 6: Bar diagram of samples in site sequence DUROSQ01

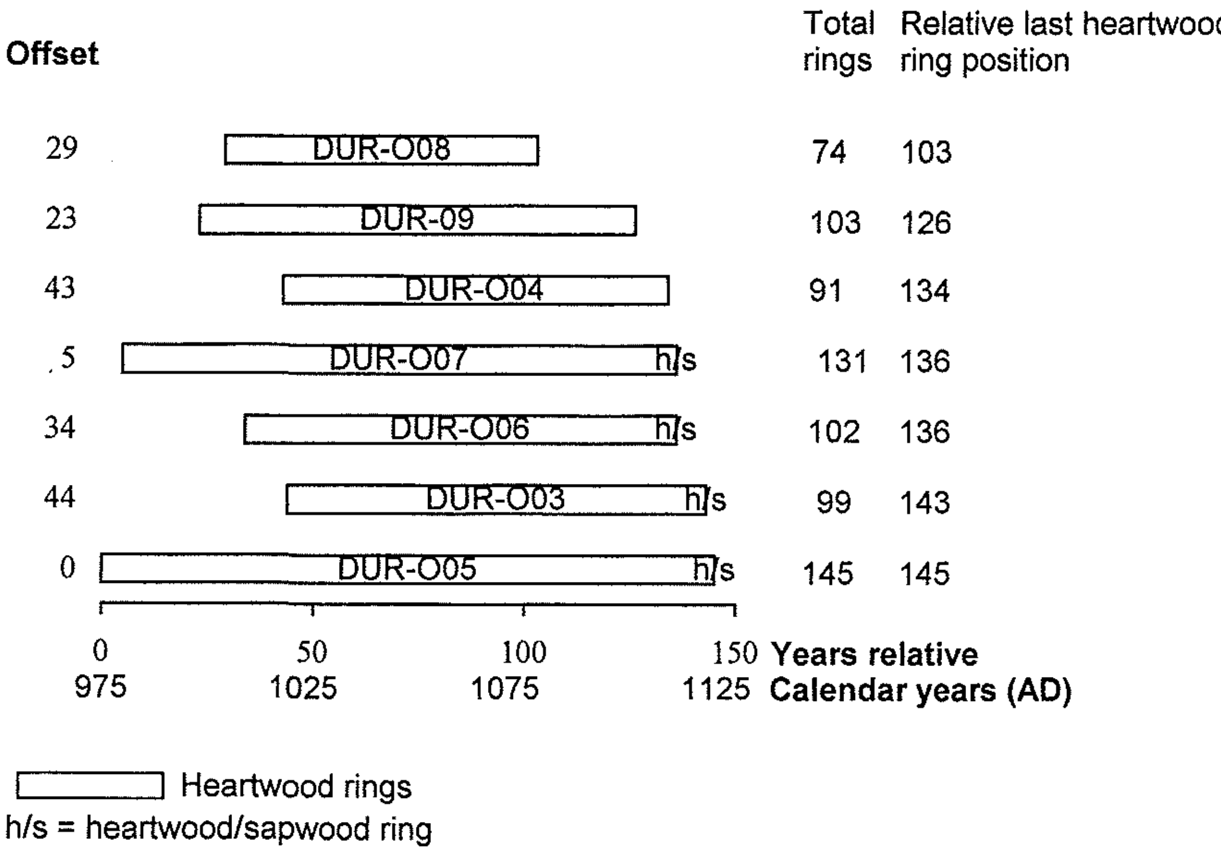
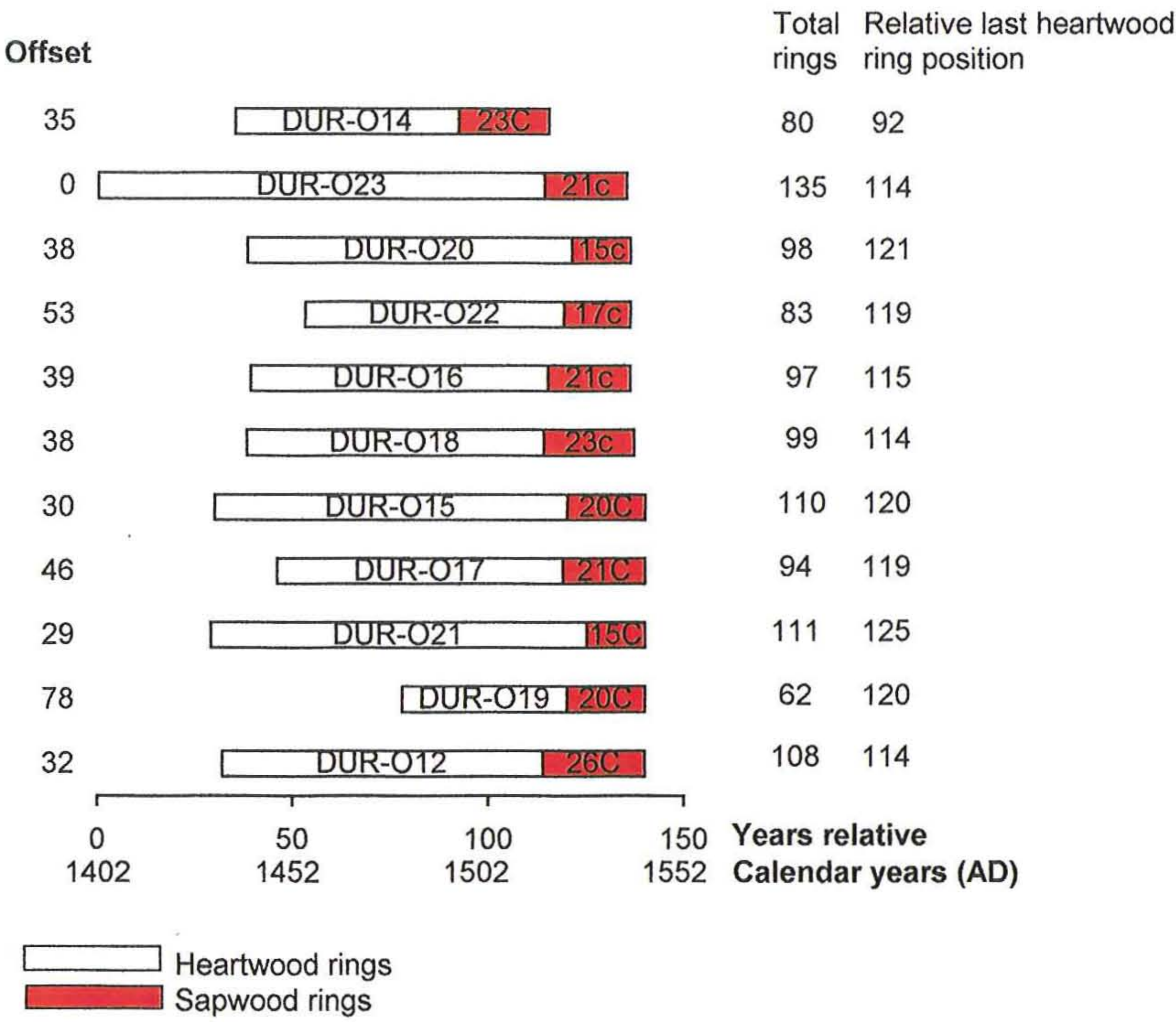


Figure 7: Bar diagram of samples in site sequence DUROSQ02



h/s = heartwood/sapwood ring
C = complete sapwood retained on sample, last measured ring date is the felling date
c = complete sapwood on timber, all or part lost in sampling

Data of measured samples – measurements in 0.01mm units

DUR-O01A 91
290 214 309 293 293 259 319 261 320 326 324 386 421 290 324 321 410 288 279 299
282 296 278 282 316 148 155 208 225 242 236 240 134 143 175 184 181 274 185 153
210 165 174 171 194 306 210 227 176 244 317 267 156 136 68 153 206 160 195 279
220 162 174 183 79 130 174 158 155 150 116 133 173 141 153 149 153 101 128 93
95 150 82 132 151 164 150 181 146 103 150
DUR-O01B 91
312 222 255 294 307 258 310 259 324 326 327 392 420 268 308 320 412 286 284 313
281 298 276 293 321 144 142 224 226 237 235 224 132 148 179 194 176 266 187 165
211 156 192 166 191 268 208 228 179 239 319 249 165 133 66 156 209 148 202 265
230 154 174 176 84 133 163 169 140 144 120 131 161 145 158 147 145 99 127 105
90 147 77 139 146 164 145 182 137 119 136
DUR-O03A 99
180 151 197 158 168 164 147 108 142 155 127 109 105 115 80 41 49 48 90 76
75 115 131 108 108 104 110 98 118 109 149 172 113 101 99 60 58 76 118 122
125 112 131 93 66 90 66 124 110 118 97 117 75 74 56 46 27 61 100 112
80 87 85 91 84 83 110 97 91 78 98 81 115 116 112 102 128 94 87 98
105 89 40 45 57 49 85 69 64 62 57 68 89 64 48 48 63 75 57
DUR-O03B 99
150 165 188 166 167 166 139 126 129 163 122 106 102 93 93 37 44 41 91 84
91 110 123 123 101 116 109 113 125 116 153 163 127 98 98 60 51 80 120 129
129 135 105 88 78 89 72 128 116 118 102 101 70 71 57 47 35 58 94 113
83 92 86 96 78 96 101 95 103 78 93 91 123 110 125 109 137 91 90 93
90 90 45 39 69 49 82 71 75 50 60 76 106 54 47 57 60 58 60
DUR-O04A 91
248 219 199 222 150 204 183 216 186 155 230 179 172 124 156 105 124 138 110 248
217 128 198 139 84 79 85 151 130 130 138 140 139 110 88 90 83 117 148 157
185 177 157 119 129 108 102 110 122 124 88 82 102 106 109 84 92 75 106 171
209 137 137 89 81 89 97 109 115 119 109 138 84 106 134 123 109 149 113 143
100 129 82 46 39 58 76 72 100 74 69
DUR-O04B 91
256 239 224 240 183 209 169 219 167 163 229 182 181 120 150 106 118 142 121 247
238 131 210 138 90 86 80 151 125 134 137 139 132 112 78 88 89 99 141 160
199 161 161 113 134 101 111 105 121 130 90 89 103 112 112 77 80 82 106 168
205 147 135 89 74 86 98 117 118 117 108 130 97 129 130 106 98 168 115 138
111 137 80 37 37 74 75 84 96 64 75
DUR-O05A 145
167 162 176 110 168 196 131 201 179 147 186 129 141 162 126 148 108 99 131 142
114 133 108 91 126 109 130 108 109 80 106 81 91 97 98 62 78 95 115 71
103 70 103 84 71 71 97 74 104 91 74 82 82 108 81 105 76 83 78 64
80 53 98 64 64 52 80 67 73 73 74 85 79 69 89 79 67 49 57 41
62 77 73 55 69 74 75 57 53 60 56 75 71 103 83 89 47 55 57 50
28 54 75 76 67 79 68 63 74 71 81 78 68 59 73 50 86 48 71 70
92 79 75 70 71 42 34 41 57 40 58 57 45 69 59 68 63 54 59 55
65 60 69 76 64

DUR-O05B 145
202 173 177 109 190 193 131 198 165 155 183 124 141 154 133 136 110 98 135 134
117 143 97 100 128 103 136 108 111 82 94 89 94 97 90 73 71 98 118 70
100 75 98 84 77 66 103 78 97 82 78 78 90 107 77 107 80 78 75 65
71 53 92 73 61 62 70 73 59 72 79 87 79 68 96 81 61 51 52 45
51 77 79 55 68 76 70 62 53 58 59 72 70 101 80 91 54 55 56 46
39 53 71 87 61 79 63 66 76 69 86 72 72 62 78 54 80 57 74 65
96 82 77 65 75 48 22 42 54 46 54 70 42 74 63 71 71 53 64 61
67 69 70 63 50
DUR-O06A 102
231 193 205 234 147 122 187 74 85 96 86 70 96 76 80 93 92 111 100 132
98 120 73 100 63 67 75 96 152 111 90 104 89 67 47 85 102 98 99 88
91 88 67 66 76 65 74 64 74 86 77 68 52 49 58 64 62 74 72 78
69 59 54 57 55 30 46 58 84 85 91 107 78 106 87 81 94 85 83 63
91 39 77 53 60 68 73 76 77 71 77 75 42 48 64 72 64 67 79 86
65 78
DUR-O06B 102
243 195 196 234 135 130 173 84 106 106 88 68 97 70 88 96 108 111 99 125
103 115 86 83 71 73 84 94 150 107 97 104 102 61 47 78 102 97 96 95
93 84 63 57 68 70 81 79 73 73 82 75 45 43 55 71 72 66 81 77
75 74 59 48 51 37 43 67 77 81 94 111 78 114 105 71 88 92 83 73
82 43 71 57 53 73 77 77 78 80 82 77 45 53 63 62 72 81 78 84
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DUR-O07A 131
111 106 178 128 142 179 116 122 153 126 109 108 114 150 113 127 157 123 113 126
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148 165 155 172 150 97 129 127 165 177 195 154 131 110 114 100 107 219 180 116
174 167 157 126 136 232 162 205 181 187 182 152 134 174 93 94 103 152 145 144
162 182 125 114 116 113 120 102 94 97 118 89 63 70 45 34 61 85 124 106
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DUR-O07B 131
135 107 179 137 137 183 110 122 154 114 102 100 111 150 104 130 160 126 113 126
131 132 161 173 139 132 130 129 165 143 136 195 183 179 184 225 120 95 116 147
144 160 144 179 149 103 137 129 168 170 197 149 141 112 104 101 106 217 184 121
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DUR-O08A 74
205 233 210 223 267 260 225 240 296 287 262 290 254 315 319 333 249 292 238 315
254 332 375 279 293 285 305 234 220 202 217 156 146 278 304 209 220 227 204 157
201 186 175 187 222 171 174 140 152 156 90 78 110 141 141 157 140 128 111 107
122 110 114 134 113 136 137 116 91 101 108 130 143 158
DUR-O08B 74
196 223 212 250 266 291 233 282 309 282 271 286 219 309 311 333 248 284 247 320
240 334 382 264 303 299 304 232 223 199 209 168 141 273 310 196 245 225 207 160
217 183 184 185 216 180 177 141 158 151 90 75 106 138 138 182 135 121 116 114
124 113 121 120 131 128 136 112 98 112 96 128 141 168

DUR-O09A 103
148 177 187 213 145 170 151 199 176 156 158 142 217 145 134 172 137 124 94 108
139 102 130 96 115 147 156 146 127 110 120 98 143 124 149 81 51 44 54 106
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90 76 63 60 72 98 60 82 94 123 93 104 85 136 143 110 90 127 121 137
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DUR-O09B 103
188 200 219 235 195 183 151 196 145 176 159 128 228 127 138 177 122 128 95 120
132 109 115 102 110 151 153 142 119 126 125 91 145 120 154 86 46 43 54 109
125 82 103 100 120 90 105 110 125 112 105 143 116 140 97 110 59 59 61 75
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90 82 63 59 70 95 65 81 107 111 92 102 84 140 137 119 86 121 133 130
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DUR-O10A 91
391 391 317 311 357 257 254 287 187 192 194 175 137 127 131 128 113 175 114 138
88 74 88 73 106 80 75 82 146 82 77 88 86 73 82 65 76 59 77 108
102 163 135 147 134 153 183 148 262 138 163 149 136 155 137 122 108 103 88 111
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DUR-O10B 91
417 387 313 319 364 252 240 278 200 185 199 180 154 124 158 122 108 162 117 131
84 88 99 79 119 98 75 84 146 82 81 90 90 70 88 62 74 64 77 102
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115 111 89 86 71 117 89 87 105 69 65 52 71 70 76 60 73 46 60 49
75 54 47 52 63 64 84 56 95 82 72
DUR-O11A 104
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80 37 80 54 80 86 74 62 103 67 106 95 125 85 85 107 93 142 125 138
128 155 108 120 133 216 171 179 168 189 121 86 73 166 134 109 114 135 136 109
90 103 113 116 139 124 155 167 216 150 227 148 69 104 81 99 108 98 99 93
100 115 91 62 69 65 75 64 92 83 79 128 94 72 88 82 105 113 91 98
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87 113 81 57 85 68 70 65 85 81 89 131 90 84 90 84 108 109 94 100
81 79 129 89
DUR-O12A 108
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67 82 82 68 72 61 61 86 101 89 94 81 98 127 107 81 69 83 88 73
136 202 167 197 177 136 103 131 113 117 166 158 118 132 70 92 65 80 92 58
77 91 123 97 104 135 113 78 79 83 130 125 121 75 95 119 111 115 78 71
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DUR-O12B 108
63 77 71 57 56 42 65 68 64 70 110 94 85 68 47 93 71 54 91 74
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118 214 163 213 177 136 109 116 124 123 178 149 117 126 64 79 73 72 92 59
80 76 130 107 96 137 118 83 85 84 127 132 119 78 98 115 118 102 78 73
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DUR-O13A 106
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170 145 111 97 110 120 174 112 120 108 124 181 178 140 155 142 81 93 117 158
148 179 169 110 107 150 87 96 130 117 115 102 116 177 114 120 92 112 135 83
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DUR-O13B 106
170 186 157 143 194 164 130 231 198 205 154 162 133 172 161 185 192 115 173 135
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DUR-O14A 80
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133 128 128 155 155 130 157 180 197 137 133 146 174 167 124 165 174 148 136 154
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DUR-O16A 97
215 182 209 245 179 171 174 138 160 172 176 217 145 170 147 203 189 181 100 78
142 187 173 232 182 234 300 296 229 269 234 166 74 110 181 239 238 268 276 240
173 186 182 220 208 227 330 264 266 240 207 227 187 203 256 286 159 210 222 132
88 76 116 196 247 263 211 256 268 189 186 153 189 165 171 163 144 129 113 133
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DUR-O16B 97
211 180 219 252 196 161 179 136 168 178 165 212 141 179 146 200 192 187 94 86
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175 179 189 215 214 232 334 260 265 255 192 245 180 212 251 315 172 199 218 120
95 74 112 192 255 259 215 251 283 205 177 150 200 165 165 150 141 128 107 113
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DUR-O17A 94
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202 224 161 190 236 147 140 164 237 175 147 162 137 105 115 119 131 202 214 164
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170 148 158 147 146 132 194 197 185 221 195 310 274 201
DUR-O17B 94
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DUR-O18A 99
301 251 155 173 223 211 158 164 130 179 170 147 194 154 155 111 150 142 124 74
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DUR-O18B 99
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DUR-O19A 62
108 192 154 165 238 178 153 234 169 178 129 123 161 118 112 143 169 107 158 136
105 81 86 87 114 176 192 126 172 189 166 156 131 123 119 133 134 129 164 196
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276 180
DUR-O19B 62
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119 86 95 80 117 182 181 129 156 214 170 139 144 118 126 135 133 143 163 204
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268 173

DUR-O20A 98
338 344 225 258 285 240 220 185 235 234 172 197 235 244 232 187 218 192 178 160
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183 184 175 178 143 128 174 186 139 153 137 118 145 96 129 152 194 171 131 148
122 110 95 109 121 160 160 137 154 145 133 154 124 110 103 139 130 121 136 119
114 152 116 120 130 133 157 125 120 125 107 142 157 108 105 159 155 150
DUR-O20B 98
299 322 226 290 287 210 238 187 214 227 176 201 246 255 235 183 218 195 173 171
170 154 161 117 147 164 190 225 307 235 198 205 163 105 85 171 160 186 151 197
181 187 171 193 122 130 182 189 158 143 157 123 140 106 134 143 210 166 133 147
114 105 98 113 122 163 163 131 156 146 134 155 132 110 100 131 133 119 143 101
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DUR-O21A 111
197 213 157 135 173 161 163 133 99 166 158 140 158 153 144 135 101 86 87 119
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175 118. 86 75 168 237 217 217 196 190 221 196 205 194 184 181 242 165 219 131
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DUR-O22A 83
189 238 203 182 155 196 165 193 154 160 175 263 253 297 232 231 223 138 81 74
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166 200 172 138 138 155 130 161 136 173 175 199 154 161 170 173 168 147 80 73
116 159 126 172 131 127 112 103 96 73 102 117 101 82 112 74 115 60 84 86
118 138 133
DUR-O22B 83
193 230 210 183 153 203 164 201 143 163 164 257 272 300 229 241 215 133 89 75
130 148 146 164 237 186 175 141 168 133 127 140 172 143 116 131 123 110 123 159
181 208 190 145 134 163 127 161 149 164 191 179 172 164 177 172 171 148 74 77
120 166 128 164 138 134 118 105 88 87 95 107 101 116 80 75 102 57 78 79
114 134 96
DUR-O23A 135
247 465 371 444 410 395 438 334 304 253 277 230 267 351 292 278 340 211 320 308
297 311 283 235 197 232 183 266 260 202 199 172 236 190 168 161 173 162 180 171
176 122 147 194 99 97 93 119 128 137 136 101 83 118 127 140 87 80 89 121
141 96 117 101 113 131 163 136 122 146 102 65 71 104 156 122 125 130 117 118
99 100 111 101 116 117 85 88 124 106 115 86 80 90 113 118 117 100 77 58
51 67 74 79 113 87 134 111 96 87 90 79 69 101 82 104 95 110 106 93
75 116 92 111 109 86 93 111 92 95 93 102 107 99 98

DUR-O23B 135
255 514 377 435 415 419 466 345 292 258 275 219 250 349 288 273 337 220 319 315
291 309 297 232 193 230 195 255 270 204 199 184 232 202 158 160 175 156 182 174
164 139 145 174 104 92 82 121 136 140 137 94 90 117 134 131 90 79 91 132
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APPENDIX

Tree-Ring Dating

The Principles of Tree-Ring Dating

Tree-ring dating, or *dendrochronology* as it is known, is discussed in some detail in the Laboratory's Monograph, '*An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Building*' (Laxton and Litton 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 University of 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.

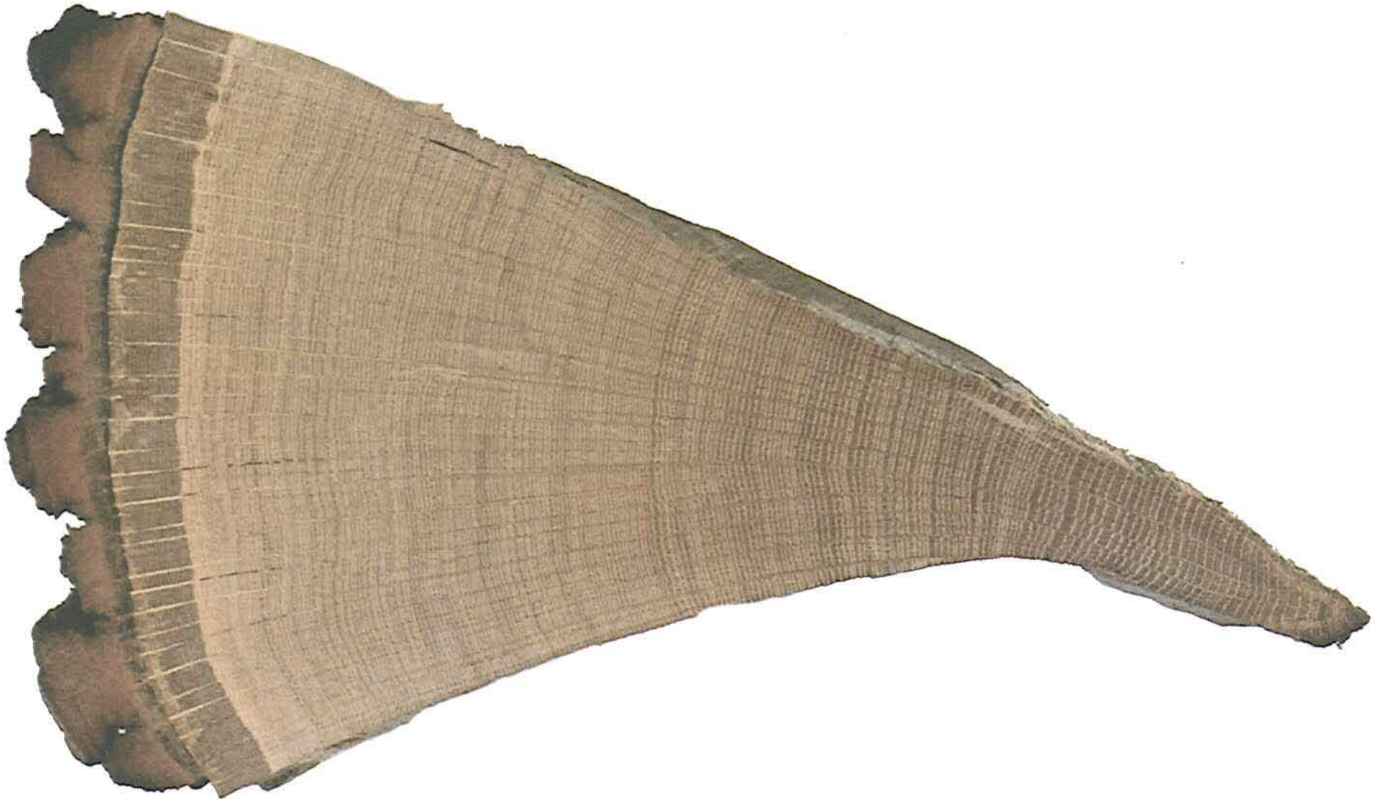


Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can determined by counting back from the outside ring, which grew in 1976.

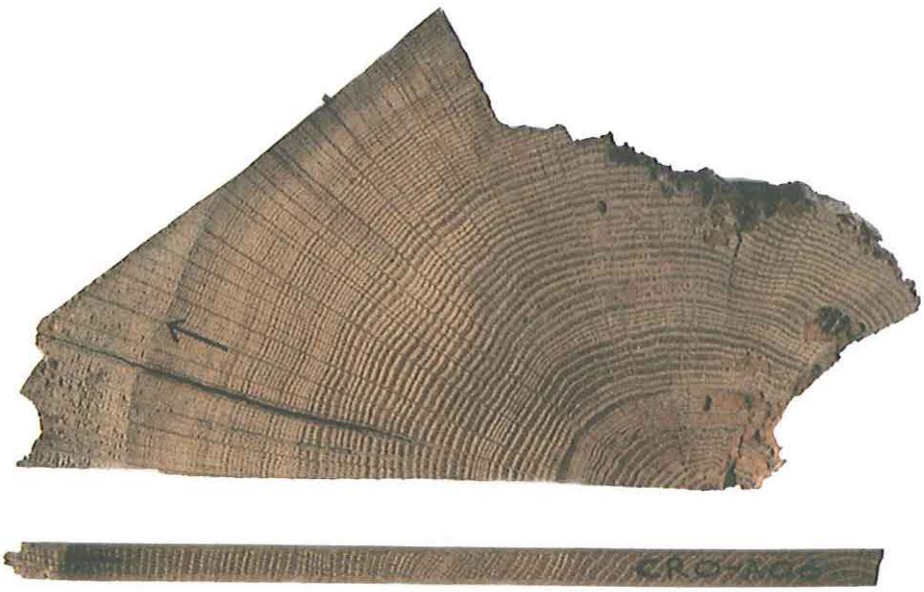


Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the left hand corner, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

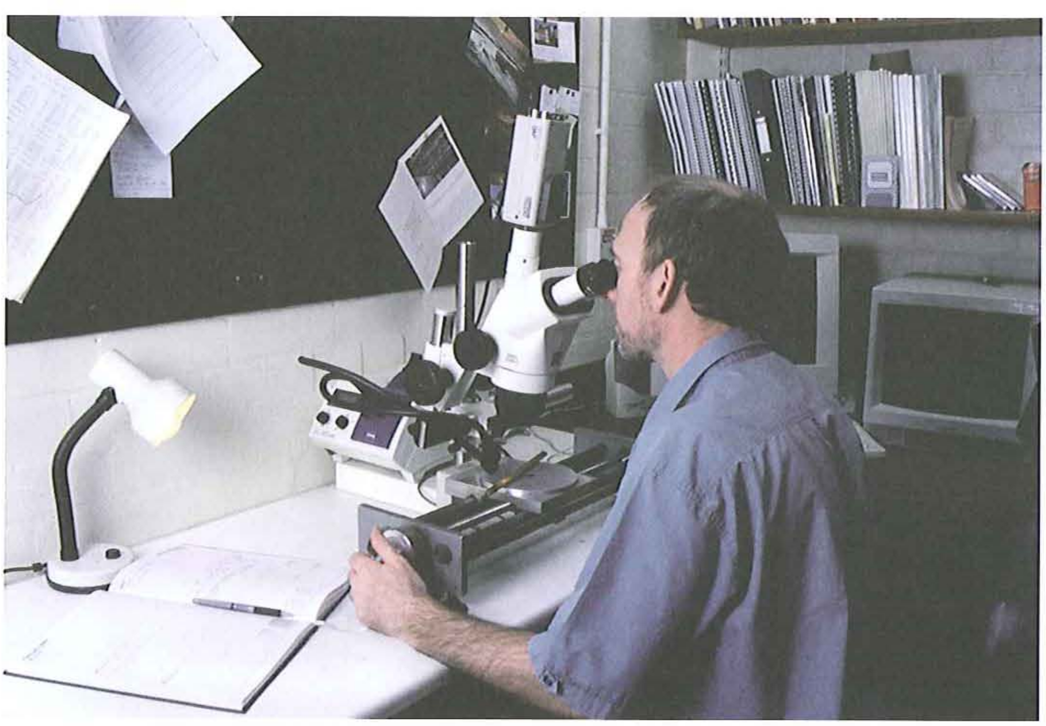


Fig. 3 Measuring ring widths under a microscope. The microscope is fixed while the sample is on a moving platform. The total sequence of widths is measure twice to ensure that an error has not been made. This type of apparatus is needed to process a large number of samples on a regular basis.

Fig 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.

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.

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 Fig 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 Fig 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 *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

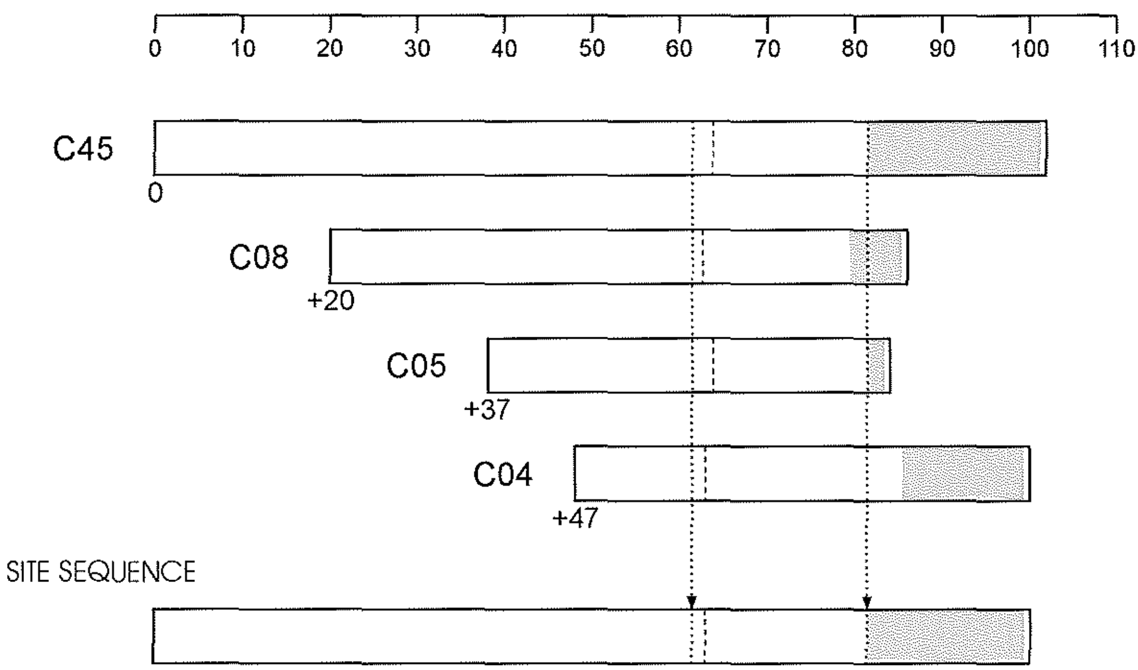


Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

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.

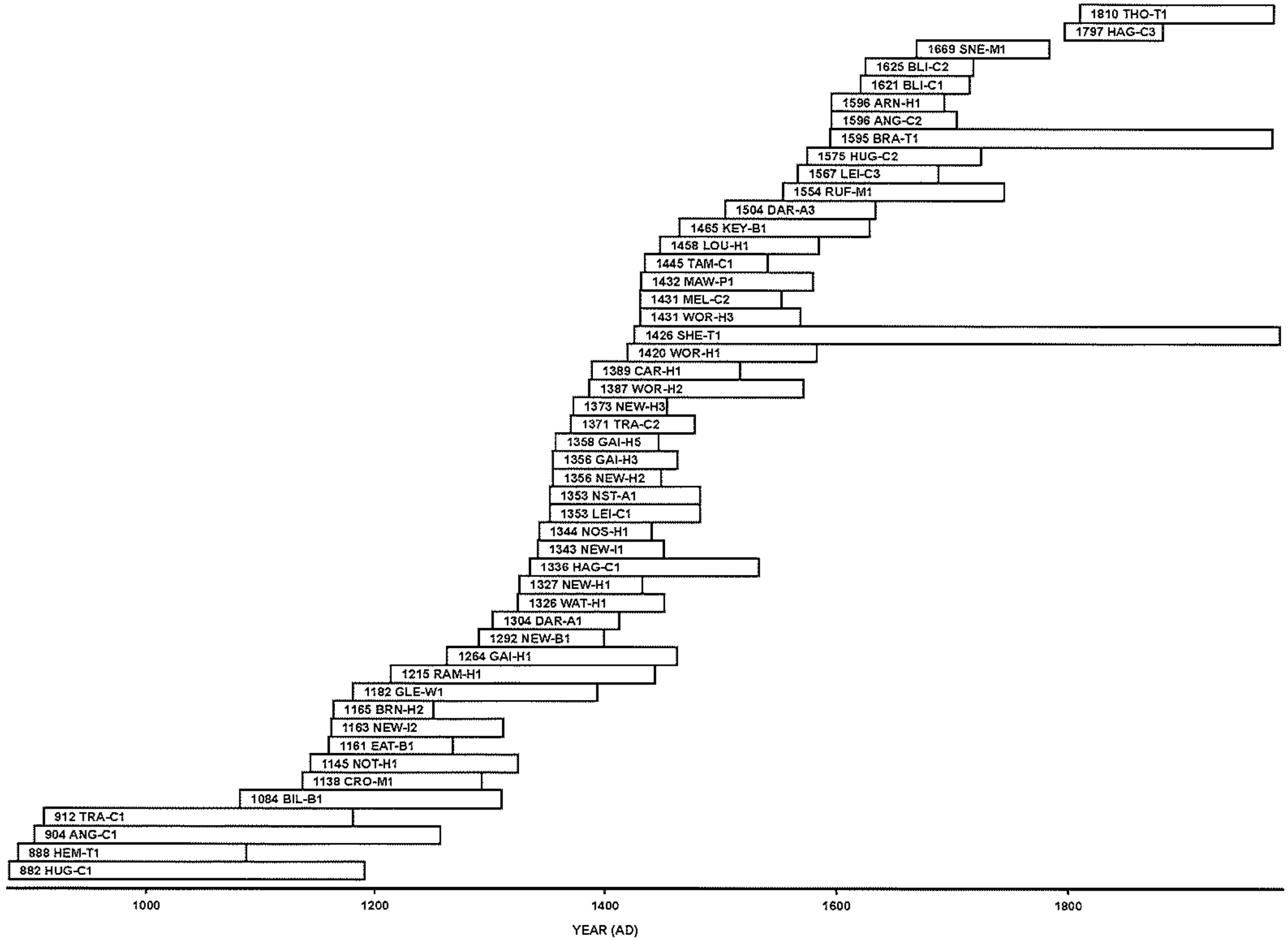
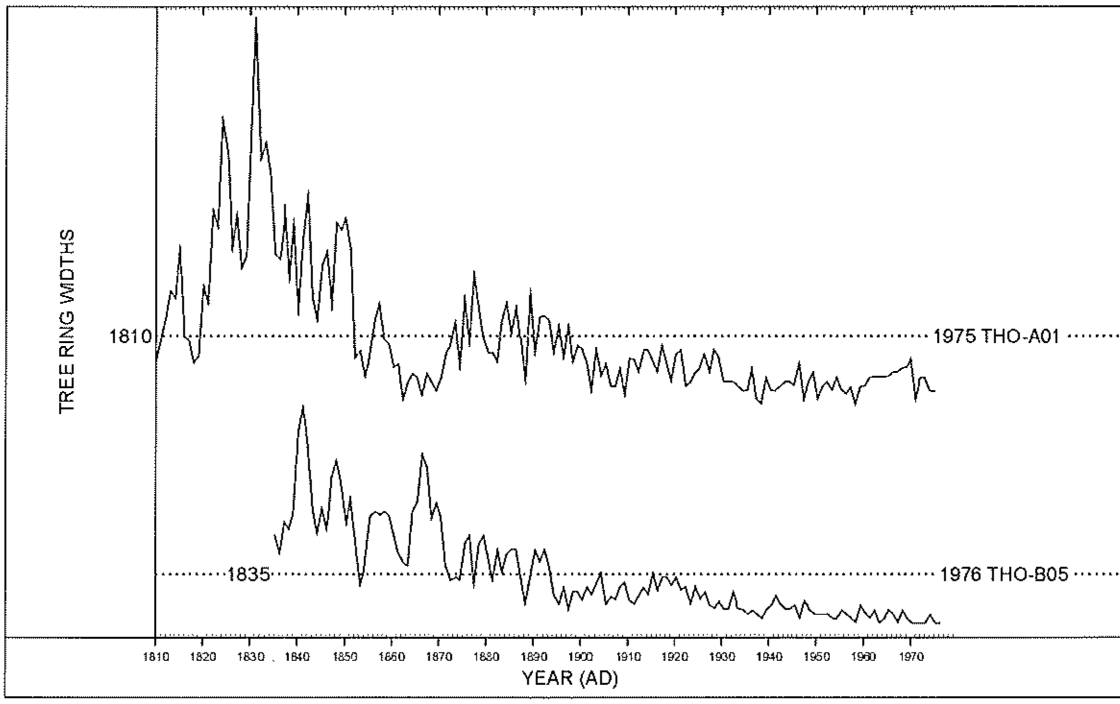


Fig. 6 Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

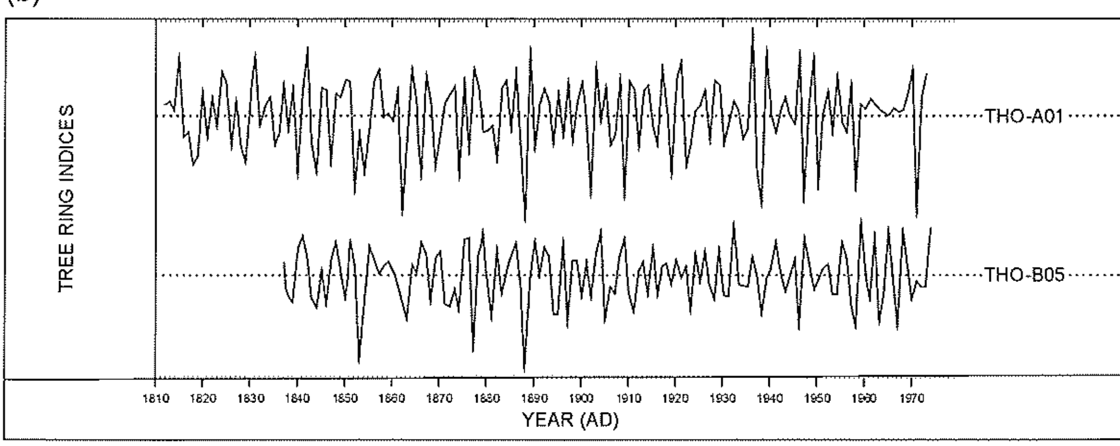


Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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