Ancient Monuments Laboratory
Report 13/96

# TREE-RING ANALYSIS OF TIMBERS FROM MERCER'S HALL, MERCER'S LANE, GLOUCESTER

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Summary

Dendrochronological analysis of samples from timbers of Mercer's Hall, Gloucester, resulted in the production of two felling dates. The earlier timbers have a felling date in the range AD 1481 to 1506. These timbers all come from the roof. The later timbers were felled in the early AD 1540s. These included all the dated timbers from the ground-floor ceiling and two others from the roof. A single site chronology of 253 years was created, spanning the period AD 1289 - 1541.

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# TREE-RING ANALYSIS OF TIMBERS FROM MERCER'S HALL, MERCER'S LANE, GLOUCESTER

## Introduction

Mercer's Hall is a two-storey building located to the rear of the burgage plot that runs south-west from 11 Westgate Street, Gloucester ( SO 831186 ). It is a Scheduled Ancient Monument and a Grade II Listed Building. Despite its size, the building does not appear on the generally reliable map of Gloucester by John Kip, dated AD 1712. It is only on a map by Hall and Pinnell, dated AD 1780, that building lines corresponding to the present Mercer's Hall are found.

The architectural style of the building is self-evidently of an earlier date and form than mid to late eighteenth-century. The Hall is of seven bays with six visible trusses, these being of simple tiebeam and collar type with principal rafters of diminishing depth. These carry double purlins with arched wind braces at two levels. The ceiling of the ground floor is supported on lateral and axial bridging beams. A drawn survey and preliminary report has been prepared by C. Miners, Conservation Officer for Gloucester City Council. His findings suggest that certain features of the timber-work present some evidence for alterations and rebuilding.

On the evidence of the maps and the probability of reconstruction, the current structure is thought to have been built on this site in the later eighteenth century, re-using timbers from an earlier building dismantled elsewhere in Gloucester. Judging by the form of the construction and the decoration on some of the timbers it is suggested that this earlier building may have been a market-house, or possibly a guildhall. It is on the basis of this re-use of an earlier structure that the current building is scheduled and listed. Proposals have been put forward for complete redevelopment of the whole area in which Mercer's Hall stands. Tree-ring dating was commissioned to establish a construction date for the original building from which timbers for the Hall were taken. Later timbers and inserted timbers were to be ignored.

## Site analysis and results

While several members are almost certainly later timbers or insertions, it had generally been assumed that most of the main timbers at this site were all of a single phase. However, upon examination immediately prior to sampling, it was seen that there were two distinct types of oak timber. It was noted that all the timbers forming the ceiling beams of the ground floor were very tightly grained and contained large numbers of rings. In contrast, all the roof timbers were less tightly grained and had fewer rings. Given the possible architectural history of the building, this suggested that either the timbers of the two parts were of the same date but from different sources or, possibly, were of different dates.

Thirteen samples were obtained from this site. Each sample was given the code GLO-A ( Gloucester, site "A" ). Five samples ( GLO-A01 - 05 ) were taken from the ground-floor ceiling timbers, with another eight samples ( GLO-A06 - 13 ) coming from the roof timbers. Full details of the samples are given in Table 1. The location of each sample was also recorded on drawings provided at the time of sampling ( Figs 2a and 2b ).

All thirteen samples were measured and compared with each other by the Litton/Zainodin grouping procedure ( Appendix ). At a level of t=4.5 twelve samples cross-matched with each other at the offsets shown in Figure 1. The ring-widths from these twelve samples were averaged at these positions to form GLOASQ01, a site chronology of 253 rings. Site chronology GLOASQ01 was successfully cross-matched with a series of reference chronologies for oak, giving a first ring date of AD 1289 and a last measured ring date of AD 1541. Evidence for this dating is given in the t-values of Table 2. Site chronology GLOASQ01 was then compared with the single remaining ungrouped sample, GLO-A02, but there was no satisfactory cross-match. This sample was compared individually with the full range of reference chronologies, but there was no satisfactory dating.

Two samples in this dated site chronology, GLO-A03 and 05, come from timbers with complete sapwood, this being retained on the samples. The last measured ring dates of these are AD 1541 and AD 1540 respectively, these thus being the felling dates for these timbers. Both these samples are from the ceiling beams of the ground floor. The relative positions of the heartwood/sapwood transition on the other dated samples from these ground floor ceiling timbers is entirely concordant with these too having a felling date in the early AD 1540s ( Table 3 ).

However, the relative positions of the heartwood/sapwood transition from most of the timbers forming the roof structure are much earlier, averaging AD 1466. The difference in the relative positions of the heartwood/sapwood boundary is clearly seen in the bar diagram of Figure 1. The timbers of the roof have a felling date in the range AD 1481 to 1506.

Two other samples, GLO-A12 and 13, from timbers of the roof have later last measured ring dates, AD 1536 and AD 1510 respectively. Sample GLO-A12 comes from a timber with complete sapwood, of which about 2 cms was lost in coring. On this sample such a loss represents only about 6 - 7 rings at most, giving a felling date for this timber of no later than AD 1543. A cross-match between these two samples with a high t-value suggests that the both timbers are from the same tree and therefore have the same felling date.

It may be noted from Table 2 that site chronology GLOASQ01 achieves a high t-value cross-match against MC10. This is a reference chronology by the late John Fletcher, believed to be made up of material from the south Midlands. The other chronologies which cross-match with high t-values are all from southern Warwickshire. This may give some intimation as to the source of the timber used here.

Sample GLO-A02 is made up of three broken cores, this being caused by shakes in the timbers. There was insufficient overlap between the portions of cores to make a single sample. Although there was some cross-matching between site chronology GLOASQ01 and the constituent cores of GLO-A02 it was not altogether satisfactory.

## Conclusion

Analysis of the timbers from the Mercer's Hall, Gloucester, resulted in the production of a single dated site chronology, GLOASQ01, spanning the period AD 1289 - 1541. It would appear that much of the timber used in the roof has a felling date in the range AD 1481 - 1506. It would further appear that two other timbers of the roof, and probably all the timbers of the ground floor ceiling, were felled in the early AD 1540s.

The question that now arises is how timbers felled between AD 1481 and 1506 and in the early AD 1540s were being reused in a building apparently built in the late eighteenth century. There are two possibilities to account for this. The first is that John Kip's map of AD 1712 is misleading and Mercer's Hall was already on this site, having been built in the early AD 1540s reusing timber from an earlier building. The alternative is that the current Mercer's Hall really was built in the late eighteenth century reusing timbers of two different dates.

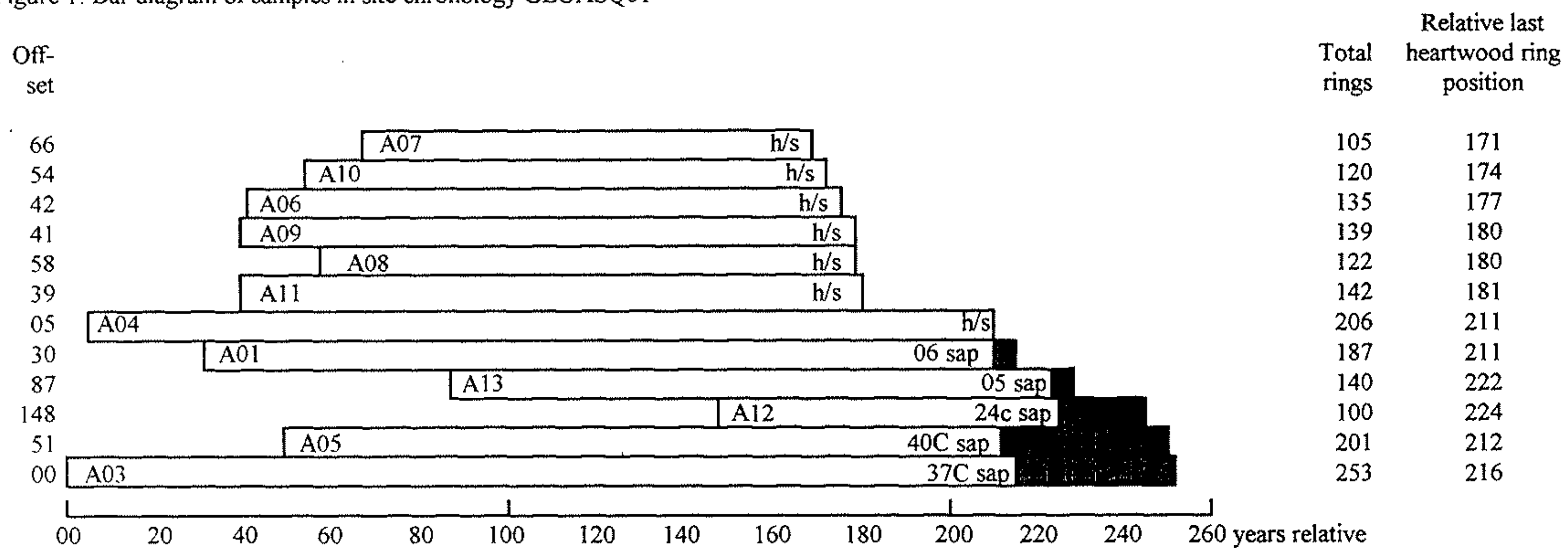
Further sampling of later timbers which appear to belong to the eighteenth-century building, and which could not have been inserted into the structure later, might be worthwhile. Apart from reliably determining the construction date of the building as it now stands, it might, if the timbers were shown to be felled before AD 1712, cast doubt on the reliability of John Kip's map. This conclusion might have implications for other structures shown on that document. If the timbers were felled after AD 1712, this would add credence to Kip's map and confirm that this is a building in which timbers of two different dates were reused.

Table 1: Details of tree-ring samples from Mercer's Hall, Gloucester

| Sample no | Sample location | Total rings | Sapwood rings* | First measured ring date | Last heartwood ring date | Last measured ring date |
|---|---|---|---|---|---|---|
| GLO-A01 | Ground floor lateral beam truss 2 | 187 | 06 | AD 1319 | 1499 | 1505 |
| GLO-A02 | Ground floor lateral beam truss 3 | 168 | h/s | ------ | ------ | ------ |
| GLO-A03 | Ground floor axial beam bay 3 | 253 | 37C | AD 1289 | 1504 | 1541 |
| GLO-A04 | Ground floor axial beam bay 4 | 206 | h/s | AD 1294 | 1499 | 1499 |
| GLO-A05 | Ground floor axial beam bay 5 | 201 | 40C | AD 1340 | 1500 | 1540 |
| GLO-A06 | Tie beam truss 5 | 135 | h/s | AD 1331 | 1465 | 1465 |
| GLO-A07 | West principal rafter truss 5 | 105 | h/s | AD 1355 | 1459 | 1459 |
| GLO-A08 | Tie beam truss 6 | 122 | h/s | AD 1347 | 1468 | 1468 |
| GLO-A09 | Tie beam truss 4 | 139 | h/s | AD 1330 | 1468 | 1468 |
| GLO-A10 | East lower purlin bay 3 | 120 | h/s | AD 1343 | 1462 | 1462 |
| GLO-A11 | East principal rafter truss 3 | 142 | h/s | AD 1328 | 1469 | 1469 |
| GLO-A12 | East principal rafter truss 1 | 100 | 24c | AD 1437 | 1512 | 1536 |
| GLO-A13 | West principal rafter truss 1 | 140 | 05 | AD 1376 | 1510 | 1515 |

*h/s = heartwood/sapwood boundary on sample
c = complete sapwood on timber but all or part lost from core in sampling
C = Complete sapwood on sample; last measured ring date is felling date of timber.

Figure 1: Bar diagram of samples in site chronology GLOASQ01




White bars = heartwood rings, shaded area = sapwood rings

*h/s = heartwood/sapwood boundary on sample

c = complete sapwood on timber but all or part lost frpm core in sampling

C = complete sapwood on sample; last ring date is felling date of timber

Table 2: Results of the cross-matching of site chronology GLOASQ01 and relevant reference chronologies when last ring date is AD 1541

| Reference chronology | Span of chronology | t-value | |
|---|---|---|---|
| East Midlands | AD 882 - 1981 | 7.9 | ( Laxton and Litton 1988 ) |
| England | AD 401 - 1981 | 8.2 | ( Baillie and Pilcher unpubl ) |
| Wales & West Midlands | AD 1341 - 1636 | 8.2 | ( Siebenlist-Kerner 1978 ) |
| Southern England | AD 1083 - 1589 | 6.7 | ( Bridge 1983 ) |
| MC10 | AD 1386 - 1585 | 11.3 | ( Fletcher 1980 ) |
| The Post Office, Oxhill, Warwicks | AD 1322 - 1447 | 10.7 | ( Alcock *et al* 1989 ) |
| Anne Hathaways Cottage, Warwicks | AD 1319 - 1462 | 8.5 | ( Alcock *et al* 1991 ) |
| Thatched Cottage, Hill Wooton, Warwicks | AD 1392 - 1469 | 7.3 | ( Alcock *et al* 1989 ) |

Table 3: Estimates of felling date ranges

| sample number | date of last heartwood ring |
|---|---|
| A01 | AD 1495 |
| A04 | AD 1499 |
| A12 | AD 1512 |
| A13 | AD 1510 |

average last heartwood ring date AD 1505
estimated felling date range AD 1520 - 1545 ( This date is consistent with the felling dates of AD 1540/41 of samples A03 & A05 which have complete sapwood ).

| sample number | date of last heartwood ring |
|---|---|
| A06 | AD1465 |
| A07 | AD 1459 |
| A08 | AD 1468 |
| A09 | AD 1468 |
| A10 | AD 1462 |
| A11 | AD 1469 |

average last heartwood ring date AD 1466
estimated felling date range AD 1481 - 1506

## Bibliography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Alcock, N W, Howard, R E, Laxton, R R, Litton, C D, and Miles, D H, 1991 List 41, no 10 - Leverhulme Cruck Project ( Warwick University and Nottingham University Tree-Ring Dating Laboratory ) results: 1990, *Vernacular Architect*, **22**, 45 - 7

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Figure 2a: Plan of locations of tree-ring samples

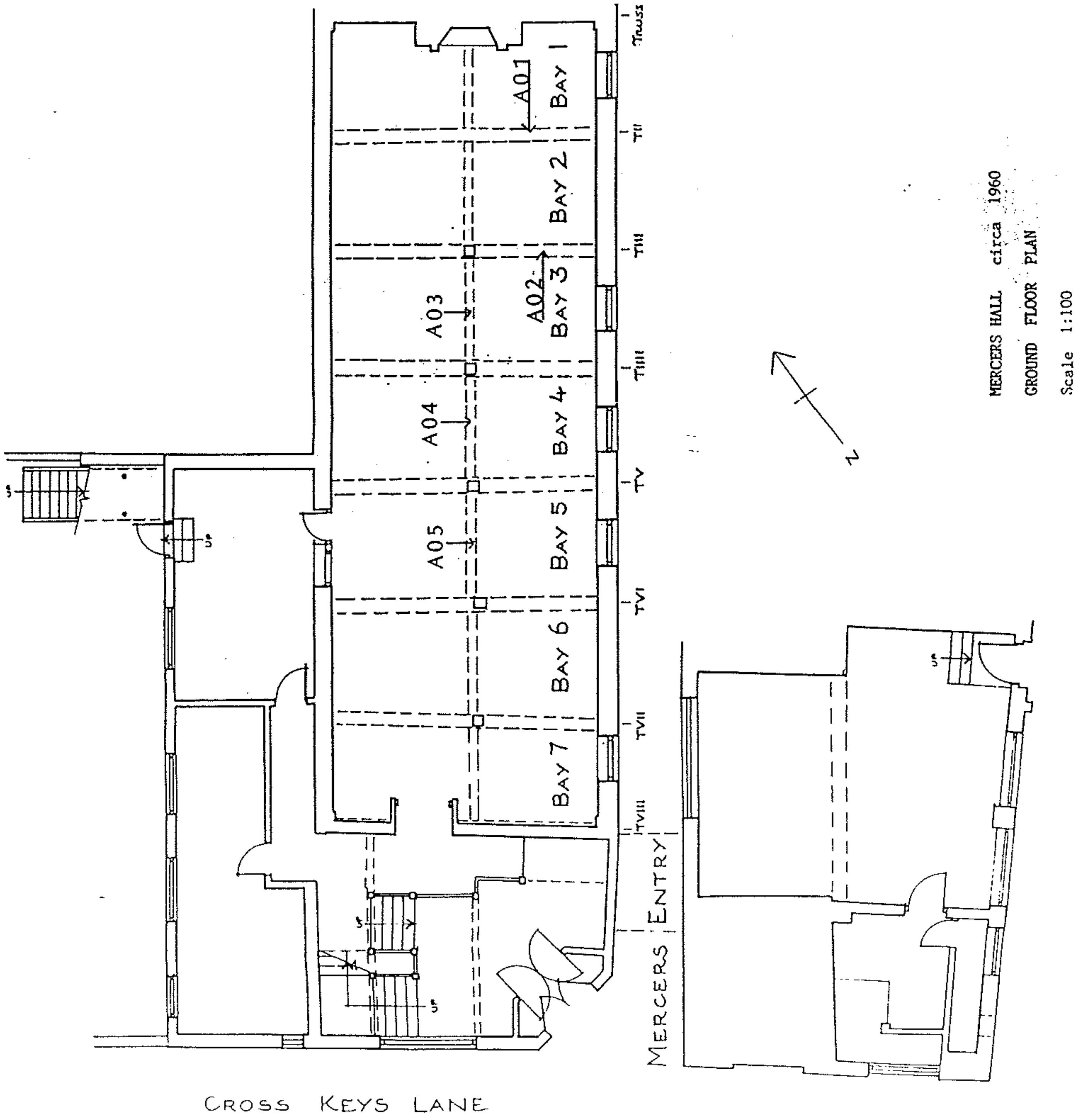
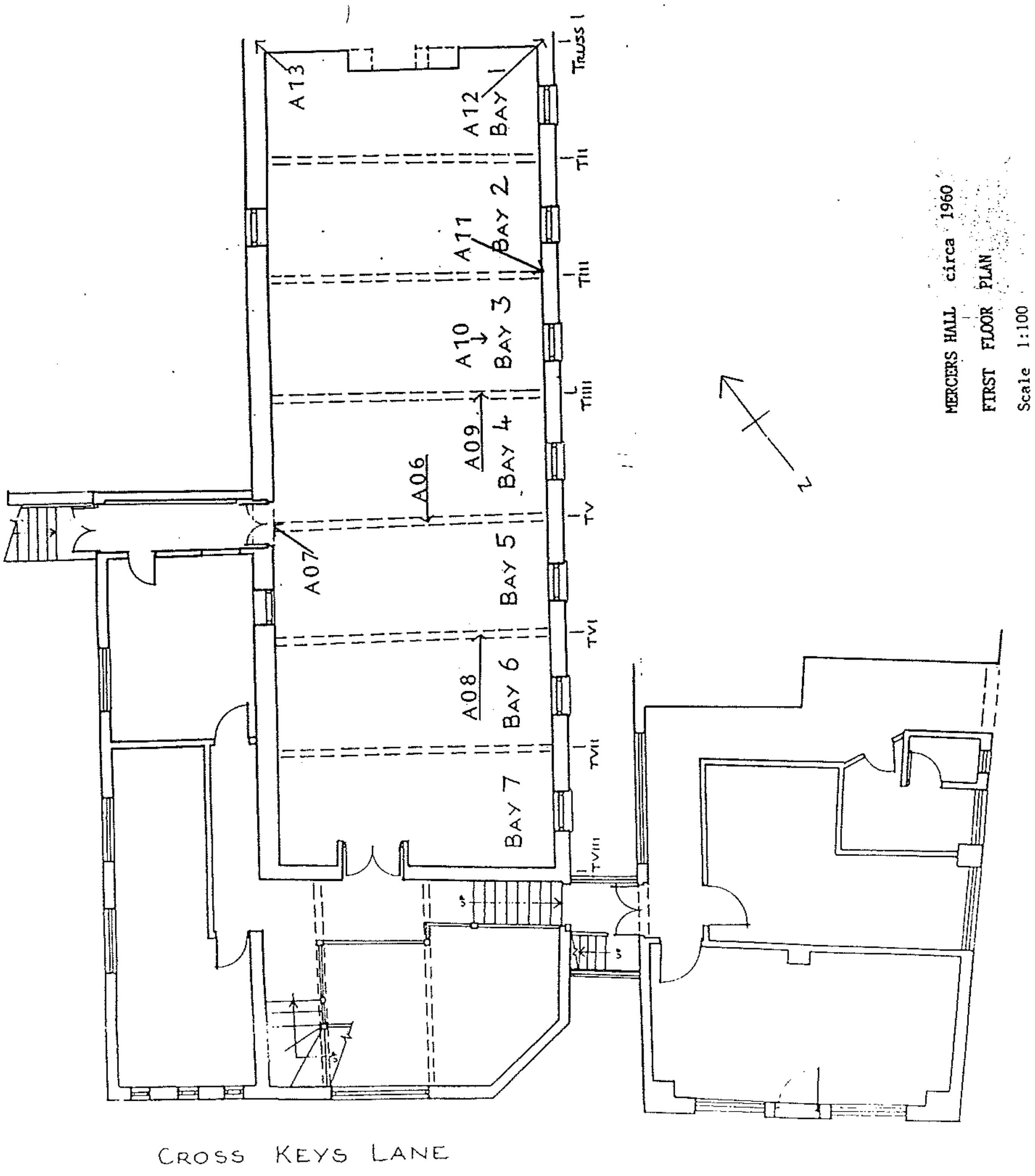


Figure 2b: Plan of locations of tree-ring samples



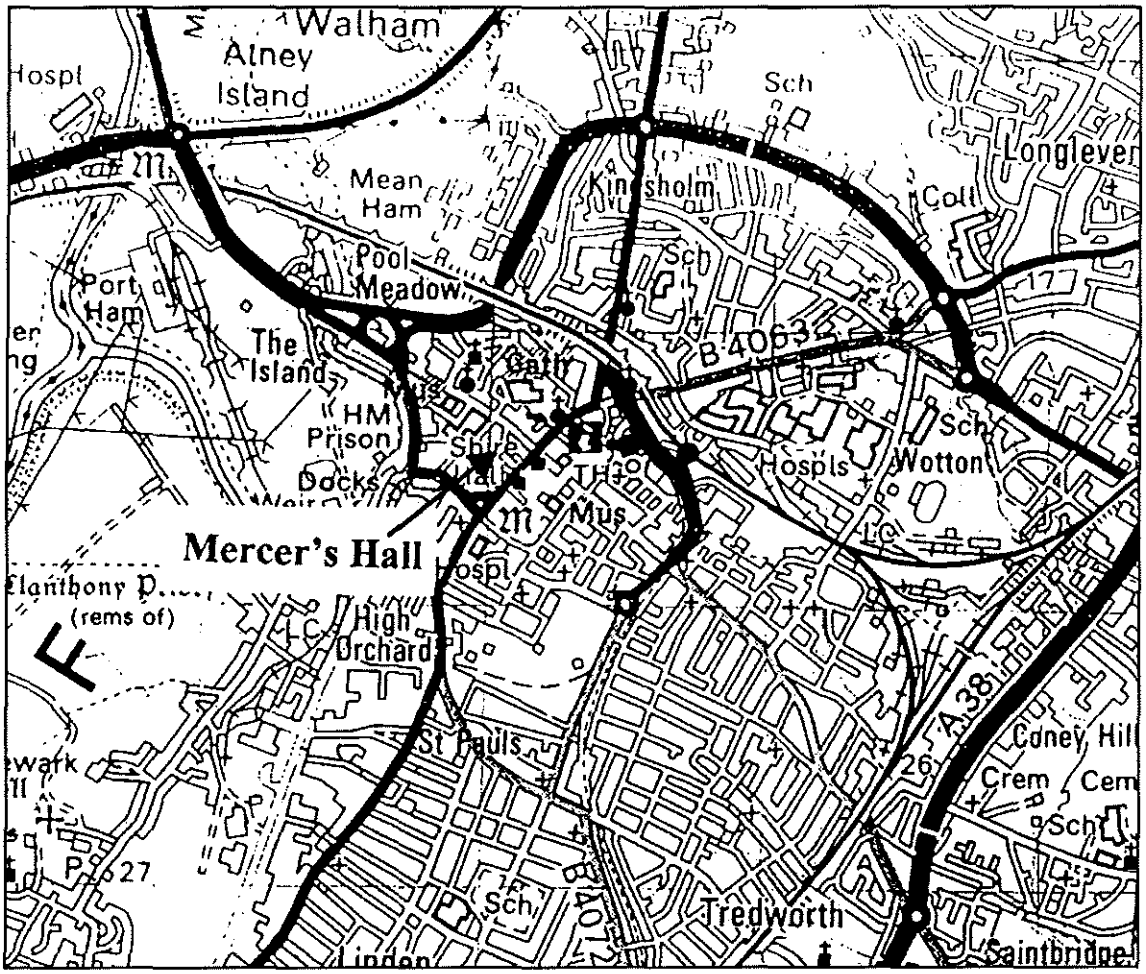

Walham
Alney
Island
Hospl
Mean
Ham
Pool
Meadow
Port
Ham
The
Island
HM
Prison
Docks
Kingsholm
Sch
Coll
Longlevens
B 4063
Hospls
Wotton
Mus
Mercer's Hall
High
Orchard
St Pauls
Sch
Tredworth
A 38
Coney Hill
Crem
Cem
Saintbridge
(rems of)

Table 4: Data of thirteen measured samples ( Ring-widths measured in 0.0001 cm units )

GLO-A01A 187

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 414 | 219 | 258 | 204 | 200 | 160 | 81 | 93 | 159 | 120 | 226 | 212 | 176 | 182 | 194 | 128 | 245 | 284 | 457 | 390 |
| 373 | 285 | 253 | 283 | 336 | 256 | 190 | 237 | 303 | 254 | 251 | 229 | 293 | 169 | 193 | 202 | 126 | 121 | 162 | 224 |
| 240 | 161 | 182 | 247 | 239 | 270 | 219 | 216 | 204 | 150 | 230 | 196 | 153 | 158 | 149 | 182 | 142 | 157 | 155 | 134 |
| 157 | 142 | 105 | 120 | 91 | 105 | 117 | 131 | 115 | 99 | 103 | 104 | 146 | 94 | 83 | 64 | 78 | 96 | 82 | 74 |
| 105 | 111 | 81 | 67 | 78 | 91 | 62 | 84 | 67 | 96 | 125 | 100 | 100 | 107 | 114 | 82 | 96 | 72 | 53 | 64 |
| 57 | 64 | 66 | 65 | 62 | 67 | 72 | 61 | 50 | 74 | 64 | 61 | 54 | 84 | 60 | 58 | 83 | 74 | 74 | 65 |
| 54 | 61 | 72 | 60 | 77 | 76 | 56 | 77 | 65 | 69 | 59 | 70 | 76 | 69 | 70 | 57 | 75 | 80 | 64 | 82 |
| 67 | 79 | 59 | 68 | 58 | 58 | 57 | 64 | 68 | 68 | 73 | 64 | 45 | 48 | 49 | 58 | 61 | 48 | 37 | 33 |
| 55 | 44 | 63 | 60 | 49 | 66 | 70 | 62 | 63 | 53 | 60 | 56 | 56 | 56 | 62 | 71 | 47 | 67 | 47 | 64 |
| 77 | 80 | 49 | 63 | 56 | 58 | 74 | | | | | | | | | | | | | |

GLO-A01B 187

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 401 | 204 | 214 | 148 | 191 | 164 | 81 | 98 | 170 | 134 | 223 | 226 | 183 | 174 | 190 | 153 | 322 | 285 | 438 | 392 |
| 396 | 302 | 272 | 269 | 318 | 268 | 228 | 253 | 291 | 247 | 240 | 241 | 292 | 166 | 194 | 200 | 124 | 120 | 165 | 202 |
| 245 | 157 | 190 | 255 | 243 | 267 | 215 | 221 | 195 | 153 | 219 | 204 | 142 | 162 | 147 | 185 | 141 | 154 | 173 | 125 |
| 170 | 144 | 99 | 128 | 93 | 104 | 116 | 133 | 109 | 97 | 102 | 109 | 138 | 91 | 86 | 67 | 75 | 102 | 80 | 74 |
| 103 | 110 | 87 | 60 | 78 | 87 | 69 | 76 | 70 | 92 | 128 | 104 | 102 | 115 | 104 | 83 | 99 | 77 | 49 | 68 |
| 59 | 63 | 68 | 60 | 72 | 63 | 76 | 52 | 48 | 72 | 64 | 62 | 52 | 88 | 52 | 60 | 85 | 73 | 82 | 69 |
| 53 | 62 | 69 | 55 | 71 | 74 | 61 | 73 | 64 | 73 | 59 | 67 | 67 | 70 | 66 | 56 | 82 | 81 | 71 | 86 |
| 59 | 88 | 52 | 64 | 57 | 57 | 62 | 56 | 67 | 70 | 64 | 55 | 42 | 49 | 52 | 63 | 61 | 42 | 58 | 37 |
| 50 | 55 | 50 | 56 | 65 | 66 | 64 | 65 | 64 | 59 | 65 | 59 | 56 | 57 | 71 | 52 | 61 | 75 | 54 | 71 |
| 75 | 71 | 61 | 81 | 60 | 60 | 86 | | | | | | | | | | | | | |

GLO-A02A 147

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| [illegible] | 151 | 191 | 177 | 196 | 190 | 152 | 156 | 153 | 138 | 177 | 152 | 141 | 98 | 123 | 127 | 111 | 100 | 66 | 100 |
| 93 | 101 | 68 | 85 | 88 | 93 | 89 | 82 | 107 | 97 | 71 | 76 | 93 | 98 | 95 | 91 | 87 | 88 | 107 | 124 |
| 117 | 86 | 101 | 122 | 148 | 129 | 129 | 116 | 110 | 101 | 96 | 77 | 80 | 97 | 91 | 75 | 89 | 73 | 89 | 91 |
| 83 | 97 | 97 | 95 | 79 | 85 | 78 | 64 | 68 | 77 | 68 | 66 | 62 | 72 | 59 | 58 | 49 | 44 | 75 | 56 |
| 64 | 48 | 38 | 47 | 52 | 40 | 48 | 52 | 49 | 52 | 53 | 44 | 33 | 55 | 42 | 48 | 58 | 53 | 71 | 68 |
| 52 | 53 | 45 | 52 | 63 | 57 | 64 | 62 | 66 | 67 | 70 | 55 | 67 | 60 | 66 | 54 | 71 | 68 | 72 | 68 |
| 59 | 65 | 68 | 73 | 75 | 68 | 59 | 60 | 78 | 70 | 64 | 65 | 80 | 89 | 59 | 66 | 52 | 65 | 73 | 50 |
| 59 | 50 | 68 | 65 | 72 | 72 | 92 | | | | | | | | | | | | | |

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GLO-A02B 96
  84  69  72  87 144 190 156 143 146 102  78  83  66  65  62  81  61  62  66  45
  47  47  33  59  56  50  72  62  46  47  37  47  53  58  76  67  60  56  82  41
  74  55  48  60  66  76  53  62  44  54  62  63  63  62  52  57  49  78  66  65
  66  71  53  57  46  49  57  49  59  60  61  65  69  72  83  75  71  81  98  67
  69  72  61  56  90  46  71  68  74  81  74  61  52  53  62  56
GLO-A02C 87
  97  77  81  81  72  64  60  51  68  67  86  62  60  63  58  57  52  67  64  59
  58  54  37  45  49  53  55  50  72  70  56  63  56  59  57  87  65  83  71  88
  97  63  93  62  54  76  86  63  72  63  66  72  52  67  77  68  61  44  73  90
  66  66  84  76  63  50  63  70  80  49  71  71  66  75  76  77  61  61  57  70
  89  59  58  55  66  63  76
GLO-A03A 253
 330 239 204 234 156 128  85 142 221 180 176 156 138 163 149 202 179 173 229 231
 120 115 108 120 104 154 160 123 143 149 144 103  96 130 109  96  76  62  85  92
 105 106  70 111  92  76 115  90 110  85  84  64  87  78  68  73  71  71  75  98
 105  71  75  61  76  69  47  43  82  81 101  67  76  99 104 109  90 107  81  87
 124  95  75  77  81  87  83 101  98  78  91  84  80  70  65  84  62  86 104 100
  76  65  82  63  61  78  70  90  70  84  85  96  89  86  90  80  84  72  59  76
  69  72  69  71  63  49  50  41  48  50  47  32  50  33  46  45  41  58  55  68
  57  52  49  55  62  41  54  51  62  60  41  45  49  52  55  58  56  45  50  53
  72  51  57  51  72  49  61  66  57  70  67  68  70  60  66  56  80  61  69  72
  83  85  76  57  60  59  68  81  69  57  52  46  71  62  54  61  43  53  47  56
  46  33  49  45  51  54  53  63  49  48  58  69  51  57  53  56  58  57  47  33
  67  52  60  44  50  45  34  26  47  48  48  46  38  45  48  51  45  44  54  59
  46  40  53  42  62  75  72  75  52  59  60  68  92
GLO-A03B 253
 334 234 201 218 155 126  84 138 221 181 173 157 150 175 158 193 180 160 226 220
 130 116 111 109 105 147 168 120 137 133 139 102  90 133 100 106  65  67  96  86
 101 106  71 110  90  71 120  85 110  97  87  60  79  80  72  64  85  72  76  94
 100  72  74  71  72  69  49  47  90  70  97  68  82  89 117 112  88 115  81  89
 127 103  73  74  90  92  79  94  98  79  83  88  75  76  62  80  75  88  98 100
  80  64  84  60  65  75  68  96  72  79  86  95  88  89  90  83  77  74  59  79
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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 70 | 76 | 61 | 74 | 65 | 42 | 56 | 51 | 44 | 44 | 34 | 43 | 53 | 29 | 37 | 46 | 49 | 56 | 49 | 66 |
| 52 | 51 | 50 | 58 | 61 | 43 | 64 | 44 | 62 | 52 | 41 | 50 | 51 | 43 | 50 | 66 | 52 | 46 | 49 | 56 |
| 56 | 62 | 56 | 59 | 62 | 43 | 70 | 52 | 68 | 73 | 61 | 75 | 65 | 57 | 63 | 67 | 67 | 63 | 78 | 77 |
| 72 | 78 | 79 | 51 | 72 | 55 | 73 | 66 | 69 | 57 | 51 | 52 | 63 | 55 | 52 | 53 | 49 | 57 | 50 | 48 |
| 41 | 43 | 50 | 50 | 55 | 48 | 49 | 66 | 44 | 48 | 50 | 64 | 61 | 56 | 58 | 62 | 67 | 50 | 55 | 47 |
| 56 | 47 | 69 | 49 | 42 | 55 | 36 | 33 | 41 | 40 | 53 | 33 | 48 | 49 | 46 | 45 | 42 | 44 | 56 | 41 |
| 46 | 55 | 54 | 47 | 60 | 75 | 66 | 63 | 70 | 59 | 60 | 68 | 95 | | | | | | | |

GLO-A04A 206

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 153 | 129 | 165 | 283 | 279 | 240 | 285 | 218 | 262 | 233 | 350 | 298 | 269 | 324 | 245 | 130 | 92 | 87 | 97 | 97 |
| 150 | 107 | 110 | 105 | 103 | 101 | 82 | 76 | 90 | 92 | 56 | 53 | 51 | 64 | 60 | 69 | 88 | 54 | 77 | 53 |
| 70 | 77 | 79 | 84 | 86 | 73 | 67 | 83 | 77 | 72 | 80 | 100 | 91 | 74 | 94 | 138 | 99 | 108 | 82 | 108 |
| 99 | 76 | 53 | 93 | 78 | 74 | 60 | 69 | 90 | 110 | 100 | 70 | 88 | 75 | 92 | 121 | 100 | 92 | 73 | 87 |
| 72 | 79 | 99 | 67 | 74 | 59 | 71 | 72 | 74 | 59 | 79 | 61 | 70 | 67 | 76 | 60 | 73 | 65 | 66 | 76 |
| 65 | 59 | 80 | 67 | 68 | 83 | 98 | 95 | 73 | 72 | 98 | 85 | 78 | 66 | 71 | 62 | 54 | 51 | 58 | 55 |
| 49 | 47 | 37 | 45 | 35 | 31 | 31 | 44 | 42 | 61 | 42 | 40 | 48 | 32 | 61 | 58 | 52 | 45 | 62 | 59 |
| 43 | 63 | 43 | 49 | 31 | 45 | 39 | 36 | 30 | 50 | 41 | 46 | 40 | 39 | 50 | 58 | 41 | 65 | 60 | 58 |
| 44 | 56 | 39 | 49 | 55 | 57 | 65 | 49 | 57 | 57 | 51 | 77 | 58 | 46 | 59 | 55 | 62 | 43 | 38 | 48 |
| 43 | 52 | 49 | 64 | 45 | 55 | 49 | 69 | 51 | 55 | 44 | 45 | 55 | 46 | 51 | 46 | 45 | 50 | 47 | 50 |
| 54 | 42 | 77 | 54 | 60 | 73 | | | | | | | | | | | | | | |

GLO-A04B 206

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|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 153 | 136 | 173 | 296 | 300 | 247 | 262 | 209 | 270 | 235 | 346 | 312 | 258 | 316 | 244 | 126 | 101 | 82 | 97 | 95 |
| 141 | 107 | 107 | 105 | 107 | 104 | 79 | 73 | 88 | 96 | 55 | 54 | 46 | 71 | 60 | 68 | 88 | 50 | 79 | 56 |
| 65 | 81 | 77 | 81 | 88 | 73 | 69 | 82 | 79 | 72 | 86 | 98 | 96 | 70 | 88 | 144 | 97 | 110 | 78 | 118 |
| 99 | 75 | 61 | 94 | 73 | 87 | 61 | 67 | 103 | 116 | 100 | 67 | 93 | 77 | 79 | 122 | 99 | 91 | 73 | 85 |
| 75 | 76 | 97 | 75 | 66 | 60 | 69 | 74 | 76 | 55 | 80 | 65 | 71 | 71 | 73 | 63 | 72 | 67 | 72 | 62 |
| 54 | 59 | 82 | 65 | 68 | 81 | 102 | 94 | 75 | 64 | 87 | 87 | 83 | 60 | 77 | 54 | 63 | 49 | 54 | 60 |
| 36 | 47 | 39 | 42 | 40 | 39 | 36 | 53 | 36 | 42 | 36 | 43 | 47 | 32 | 64 | 55 | 55 | 48 | 64 | 57 |
| 42 | 59 | 37 | 48 | 36 | 39 | 38 | 39 | 42 | 38 | 48 | 49 | 40 | 31 | 44 | 53 | 60 | 40 | 61 | 60 |
| 42 | 58 | 41 | 48 | 60 | 60 | 60 | 46 | 55 | 65 | 48 | 74 | 63 | 52 | 51 | 59 | 54 | 43 | 39 | 48 |
| 50 | 58 | 50 | 48 | 43 | 64 | 52 | 67 | 58 | 47 | 50 | 51 | 49 | 46 | 40 | 53 | 40 | 45 | 50 | 47 |
| 59 | 45 | 71 | 51 | 61 | 60 | | | | | | | | | | | | | | |

GLO-A05A 201

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 278 | 268 | 215 | 237 | 242 | 317 | 267 | 238 | 282 | 244 | 139 | 126 | 98 | 182 | 171 | 122 | 90 | 147 | 126 | 135 |

86 117 99 170 134 127 121 103 82 137 137 114 112 96 90 100 110 110 123 153
126 120 108 102 145 110 147 116 123 114 92 126 90 116 93 110 124 114 100 97
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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 Buildings*' (Laxton and Litton 1988b) and, for example, in *Tree-Ring Dating and Archaeology* (Baillie 1982) or *A Slice Through Time* (Baillie 1995). 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 Figure1 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, 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 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. 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 we inspect the timbers in a building 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. Similarly the core has just over 100 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.

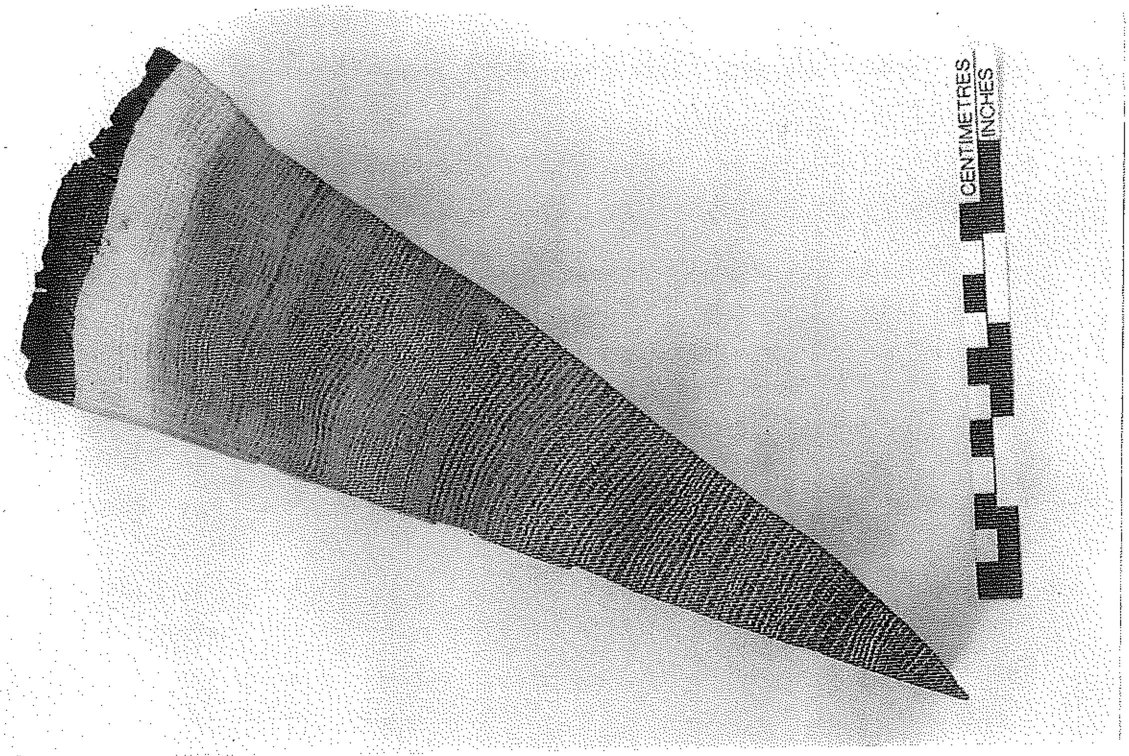


Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

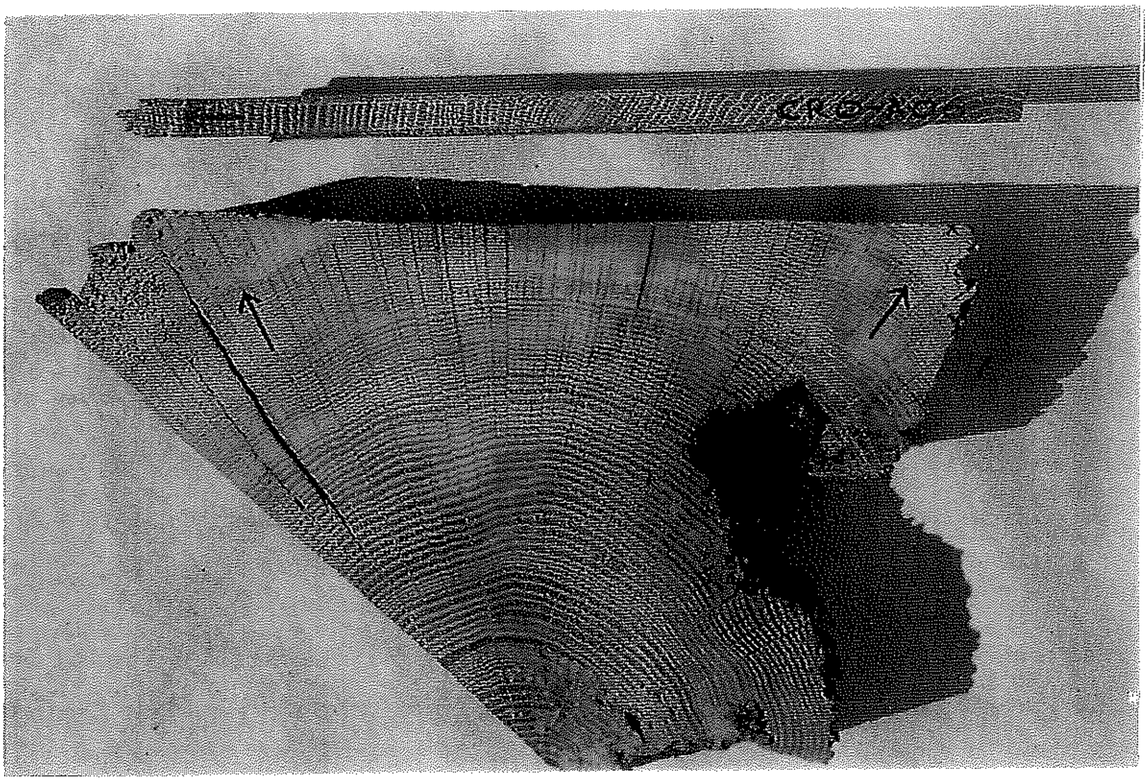

Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners; the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

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 measured twice to ensure that an error has not been made. This type of apparatus is needed to process a large number of samples on a regular basis.

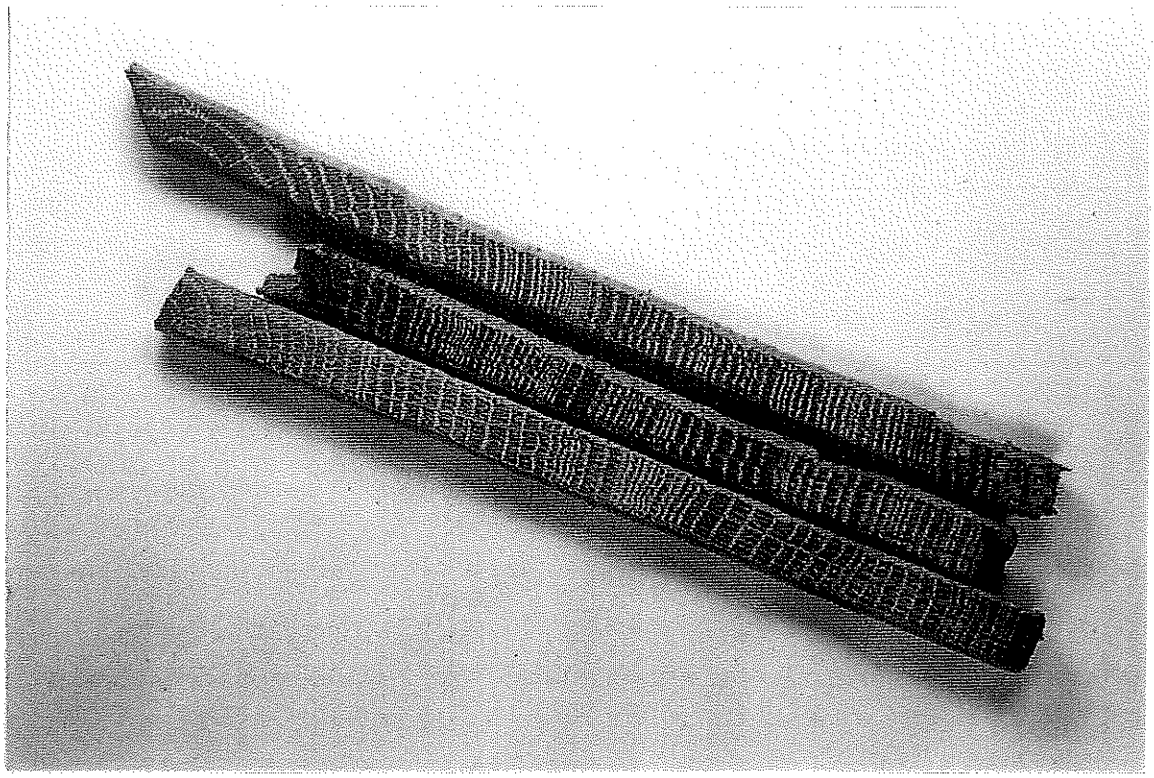

Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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. 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 inspecton 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 is insured with the CBA.

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 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton *et al* 1988a,b; 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. C08 matches C45 best when it is at a position starting 20 rings after the first ring of 45, 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 between these two whatever the position of one sequence relative to the other.

   It is standard practice in our Laboratory first to cross-match as many as possible of the 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 from 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. 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.

average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

This 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'. This was developed and tested in the Laboratory and has been published (Litton and Zainodin 1991; Laxton *et al* 1988a). To illustrate the difference between the two approaches with the above example, consider sequences C08 and C05. They are the most similar pair with a t-value of 10.4. Therefore, these two are first averaged with the first ring of C05 at +17 rings relative to C08 (the offset at which they match each other). This average sequence is then used in place of the individual sequences C08 and C05. The cross-matching continues in this way gradually building up averages at each stage eventually to form the site sequence.

4. ***Estimating the Felling Date.*** 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, they can be seen in two upper corners of the rafter and at the outer end of the core in Figure 2. 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 for 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. Thus in these circumstances the date of the present last ring is at least close to the date of the original last ring on the tree, and so to the date of felling.

   Various estimates have been made for the average number of sapwood rings in a mature oak. One estimate is 30 rings, based on data from living oaks. So, in the case of the core in Figure 2 where 9 sapwood rings remain, this would give an estimate for the felling date of 21 ( = 30 - 9) years later than of the date of the last ring on the core. Actually, it is better in these situations to give an estimated range for the felling date. Another estimate is that in 95% of mature oaks there are between 15 and 50 sapwood rings. So in this example this would mean that the felling took place between 6 ( = 15 - 9 ) and 41 ( = 50 - 9) years after the date of the last ring on the core and is expected to be right in at least 95% of the cases (Hughes *et al* 1981; see also Hillam *et al* 1987).

   Data from the Laboratory has shown that when sequences are considered together in groups, rather than separately, the estimates for the number of sapwood can be put at between 15 and 40 rings in 95% of the cases with the expected number being 25 rings. We would use these estimates, for example, in calculating the range for the common felling date of the four sequences from Lincoln Cathedral using the average position of the heartwood/sapwood boundary (Fig 5). These new estimates are now used by us in all our publications except for timbers from Kent and Nottinghamshire where 25 and between 15 to 35 sapwood rings, respectively, is used instead (Pearson 1995).

   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. Sapwood rings were only lost in coring, because of their softness. By measuring in the timber the depth of sapwood lost, say 2 cm., a reasonable estimate can be made of the number of sapwood rings missing from the core, 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 40 years later we would have estimated without this observation.

**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**

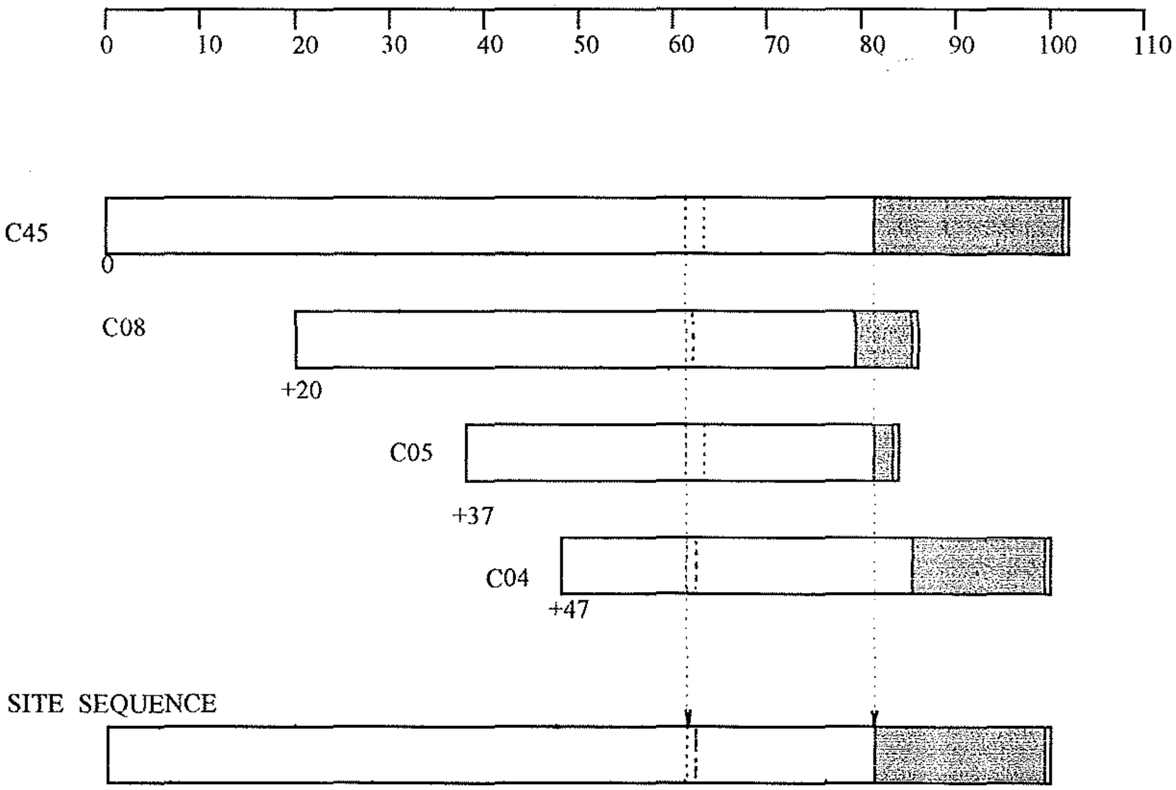


Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.
The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set 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.

Even if all the sapwood rings are missing on all the timbers sampled, an estimate of the felling date is still possible in certain cases. For provided the original last heartwood ring of the tree, called the heartwood/sapwood boundary (H/S), is still on some of the samples, an estimate for the felling date of the group of trees can be obtained by adding on the full 25 years, or 15 to 40 for the range of felling dates.

If none of the timbers have their heartwood/sapwood boundaries, then only a *post quem* date for felling is possible.

5. ***Estimating the Date of Construction.*** There is a considerable body of evidence in the data collected by the Laboratory that the oak timbers used in vernacular buildings, at least, were used 'green' (see also Rackham (1976 )). Hence provided the samples are taken *in situ*, and several dated with the same estimated common felling date, then this felling date will give an estimated date for the construction of the building, or for the phase of construction. If for some reason or other we are rather restricted in what samples we can take, then an estimated common felling date may not be such a precise estimate of the date of construction. More sampling may be needed 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 1988b, 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* 1988a). 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 (1988b) 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 (a), the generally large early growth after 1810 is very apparent as is the smaller generally later growth from about 1900 onwards. A similar difference can be observed in the lower sequence 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, hopefully corresponding to good and poor growing seasons, respectively. The two corresponding sequences of Baillie-Pilcher indices are plotted in (b) where the differences in the early and late growths have been removed and only the rapidly changing peaks and troughs remain. only associated with the common climatic signal and so make cross-matching easier.

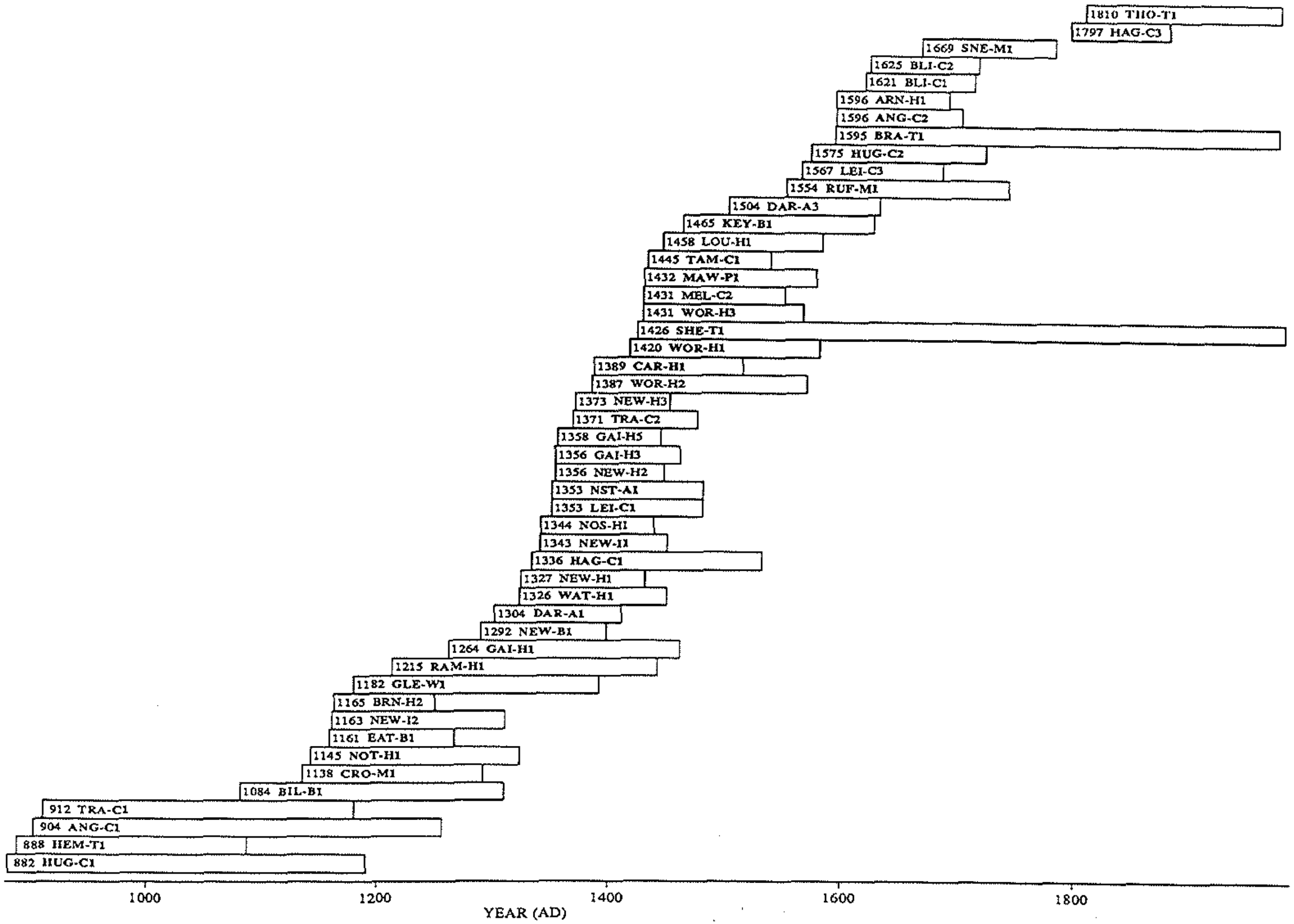


Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

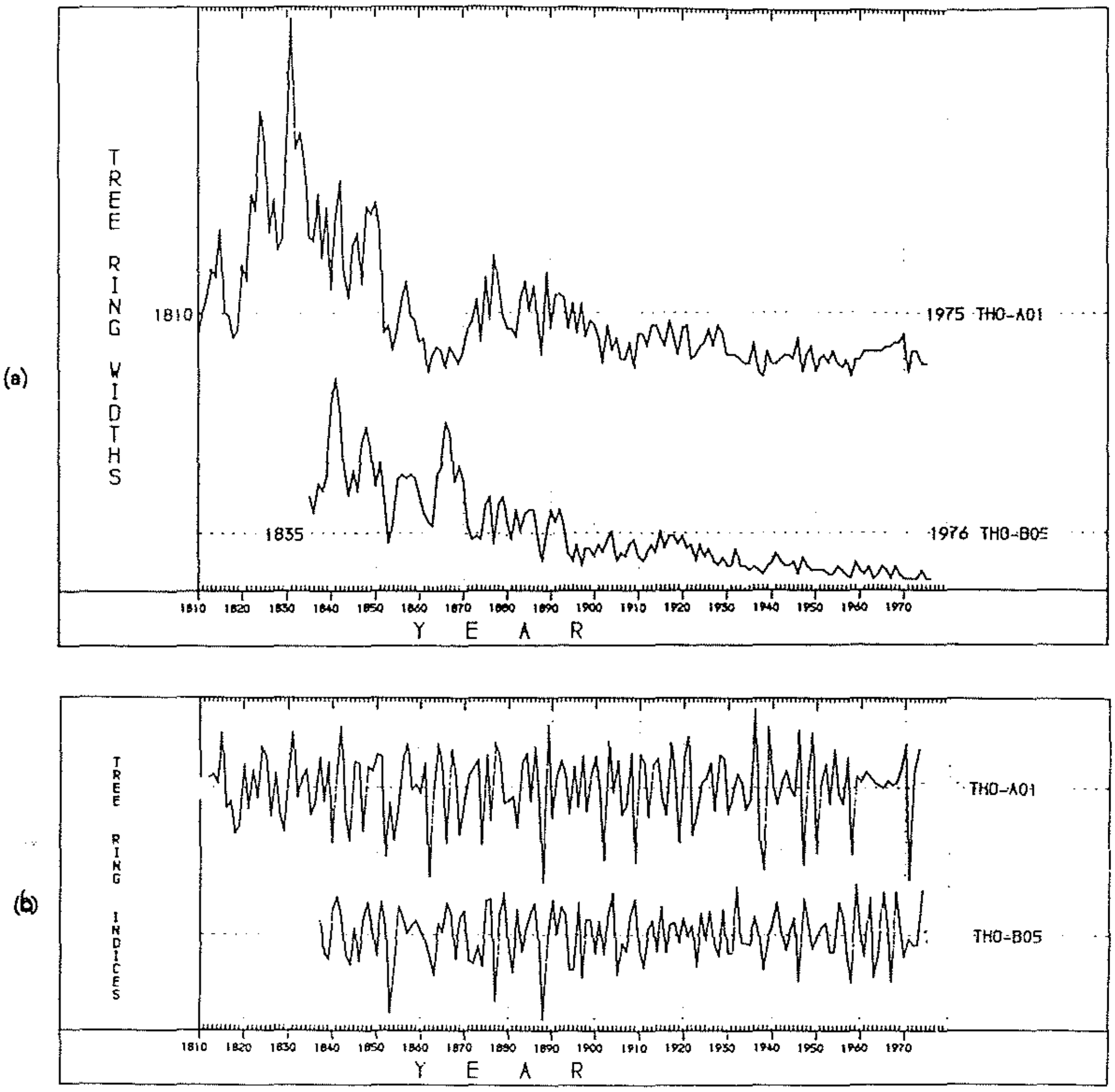


Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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

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

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