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Tree-Ring Analysis of Timbers from Manor House, High Street/Kings Street, Fordwich, Kent

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Summary

Analysis undertaken on seventeen samples from beams at this property resulted in the construction of a single site sequence and two individually dated samples.

Site sequence KMFASQ01, of 293 rings, contains twelve samples and spans the period AD 1264-1556. One of the samples has complete sapwood and a last ring date of AD 1556, the felling date of the timber represented. Eight further samples have the heartwood/sapwood boundary ring, which allows an estimated felling date for the timbers represented to be calculated to within the range AD 1549-72, consistent with an AD 1556 felling also.

Sample KMF-A06 was dated individually to the period AD 1510-56. This sample has complete sapwood and so its last ring is the felling date. Sample KMF-A16 spans the period AD 1289-1459. This sample does not have the heartwood/sapwood boundary ring and so no estimated felling date can be calculated except to say that this would be AD 1475 at the earliest, but could be much later.

Tree-ring analysis of timbers from this house has shown it to be built from trees felled in AD 1556.

Keywords
Dendrochronology
Standing Building

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Introduction

Manor House is located on the corner of High Street and Kings Street in the centre of Fordwich (Figs 1 and 2; TR 184599). The building, thought to date from the early seventeenth century, comprises two distinct but contemporary ranges, forming an 'L' shape. The upper floors are timber-framed and jettied in a conventional manner whilst the ground-floor elevations are of brick construction.

The rooms and features of the Kings Street range are clearly domestic. However, the upper chambers of the High Street range are poorly lit, unheated, and open to the roof, and the ground floor is one long, undivided, and unheated room. This half of the building does not appear to have been for domestic use and is more likely to have been a workshop and/or store.

The name Manor House is thought to have been acquired in recent times simply because it was occupied by a person named Manners (Austin 1997 unpubl).

This building was sampled and analysed as part of a project, funded by English Heritage, to establish a master chronology for Kent, covering the later part of the sixteenth century to the present day.

The Laboratory would like to thank Rupert Austin of Canterbury Archaeological Trust on whose report the above buildings description is based and for providing drawings with which to illustrate this report (Figs 3-6). Thanks are also given to Mr and Mrs Kingston, the owners of the property for allowing sampling to be undertaken.

Sampling

Twenty core samples were taken from a variety of different beams, from both ranges, with the core holes being plugged with dowel and stained. Each sample was given the code KMF-A (for Kent, Manor house, Fordwich; site A) and numbered 01-20. The position of all samples was noted at the time of sampling and has been marked on Figures 3-8. Further details relating to the samples are recorded in Table 1.

Analysis and Results

At this stage three of the samples were discarded as having too few rings to make successful dating a possibility. The remaining seventeen 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=5 twelve samples grouped and site sequence KMFASQ01, of 293 rings, was constructed containing these samples at the offsets shown in the bar diagram (Fig 9). This site sequence was successfully matched against the relevant reference chronologies for oak at a first-ring date of AD 1264 and a last-ring date of AD 1556. The evidence for this dating is given by the t-values in Table 2.

Attempts were then made to date the remaining five samples individually by comparing them with the reference chronologies. As a result samples KMF-A06 and KMF-A16 were dated to the periods AD 1510-56, and AD 1289-1459, respectively. The evidence for both of these dates is given by the t-values in Tables 3 and 4.

Interpretation

Analysis of samples from the timbers of this house has resulted in the production of one site sequence and two individually dated samples.

Site sequence KMFASQ01, contains twelve samples and spans the period AD 1264-1556. One of these samples, KMF-A08, has complete sapwood and a last-ring date of AD 1556, the felling date of the timber represented. Eight further samples have the heartwood/sapwood boundary ring, the average of which is AD 1532. This allows the calculation of an estimated felling date for the eight timbers represented to within the range AD 1549-72, consistent with an AD 1556 felling also. The other three samples in this site sequence do not have the heartwood/sapwood boundary ring and so estimated felling dates cannot be calculated for these timbers. However, with last measured ring dates of AD 1439 (KMF-A20), AD 1526 (KMF-A03), and AD 1529 (KMF-A05), these would be AD 1455, AD 1542, and AD 1545 at the earliest, respectively.

Sample KMF-A06 was individually dated to a first-ring date of AD 1510 and a last-ring date of AD 1556. This sample has complete sapwood and so the last measured ring date of AD 1556 is the felling date of the timber represented. Sample KMF-A16 was also individually dated, to spanning the period AD 1289-1459. This sample does not have the heartwood/sapwood boundary ring, however, the earliest it is estimated to have been felled is AD 1475.

All felling date ranges have been calculated using the estimate that 95% of mature oak trees in this area have between 15-40 sapwood rings.

Discussion

Tree-ring analysis has resulted in the successful dating of fourteen timbers at this house. Two of these are from trees felled in AD 1556 with a further eight having a felling date range entirely consistent with this felling date also.

As mentioned above, prior to the analysis being carried out, this building was believed to date to the early part of the seventeenth century. It is now known that it is constructed from timbers felled in AD 1556, and is therefore likely to be over half a century earlier than expected. With samples from both ranges being dated to AD 1556 this also supports the interpretation that both ranges are coeval.

Sample KMF-A06, with only 47 rings, is shorter than would usually be preferred when dating single samples. However, it matches against the reference chronologies consistently and strongly at the last ring date of AD 1556. Additionally this date corresponds with those produced by the site sequence.

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Table 1: Details of tree-ring samples from Manor House, High Street/Kings Street, Fordwich, Kent

Sample number	Sample location	Total rings	Sapwood rings*	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
King Street Range						
KMF-A01	North purlin, trusses 2-3	79	h/s	1459	1537	1537
KMF-A02	South purlin, trusses 2-3	82	9c	1467	1539	1548
KMF-A03	East brace, north, truss 3	89	--	1438	----	1526
KMF-A04	Collar, truss 2	NM	--	----	----	----
KMF-A05	West brace, north, truss 2	83	--	1447	----	1529
KMF-A06	South rafter, first from east, bay 1	47	24C	1510	1532	1556
KMF-A07	Major stud	NM	--	----	----	----
KMF-A08	Collar, truss 3	92	19C	1465	1537	1556
KMF-A09	West brace, north, truss 3	61	15C	----	----	----
KMF-A10	Rail	56	8	----	----	----
KMF-A11	East brace, north, truss 4	127	h/s	1408	1534	1534
KMF-A12	Tiebeam, truss 4	NM	--	----	----	----
High Street Range						
KMF-A13	West purlin, trusses 1-2	112	12c	1431	1530	1542
KMF-A14	Tiebeam, truss 2	73	2c	1457	1527	1529
KMF-A15	West principal rafter, truss 1	148	h/s	1385	1532	1532
KMF-A16	South-west corner post	171	--	1289	----	1459
KMF-A17	West purlin, T1-north end	92	h/s	1436	1527	1527
KMF-A18	East purlin, trusses 1-2	105	h/s	1423	1527	1527
KMF-A19	Tiebeam, truss 1	71	13	----	----	----
KMF-A20	Axial spine beam, trusses 1-2	174	--	1264	----	1439

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

Table 2: Results of the cross-matching of site sequence KMFASQ01 and relevant reference chronologies when the first-ring date is AD 1264 and the last-ring date is AD 1556

Reference chronology	*t*-value	Span of chronology	Reference
England London	8.5	AD 413-1728	Tyers 1999 unpubl
Kent	8.4	AD 1158-1540	Laxton and Litton 1989
East Midlands	5.8	AD 882-1982	Laxton and Litton 1988
Tower-lo	7.7	AD 1379-1534	Bridge 1988
Chilton Manor ('Secret Room'), Sittingbourne	6.6	AD 1368-1520	Laxton and Litton 1989
Archbishops Palace, Charing, Kent	6.3	AD 1451-1559	Howard *et al* 1998a
Charterhouse, Charterhouse Square, London	6.1	AD 1382-1545	Howard *et al* 1996
Brewhouse Yard Museum, Nottingham, Notts	5.9	AD 1445-1551	Howard *et al* 1994
Church House, Edenbridge, Kent	5.9	AD 1377-1538	Howard *et al* 2000
Walmer Castle, Kent	5.8	AD 1396-1523	Howard *et al* 1997a
Old Rectory, Cossington, Leics	5.6	AD 1375-1526	Howard *et al* 1992

Table 3: Results of the cross-matching of sample KMF-A06 and relevant reference chronologies when the first-ring date is AD 1510 and the last ring date is AD 1556

Reference chronology	*t*-value	Span of chronology	Reference
Southern England and Wales	5.9	AD 1386-1585	Fletcher 1980
Essex	5.9	AD 878-1622	Tyers 1997 unpubl
Western England Wales	5.4	AD 1341-1636	Siebenlist-Kerner 1978
Sinai Park, Burton, Staffs	6.7	AD 1227-1750	Tyers 1997
Owston Church, Oakham	6.2	AD 1485-1611	Howard *et al* 1999
Windsor Castle (kitchen), Berks	5.1	AD 1331-1573	Hillam 1997 unpubl
Ely Cathedral, Cambs	5.0	AD 1466-1610	Howard *et al* 1992 unpubl
White House, Main Street, Blyth, Notts	4.8	AD 1453-1595	Howard *et al* 1994
Charterhouse (Great Hall), London	4.6	AD 1452-1592	Howard *et al* 1997 unpubl
Lounge Opencast Coal Pit, Coleorton, Leics	4.6	AD 1502-1598	Howard *et al* 1990 unpubl
Keyworth Barn, Notts	4.3	AD 1451-1628	Laxton and Litton 1988
15/19 Station Street, Mansfield Woodhouse, Notts	4.2	AD 1432-1621	Howard *et al* 1997b

Table 4: Results of the cross-matching of sample KMF-A16 and relevant reference chronologies when the first-ring date is AD 1289 and the last ring date is AD 1459

Reference chronology	*t*-value	Span of chronology	Reference
England London	5.0	AD 413-1728	Tyers and Groves 1999 unpubl
Kent	4.9	AD 1158-1540	Laxton and Litton 1989
Southern England	4.4	AD 1083-1589	Bridge 1988
High Halden Church, Kent	6.7	AD 1299-1462	Bridge 1985
Chicksands Priory, Chicksands, Beds	6.3	AD 1200-1541	Howard *et al* 1998b
Cobham Hall (combined), Kent	6.3	AD 1317-1662	Howard *et al* 2002 unpubl
Manor Farm Barn, Frindsbury, Kent	5.5	AD 1254-1403	Arnold *et al* 2002
244 Forrest Road, Woodhouse Eaves, Leics	5.4	AD 1374-1455	Alcock *et al* 1990
Old Manor House, Mapledurham	5.4	AD 1278-1438	Haddon-Reece and Miles 1987
Lacock Abbey (frater), Lacock, Wilts	5.0	AD 1314-1448	Esling *et al* 1990
Walmer Castle	5.0	AD 1396-1523	Howard *et al* 1997a

Figure 1: Map to show the location of Fordwich, Kent

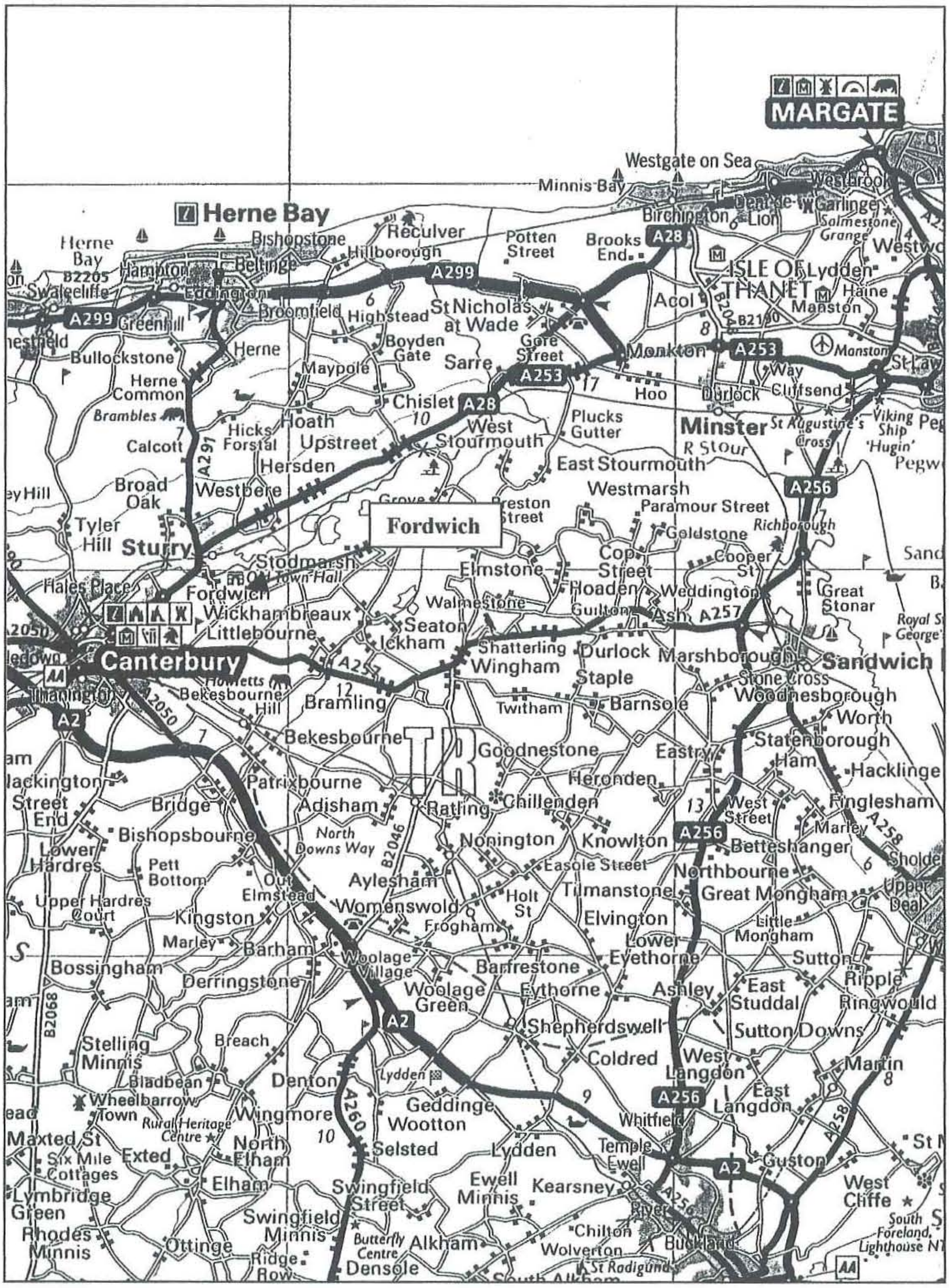


Figure 2: Map to show the location of Manor House, Fordwich, Kent (

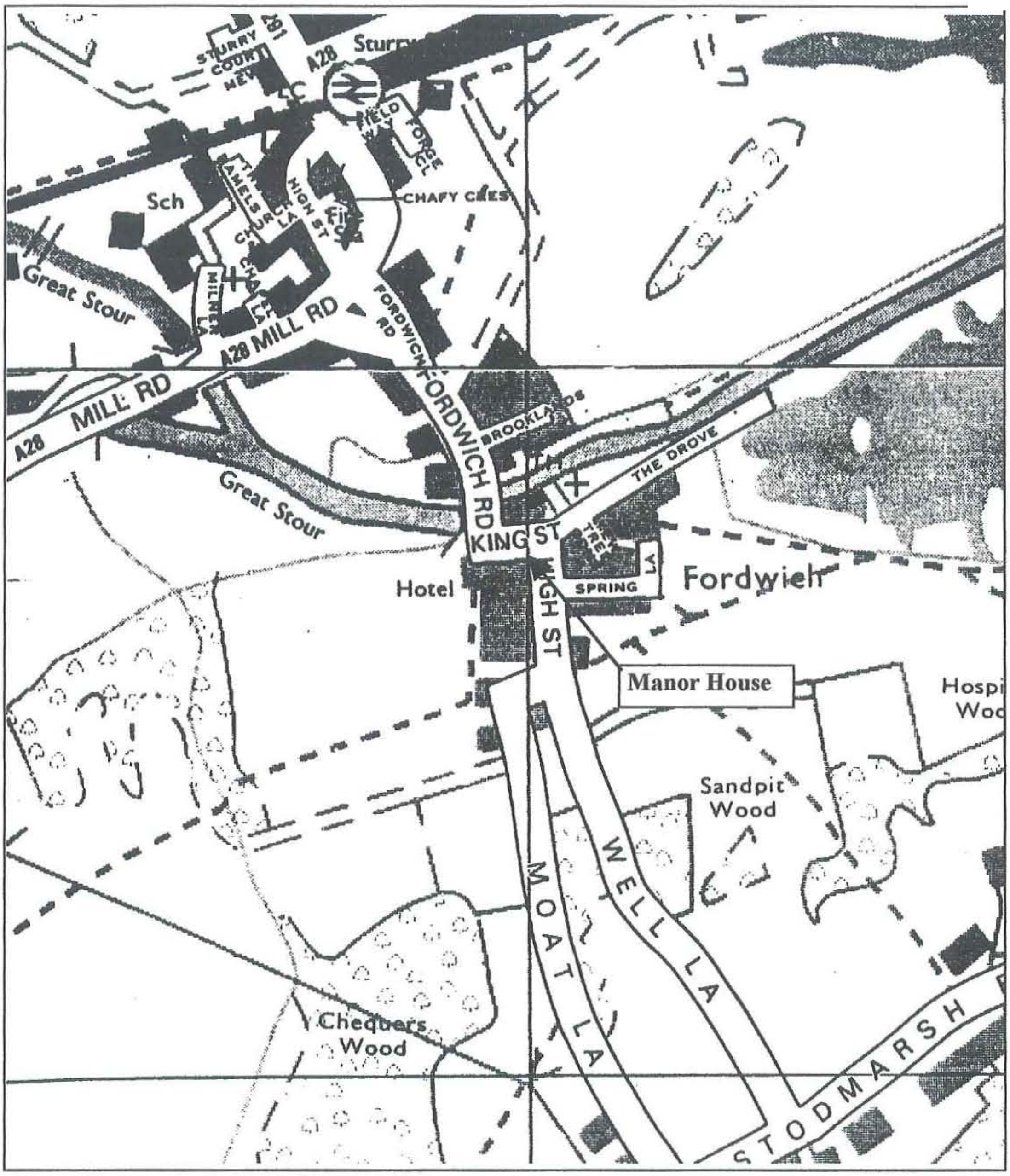


Figure 3: Manor House, Fordwich – ground-floor plan (drawn by Rupert Austin)

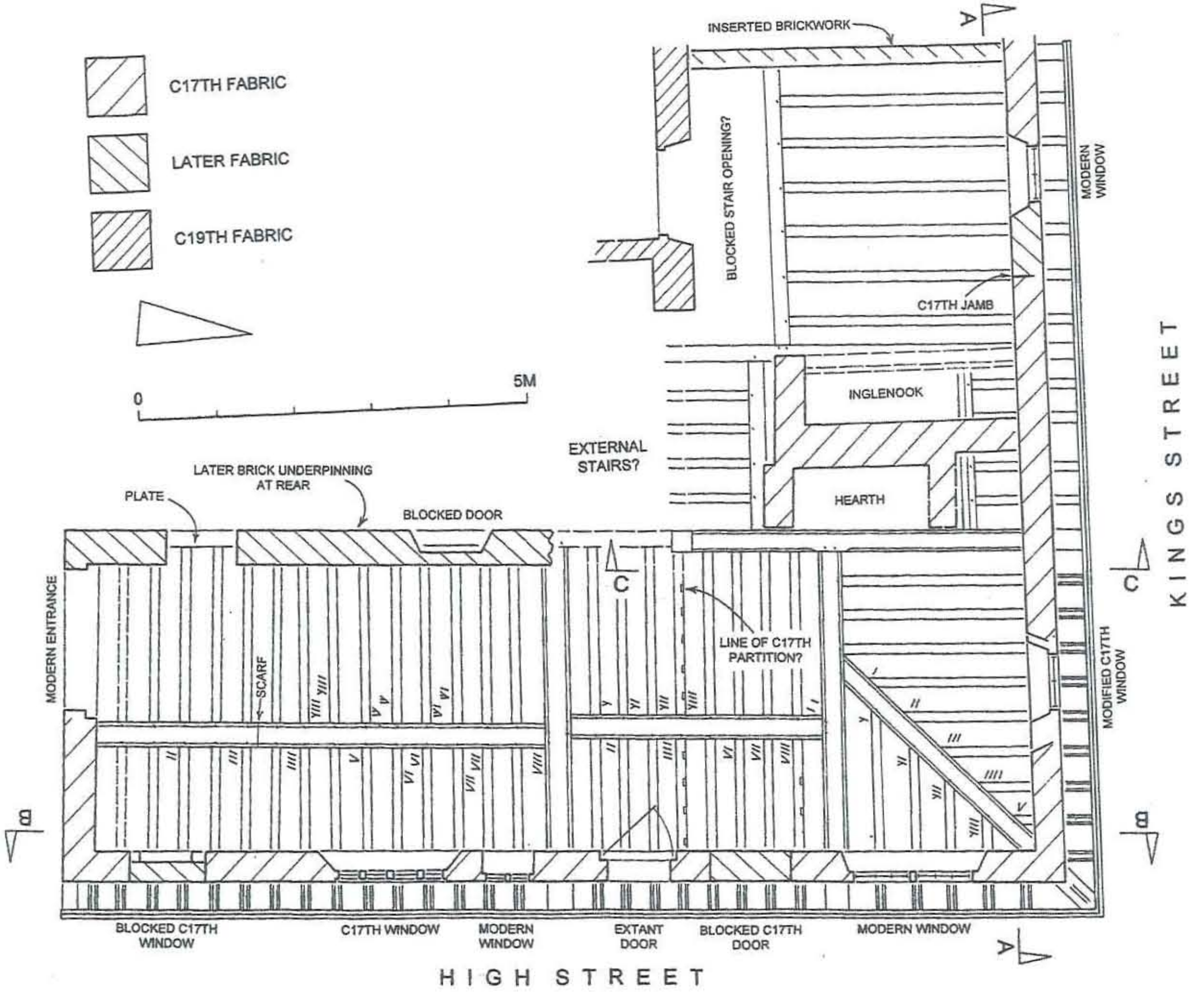


Figure 4: Manor House, Fordwich – section A-A to north, showing the location of samples KMF-A01, KMF-A03-06, KMF-A08-09, and KMF-A11-12 (drawn by Rupert Austin)

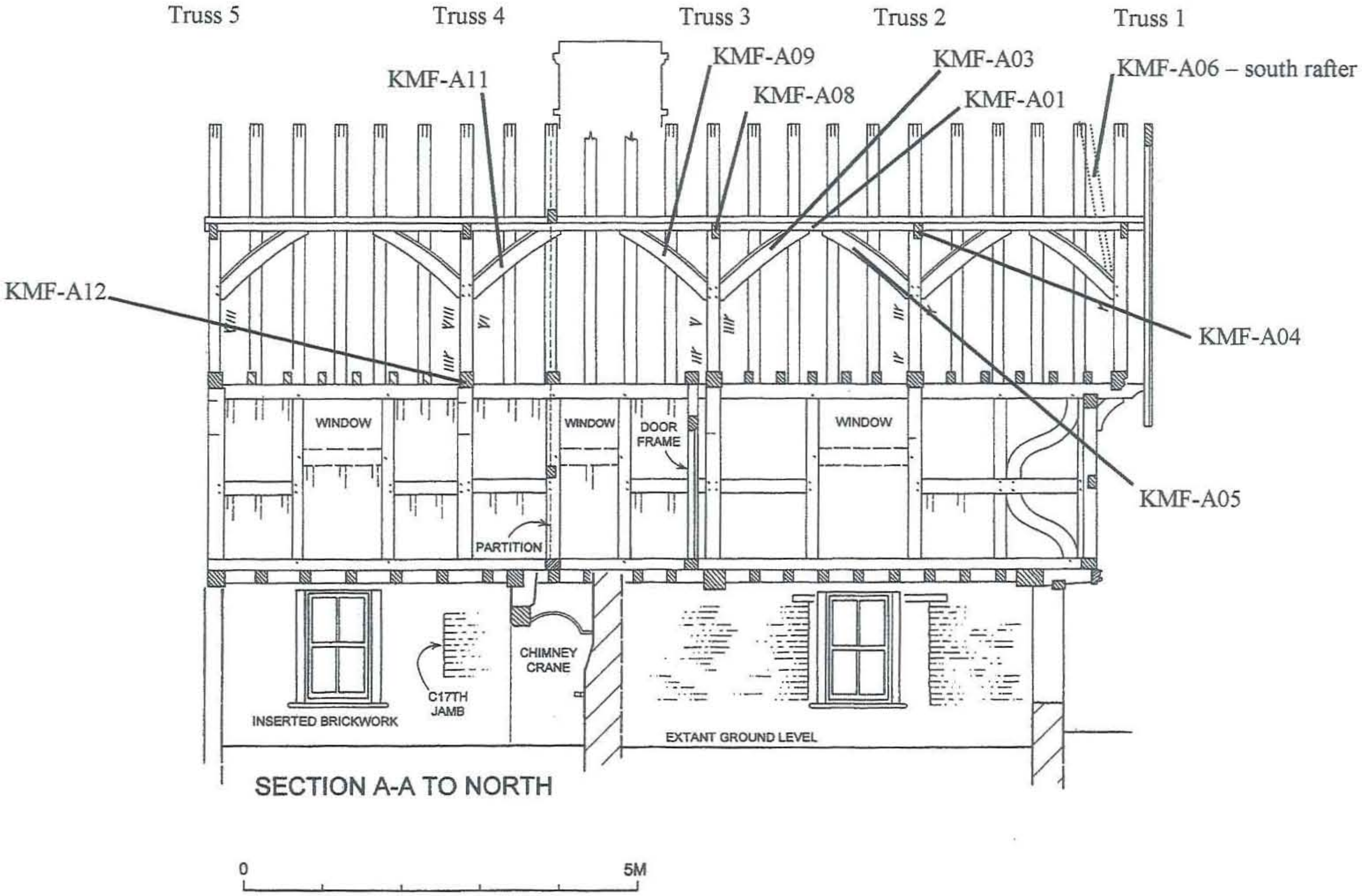


Figure 5: Manor House, Fordwich – section B-B to east, showing the location of samples KMF-A14, and KMF-A18-19 (drawn by Rupert Austin)

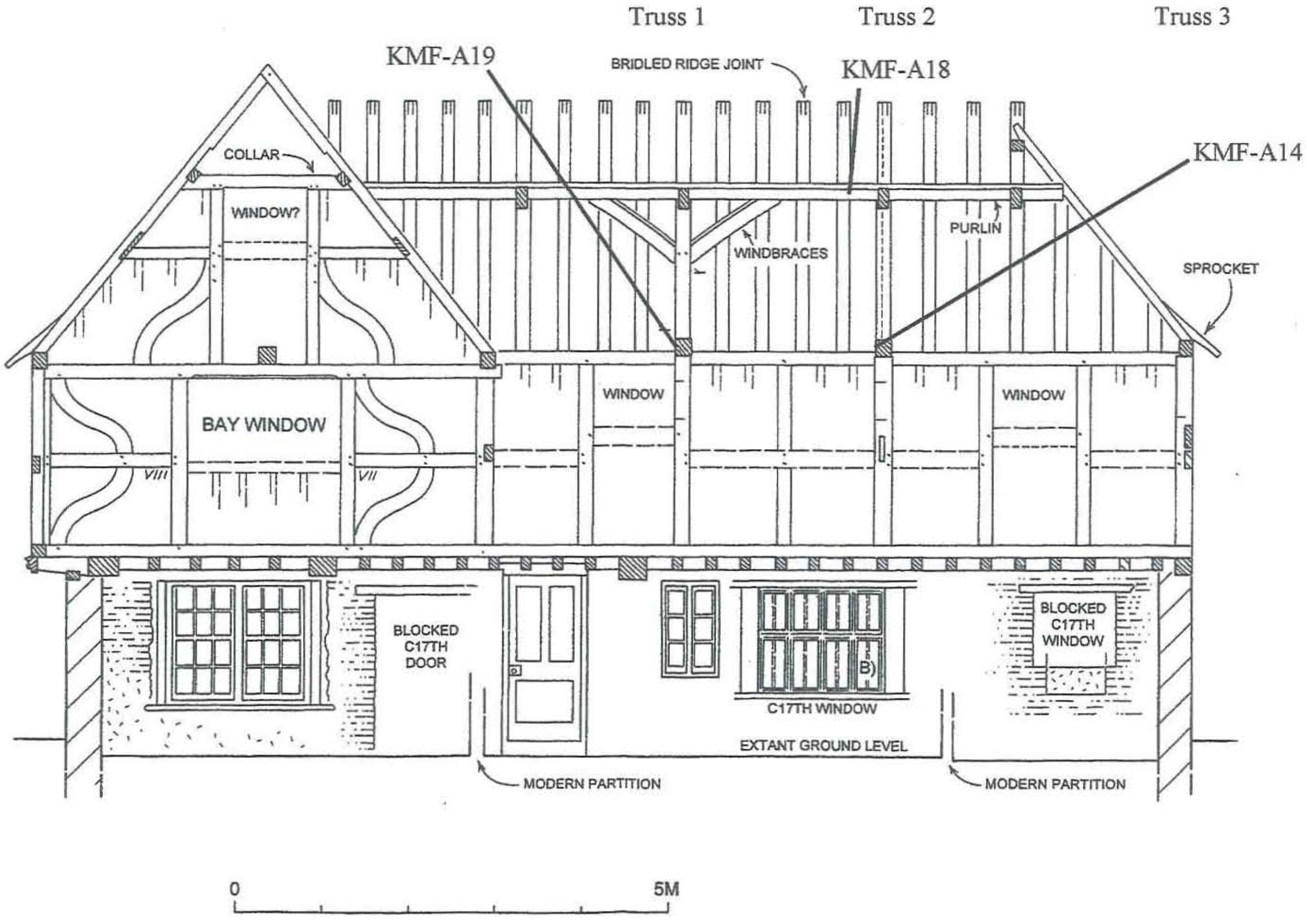


Figure 6: Manor House, Fordwich – section C-C to west, showing the location of sample KMF-A02 (drawn by Rupert Austin)

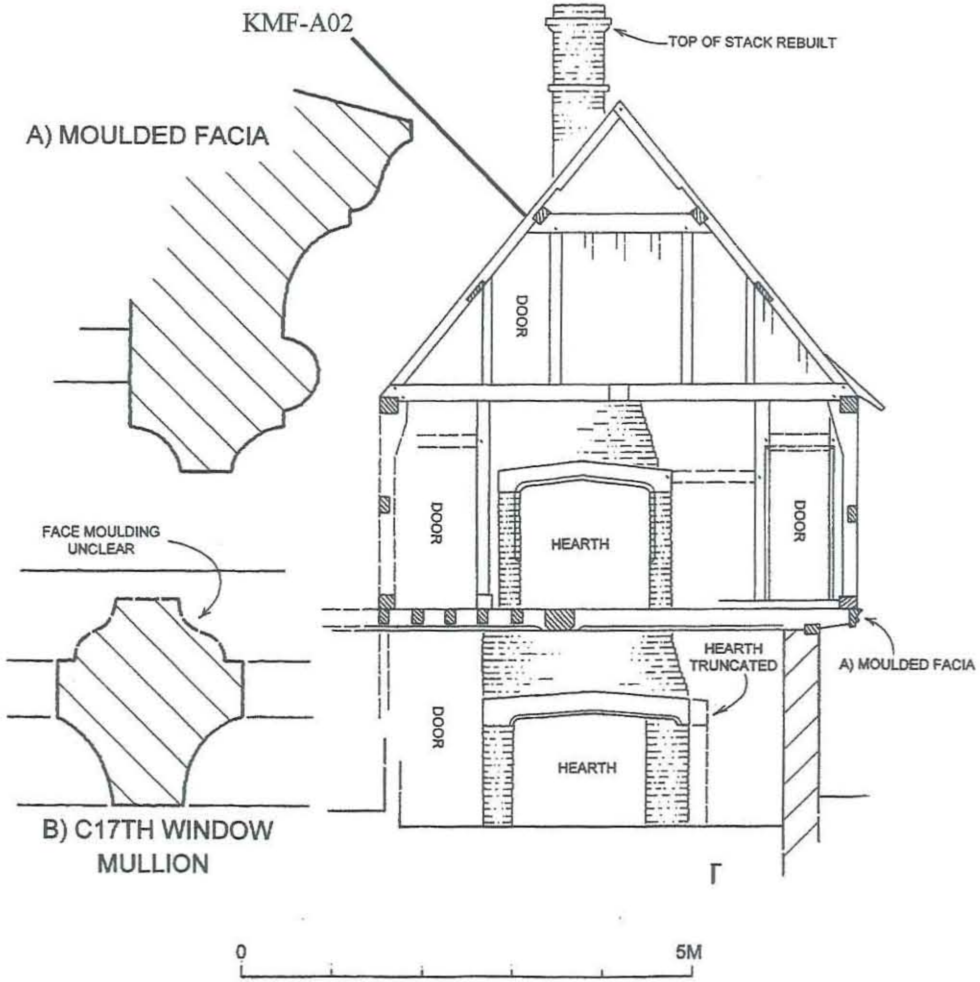


Figure 7: Manor House, Fordwich –sketch of truss 5 to west at first-floor/roof level, showing the location of samples KMF-A07 and KMF-A10

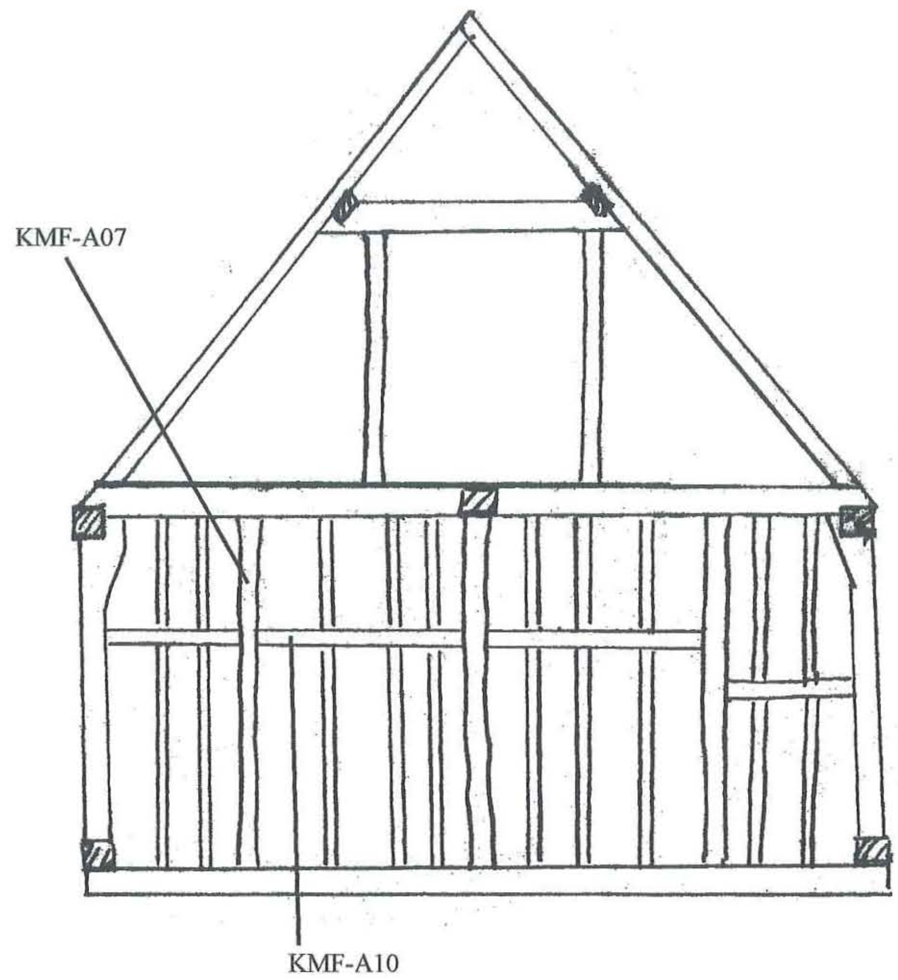


Figure 8: Manor House, Fordwich – sketch first-floor plan, showing the location of samples KMF-A13, KMF-A15, KMF-A16-17, and KMF-A20

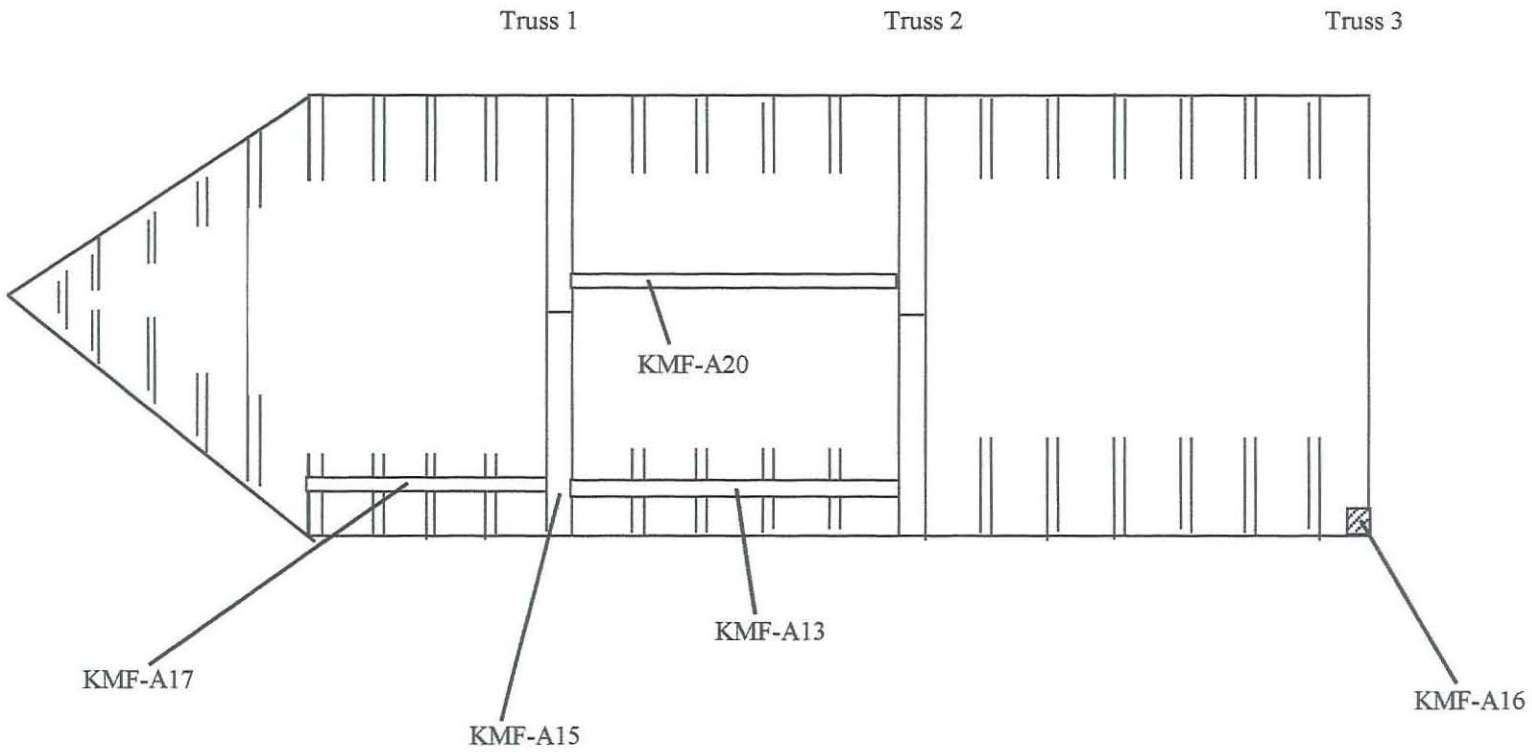
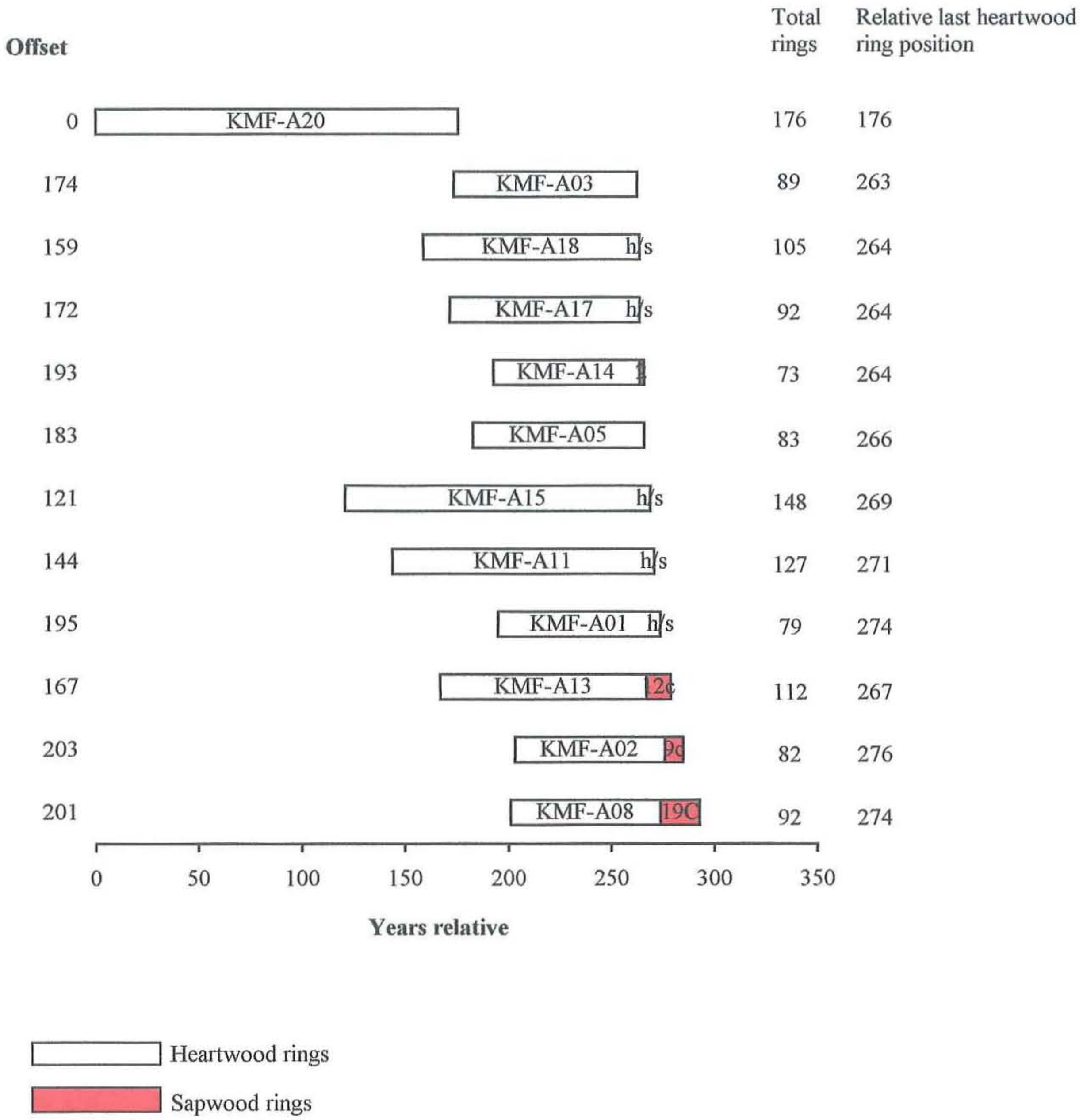


Figure 9: Bar diagram of samples in site sequence KMFASQ01



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

Data of measured samples – measurements in 0.01mm units

KMF-A01A 79
144 205 191 175 186 137 203 192 151 183 151 106 88 123 122 153 203 156 93 83
82 103 165 158 186 180 126 129 137 109 143 136 133 106 147 117 137 195 167 124
134 116 88 117 81 80 84 100 137 97 113 95 82 80 61 81 108 102 102 109
170 114 101 110 83 86 80 86 94 85 96 61 87 82 72 64 61 63 80
KMF-A01B 79
138 182 163 165 187 157 203 187 158 172 160 104 96 124 126 145 211 143 106 74
90 98 170 151 178 189 123 132 135 117 140 135 134 104 136 131 136 210 160 112
160 115 86 117 80 74 85 111 99 101 97 96 80 75 64 102 110 102 97 107
178 112 104 118 87 80 82 96 84 93 94 59 80 77 88 54 59 66 64
KMF-A02A 82
160 229 179 103 108 143 150 182 247 176 104 87 103 119 197 178 172 210 156 149
185 176 205 188 159 138 151 121 125 158 154 102 118 100 92 101 89 70 78 150
88 100 109 110 89 83 77 85 103 93 100 107 155 104 104 112 90 108 125 95
88 101 77 73 76 81 91 63 86 81 91 93 136 180 183 172 190 161 134 168
180 209
KMF-A02B 57
151 132 143 135 158 185 178 127 132 102 105 121 97 64 101 140 86 100 104 117
81 80 88 82 99 100 94 94 141 107 95 105 95 125 124 121 99 119 88 82
92 92 79 67 82 76 98 98 117 148 190 175 197 148 123 165 128
KMF-A03A 89
94 90 95 88 82 81 84 102 120 107 98 83 57 70 90 89 105 89 121 146
141 117 122 171 181 96 112 113 91 113 98 116 107 138 174 125 138 185 147 87
71 93 80 115 84 79 81 69 76 75 103 123 145 125 145 132 162 155 213 161
132 134 209 145 127 82 81 84 94 78 98 92 95 87 120 76 124 109 119 94
113 162 107 99 176 131 121 153 140
KMF-A03B 89
109 94 103 83 96 62 98 118 126 116 107 88 50 64 95 87 92 99 129 131
147 116 136 165 180 84 108 127 93 109 100 109 123 153 170 138 134 188 150 91
72 89 84 93 100 78 79 80 77 91 90 124 128 163 144 148 175 162 202 166
157 123 216 163 128 77 84 79 83 91 96 90 85 102 113 88 119 108 123 89
119 160 113 100 160 133 123 146 124
KMF-A05A 83
144 144 133 124 142 149 138 201 148 186 170 171 136 196 178 165 122 133 120 138
127 133 133 109 110 165 148 135 166 168 80 61 75 99 116 132 139 128 68 117
126 102 113 148 142 127 159 125 147 193 161 140 140 166 191 161 121 114 146 141
190 166 243 215 158 157 135 163 172 176 113 144 114 157 165 234 140 171 167 199
143 150 129
KMF-A05B 83
116 151 135 130 135 146 136 196 148 180 174 173 140 188 174 165 134 132 128 119
127 118 129 100 111 157 143 157 160 173 81 58 82 112 129 123 141 122 89 99
114 99 97 148 139 119 161 144 142 193 154 142 159 162 187 154 121 119 136 148
195 165 240 217 143 165 122 164 172 178 116 142 121 149 162 229 143 176 165 202
139 146 145
KMF-A06A 47
164 195 199 230 185 222 148 130 131 148 100 116 167 190 306 154 112 131 137 150
129 239 199 166 145 227 159 203 178 174 154 164 93 118 202 186 144 118 215 276
198 298 236 279 242 180 153
KMF-A06B 47
185 197 211 222 194 233 163 136 143 146 105 122 198 182 294 158 126 119 150 147
154 229 189 182 128 224 125 213 174 181 165 159 95 123 179 194 142 117 215 308
202 321 241 265 250 214 172
KMF-A08A 92
124 170 160 146 119 118 127 131 95 86 168 154 119 109 107 85 111 115 155 200
162 157 232 122 126 138 90 83 80 123 135 199 146 109 101 87 104 107 118 92
98 131 112 149 128 134 161 149 138 165 169 167 186 183 169 143 123 157 92 115
81 102 87 91 78 67 95 107 101 117 144 153 145 191 201 187 141 150 135 118
120 114 97 136 191 97 165 187 130 89 188 166

KMF-A08B 92
148 170 149 145 110 98 140 113 90 103 168 160 104 102 95 84 96 104 153 223
158 157 248 116 108 130 95 93 66 133 128 204 155 107 116 79 91 113 116 89
95 112 129 146 119 120 146 145 124 165 169 160 182 181 162 146 121 147 86 106
78 102 82 83 81 62 107 99 95 109 149 161 155 167 211 199 130 126 144 134
108 100 112 145 153 114 145 185 138 129 103 128
KMF-A09A 61
100 114 141 61 129 107 81 78 97 203 191 178 212 96 116 75 132 163 163 236
256 172 124 141 186 272 140 209 150 118 116 110 106 106 142 90 94 100 149 132
153 118 174 182 192 64 86 69 73 98 112 200 176 175 177 146 178 140 170 188
150
KMF-A09B 61
85 108 141 70 126 113 82 74 105 201 204 183 208 86 116 84 137 163 155 240
260 166 127 142 175 285 122 205 145 126 122 137 87 111 146 92 88 100 150 129
154 114 176 200 192 62 80 71 74 104 118 205 212 178 182 146 186 186 116 199
178
KMF-A10A 56
140 199 222 208 116 187 140 104 151 158 148 111 106 92 73 88 97 99 78 83
84 95 75 104 121 112 135 149 90 98 87 79 59 52 48 57 73 70 56 65
55 71 58 53 40 35 65 68 50 84 64 53 54 54 66 71
KMF-A10B 56
123 190 227 199 123 185 140 110 151 154 152 112 103 76 66 96 92 104 81 83
80 95 80 100 122 113 132 146 66 98 85 73 56 54 45 62 72 58 61 58
57 73 55 68 43 46 60 50 49 52 55 56 93 61 59 66
KMF-A11A 127
117 102 77 112 114 97 96 135 136 115 185 193 234 224 156 179 190 199 191 225
221 264 298 287 243 184 152 144 126 116 120 117 129 98 108 78 94 91 101 179
201 189 160 142 181 167 188 167 209 201 154 125 142 178 150 144 137 115 120 117
93 153 121 128 143 128 127 182 167 75 45 91 107 123 106 96 105 87 102 106
147 128 138 153 146 167 133 172 251 187 142 108 141 158 126 91 91 114 140 123
117 134 139 122 111 109 113 128 129 89 98 111 102 112 205 129 141 159 162 119
138 128 107 193 116 109 129
KMF-A11B 127
116 98 86 107 117 99 96 136 137 111 185 192 227 232 153 179 192 202 194 230
219 272 298 293 245 191 149 138 121 126 131 124 123 97 107 79 97 92 98 175
198 192 170 145 181 166 189 173 206 198 166 134 147 183 157 139 134 118 128 105
107 139 113 134 135 125 131 180 164 72 57 87 101 119 105 106 102 88 105 99
148 133 133 154 142 157 133 180 254 192 138 112 151 162 123 98 85 119 147 132
112 124 156 111 119 99 122 125 133 84 98 113 109 109 204 130 142 148 177 111
136 129 111 187 118 105 130
KMF-A13A 112
204 272 154 165 185 113 116 103 81 95 110 138 116 144 159 141 107 147 163 141
139 111 80 108 102 141 148 132 138 125 120 134 117 62 101 74 92 105 107 85
66 70 87 70 99 63 49 44 46 59 65 88 59 73 39 59 62 38 53 54
35 32 36 57 47 46 33 38 35 38 41 32 39 37 22 41 46 41 48 38
42 37 40 52 50 47 33 46 43 48 42 48 34 51 55 76 77 65 70 52
61 71 66 74 75 69 73 70 54 59 81 66
KMF-A13B 112
178 274 155 162 190 145 111 102 83 93 123 127 128 129 163 159 106 142 158 148
139 111 78 94 107 131 143 137 130 128 113 135 117 58 112 77 85 111 107 79
71 73 81 71 97 68 50 41 41 62 72 77 62 77 40 51 63 48 49 50
41 38 33 54 52 49 32 34 38 35 33 38 36 38 34 41 35 36 46 37
40 47 39 44 51 44 45 44 55 42 49 47 39 49 72 74 68 72 69 49
69 64 67 74 68 69 75 65 60 69 75 92
KMF-A14A 73
147 172 134 156 135 173 214 109 167 127 112 131 132 102 82 92 99 74 90 71
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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.

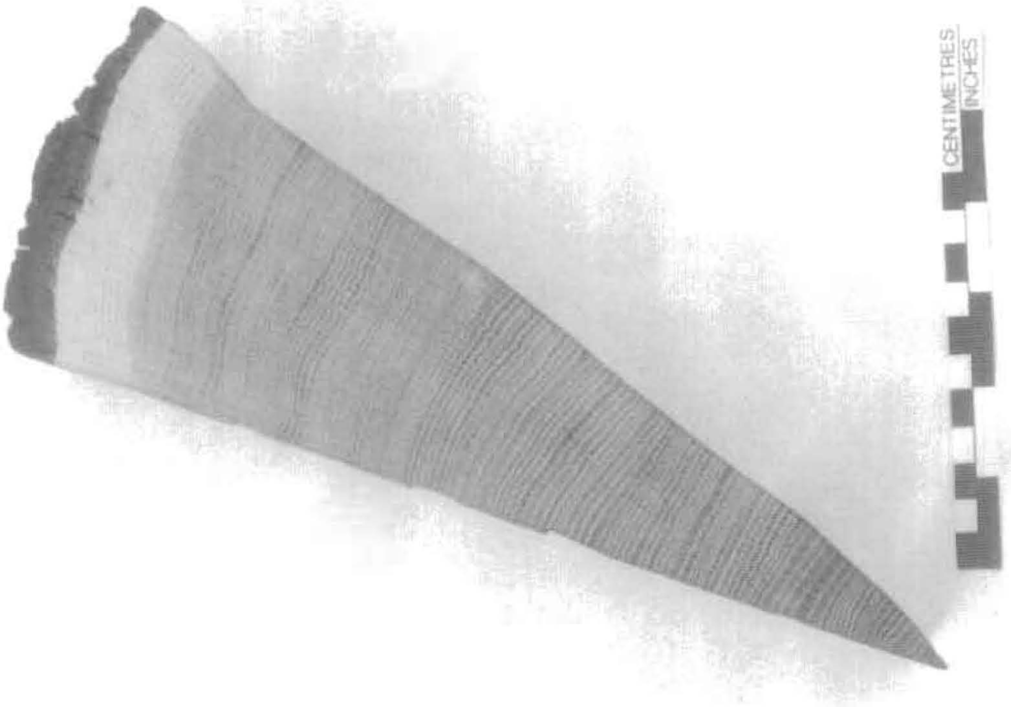

Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

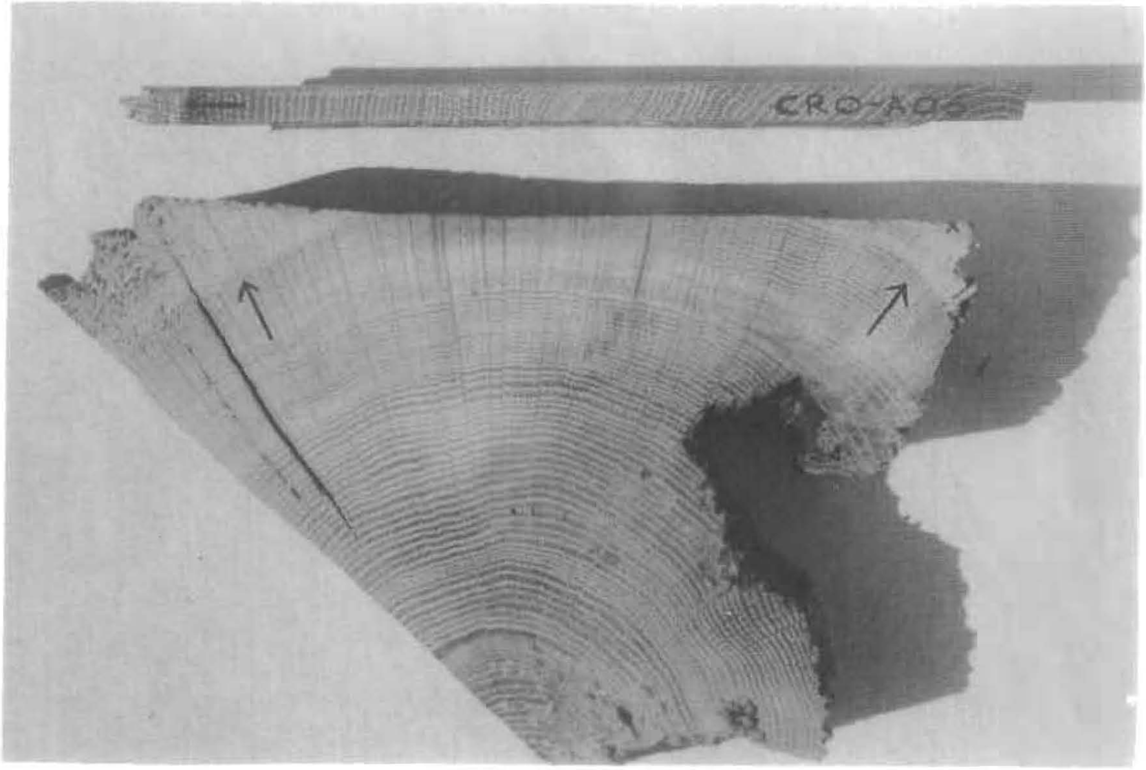

Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

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.

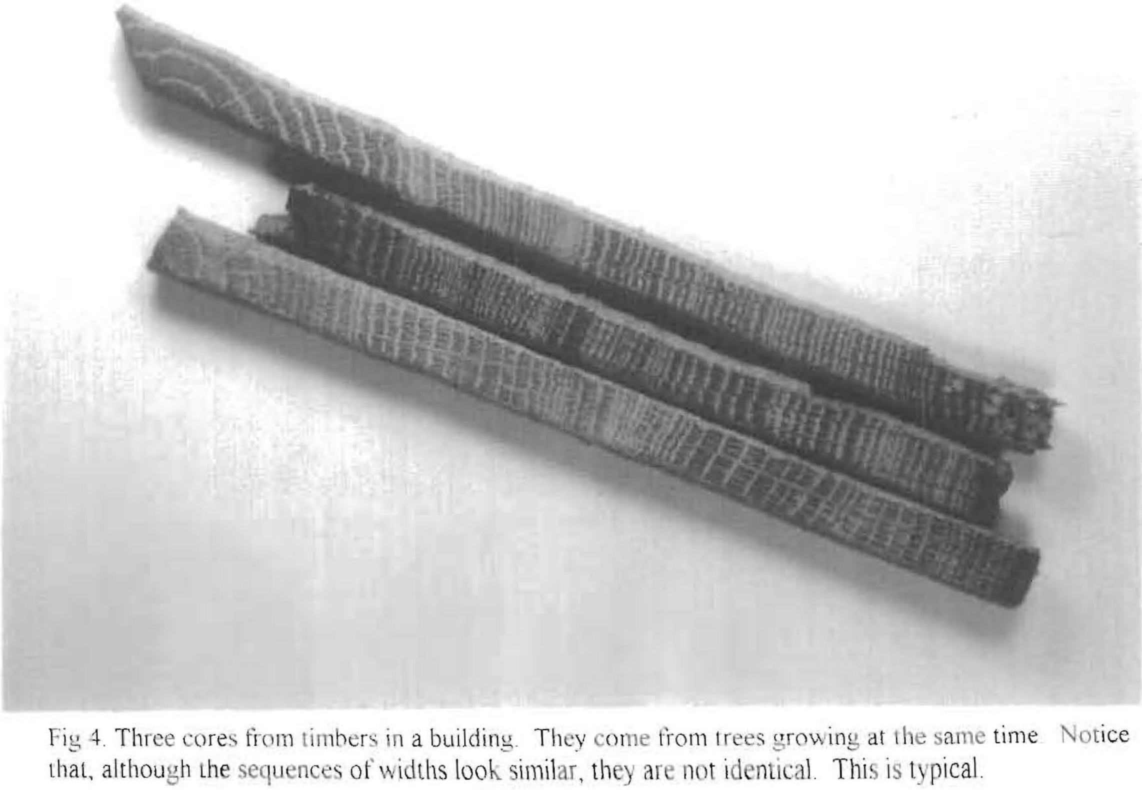

Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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

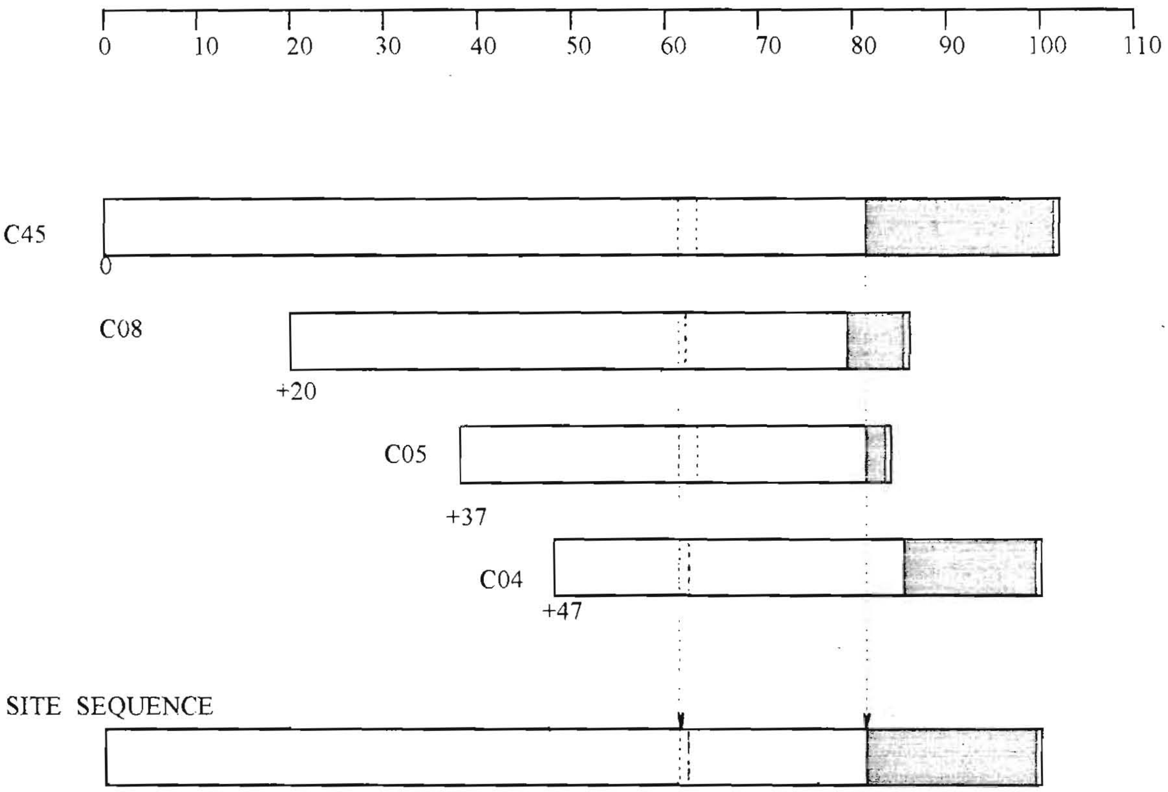

Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.
The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set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

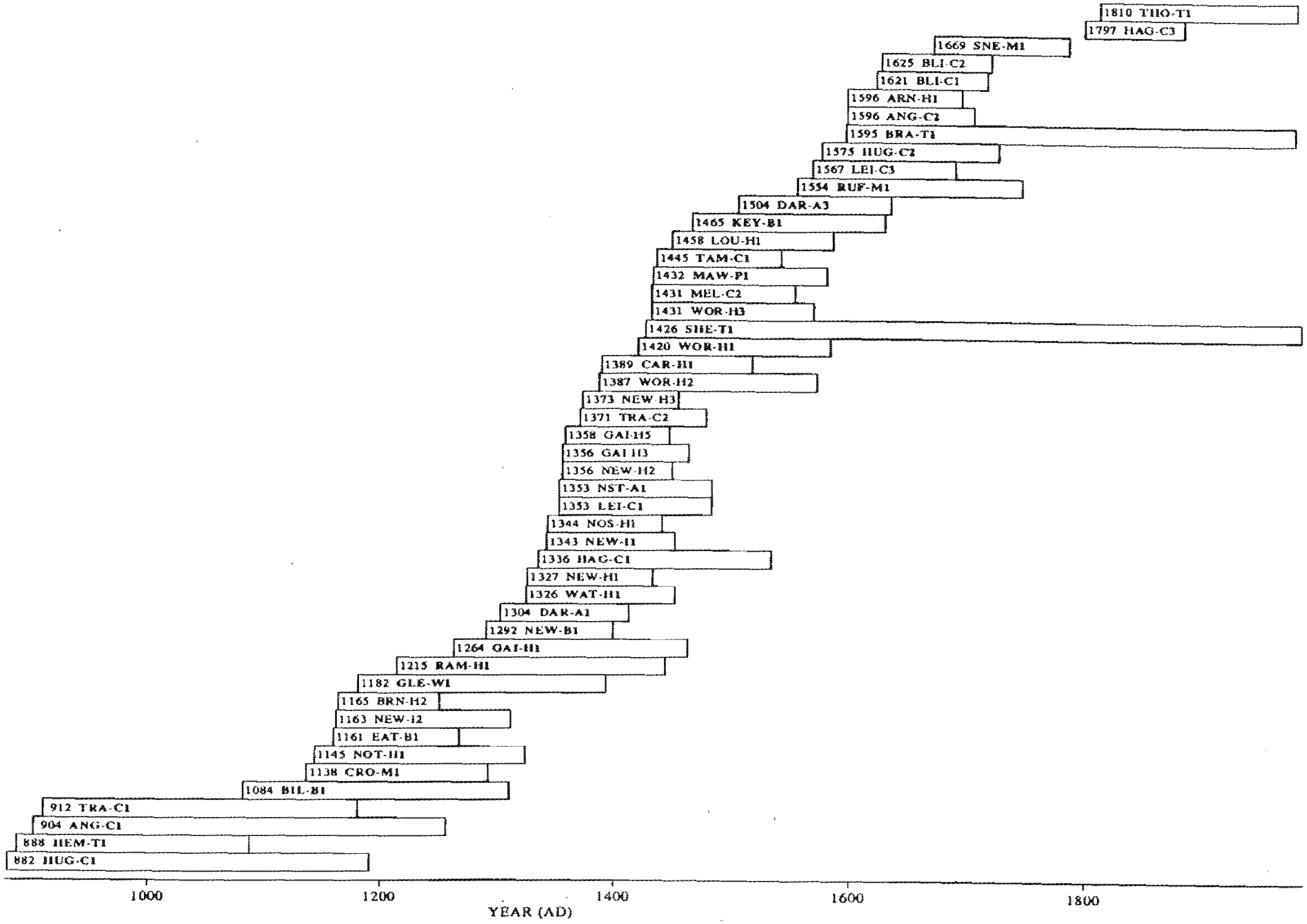

Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

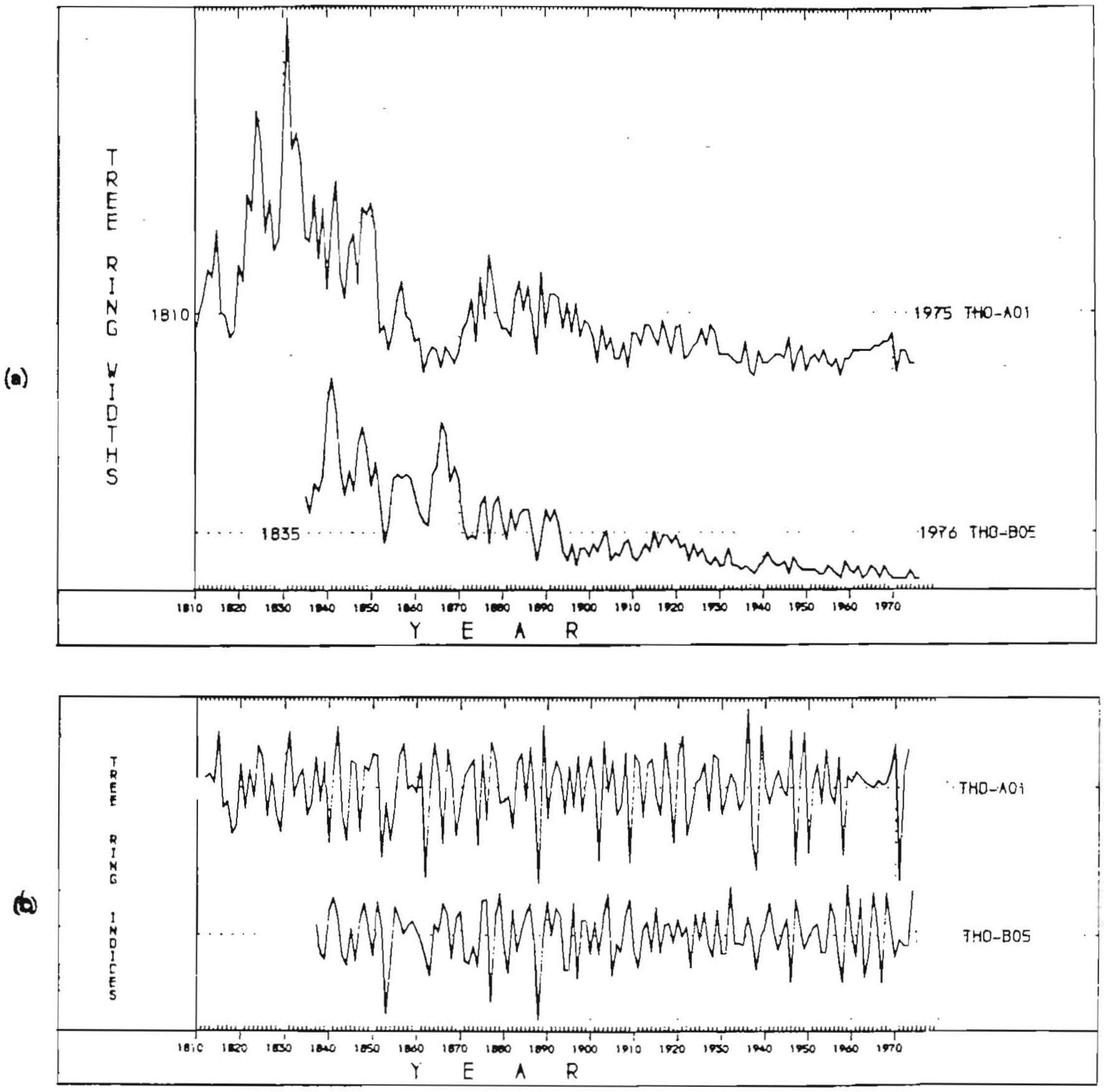

Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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