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Summary

A total of twenty-seven samples were obtained from this building, but of this number three were unsuitable for tree-ring dating. Analysis of the remaining twenty-four samples produced two dated site chronologies, and dated three samples individually.

The first site chronology consists of fourteen samples, all from the main structural timbers, and is 101 rings long. This site chronology is dated as spanning the years AD 1439 to AD 1539. Interpretation of the sapwood would suggest that all the timbers represented were felled in the period AD 1545-9.

The second site chronology consists of three samples, all from common rafters, and is 96 rings long. This is dated as spanning the years AD 1629 to AD 1724. Interpretation of the sapwood would suggest that the timbers represented have a felling date of AD 1724. Such a felling for timbers of the roof is in part supported by the dating of at least one, and possibly two, other samples individually.

The dating of a third sample individually provides some evidence for the use of timber that is estimated to have been felled in the period AD 1684 - AD 1709.

Thus, while the main structure of the barn appears to be mid-sixteenth century in date, the roof may have been replaced in the early eighteenth century.

Keywords

Dendrochronology
Standing Building

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Introduction

The barn at Manor Farm under consideration in this report lies in the centre of the village, set in north east Nottinghamshire (SK740749; Figs 1 and 2). Within its red brick and part stone rubble encasing lie the remains of six principal post with tiebeam trusses, producing a five-bay building. There is a, probably original, aisle range to the south side of the barn. The listing description proposes that the building is originally of eighteenth-century date, with nineteenth-century alterations. However, inspection by Jason Morden and Graham Beaumont of Nottinghamshire County Council's Heritage Team prior to conversion of the barn into dwellings suggests that, based on the architectural evidence (the cross-frames having unusual double down-braces), this is incorrect and that the building may actually date to the early seventeenth century or even earlier.

Sampling

Sampling and analysis by tree-ring dating of timbers from this building was commissioned by English Heritage. The purpose of this was to provide a precise date for the original timber framed structure and to establish whether or not the roof was of the same date, given that it displayed substantial evidence of repair and alteration. The results of analysis were to inform a possible listing upgrade from the barn's present grade II to grade II*.

Thus, after discussion with Graham Beaumont and Jason Morden, and in conjunction with the English Heritage brief, a total of twenty-seven cores samples was obtained. Sixteen samples were taken from the timbers of the main trusses and other framework, and eleven samples were taken from the common rafters of the roof.

Each sample was given the code ASK-A (for Askham, site "A") and numbered 01 - 27. The positions of these cores are shown on the drawing made and provided by Graham Beaumont. These are reproduced here as Figure 3a/b. Details of the samples are given in Table 1 and can be used in conjunction with the drawing to locate the timbers sampled. In this Table and the drawing all frames and other timbers are numbered and described on an east to west, or north to south, basis, as appropriate.

Analysis

Each of the twenty-seven samples was prepared by sanding and polishing. It was seen at this point that three samples had too few rings and these had to be rejected from analysis. The data of the twenty-four measured samples is given at the end of the report. These measured samples were then compared with each other by the Litton/Zainodin grouping procedure (see appendix). At a minimum t-value of 4.5 a single group of samples formed, the samples cross-matching with each other as shown in the bar diagram, Figure 4.

The growth-ring widths of the cross-matching samples were combined at their indicated relative off-set positions to form site chronology ASKASQ01 of length 101 rings. Site chronology ASKASQ01 was then compared with a series of relevant reference chronologies for oak. This indicated a cross-match when the date of the first ring of the site chronology is AD 1439 and the date of its last ring is AD 1539. Evidence for this dating is given in the t-values of Table 2.

Site chronology ASKASQ01 was then compared with the measured but ungrouped samples, but there was no further satisfactory cross-matching. Each of the ungrouped samples was then compared individually with a full range of reference chronologies.

This process indicated cross-matching and dating with satisfactory *t*-values for a further six samples, some of them with overlapping date spans, others with no, or insufficient, overlap for satisfactory cross-matching. By reducing the Litton/Zainodin grouping procedure to a *t*-value of 3.8, three of these six samples could be combined at relative positions consistent with their independent dating. Although such a *t*-value is lower than that normally used by this Laboratory, for the purposes of analysis the three dated and cross-matching samples were combined to form a second site chronology, ASKASQ02, of length 96 rings. Site chronology ASKASQ02 was then compared with a series of relevant reference chronologies for oak indicating a cross-match when the date of its first ring is AD 1629 and the date of its last ring is AD 1724. Evidence for this dating is given in the *t*-values of Table 3.

The relative positions of the three samples in site chronology ASKASQ02 are shown in the bar diagram, Figure 5. For illustrative purposes this bar diagram also shows the relative positions of the three other dated, but non cross-matching, samples at relative positions indicated by their independent dating and the dating of the site chronology. The *t*-values for the dating of the three individual samples are shown in Tables 4 – 6.

This analysis is summarised below:

Site chronology or sample	**Number of samples**	**Number of rings**	**Date span (where dated)**
ASKASQ01	14	101	AD 1439 – 1539
ASKASQ02	3	96	AD 1629 – 1724
ASK-A19	1	57	AD 1610 – 1672
ASK-A24	1	66	AD 1633 – 1698
ASK-A25	1	57	AD 1607 – 1663

<u>Interpretation</u>

Analysis by dendrochronology has produced two dated site chronologies, and dated three samples individually.

Site chronology ASKASQ01; Fig 4

The average heartwood/sapwood boundary date of the thirteen samples in site chronology ASKASQ01 where it exists, is AD 1526. If we use a 95% confidence limit for the amount of sapwood on mature oaks of 15 - 40 rings, this date would give the timbers represented an estimated felling date in the range AD 1541 – 66.

However, one sample in this group, ASK-A12, is from a timber which had complete sapwood, that is, it had the last ring produced by the tree before it was felled. This sample has the latest dated ring of any in this site chronology, AD 1539. Unfortunately a small amount of this sapwood, about 5mm, was lost during coring. It is estimated that such a loss represents at least 5, and at the very most 10, sapwood rings, indicating that the timber represented has a felling date of between AD 1544 and AD 1549. Given the consistency in the relative positions of the heartwood/sapwood boundaries on all the other samples in this group it is likely that this is the felling date for all the timbers too.

Site chronology ASKASQ02; Fig 5

One sample in site chronology ASKASQ02, ASK-A21, retains complete sapwood, with a date of AD 1724. The relative positions of the heartwood/sapwood boundaries on the other two samples in this group is indicative for this being their felling date also.

The individually dated samples, ASK-A19, A24, and A25; Fig 5

Three samples have been dated individually. It is estimated that one of these, ASK-A24, is from a timber with a felling date in the range AD 1713 to AD 1738. This date is based on the sample having a heartwood/sapwood boundary date of AD 1698 and using a 95% confidence limit for the amount of sapwood on mature oaks of 15 - 40 rings. It may be noticed that this is a felling date range within which falls the date for the felling of the timbers in site chronology ASKASQ02 (AD 1724). The timbers represented may therefore be contemporary.

It is estimated that sample ASK-A19 is from a timber with a felling date in the range AD 1684 to AD 1709, this date being based on it having a heartwood/sapwood boundary date of AD 1669 and using the same 95% confidence limit as above.

The felling date for the timber represented by sample ASK-A25, on the other hand, is not possible to estimate because it does not have the heartwood/sapwood boundary. It is unlikely, however, to be before AD 1678, given that its last ring is dated to AD 1663.

This interpretation can be summarised below;

Site chronology	Sampling area	Felling date (actual or estimated)
ASKASQ01	Primary structural timbers	AD 1544 - 49
ASKASQ02	Roof timbers (common rafters)	AD 1724
ASK-A19	(common rafter)	AD 1684 – 1709
ASK-A24	(common rafter)	AD 1713 – 1738
ASK-A25	(common rafter)	Not before AD 1678

Conclusion

Analysis by dendrochronology has produced two dated site chronologies, and dated three samples individually.

It is estimated that the primary structural phase of this building, represented by site chronology ASKASQ01, dates to the mid-sixteenth century, the timbers having a felling date of between AD 1544 and AD 1549. This is somewhat earlier than the early seventeenth-century date suggested on the basis of architectural style, and significantly earlier than that given in the current listing. A number of roof timbers on the other hand, are early eighteenth century, a small group of four, represented by samples ASK-A18, A21, A22 and A24, having been felled, it is estimated, in AD 1724. These timbers would represent a later repair phase.

Another timber, sample ASK-A19, appears to have been felled slightly earlier in the late-seventeenth or early- eighteenth century. A final dated timber, represented by ALF-A25, could be contemporary with either of these later felling phases, or belong to another phase entirely. The different felling dates identified from the roof timbers may represent different phases of repair or could indicate re-use of timber from the AD 1724 work

Four measured samples remain undated, ASK-A06, A08, A20, and A23. Two samples are a little short, with only 54 and 56 rings, but the others are certainly long enough for satisfactory analysis. None of the undated samples show any sign of distress or distortion etc that might make cross-matching difficult.

Bibliography

Baillie, M G L, and Pilcher, J R, 1982 unpubl A master tree-ring chronology for England, unpubl computer file *MGB-EOI,* Queens Univ, Belfast

Hillam, J, and Groves, C, 1996 *Tree-ring analysis of oak timbers from the roof of 3-3A Vicar's Court, Lincoln*, Anc Mon Lab Rep, **21/96**

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1984 unpubl site chronology from Worksop Manor, Worksop, Notts, unpubl computer file *WOR-H3*, Nottingham University Tree-Ring Dating Laboratory

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1992 List 44 no 6 - Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect,* **23**, 51 – 6

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1994 List 57 nos 7, 10a, 11b - Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect,* **25**, 36 – 40

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1995 unpubl site chronology from Cropwell Bishop, unpubl computer file *CRWBSQ03,* Nottingham University Tree-Ring Dating Laboratory

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1996 List 65 no 10 - Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect,* **27**, 78 – 81

Howard, R E, Laxton, R R, and Litton, C D, 1997 List 75 nos 8, 9 - Nottingham University Tree-Ring Dating Laboratory results, *Vernacular Architect,* **28**, 124 –7

Laxton, R R, and Litton, C D, 1988 An East Midlands master tree-ring chronology and its use for dating vernacular buildings, University of Nottingham, Dept of Classical and Archaeol Studies, Monograph Series, **III**

Tyers, I, 1999 unpubl England London, unpubl computer file *LON1175,* Sheffield Univ

Table 1: Details of samples from Manor Farm, Askham, Nottinghamshire

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Structural timbers (primary phase)					
ASK-A01	Tiebeam, posts 1 - 2	84	3	AD 1448	AD 1528	AD 1531
ASK-A02	Aisle plate, posts 4 - 6	61	5	AD 1467	AD 1522	AD 1527
ASK-A03	Brace from post 4 to aisle plate	75	h/s	AD 1453	AD 1527	AD 1527
ASK-A04	Tiebeam, posts 3 - 4	79	2	AD 1447	AD 1523	AD 1525
ASK-A05	Post 4	74	no h/s	AD 1447	------	AD 1520
ASK-A06	Post 6	84	h/s	------	------	------
ASK-A07	Aisle plate, posts 6 - 8	56	2	AD 1474	AD 1527	AD 1529
ASK-A08	Tiebeam, posts 7 - 8	54	h/s	------	------	------
ASK-A09	Wall plate, posts 7 - 9	81	h/s	AD 1446	AD 1526	AD 1526
ASK-A10	Post 10	74	1	AD 1455	AD 1527	AD 1528
ASK-A11	Brace from post 10 to tiebeam	81	h/s	AD 1444	AD 1524	AD 1524
ASK-A12	Brace from post 10 to aisle plate	81	17c	AD 1459	AD 1522	AD 1539
ASK-A13	Tiebeam, posts 9 - 10	73	h/s	AD 1461	AD 1533	AD 1533
ASK-A14	Tiebeam, posts 11 - 12	83	h/s	AD 1445	AD 1527	AD 1527
ASK-A15	Brace from post 12 to tiebeam	78	h/s	AD 1449	AD 1526	AD 1526
ASK-A16	Post 12	88	1	AD 1439	AD 1525	AD 1526

Table 1 continued

Sample number	Sample location	Total rings	*Sapwood rings	First measured ring date	Last heartwood ring date	Last measured ring date
	Roof timbers (later phase)					
ASK-A17	South rafter, frame 3	nm	---	------	------	------
ASK-A18	South rafter, frame 5	54	h/s	AD 1640	AD 1693	AD 1693
ASK-A19	South rafter, frame 4	57	3	AD 1610	AD 1669	AD 1672
ASK-A20	South rafter, frame 6	56	no h/s	------	------	------
ASK-A21	South rafter, frame 7	88	23C	AD 1637	AD 1701	AD 1724
ASK-A22	South rafter, frame 17	79	3	AD 1629	AD 1704	AD 1707
ASK-A23	South rafter, frame 21	56	5	------	------	------
ASK-A24	South rafter, frame 22	66	h/s	AD 1633	AD 1698	AD 1698
ASK-A25	South rafter, frame 23	57	no h/s	AD 1607	------	AD 1663
ASK-A26	Hip rafter, frame 7	nm	---	------	------	------
ASK-A27	Hip rafter, frame 8	nm	---	------	------	------

*h/s = the heartwood/sapwood boundary is the last ring on the sample
c = complete sapwood on timber, all or part lost from sample during coring
C = complete sapwood retained on sample, last ring date is felling date of tree

Table 2: Results of the cross-matching of site chronology ASKASQ01and relevant reference chronologies when first ring date is AD 1439 and last ring date is AD 1539

Reference chronology	Span of chronology	*t*-value	
East Midlands	AD 882 – 1981	8.4	(Laxton and Litton 1988)
St Hugh's Choir, Lincoln Cathedral	AD 1575 – 1724	7.3	(Laxton and Litton 1988)
England	AD 401 – 1981	6.7	(Baillie and Pilcher 1982 unpubl)
White Farm, South Leverton, Notts	AD 1399 – 1506	6.6	(Howard *et al* 1994)
Lowdham Old Hall, Lowdham, Notts	AD 1422 – 1527	6.1	(Howard *et al* 1997)
White House, Blythe, Notts	AD 1453 – 1595	5.5	(Howard *et al* 1994)
Worksop Manor, Worksop, Notts	AD 1431 – 1568	5.7	(Howard *et al* 1984 unpubl)
England London	AD 413 – 1728	5.2	(Tyers 1999 unpubl)

Table 3: Results of the cross-matching of site chronology ASKASQ02 (samples ASK-A18, A21, and A22 only) and relevant reference chronologies when first ring date is AD 1629 and last ring date is AD 1724

Reference chronology	Span of chronology	*t*-value	
Cropwell Bishop, Notts	AD 1604 – 1703	7.5	(Howard *et al* 1995 unpubl)
Old Barn, Stratford upon Avon, Warwicks	AD 1591 – 1735	7.4	(Howard *et al* 1996)
Brewhouse Yard, Nottingham	AD 1544 – 1701	7.2	(Howard *et al* 1994)
Ragnall barn, Ragnall, Notts	AD 1607 – 1717	6.3	(Howard *et al* 1997)
East Midlands	AD 882 – 1981	6.1	(Laxton and Litton 1988)
St Hugh's Choir, Lincoln Cathedral	AD 1575 – 1724	5.0	(Laxton and Litton 1988)
England	AD 401 – 1981	4.4	(Baillie and Pilcher 1982 unpubl)

Table 4: Results of the cross-matching of sample ASK-A19 and relevant reference chronologies when first ring date is AD 1616 and last ring date is AD 1672

Reference chronology	Span of chronology	*t*-value	
Lincoln, Vicar's Court	AD 1573 – 1663	7.9	(Hillam and Groves 1996)
East Midlands	AD 882 – 1981	5.6	(Laxton and Litton 1988)
England	AD 401 – 1981	5.3	(Baillie and Pilcher 1982 unpubl)
Cropwell Bishop, Notts	AD 1604 – 1703	4.7	(Howard *et al* 1995 unpubl)
Old Barn, Stratford upon Avon, Warwicks	AD 1591 – 1735	4.7	(Howard *et al* 1996)
Brewhouse Yard, Nottingham	AD 1544 – 1701	4.4	(Howard *et al* 1994)
Ragnall barn, Ragnall, Notts	AD 1607 – 1717	4.4	(Howard *et al* 1997)
England London	AD 413 – 1728	4.3	(Tyers 1999 unpubl)

Table 5: Results of the cross-matching of sample ASK-A24 and relevant reference chronologies when first ring date is AD 1633 and last ring date is AD 1698

Reference chronology	Span of chronology	*t*-value	
Home Farm, Formark, Derbys	AD 1605 – 1752	7.9	(Howard *et al* 1992)
Cropwell Bishop, Notts	AD 1604 – 1703	5.7	(Howard *et al* 1995 unpubl)
St Hugh's Choir, Lincoln Cathedral	AD 1575 – 1724	4.7	(Laxton and Litton 1988)
Angel Choir, Lincoln Cathedral	AD 1576 – 1669	4.7	(Laxton and Litton 1988)
Ragnall barn, Ragnall, Notts	AD 1607 – 1717	4.3	(Howard *et al* 1997)

Table 6: Results of the cross-matching of sample ASK-A25 and relevant reference chronologies when first ring date is AD 1607 and last ring date is AD 1663

Reference chronology	Span of chronology	*t*-value	
Home Farm, Formark, Derbys	AD 1605 – 1752	7.9	(Howard *et al* 1992)
Old Barn, Stratford upon Avon, Warwicks	AD 1591 - 1735	6.1	(Howard *et al* 1996)
Lincoln, Vicar's Court	AD 1573 – 1663	5.7	(Hillam and Groves 1996)
Cropwell Bishop, Notts	AD 1604 – 1703	5.7	(Howard *et al* 1995 unpubl)
St Hugh's Choir, Lincoln Cathedral	AD 1575 – 1724	5.2	(Laxton and Litton 1988)
East Midlands	AD 882 – 1981	4.5	(Laxton and Litton 1988)
Ragnall barn, Ragnall, Notts	AD 1607 – 1717	4.3	(Howard *et al* 1997)
Angel Choir, Lincoln Cathedral	AD 1576 – 1669	3.8	(Laxton and Litton 1988)

Figure 1: Map to show general location of Askham

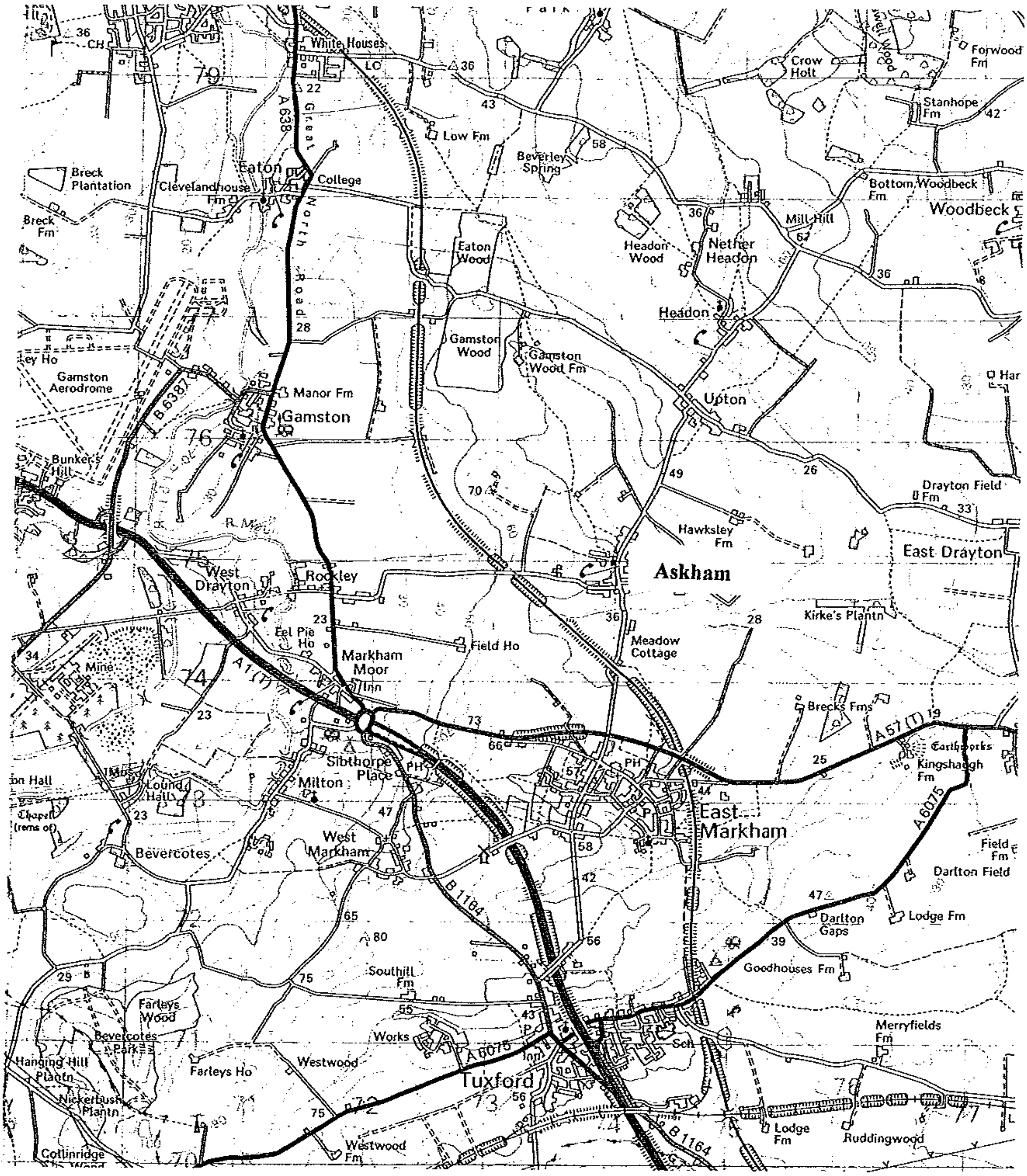


Figure 2: Map to show general location of Manor Farm

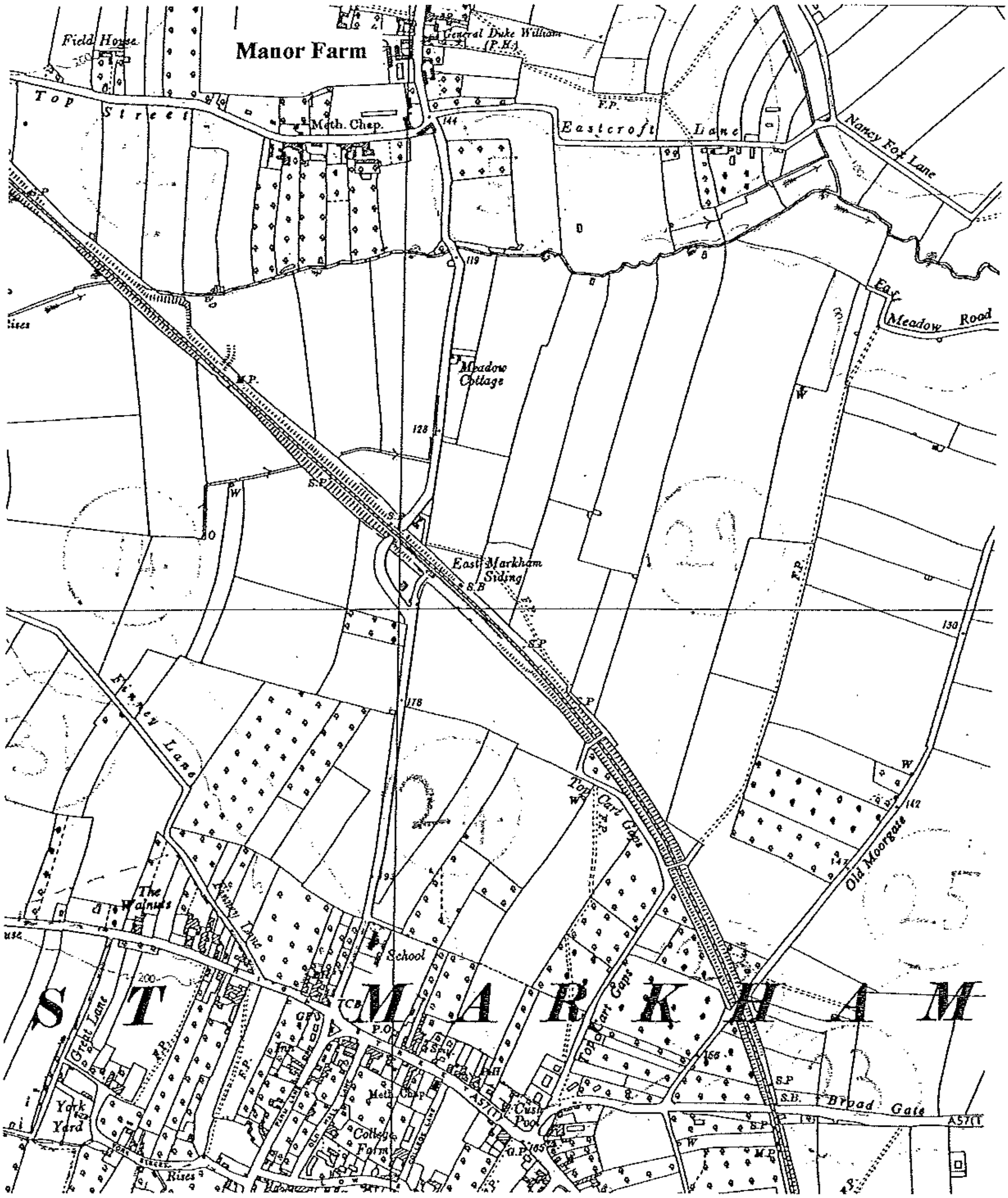


Figure 3a: Drawing to show location of samples from main timbers

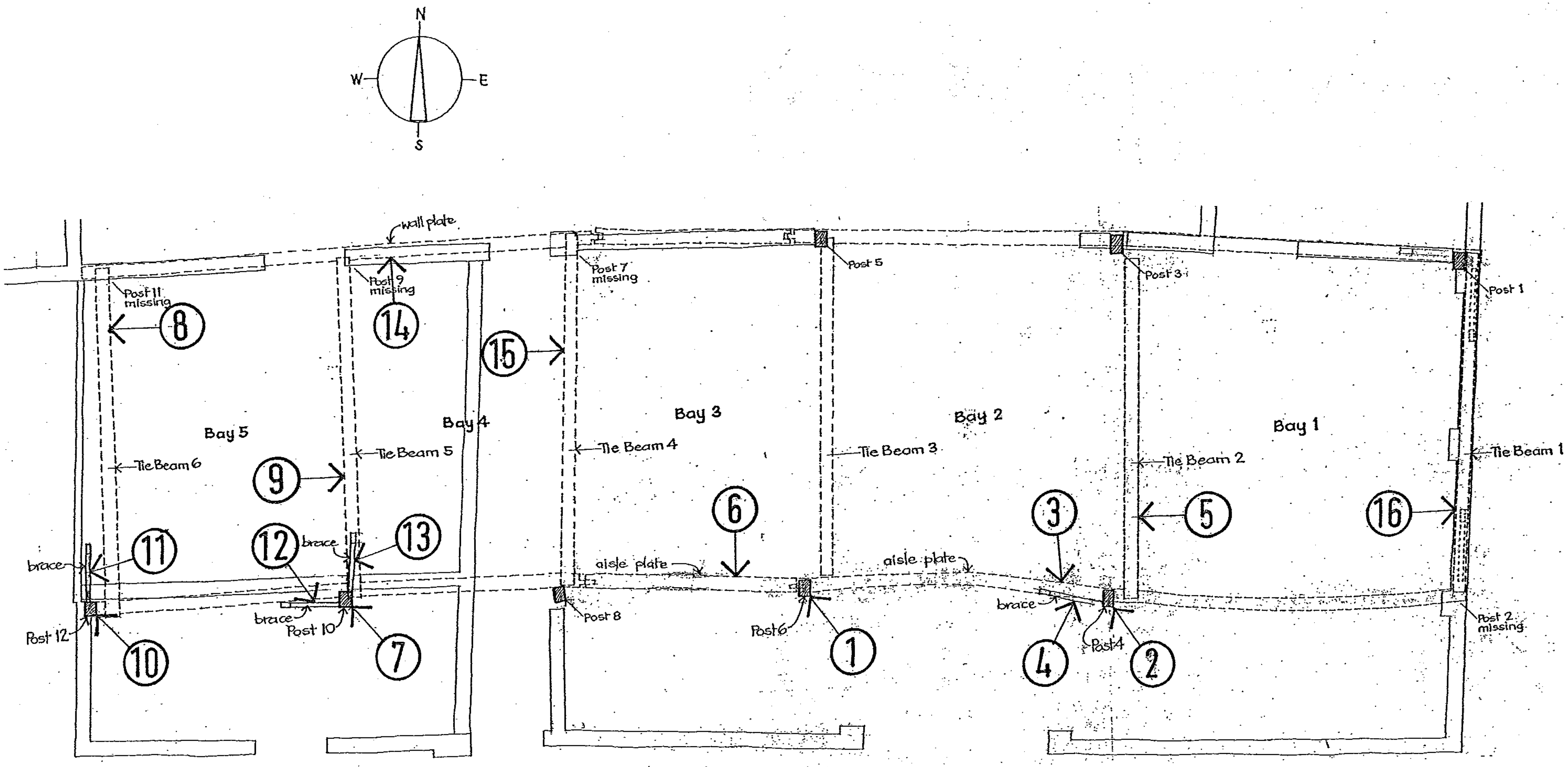


Figure 3b: Drawing to show location of samples from roof timbers

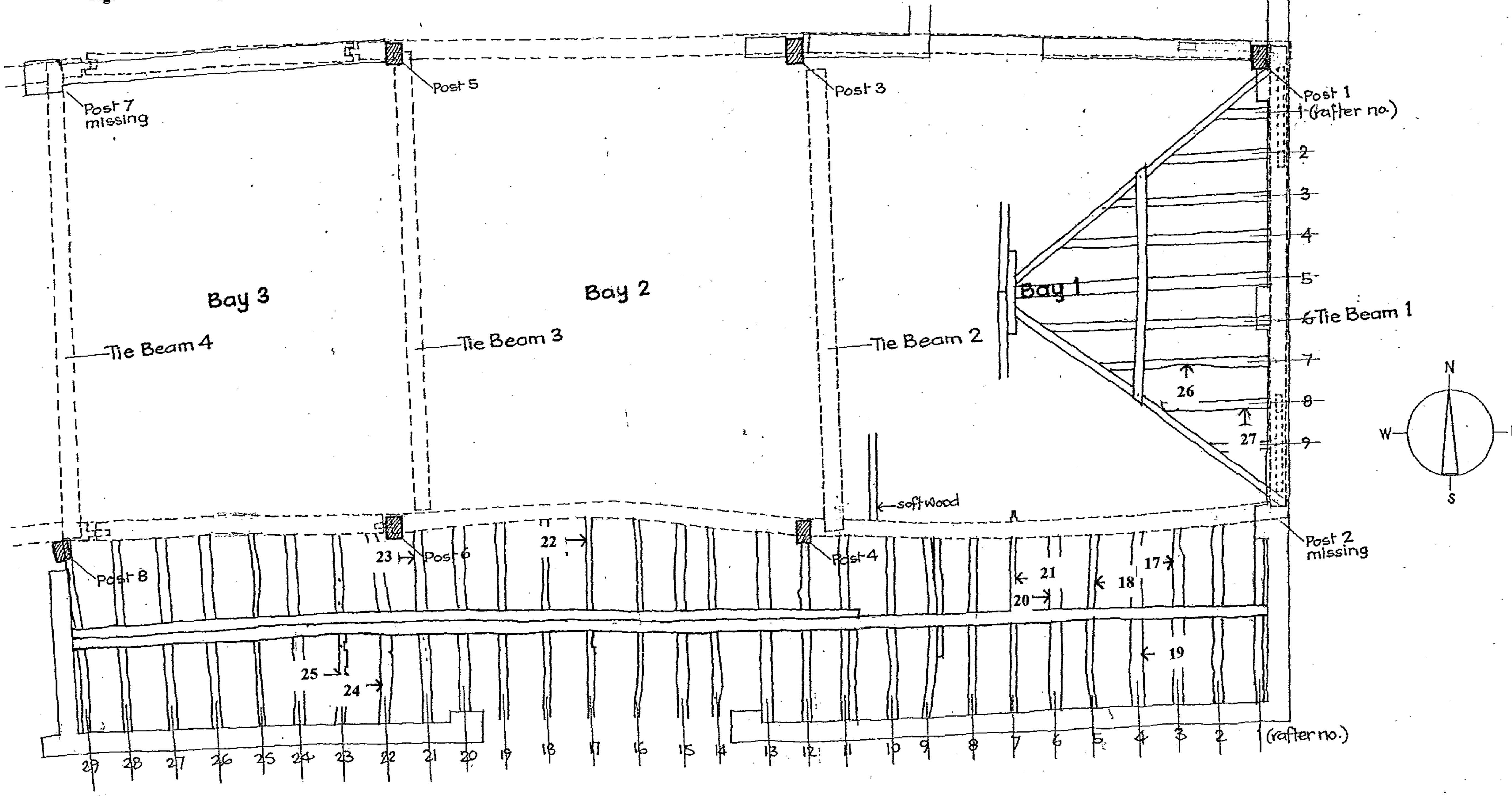
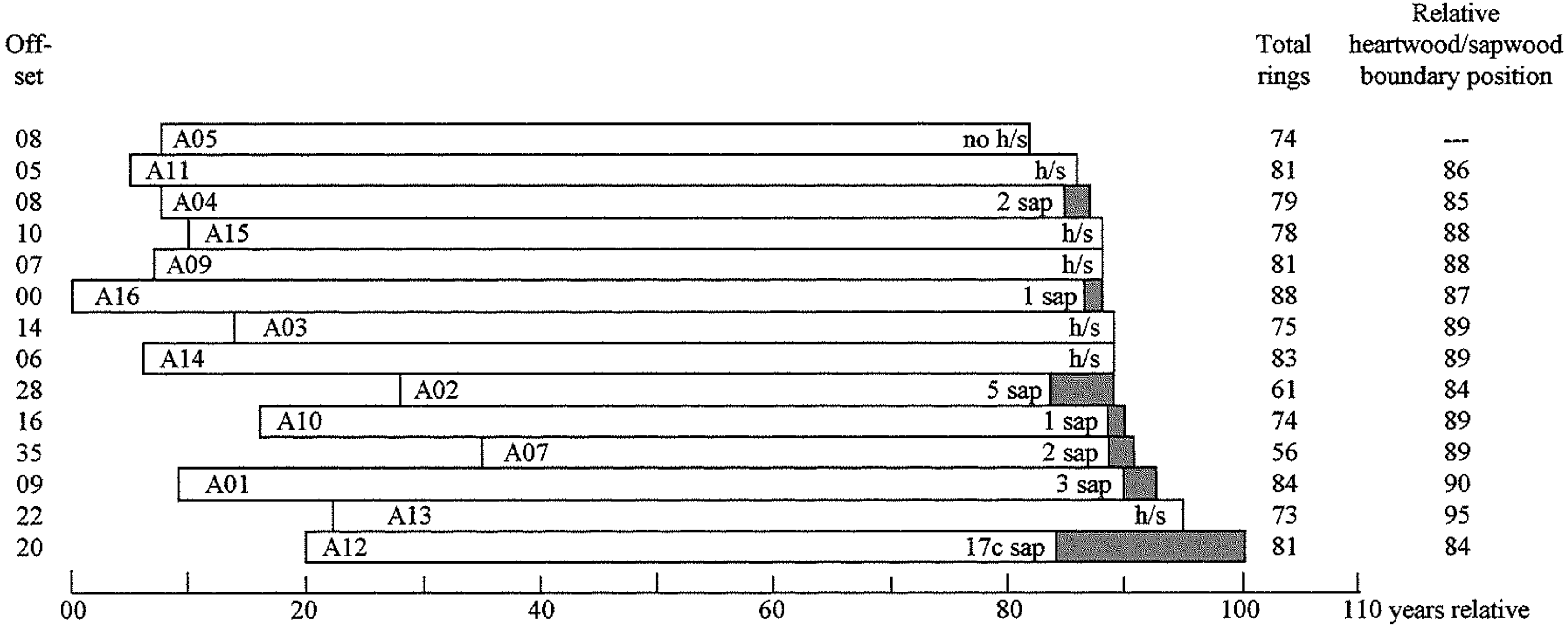
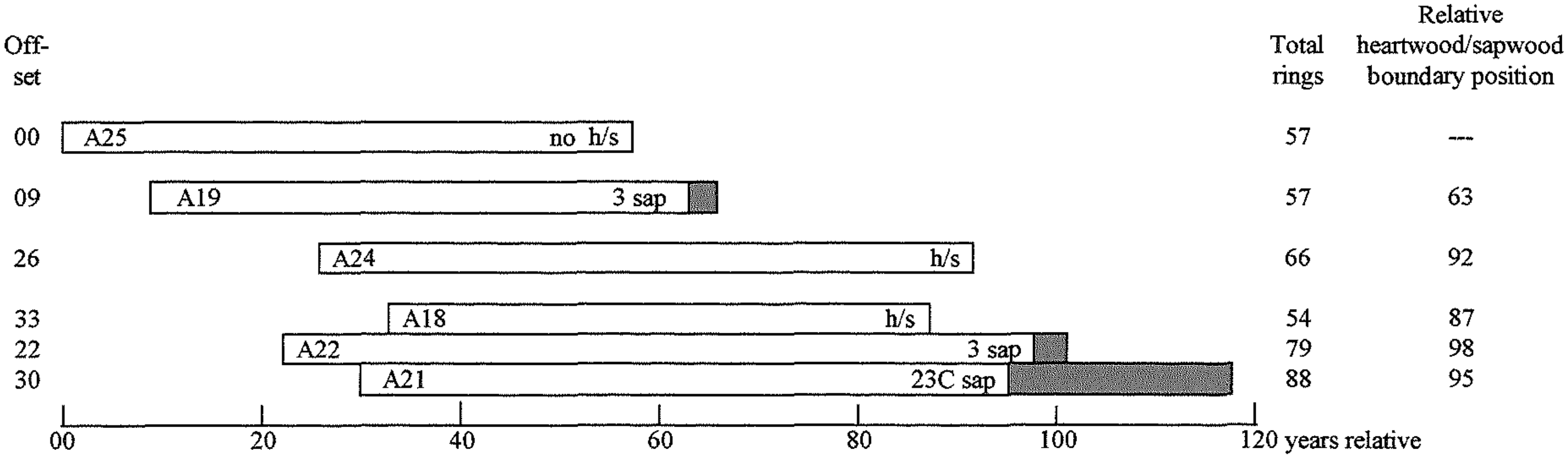


Figure 4: Bar diagrams of the samples in site chronology ASKASQ01



white bars = heartwood rings, shaded area = sapwood rings
h/s = heartwood/sapwood boundary is last ring on sample
c = complete sapwood on sample, all or part lost during sampling

Figure 5: Bar diagrams of the samples in site chronology ASKASQ02 (ASK-A18, A21, and A22), plus independently dated samples, all shown at relative off-set positions in relation to indicated dating



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

Data of measured samples – measurements in 0.01 mm units

ASK-A01A 84
409 355 324 449 413 257 354 394 342 361 314 353 313 214 227 233 193 180 205 242
229 150 208 213 212 207 215 247 178 123 118 189 169 223 174 210 152 144 142 180
147 177 239 142 147 174 175 121 205 128 92 135 136 85 97 110 121 184 228 223
152 172 190 163 192 204 180 195 190 119 163 241 151 200 205 148 137 112 148 185
249 152 144 153
ASK-A01B 84
320 375 311 416 418 239 338 399 360 353 316 349 319 211 227 219 183 196 191 252
178 147 197 222 203 226 196 245 170 120 110 196 169 227 174 214 175 142 130 175
167 195 206 155 139 173 160 143 203 150 98 134 146 68 97 117 119 185 220 219
137 161 194 171 192 207 176 209 179 122 165 243 159 193 204 145 137 113 142 199
226 154 157 144
ASK-A02A 61
453 360 411 434 306 300 301 315 357 310 266 207 246 247 206 202 209 148 141 128
177 137 195 158 136 135 163 213 195 178 127 90 96 105 119 128 115 139 168 228
157 111 128 96 116 138 185 196 163 119 111 130 138 116 145 145 121 107 106 179
201
ASK-A02B 61
478 356 403 416 324 303 283 305 364 285 252 244 259 222 203 206 185 160 118 128
186 176 189 162 127 126 175 238 199 179 137 99 84 106 124 134 108 123 179 229
174 119 114 98 108 145 176 199 166 113 98 131 141 117 145 145 119 98 116 173
200
ASK-A03A 75
147 313 336 286 241 332 295 288 224 263 232 171 182 183 260 245 190 309 220 149
174 232 298 158 150 137 248 204 249 204 235 166 143 155 225 198 172 143 123 172
165 164 185 258 116 98 122 108 66 79 100 143 164 251 217 158 173 151 174 188
170 142 132 154 154 227 232 141 162 141 123 111 74 117 159
ASK-A03B 75
132 303 324 301 250 333 301 316 224 260 230 172 191 175 259 250 183 300 237 146
180 237 296 158 146 139 252 202 251 192 207 189 125 153 250 184 185 154 125 173
171 164 188 255 116 96 117 129 51 78 97 149 173 263 216 155 185 139 182 181
175 135 139 157 150 224 225 129 184 148 109 96 84 123 162
ASK-A04A 79
357 318 296 260 292 258 349 319 349 357 395 388 358 252 248 269 269 202 249 262
232 170 181 225 152 150 132 151 206 147 148 116 153 142 159 112 124 122 96 158
198 143 189 218 158 203 178 210 240 316 181 153 204 232 175 127 170 205 141 170
208 172 243 246 319 428 299 310 225 238 189 319 387 273 207 219 202 197 223
ASK-A04B 79
433 340 302 243 278 279 350 341 331 368 398 381 355 253 231 249 265 214 252 262
234 181 187 218 148 145 139 152 198 143 154 123 158 152 174 108 130 126 102 141
193 142 186 192 159 197 183 200 245 318 189 153 210 234 168 128 181 199 160 163
213 131 265 237 305 437 264 299 258 266 204 302 390 280 204 214 207 201 196
ASK-A05A 69
306 330 435 258 413 335 258 182 160 185 170 171 151 153 162 183 157 109 154 142
119 161 162 200 130 168 164 177 225 233 220 202 173 123 143 184 142 139 130 98
121 168 158 186 165 146 131 119 121 146 131 140 152 166 180 126 145 184 151 197
199 183 192 164 136 122 160 192 206

ASK-A05B 74
402 368 459 358 400 314 324 435 262 407 339 260 185 161 180 171 166 154 147 163
181 168 107 156 143 121 161 161 199 136 169 168 182 216 226 216 206 169 131 132
194 136 144 130 92 114 170 165 179 170 134 140 118 118 156 129 137 156 162 178
124 150 176 160 194 198 188 185 170 145 125 151 178 234
ASK-A06A 84
287 294 386 262 344 319 249 278 272 478 896 836 706 364 443 476 381 252 340 314
391 368 318 288 266 279 326 313 276 253 315 190 211 230 242 199 225 266 291 257
247 236 239 260 340 257 297 265 336 260 243 248 261 185 220 204 174 261 237 230
304 243 245 206 249 191 158 250 236 243 227 230 272 290 216 158 190 200 139 169
183 133 128 169
ASK-A06B 84
256 267 385 261 353 328 232 281 280 431 870 797 704 351 446 477 381 243 351 310
383 373 316 286 273 288 327 296 282 256 276 194 222 265 210 208 195 235 297 275
213 226 233 230 339 244 283 279 327 261 247 249 262 194 221 193 173 259 252 222
311 241 245 196 247 185 162 245 227 256 233 219 274 303 226 169 185 193 141 156
199 137 158 176
ASK-A07A 56
379 584 388 247 191 162 207 304 327 184 164 185 228 371 263 282 248 131 188 223
199 241 385 167 145 187 317 172 258 240 393 287 216 242 113 116 179 191 355 298
238 181 161 124 272 268 184 148 171 108 109 110 160 159 197 178
ASK-A07B 56
398 572 394 204 208 177 200 293 280 207 177 190 222 382 265 288 232 151 183 220
241 222 356 190 156 177 305 180 256 240 405 315 230 232 114 110 198 185 335 303
261 171 167 127 269 249 193 146 164 104 110 112 164 158 198 149
ASK-A08A 54
245 343 298 283 285 259 226 258 234 224 164 205 118 261 228 189 153 168 106 101
273 270 374 207 258 213 136 297 376 451 473 492 327 326 303 295 355 235 292 264
131 225 257 278 173 161 204 157 146 146 132 163 176 179
ASK-A08B 54
251 343 306 283 287 254 222 252 239 224 157 209 125 256 230 193 150 165 107 106
256 257 375 202 253 207 151 301 394 461 466 505 334 336 303 306 367 250 297 250
127 236 261 250 172 169 204 132 147 157 156 100 129 167
ASK-A09A 81
194 255 328 312 226 320 274 243 327 323 297 287 320 259 138 170 257 242 179 216
290 265 190 135 208 192 173 136 172 227 138 188 258 309 255 255 270 203 178 171
171 226 234 189 214 149 165 177 209 252 249 151 144 175 205 184 165 168 162 210
223 187 150 149 162 131 122 133 125 122 122 118 111 130 115 163 147 116 142 107
182
ASK-A09B 81
228 242 311 314 201 328 263 234 325 319 304 310 332 248 148 181 255 241 176 210
293 246 181 140 202 187 177 137 168 230 134 198 248 291 257 258 272 212 177 172
167 223 236 185 218 144 163 180 209 261 254 152 141 180 204 177 160 171 168 195
218 185 156 143 167 135 123 117 127 123 125 115 112 126 127 168 157 116 143 110
156
ASK-A10A 74
410 551 446 392 355 348 146 142 260 190 322 390 361 331 206 338 299 369 336 358
482 348 372 315 340 274 371 410 317 176 265 340 461 301 300 288 154 325 404 238
227 315 147 201 178 219 148 184 141 186 141 240 120 131 201 172 204 294 185 155
162 168 100 153 322 183 155 191 157 121 95 145 178 213

ASK-A10B 74
421 545 448 361 386 335 150 132 277 184 315 394 355 330 215 341 293 377 324 383
450 353 376 315 333 272 350 391 330 187 252 321 440 321 294 301 157 316 370 224
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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.

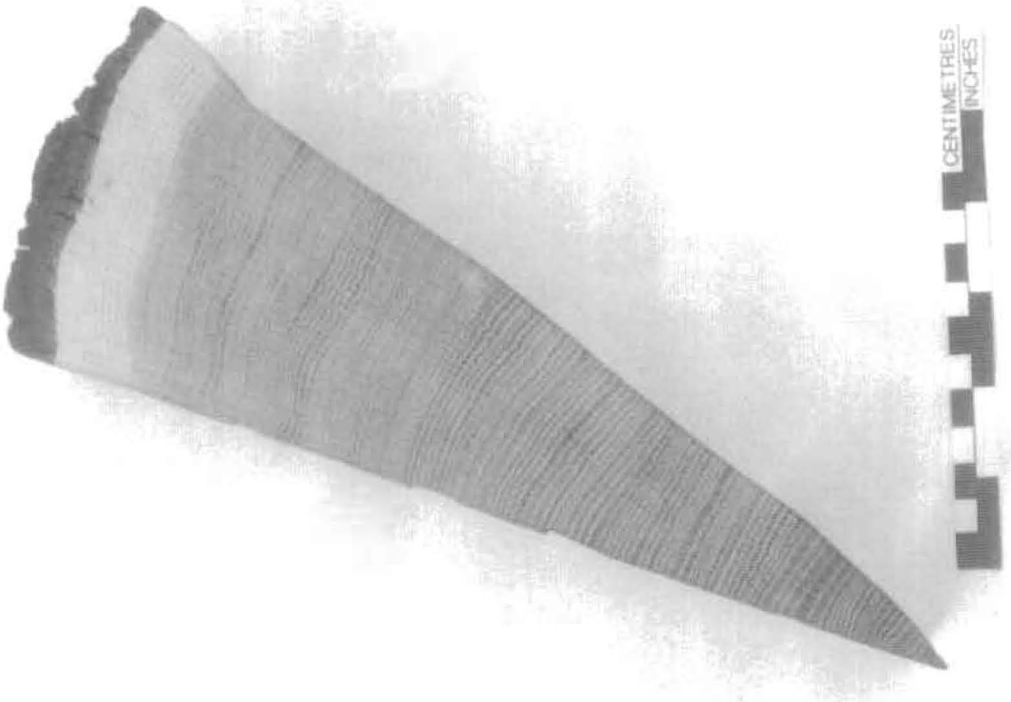

Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976.

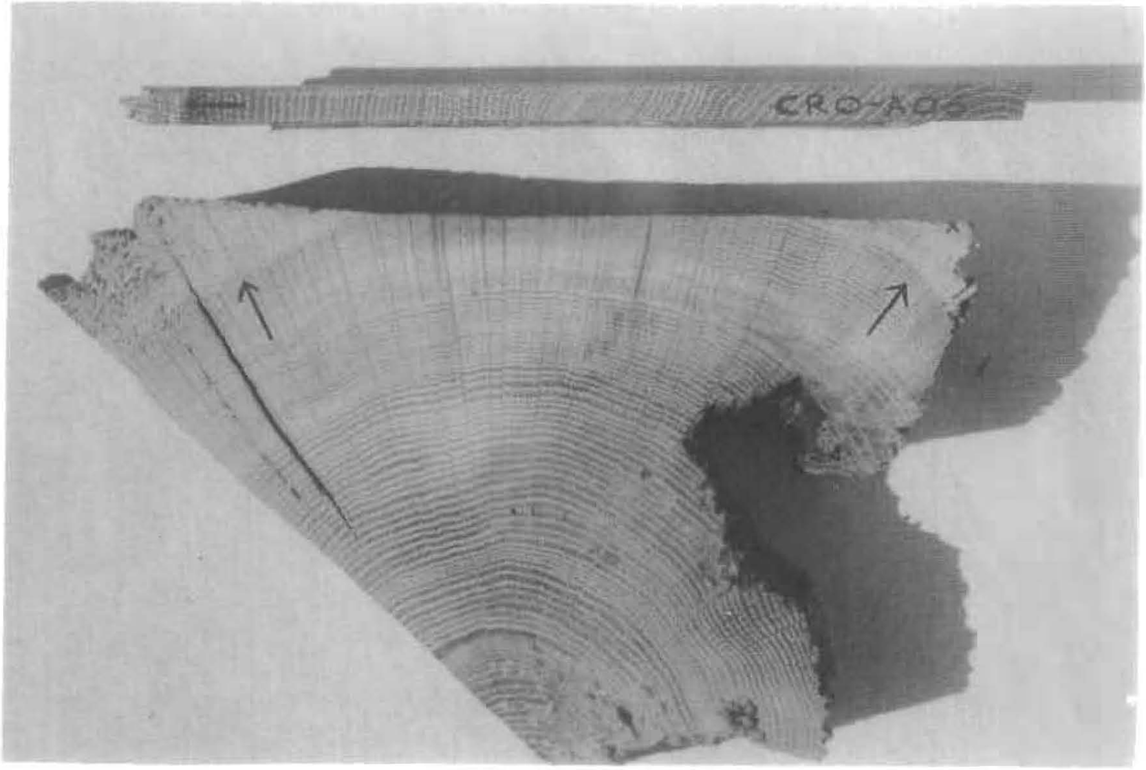

Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the corners, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

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.

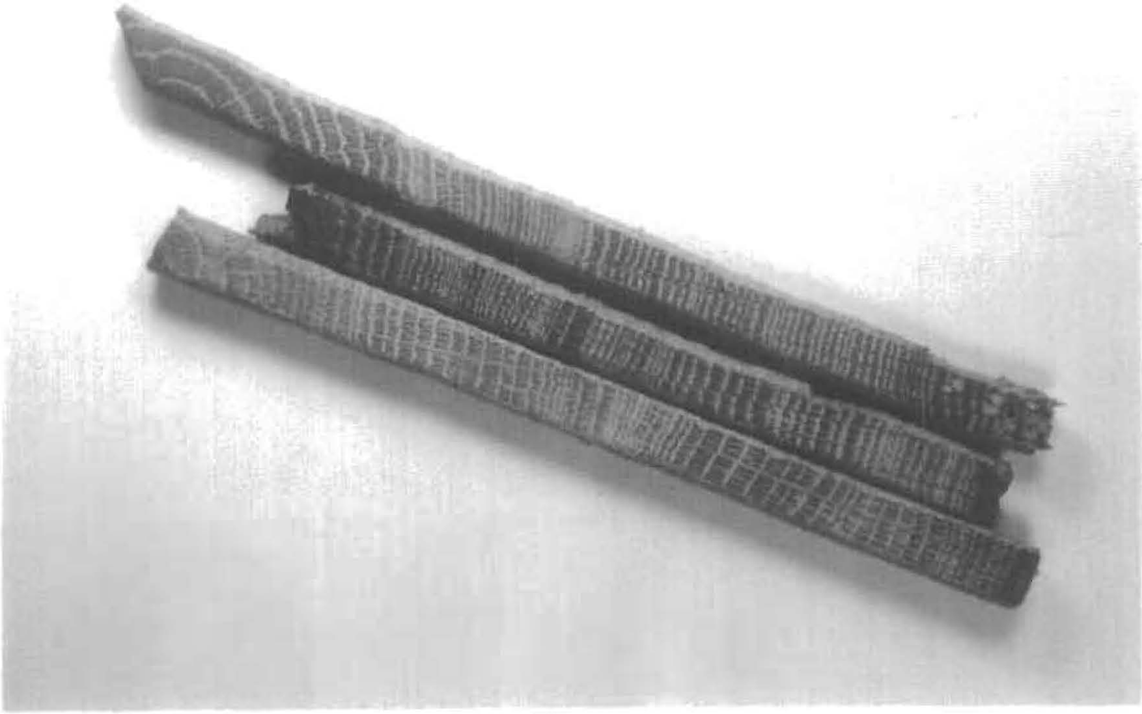

Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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

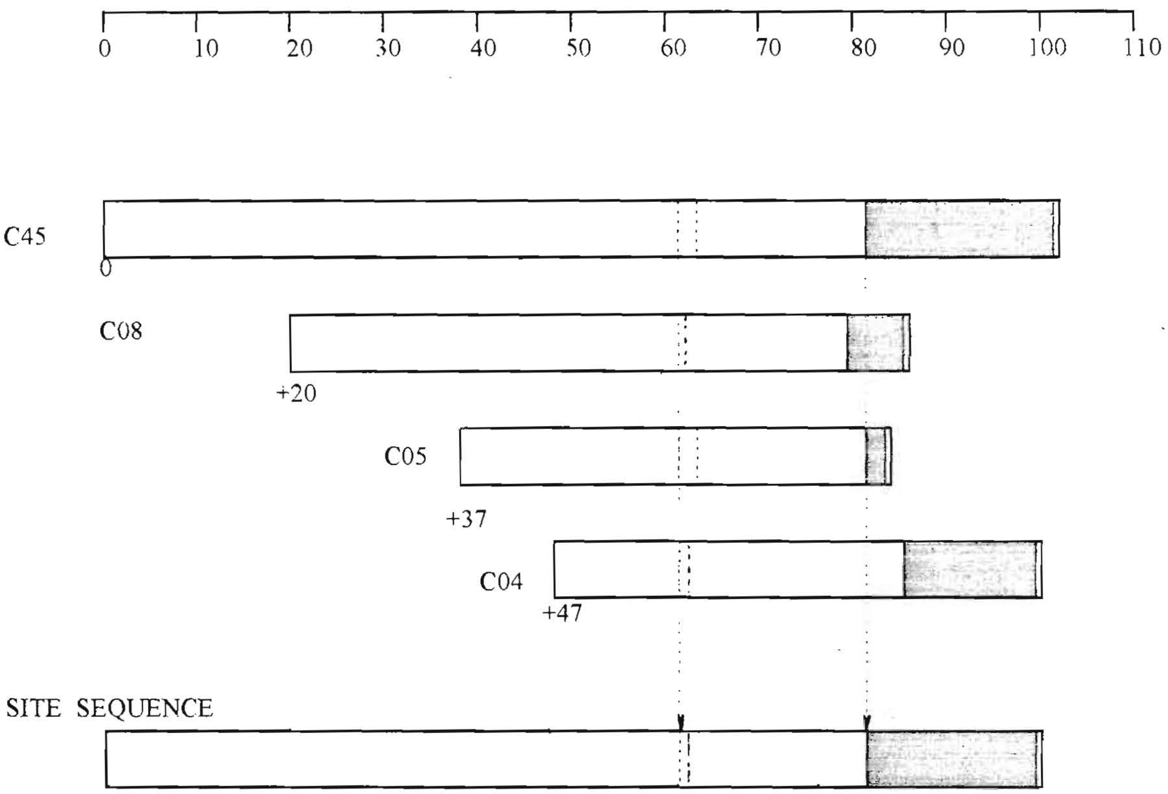

Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.
The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set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

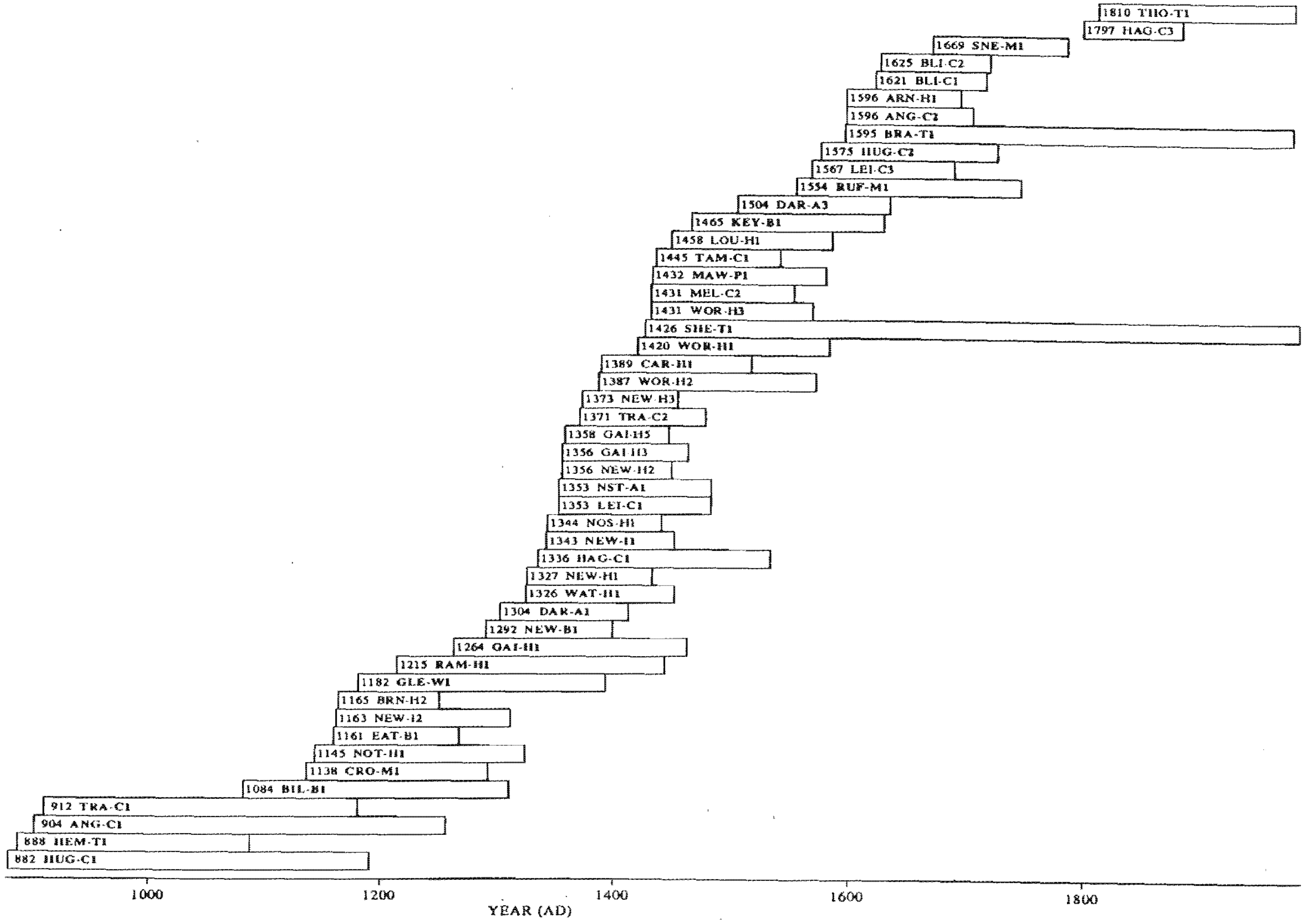

Fig 6. Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87.

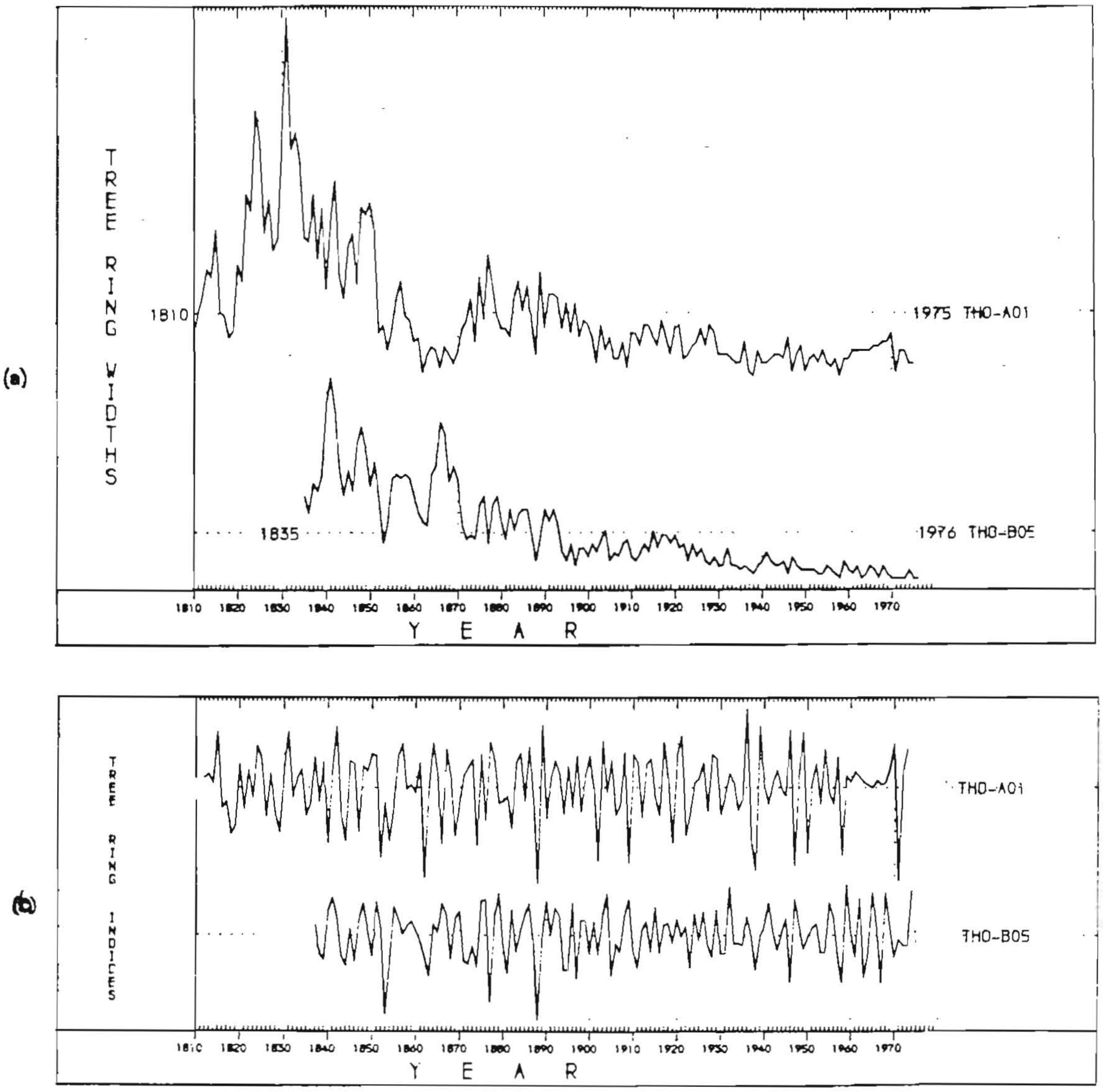

Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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

REFERENCES

Baillie, M G L, 1982 *Tree-Ring Dating and Archaeology*, London.

Baillie, M G L, 1995 *A Slice Through Time*, London

Baillie, M G L, and Pilcher, J R, 1973, A simple cross-dating program for tree-ring research, *Tree-Ring Bulletin*, **33**, 7-14

Hillam, J, Morgan, R A, and Tyers, I, 1987, Sapwood estimates and the dating of short ring sequences, *Applications of tree-ring studies*, BAR Int Ser, **3**, 165-85

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1984-95, Nottingham University Tree-Ring Dating Laboratory Results, *Vernacular Architecture*, **15 - 26**

Hughes, M K, Milson, S J, and Legett, P A, 1981 Sapwood estimates in the interpretation of tree-ring dates, *J Archaeol Sci*, **8**, 381-90

Laxton, R R, Litton, R R, and Zainodin, H J, 1988a An objective method for forming a master ring-width sequence, *P A C T*, **22**, 25-35

Laxton, R R, and Litton, C D, 1988b *An East Midlands Master Chronology and its use for dating vernacular buildings*, University of Nottingham, Department of Archaeology Publication, Monograph Series III

Laxton, R R, and Litton, C D, 1989 Construction of a Kent Master Dendrochronological Sequence for Oak, A.D. 1158 to 1540, *Medieval Archaeol*, **33**, 90-8

Litton, C D, and Zainodin, H J, 1991 Statistical models of Dendrochronology, *J Archaeol Sci*, **18**, 429-40

Pearson, S, 1995 *The Medieval Houses of Kent, An Historical Analysis*, London

Rackham, O, 1976 *Trees and Woodland in the British Landscape*, London