RESEARCH DEPARTMENT REPORT SERIES no. 45/2007 ISSN 1749-8775

NETHERHALL BARN, DALTON, HUDDERSFIELD, WEST YORKSHIRE
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

ARCHAEOLOGICAL SCIENCE

ENGLISH HERITAGE

Research Department Report Series 45/2007

Netherhall Barn, Dalton, Huddersfield, West Yorkshire Tree-Ring Analysis of Timbers

Alison Arnold and Robert Howard

ISSN 1749-8775

Research Department Report Series 45/2007

Netherhall Barn, Dalton, Huddersfield, West Yorkshire
Tree-Ring Analysis of Timbers

Alison Arnold and Robert Howard

Summary

Dendrochronological analysis undertaken on ten samples from the roof structure of this building has resulted in the construction and dating of two site sequences and the individual dating of two samples.

Site sequence NTHBSQ01, of 74 rings, contains three samples and spans the period AD 1356–1429.
Site sequence NTHBSQ02, of 78 rings, contains four samples and spans the period AD 1376–1453.

Samples NTH-B01 and NTH-B06 were dated individually to the periods AD 1386–1433 and AD 1379–1451, respectively.

Two of these dated samples were felled in AD 1453 with interpretation of the heartwood/sapwood boundary of the other seven samples suggesting that these were also felled at this time.

Tree-ring analysis has shown this barn to be constructed with timbers felled in AD 1453 and confirms the survival of many of the medieval timbers.

Keywords

Dendrochronology
Standing Building

Author's Address
Nottingham Tree-Ring Dating Laboratory, 20 Hillcrest Grove, Sherwood, Nottingham, NG5 1FT.
Telephone:0115 9603833. Email: alisonjarnold@hotmail.com, roberthoward10@hotmail.com

Introduction

Netherhall Barn is a medieval timber-framed aisled barn, now used as a riding stables and residence (Fig 1; SE165 177). It has seven bays, with the northern bays being replaced, probably in the nineteenth century. It is 23m long and 10.5m wide. The roof is of common rafter type with single side purlins supported by raked queen struts. The arcade plate is stop splayed, scarfed with diminished bridled butts, two edge pins and one face key. It has arch braces and wind braces to arcade plates (Figs 2–4). The outside walls are stone-clad and the roof is composed of stone slabs, probably dating from the seventeenth century. The extant medieval parts were thought to be restricted to the timber arcade posts set on stone bases (Fig 4) and some of the roof beams.

The northern part of the barn has been adapted to provide stalls for animals and the central part has an inserted floor providing a hay loft above and storage space below. The south end of the barn has been completely partitioned off to form a residence which consists of three rooms. The central room has a fireplace bearing the date AD 1631.

The barn is to receive grant-aid for repairs and tree-ring analysis was requested to determine the date of construction. Sampling and analysis by tree-ring dating was commissioned and funded by English Heritage.

Acknowledgements

The Laboratory would like to thank Richard Jaques of English Heritage for his assistance with access and advice, and for providing drawings of the building (Figs 2 and 6–8). Adele Clayton, owner of the riding stables, kindly agreed to allow access for sampling.

Sampling

The timbers of the northernmost bays are replacements, probably from the nineteenth century, whilst the southernmost bays have been converted to residential use. Therefore, sampling was restricted to the central bays of the building. A total of 13 timbers was sampled, with each being given the code NTH-B (for Netherhall Barn) and numbered 01–13. The position of each sample was noted at the time of sampling and has been marked on Figures 6–8. Further details relating to all samples can be found in Table 1.

Analysis and Results

At this stage it was noticed that three of the samples (two from rafters, NTH-B08 and NTH-B10, and NTH-B12 from a brace) had too few rings for secure dating, and so these were rejected prior to measurement. The remaining ten 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. All ten samples were compared with each other by the Litton/Zainodin grouping procedure (see appendix).

At a least value of t=4.5, seven samples had formed two groups. Firstly, three samples matched and were combined at the relevant offset positions to form NTHBSQ01, a site sequence of 74 rings (Fig 9). This site sequence was then compared with a large number of relevant reference chronologies for oak indicating a consistent match when the date of its first ring is AD 1356 and of its last measured ring is AD 1429. The evidence for this dating is given by the t-values in Table 2.

Four samples matched and were combined at the relevant offset positions to form NTHBSQ02, a site sequence of 78 rings (Fig 9). This site sequence was again compared with a large number of relevant reference chronologies where it was found to match at a first-ring date of AD 1376 and a last-ring date of AD 1453. The evidence for this dating is given by the t-values in Table 3.

Attempts to date the remaining three ungrouped samples resulted in sample NTH-B01 being matched at a first-ring date of AD 1386 and a last-ring date of AD 1433 and sample NTH-B06 being found to span the period AD 1379–1451. The evidence for these dates is given in Tables 4 and 5. Sample NTH-B07 could not be matched and remains undated.

Interpretation

Analysis of ten samples taken from the structural timbers of this barn has resulted in the successful dating of nine samples. Two of these samples (NTH-B05 and NTH-B13) have complete sapwood and the last-measured ring date of AD 1453, the felling date of the timbers represented. All seven other dated samples have the heartwood/sapwood boundary ring, which is broadly contemporary, suggestive of a single felling. The average of these is AD 1431, allowing an estimated felling date to be calculated for the seven timbers represented to within the range AD 1452–71 (this allows for sample NTH-B06 having a last measured ring date of AD 1451 with incomplete sapwood). This felling date range is consistent with a felling of AD 1453.

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

Discussion

The tree-ring analysis has resulted in the dating of nine of the structural timbers of this barn. Two of these are known to have been felled in AD 1453 with a further seven having a felling date range (AD 1451–71) consistent with this precise felling date.

Dendrochronological analysis has shown this barn to be built from timbers felled in AD 1453, with construction likely to have occurred soon after this date. This confirms the survival of many of the medieval elements of this construction, with arcade posts, braces, rafters, and an arcade plate being dated to the mid-fifteenth century.

It should be noted that the heartwood/sapwood boundary on sample NTH-B02, a brace, is slightly later than that of the other samples (Fig 9), and for it to have been felled in AD 1453 it would have fewer sapwood rings than would usually be expected. However, given that there were no obvious signs that this is an inserted or repair timber, and its heartwood/sapwood boundary ring date is only 5 years later than that of NTH-B05, felled in AD 1453, it appears reasonable to assume that it is of the same date as the rest of the samples and represents the one in twenty samples that have more or less than the expected number of sapwood rings.

Bibliography

Arnold, A J, Howard, R E, and Litton, C D, 2003 *Tree-ring analysis of timbers from the Abbey Gatehouse, Bristol Cathedral, Bristol,* Cent for Archaeol Rep, **100/2003**

Arnold, A J, Howard, R E, and Litton, C D, 2004 *Tree-ring analysis of timbers from Ordsall Hall, Taylorson Street, Salford, Greater Manchester,* Cent for Archaeol Rep, **49/2004**

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, 1984 *Tree-ring analysis of timbers from Elland Old Hall, West Yorkshire*, Anc Mon Lab Rep, **4165**

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1988 unpubl Seaton Holme, Easington, Co Durham, unpubl computer file *EASASQ02, EASASQ10,* Nottingham Univ Tree-Ring Dating Laboratory

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1991 List 39 no 10 – Nottingham University Tree-Ring Dating Laboratory: results, *Vernacular Architect,* **22**, 40–3

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1992a Nottingham University Tree-Ring Dating Laboratory: results, *Vernacular Architect,* **23**, 51–6

Howard, R E, Laxton, R R, and Litton, C D, Nottingham University Tree-ring Dating Laboratory, Hook R, Royal Commission on the Historical Monuments of England, 1992b Nottingham University Tree-Ring Dating Laboratory: truncated principal trusses project, *Vernacular Architect,* **23**, 59–60

Howard, R E, Laxton, R R, and Litton, C D, 1993 unpubl Lounge Opencast Coal Site, Coleorton, Leics, unpubl computer file *COLFSQ01*, Nottingham Univ Tree-Ring Dating Laboratory

Howard, R E, Laxton, R R, Litton, C D, and Simpson, W G, 1994 Nottingham University Tree-Ring Dating Laboratory: results, *Vernacular Architect,* **25**, 36–40

Howard, R E, Laxton, R R, and Litton, C D, Nottingham University Tree-ring Dating Laboratory, and Roberts, H M, North East Vernacular Architecture Group, 1995 Nottingham University Tree-Ring Dating Laboratory: buildings of the religious estates in medieval Durham; dendrochronological survey 1994–5, *Vernacular Architect*, **26**, 55–6

Howard, R E, Laxton, R R, and Litton, C D, 1996a *Tree-ring analysis of timbers from Mercer's Hall, Mercer's Lane, Gloucester,* Anc Mon Lab Rep **13/96**

Howard, R E, Laxton, R R, and Litton, C D, Nottingham University Tree-ring Dating Laboratory, and Roberts, H M, North East Vernacular Architecture Group, 1996b Nottingham University Tree-Ring Dating Laboratory: buildings of the religious estates in medieval Durham; dendrochronological survey 1994–5, *Vernacular Architect*, **27**, 85–6

Howard, R E, Laxton, R R, Litton, C D, and Jennings, N, 1998a Nottingham University Tree-Ring Dating Laboratory: Cumbria mud-walled buildings dendrochronology project, *Vernacular Architect,* **29**, 108–10

Howard, R E, Laxton, R R, and Litton, 1998b *Tree-ring analysis of timbers from Brockworth Court Barn, Brockworth, Gloucestershire,* Anc Mon Lab Rep, **46/1998**

Howard, R E, Laxton, R R, and Litton, 1999 *Tree-ring analysis of timbers St Briavel's Castle, Gloucestershire,* Anc Mon Lab Rep, **42/1999**

Howard, R E, Laxton, R R, and Litton, 2000 *Tree-ring analysis of timbers from Headstone Manor Tythe Barn, Pinner View, Harrow, London,* Anc Mon Lab Rep, **61/2000**

Howard, R E, 2002 unpubl, site chronology for 9–11 East St, Crowland, Lincs, unpubl computer file *CRWASQ01,* Nottingham Univ Tree-Ring Dating Laboratory

Howard, R E, Laxton, R R, and Litton, C D, 2002 *Tree-ring analysis of timbers from Tunstall Hall Farm, Elwick Road, Hartlepool, Cleveland,* Anc Mon Lab Rep, **61/2002**

Howard, R E, Laxton, R R, and Litton, C D, 2003 *Tree-ring analysis of timbers from Combermere Abbey, Whitchurch, Cheshire,* Anc Mon Lab Rep, **83/2003**

Laxton, R R, Litton, C D, and Simpson, W G, 1984 Nottingham University Tree-Ring Dating Laboratory: tree-ring dates for buildings in Eastern and Midland England, *Vernacular Architect,* **15**, 65–8

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**

Morgan, R A, 1977 Dendrochronological dating of a Yorkshire timber-framed building, *Vernacular Architect*, **8**, 9–14

Tyers, I, 2002 *Dendrochronological analysis of timbers from 41–43 Church Street, Barnsley, Yorkshire*, ARCUS Rep, **574t**

Table 1: Details of tree-ring samples from Netherhall Barn, Dalton, Huddersfield, West Yorkshire

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
NTH-B01	East common rafter (low) 4, truss 1–2	48	h/s	1386	1433	1433
NTH-B02	North brace, east arcade post 2 to arcade plate	64	h/s	1379	1442	1442
NTH-B03	West brace, east arcade post 2 to tiebeam	68	13	1378	1432	1445
NTH-B04	West common rafter (low) 3, truss 1–2	49	h/s	1375	1423	1423
NTH-B05	West arcade plate, truss 1–2	72	16C	1382	1437	1453
NTH-B06	West arcade post, truss 2	73	20	1379	1431	1451
NTH-B07	West brace, east arcade post 3 to tiebeam	75	h/s	----	----	----
NTH-B08	East common rafter (low) 2, truss 3–4	NM	--	----	----	----
NTH-B09	West arcade post, truss 3	66	h/s	1364	1429	1429
NTH-B10	West common rafter (upper) 5, truss 3–4	NM	--	----	----	----
NTH-B11	North brace, west arcade post 4 to arcade plate	74	h/s	1356	1429	1429
NTH-B12	South brace, east arcade post 3 to arcade plate	NM	--	----	----	----
NTH-B13	South brace, west arcade post 3 to arcade plate	78	23C	1376	1430	1453

*NM = not measured
**h/s = the heartwood/sapwood ring is the last ring on the sample
C = complete sapwood retained on sample, last measured ring is the felling date

Table 2: Results of the cross-matching of site sequence NTHBSQ01 and relevant reference chronologies when the first-ring date is AD 1356 and the last-ring date is AD 1429

Reference chronology	*t*-value	Span of chronology	Reference
Elland Old Hall, West Yorkshire	7.0	AD 1372–1574	Hillam 1984
41–43 Church St Barnsley, South Yorkshire	6.8	AD 1378–1463	Tyers 2002
Horbury Hall, Wakefield	6.6	AD 1368–1473	Howard *et al* 1992a
Byers Garth Barn, Sherburn, Durham	4.8	AD 1330–1439	Howard *et al* 1995
St Briavels Castle, Glos	4.8	AD 1362–1636	Howard *et al* 1999
Combermere Abbey, Whitchurch, Cheshire	4.8	AD 1363–1564	Howard *et al* 2003
35 The Close, Newcastle upon Tyne	4.7	AD 1365–1513	Howard *et al* 1991
Crook Hall, Sidegate, Durham	4.6	AD 1354–1467	Howard *et al* 1992b

Table 3: Results of the cross-matching of site sequence NTHBSQ02 and relevant reference chronologies when the first-ring date is AD 1376 and the last-ring date is AD 1453

Reference chronology	*t*-value	Span of chronology	Reference
East Midlands	8.2	AD 882–1981	Laxton and Litton 1988
Bishop's House, Sheffield	7.2	AD 1359–1591	Morgan 1977
England	7.0	AD 401–1981	Baillie and Pilcher 1982 unpubl
Seaton Holme, Easington, C Durham	6.9	AD 1375–1489	Howard *et al* 1988 unpubl
Ordsall Hall, Salford, Greater Manchester	6.9	AD 1385–1512	Howard *et al* 1994
Mercer's Hall, Gloucester	6.8	AD 1289–1541	Howard *et al* 1996a
Combermere Abbey, Whitchurch, Cheshire	6.6	AD 1363–1564	Howard *et al* 2003
Horbury Hall, Wakefield	6.4	AD 1368–1473	Howard *et al* 1992a

Table 4: Results of the cross-matching of sample NTH-B01 and relevant reference chronologies when the first-ring date is AD 1386 and the last-ring date is AD 1433

Reference chronology	*t*-value	Span of chronology	Reference
England	4.8	AD 401–1981	Baillie and Pilcher 1982 unpubl
East Midlands	4.6	AD 882–1981	Laxton and Litton 1988
Horbury Hall, Wakefield	5.9	AD 1368–1473	Howard *et al* 1992a
Headstone Manor Barn, Harrow, Greater London	5.0	AD 1374–1505	Howard *et al* 2000
Lounge Opencast Coal Site, Coleorton, Leics	4.8	AD 1374–1509	Howard *et al* 1993 unpubl
Newstead Abbey, Newstead, Notts	4.7	AD 1353–1495	Laxton *et al* 1984
Ordsall Hall, Salford, Greater Manchester	4.6	AD 1368–1534	Arnold *et al* 2004
Whites Farm, South Leverton, Notts	4.6	AD 1344–1496	Howard *et al* 1994

Table 5: Results of the cross-matching of sample NTH-B06 and relevant reference chronologies when the first-ring date is AD 1379 and the last-ring date is AD 1451

Reference chronology	*t*-value	Span of chronology	Reference
East Midlands	5.4	AD 882–1981	Laxton and Litton 1988
Durham Cathedral (Choir roof), Durham	7.0	AD 1346–1458	Howard *et al* 1992b
Tunstall Hall Farm, Hartlepool	5.6	AD 1316–1484	Howard *et al* 2002
Brewery Farm, Longburgh, Cumbria	5.5	AD 1337–1489	Howard *et al* 1998a
9–11 East St, Crowland, Lincs	5.3	AD 1345–1444	Howard 2002 unpubl
Kepier Farm Hospital, Durham	5.0	AD 1304–1522	Howard et al 1996b
Brockworth Court Barn, Glos	5.0	AD 1352–1456	Howard *et al* 1998b
Abbey Gatehouse roof, Bristol Cathedral	4.9	AD 1306–1494	Arnold *et al* 2003

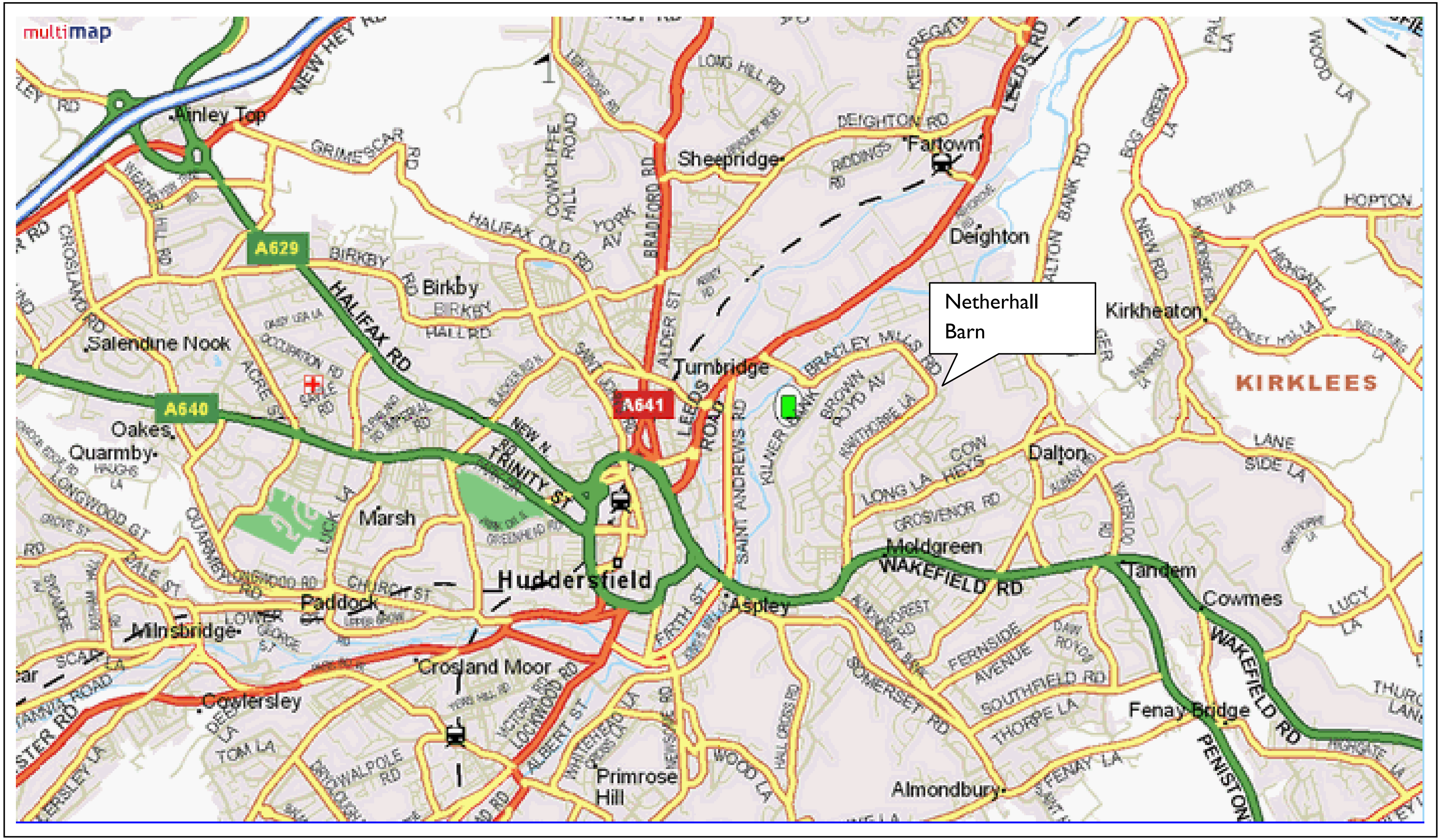


Figure 1: Map to show the general location of Netherhall Barn, Dalton

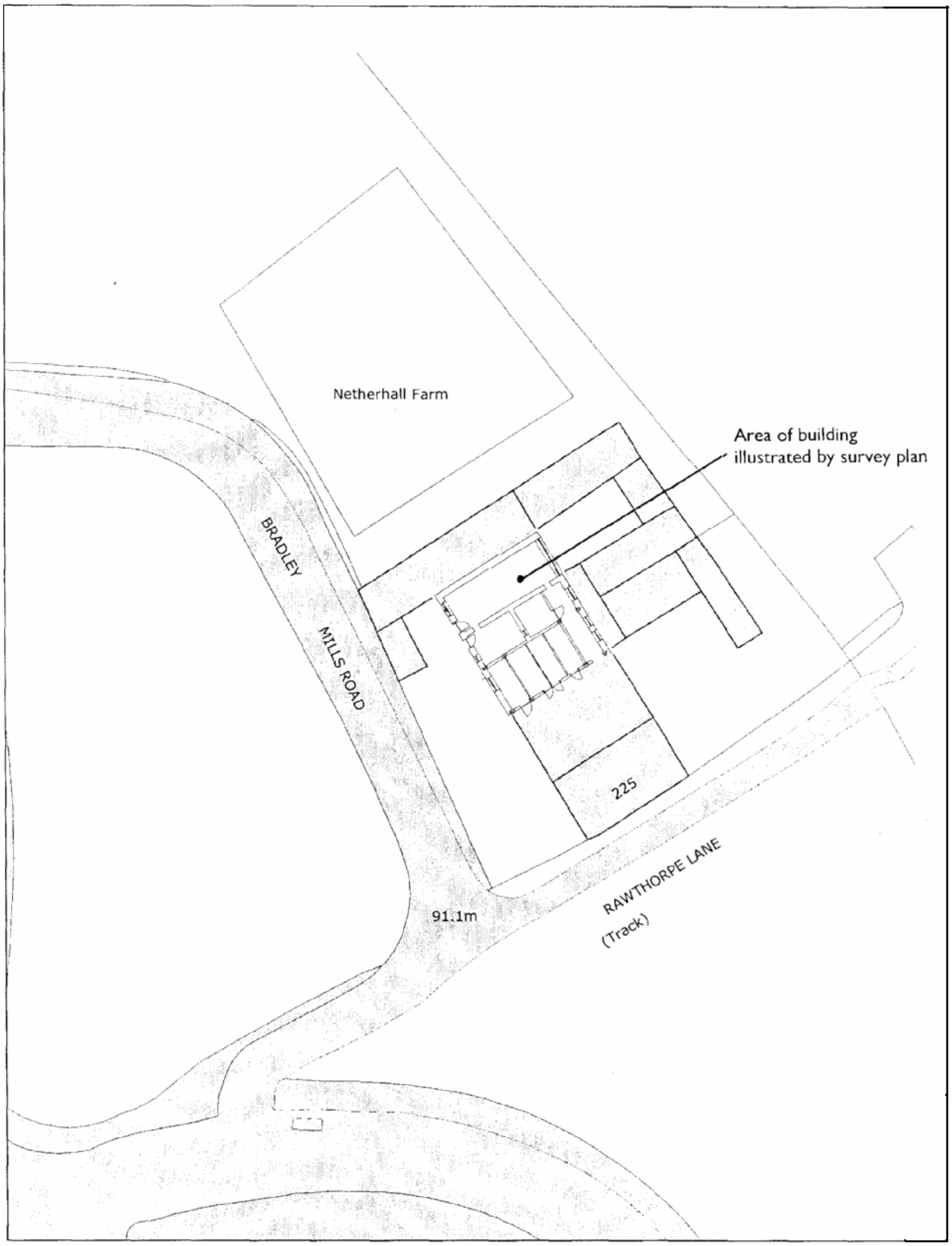


Figure 2: Site plan showing the area illustrated by the survey plan (R Jaques)

Figure 3: Truss 2–3, looking east

Figure 4: East arcade post braces, truss 2

Figure 5: Truss 2 showing one of the arcade posts on a stone slab

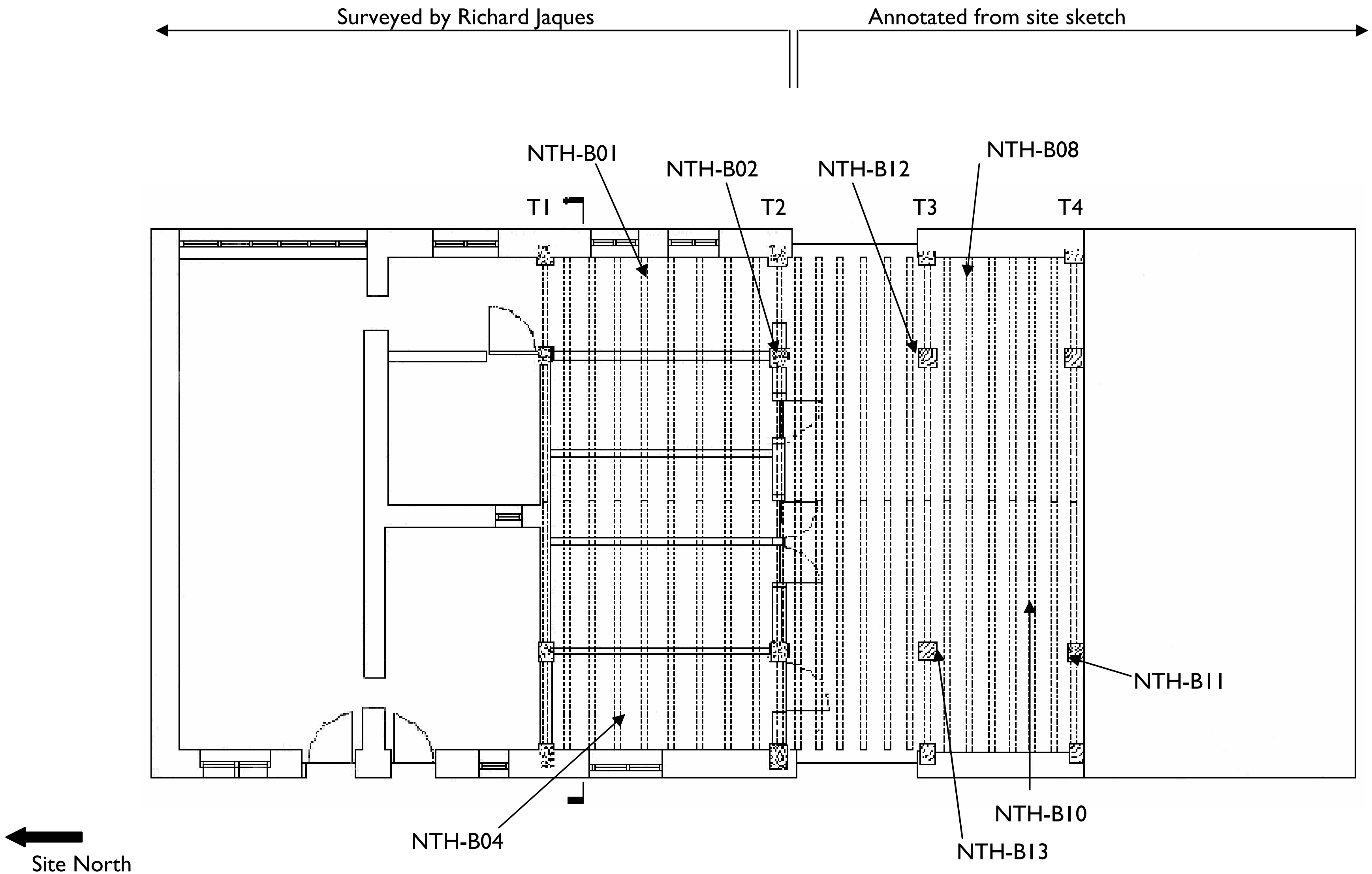


Figure 6: Ground-floor plan, showing the location of samples NTH-B01–02, NTH-B04, NTH-B08, and NTH-B10–13 (based on a drawing by R Jaques)

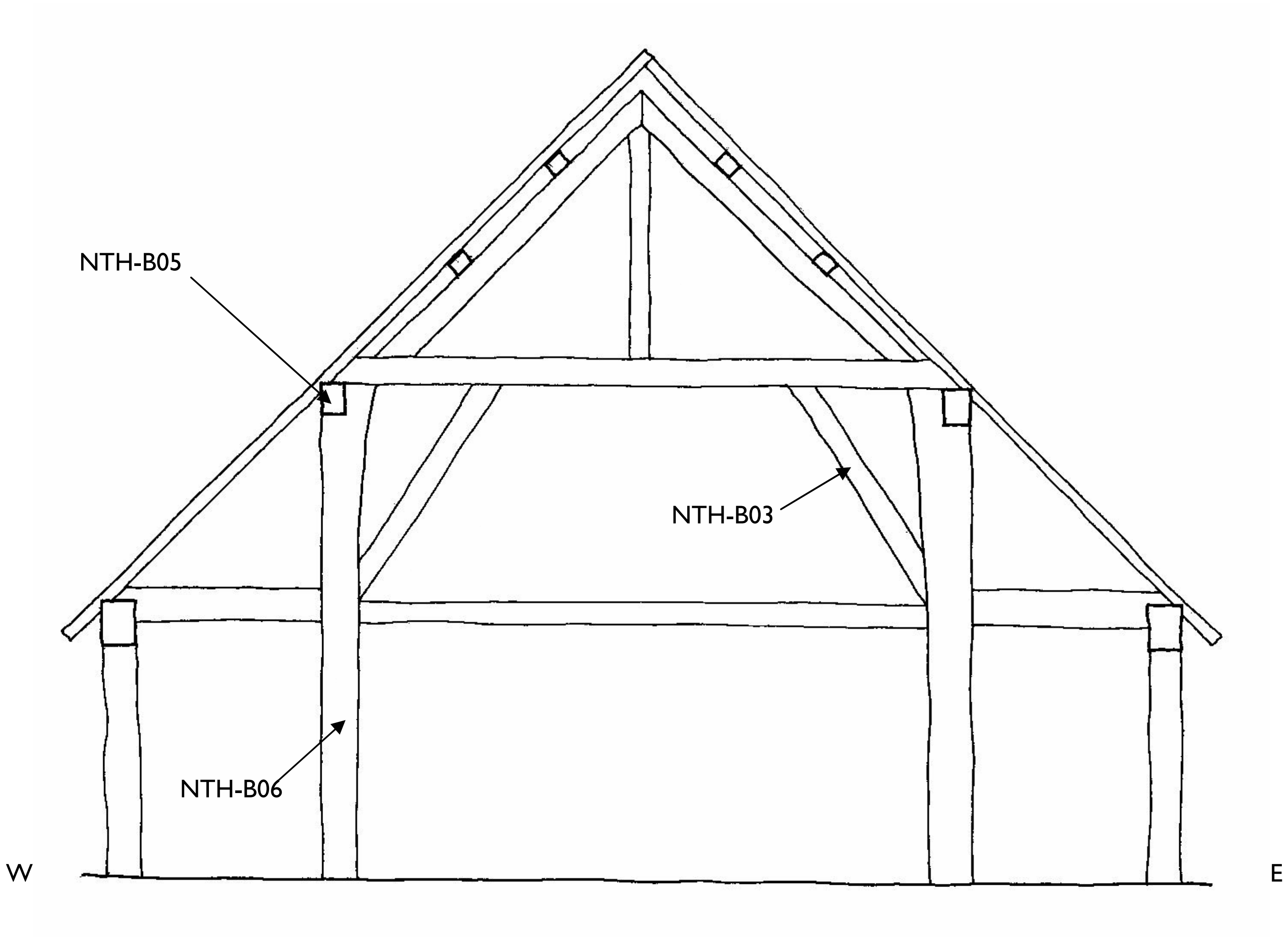


Figure 7: Truss 2 (south face), showing the location of samples NTH-B03, NTH-B05, and NTH-B06 (R Jaques)

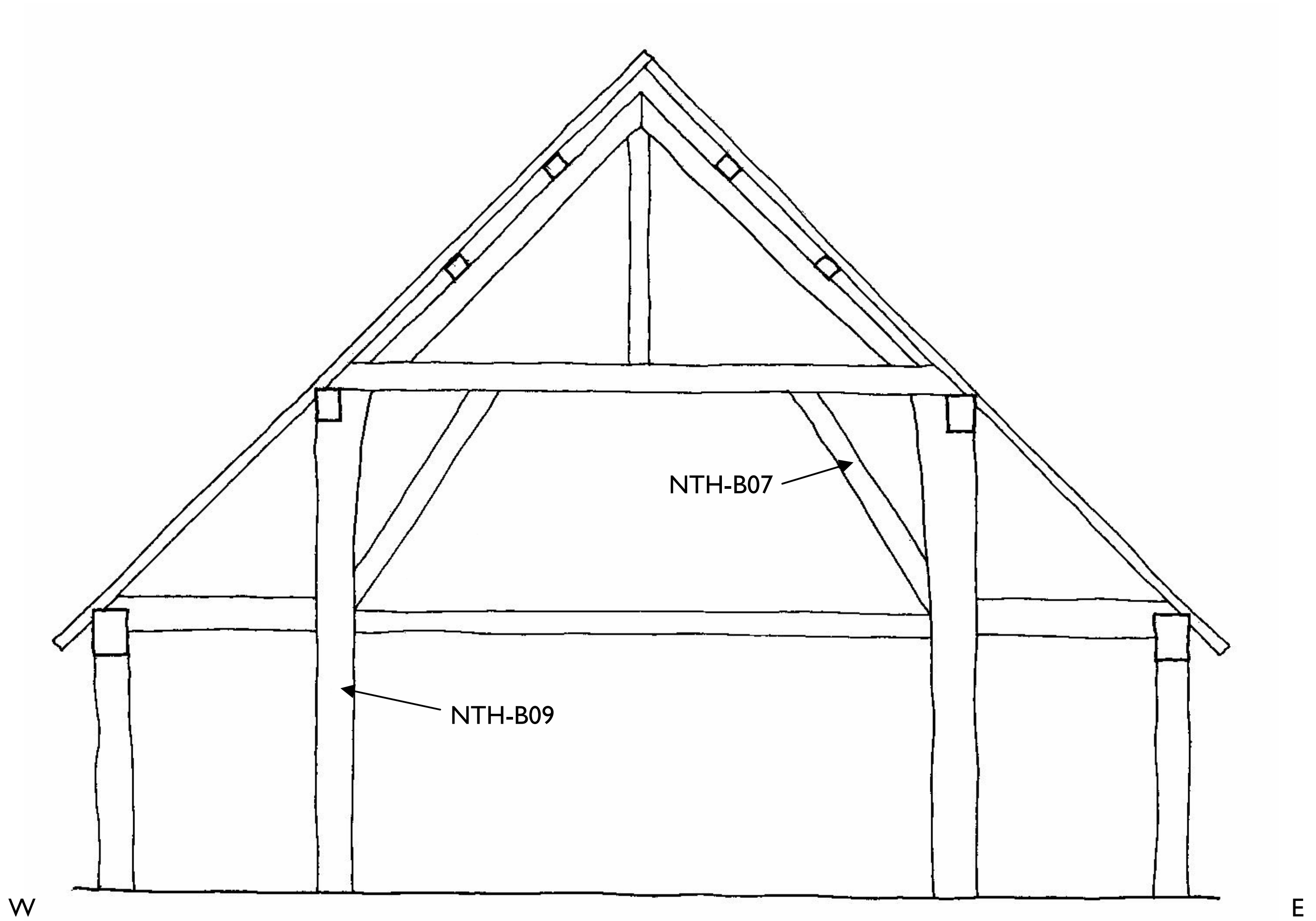
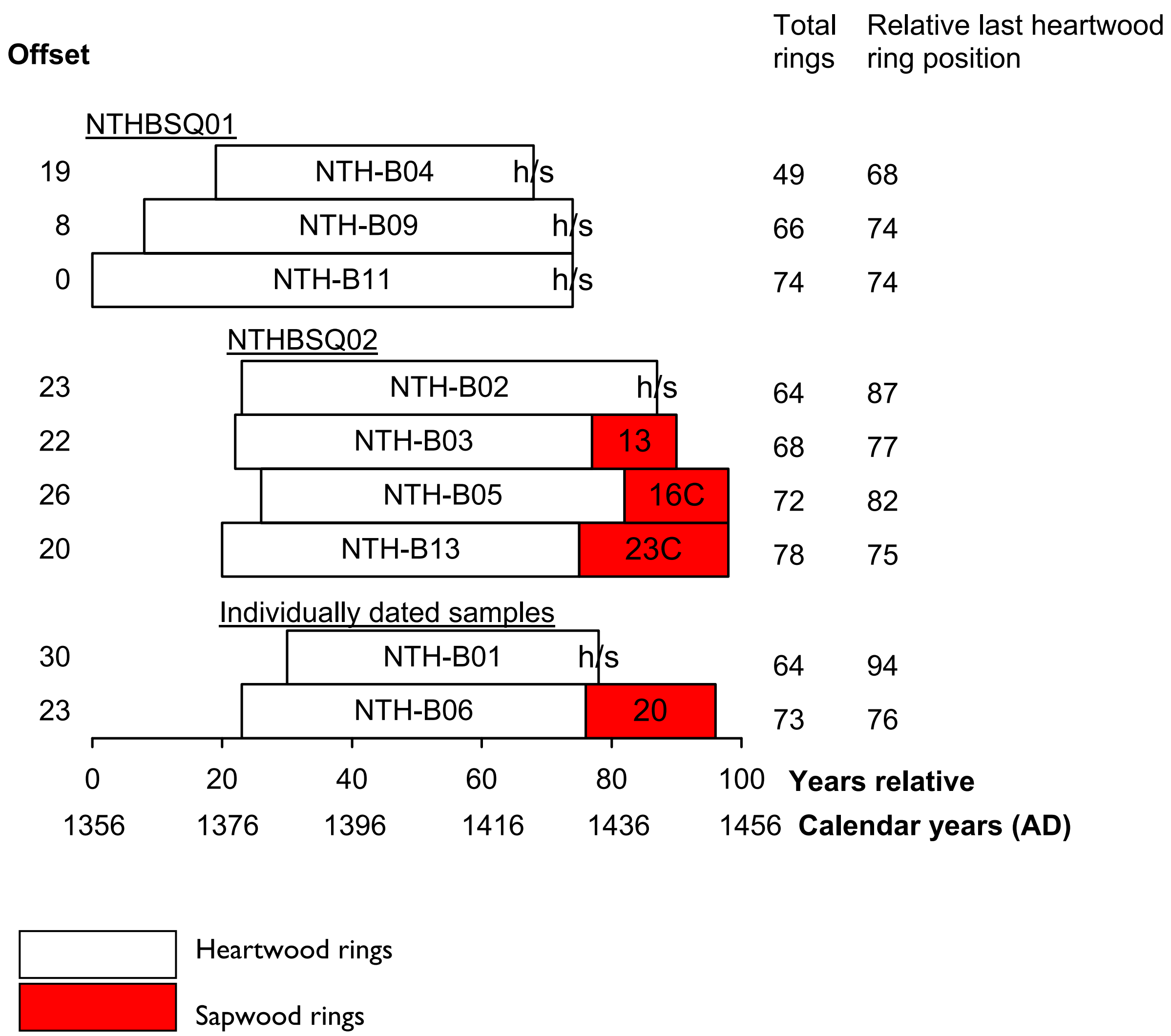


Figure 8: Truss 3 (south face), showing the location of samples NTH-07 and NTH-B09 (R Jaques)



h/s = the heartwood/sapwood boundary ring is the last measured ring on the sample
C = complete sapwood retained on sample, last measured ring is the felling date.

Figure 9: Bar diagram of dated samples

Data of measured samples – measurements in 0.01mm units

NTH-B01A 48
283 275 223 269 250 297 280 243 222 261 249 184 198 165 181 161 143 161 153 121
146 99 109 148 104 114 124 109 110 56 29 56 56 39 74 93 72 89 89 89
103 117 143 124 124 132 189 128
NTH-B01B 48
309 277 267 282 249 296 277 264 217 258 253 179 206 156 184 170 135 155 159 121
152 97 112 144 103 111 116 116 99 60 39 58 48 43 63 96 73 89 93 97
87 121 142 120 127 133 194 121
NTH-B02A 64
124 225 195 197 172 216 193 301 278 255 154 159 303 311 201 195 226 200 188 162
201 343 280 355 406 418 394 332 316 386 281 423 393 404 352 323 269 249 265 237
196 353 260 216 316 245 208 134 155 232 218 207 238 331 224 220 261 244 232 274
212 242 287 241
NTH-B02B 64
157 231 202 192 165 219 192 306 260 256 136 158 335 287 202 200 229 196 185 160
187 342 279 359 400 416 397 348 298 362 275 421 403 405 349 335 272 250 254 233
198 358 239 220 305 253 209 141 154 228 218 226 251 330 232 219 276 238 242 270
201 265 287 250
NTH-B03A 68
314 356 138 171 198 223 316 307 348 296 283 193 213 332 287 241 226 176 202 165
210 233 346 244 237 254 240 291 266 222 177 240 242 174 228 187 132 176 168 196
179 148 192 258 198 311 286 306 217 241 184 172 147 169 233 148 174 197 162 143
181 123 132 109 81 115 190 111
NTH-B03B 68
269 364 96 153 184 234 258 292 332 318 287 190 219 309 287 235 213 186 206 155
190 227 339 235 245 235 250 273 267 211 181 243 246 175 223 184 120 187 170 196
184 155 195 257 197 312 286 318 216 240 181 182 137 162 226 138 170 159 163 149
167 129 134 105 86 114 186 108
NTH-B04A 49
162 275 284 311 270 151 165 157 219 225 166 196 193 234 203 198 232 247 280 232
161 191 142 131 121 239 181 214 245 287 236 182 131 179 188 150 146 160 116 131
127 121 128 125 109 124 123 109 164
NTH-B04B 49
162 278 287 308 276 160 152 171 215 222 168 203 189 244 197 192 243 258 263 238
158 175 155 129 124 248 172 220 248 279 233 188 130 182 185 157 150 147 120 128
133 116 138 133 115 115 127 112 130
NTH-B05A 72
185 253 236 168 275 324 250 208 274 248 229 211 217 181 197 153 226 169 248 271
201 243 257 250 262 153 235 272 318 193 296 173 165 149 277 193 216 117 225 130
134 229 144 166 97 149 295 229 174 274 298 154 209 293 256 227 223 177 277 208
143 316 280 281 145 197 246 265 224 321 308 82
NTH-B05B 72
167 245 230 169 268 320 247 205 267 252 241 201 201 186 182 146 223 147 243 265
211 224 274 223 269 140 247 269 320 190 265 202 154 155 266 197 209 123 219 136
128 230 147 155 107 136 302 223 180 265 294 151 206 292 240 250 206 196 284 190
150 303 294 285 132 203 244 259 223 317 302 110
NTH-B06A 73
428 550 470 457 561 485 490 540 601 608 523 531 503 473 570 469 442 484 314 329
406 533 433 418 430 467 430 420 350 433 436 346 314 310 305 300 311 208 296 323
193 121 117 143 235 192 136 131 166 232 216 216 169 227 183 210 192 257 279 186
126 166 127 126 149 185 151 131 145 156 183 160 65

NTH-B06B 73
446 579 451 484 550 524 490 552 625 585 531 507 516 433 575 450 454 480 310 337
418 531 422 425 436 458 422 425 337 443 433 347 320 322 294 310 309 212 271 326
191 112 115 144 236 202 135 123 158 227 217 216 174 233 170 198 201 272 243 218
135 170 139 121 149 186 149 117 142 160 177 159 68
NTH-B07A 75
326 387 409 387 352 403 339 334 295 322 305 164 238 269 311 301 263 160 168 96
130 157 160 217 134 145 149 143 131 98 122 138 115 122 97 130 191 209 109 151
109 161 146 100 110 106 95 75 132 217 128 180 108 168 138 94 78 64 132 112
84 106 88 74 77 50 47 75 73 86 76 62 115 74 76
NTH-B07B 75
284 389 416 377 350 428 350 338 290 329 314 163 241 262 302 317 247 171 157 106
122 149 150 231 127 138 155 130 147 90 122 130 117 128 102 139 200 207 93 140
126 157 127 115 115 120 87 77 119 216 102 162 116 164 133 103 78 77 137 103
81 117 92 70 79 45 42 82 75 81 66 67 107 71 78
NTH-B09A 66
193 347 451 452 371 416 391 413 512 439 513 268 411 331 382 431 370 344 365 416
387 249 310 294 184 196 182 240 266 246 221 204 312 217 257 171 326 251 221 225
310 222 280 194 275 378 348 243 298 214 189 228 188 189 207 125 231 260 267 328
263 218 175 147 236 162
NTH-B09B 66
169 358 454 423 301 424 368 435 488 466 525 254 398 331 387 419 375 338 364 415
397 228 321 302 186 191 186 238 261 234 220 209 309 227 245 169 325 254 225 219
315 220 287 197 279 373 324 242 309 207 195 226 189 182 222 121 239 259 274 321
269 221 172 156 226 160
NTH-B11A 74
97 229 138 103 114 91 91 105 91 183 301 199 227 227 266 260 261 208 301 177
186 210 213 211 182 169 170 197 186 107 126 168 132 163 155 168 183 173 145 152
167 173 147 138 169 156 137 144 121 119 121 97 101 154 132 102 89 78 86 75
85 79 74 65 64 93 96 85 61 98 74 82 128 123
NTH-B11B 74
95 216 126 110 116 72 71 100 94 173 305 215 222 230 264 281 257 206 314 164
173 191 205 201 189 167 176 190 182 116 128 169 143 161 174 185 208 164 144 153
159 170 153 131 173 165 139 143 116 124 119 95 104 149 130 105 93 78 83 73
85 77 80 65 62 90 93 94 70 93 77 80 134 116
NTH-B13A 78
402 328 228 261 262 223 262 237 254 252 252 293 266 318 308 415 361 325 305 307
338 270 320 213 280 240 183 198 195 177 208 158 124 149 134 155 117 134 127 125
105 122 121 84 134 140 112 155 175 120 126 112 168 126 137 134 168 102 113 117
121 111 120 105 143 152 102 119 175 140 109 135 167 140 170 196 141 56
NTH-B13B 78
386 331 228 256 273 231 254 233 261 243 266 306 268 324 327 415 372 342 315 277
354 272 318 212 288 262 194 187 200 171 204 161 134 153 142 145 117 141 120 122
109 129 106 97 124 145 111 155 176 125 119 132 164 126 126 130 170 114 129 110
136 105 123 117 136 137 113 121 169 132 110 147 163 146 169 194 134 71

APPENDIX

Tree-Ring Dating

The Principles of Tree-Ring Dating

Tree-ring dating, or *dendrochronology* as it is known, is discussed in some detail in the Laboratory's Monograph, '*An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Building*' (Laxton and Litton 1988) and *Dendrochronology: Guidelines on Producing and Interpreting Dendrochronological Dates* (English Heritage 1988). Here we will give the bare outlines. Each year an oak tree grows an extra ring on the outside of its trunk and all its branches just inside its bark. The *width* of this annual ring depends largely on the weather during the growing season, about April to October, and possibly also on the weather during the previous year. Good growing seasons give rise to relatively wide rings, poor ones to very narrow rings and average ones to relatively average ring widths. Since the climate is so variable from year to year, almost random-like, the widths of these rings will also appear random-like in sequence, reflecting the seasons. This is illustrated in Figure 1 where, for example, the widest rings appear at irregular intervals. This is the key to dating by tree rings, or rather, by their widths. Records of the average ring widths for oaks, one for each year for the last 1000 years or more, are available for different areas. These are called master chronologies. Because of the random-like nature of these sequences of widths, there is usually only one position at which a sequence of ring widths from a sample of oak timber with at least 70 rings will match a master. This will date the timber and, in particular, the last ring.

If the bark is still on the sample, as in Figure 1, then the date of the last ring will be the date of felling of the oak from which it was cut. There is much evidence that in medieval times oaks cut down for building purposes were used almost immediately, usually within the year or so (Rackham 1976). Hence if bark is present on several main timbers in a building, none of which appear reused or are later insertions, and if they all have the same date for their last ring, then we can be quite confident that this is the date of construction or soon after. If there is no bark on the sample, then we have to make an estimate of the felling date; how this is done is explained below.

The Practice of Tree-Ring Dating at the Nottingham Tree-Ring Dating Laboratory

1. *Inspecting the Building and Sampling the Timbers*. Together with a building historian the timbers in a building are inspected to try to ensure that those sampled are not reused or later insertions. Sampling is almost always done by coring into the timber, which has the great advantage that we can sample *in situ* timbers and those judged best to give the date of construction, or phase of construction if there is more than one in the building. The timbers to be sampled are also inspected to see how many rings they have. We normally look for timbers with at least 70 rings, and preferably more. With fewer rings than this, 50 for example, sequences of widths become difficult to match to a unique position within a master sequence of ring widths and so are difficult to date (Litton and Zainodin 1991). The cross-section of the rafter shown in Figure 2 has about 120 rings; about 20 of which are sapwood rings – the lighter rings on the outside. Similarly the core has just over 100 rings with a few sapwood rings.

To ensure that we are getting the date of the building as a whole, or the whole of a phase of construction if there is more than one, about 8 to 10 samples per phase are usually taken. Sometimes we take many more, especially if the construction is complicated. One reason for taking so many samples is that, in general, some will fail to give a date. There may be many reasons why a particular sequence of ring widths from a sample of timber fails to give a date even though others from the same building do. For example, a particular tree may have grown in an odd ecological niche, so odd indeed that the widths of its rings were determined by factors other than the local climate! In such circumstances it will be impossible to date a timber from this tree using the master sequence whose widths, we can assume, were predominantly determined by the local climate at the time.

Sampling is done by coring into the timber with a hollow corer attached to an electric drill and usually from its outer rings inwards towards where the centre of the tree, the pith, is judged to be. An illustration of a core is shown in Figure 2; it is about 15cm long and 1cm diameter. Great care has to be taken to ensure that as few as possible of the outer rings are lost in coring. This can be difficult as these outer rings are often very soft (see below on sapwood). Each sample is given a code which identifies uniquely which timber it comes from, which building it is from and where the building is located. For example, CRO-A06 is the sixth core taken from the first building (A) sampled by the Laboratory in Cropwell Bishop. Where it came from in that building will be shown in the sampling records and drawings. No structural damage is done to any timbers by coring, nor does it weaken them.

During the initial inspection of the building and its timbers the dendrochronologist may come to the conclusion that, as far as can be judged, none of the timbers have sufficient rings in them for dating purposes and may advise against sampling to save further unwarranted expense.

All sampling by the Laboratory is undertaken according to current Health and Safety Standards. The Laboratory's dendrochronologists are insured.

Figure 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.

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

Figure 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.

Figure 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.

2. *Measuring Ring Widths*. Each core is sanded down with a belt sander using medium-grit paper and then finished by hand with flourgrade-grit paper. The rings are then clearly visible and differentiated from each other with a result very much like that shown in Figure 2. The core is then mounted on a movable table below a microscope and the ring-widths measured individually from the innermost ring to the outermost. The widths are automatically recorded in a computer file as they are measured (see Fig 3).

3. *Cross-matching and Dating the Samples*. Because of the factors besides the local climate which may determine the annual widths of a tree's rings, no two sequences of ring widths from different oaks growing at the same time are exactly alike (Fig 4). Indeed, the sequences may not be exactly alike even when the trees are growing near to each other. Consequently, in the Laboratory we do not attempt to match two sequences of ring widths by eye, or graphically, or by any other subjective method. Instead, it is done objectively (ie statistically) on a computer by a process called cross-matching. The output from the computer tells us the extent of correlation between two sample sequences of widths or, if we are dating, between a sample sequence of widths and the master, at each relative position of one to the other (offsets). The extent of the correlation at an offset is determined by the *t*-value (defined in almost any introductory book on statistics). That offset with the maximum *t*-value among the *t*-values at all the offsets will be the best candidate for dating one sequence relative to the other. If one of these is a master chronology, then this will date the other. Experiments carried out in the past with sequences from oaks of known date suggest that a *t*-value of at least 4.5, and preferably at least 5.0, is usually adequate for the dating to be accepted with reasonable confidence (Laxton and Litton 1988; Laxton *et al* 1988; Howard *et al* 1984–1995).

   This is illustrated in Figure 5 with timbers from one of the roofs of Lincoln Cathedral. Here four sequences of ring widths, LIN-C04, 05, 08, and 45, have been cross-matched with each other. The ring widths themselves have been omitted in the *bar-diagram*, as is usual, but the offsets at which they best cross-match each other are shown; eg the sequence of ring widths of C08 matches the sequence of ring widths of C45 best when it is at a position starting 20 rings after the first ring of C45, and similarly for the others. The actual *t*-values between the four at these offsets of best correlations are in the matrix. Thus at the offset of +20 rings, the *t*-value between C45 and C08 is 5.6 and is the maximum found between these two among all the positions of one sequence relative to the other.

   It is standard practice in our Laboratory first to cross-match as many as possible of the ring-width sequences of the samples in a building and then to form an average from them. This average is called a *site sequence* of the building being dated and is illustrated in Figure 5. The fifth bar at the bottom is a site sequence for a roof at Lincoln Cathedral and is constructed from the matching sequences of the four timbers. The site sequence width for each year is the average of the widths in each of the sample sequences which has a width for that year. Thus in Fig 5 if the widths shown are 0.8mm for C45, 0.2mm for C08, 0.7mm for C05, and 0.3mm for C04, then the corresponding width of the site sequence is the average of these, 0.55mm. The actual sequence of widths of this site sequence is stored on the computer. The reason for creating site sequences is that it is usually easier to date an average sequence of ring widths with a master sequence than it is to date the individual component sample sequences separately.

   The straightforward method of cross-matching several sample sequences with each other one at a time is called the 'maximal *t*-value' method. The actual method of cross-matching a group of sequences of ring-widths used in the Laboratory involves grouping and averaging the ring-width sequences and is called the 'Litton-Zainodin Grouping Procedure'. It is a modification of the straight forward method and was successfully developed and tested in the Laboratory and has been published (Litton and Zainodin 1991; Laxton *et al* 1988).

4. *Estimating the Felling Date*. As mentioned above, if the bark is present on a sample, then the date of its last ring is the date of the felling of its tree. Actually it could be the year after if it had been felled in the first three months before any new growth had started, but this is not too important a consideration in most cases. The actual bark may not be present on a timber in a building, though the dendrochronologist who is sampling can often see from its surface that only the bark is missing. In these cases the date of the last ring is still the date of felling.

Quite often some, though not all, of the original outer rings are missing on a timber. The outer rings on an oak, called *sapwood* rings, are usually lighter than the inner rings, the *heartwood*, and so are relatively easy to identify. For example, sapwood can be seen in the corner of the rafter and at the outer end of the core in Figure 2, both indicated by arrows. More importantly for dendrochronology, the sapwood is relatively soft and so liable to insect attack and wear and tear. The builder, therefore, may remove some of the sapwood for precisely these reasons. Nevertheless, if at least some of the sapwood rings are left on a sample, we will know that not too many rings have been lost since felling so that the date of the last ring on the sample is only a few years before the date of the original last ring on the tree, and so to the date of felling.

Various estimates have been made and used for the average number of sapwood rings in mature oak trees (English Heritage 1998). A fairly conservative range is between 15 and 50 and that this holds for 95% of mature oaks. This means, of course, that in a small number of cases there could be fewer than 15 and more than 50 sapwood rings. For example, the core CRO-A06 has only 9 sapwood rings and some have obviously been lost over time – either they were removed originally by the carpenter and/or they rotted away in the building and/or they were lost in the coring. It is not known exactly how many sapwood rings are missing, but using the above range the Laboratory would estimate between a minimum of 6 (=15-9) and a maximum of 41 (=50-9). If the last ring of CRO-A06 has been dated to 1500, say, then the estimated felling-date range for the tree from which it came originally would be between 1506 and 1541. The Laboratory uses this estimate for sapwood in areas of England where it has no prior information. It also uses it when dealing with samples with very many rings, about 120 to the last heartwood ring. But in other areas of England where the Laboratory has accumulated a number of samples with complete sapwood, that is, no sapwood lost since felling, other estimates in place of the conservative range of 15 to 50 are used. In the East Midlands (Laxton *et al* 2001) and the east to the south down to Kent (Pearson 1995) where it has sampled extensively in the past, the Laboratory uses the shorter estimate of 15 to 35 sapwood rings in 95% of mature oaks growing in these parts. Since the sample CRO-A06 comes from a house in Cropwell Bishop in the East Midlands, a better estimate of sapwood rings lost since felling is between a minimum of 6 (=15-9) and 26 (=35-9) and the felling would be estimated to have taken place between 1506 and 1526, a shorter period than before. (Oak boards quite often come from the Baltic and in these cases the 95% confidence limits for sapwood are 9 to 36 (Howard *et al* 1992, 56)).

Even more precise estimates of the felling date and range can often be obtained using knowledge of a particular case and information gathered at the time of sampling. For example, at the time of sampling the dendrochronologist may have noted that the timber from which the core of Figure 2 was taken still had complete sapwood but that none of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 2 cm, a reasonable estimate can be made of the number of sapwood rings lost, say 12 to 15 rings in this case. By adding on 12 to 15 years to the date of the last ring on the sample a good tight estimate for the range of the felling date can be obtained, which is often better than the 15 to 35 years later we would have estimated without this observation. In the example, the felling is now estimated to have taken place between AD 1512 and 1515, which is much more precise than without this extra information.

Even if all the sapwood rings are missing on a sample, but none of the heartwood rings are, then an estimate of the felling-date range is possible by adding on the full compliment of, say, 15 to 35 years to the date of the last heartwood ring (called the heartwood/sapwood boundary or transition ring and denoted H/S). Fortunately it is often easy for a trained dendrochronologist to identify this boundary on a timber. If a timber does not have its heartwood/sapwood boundary, then only a *post quem* date for felling is possible.

5. *Estimating the Date of Construction*. There is a considerable body of evidence collected by dendrochronologists over the years that oak timbers used in buildings were not seasoned in medieval or early modern times (English Heritage 1998 and Miles 1997, 50-55). Hence provided all the samples in a building have estimated felling-date ranges broadly in agreement with each other, so that they appear to have been felled as a group, then this should give an accurate estimate of the period when the structure was built, or soon after (Laxton *et al* 2001, figure 8 and pages 34-5 where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storing before use or if there is evidence the oak came from abroad (eg Baltic boards), then some allowance has to be made for this.

6. *Master Chronological Sequences*. Ultimately, to date a sequence of ring widths, or a site sequence, we need a master sequence of dated ring widths with which to cross-match it, a Master Chronology. To construct such a sequence we have to start with a sequence of widths whose dates are known and this means beginning with a sequence from an oak tree whose date of felling is known. In Fig 6 such a sequence is SHE-T, which came from a tree in Sherwood Forest which was blown down in a recent gale. After this other sequences which cross-match with it are added and gradually the sequence is 'pushed back in time' as far as the age of samples will allow. This process is illustrated in Fig 6. We have a master chronological sequence of widths for Nottinghamshire and East Midlands oak for each year from AD 882 to 1981. It is described in great detail in Laxton and Litton (1988), but the components it contains are shown here in the form of a bar diagram. As can be seen, it is well replicated in that for each year in this period there are several sample sequences having widths for that year. The master is the average of these. This master can now be used to date oak from this area and from the surrounding areas where the climate is very similar to that in the East Midlands. The Laboratory has also constructed a master for Kent (Laxton and Litton 1989). The method the Laboratory uses to construct a master sequence, such as the East Midlands and Kent, is completely objective and uses the Litton-Zainodin grouping procedure (Laxton *et al* 1988). Other laboratories and individuals have constructed masters for other areas and have made them available. As well as these masters, local (dated) site chronologies can be used to date other buildings from nearby. The Laboratory has hundreds of these site sequences from many parts of England and Wales covering many short periods.

7. *Ring-width Indices*. Tree-ring dating can be done by cross-matching the ring widths themselves, as described above. However, it is advantageous to modify the widths first. Because different trees grow at different rates and because a young oak grows in a different way from an older oak, irrespective of the climate, the widths are first standardized before any matching between them is attempted. These standard widths are known as ring-width indices and were first used in dendrochronology by Baillie and Pilcher (1973). The exact form they take is explained in this paper and in the appendix of Laxton and Litton (1988) and is illustrated in the graphs in Fig 7. Here ring-widths are plotted vertically, one for each year of growth. In the upper sequence of (a), the generally large early growth after 1810 is very apparent as is the smaller later growth from about 1900 onwards when the tree is maturing. A similar phenomenon can be observed in the lower sequence of (a) starting in 1835. In both the widths are also changing rapidly from year to year. The peaks are the wide rings and the troughs are the narrow rings corresponding to good and poor growing seasons, respectively. The two corresponding sequence of Baillie-Pilcher indices are plotted in (b) where the differences in the immature and mature growths have been removed and only the rapidly changing peaks and troughs remain, that are associated with the common climatic signal. This makes cross-matching easier.

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

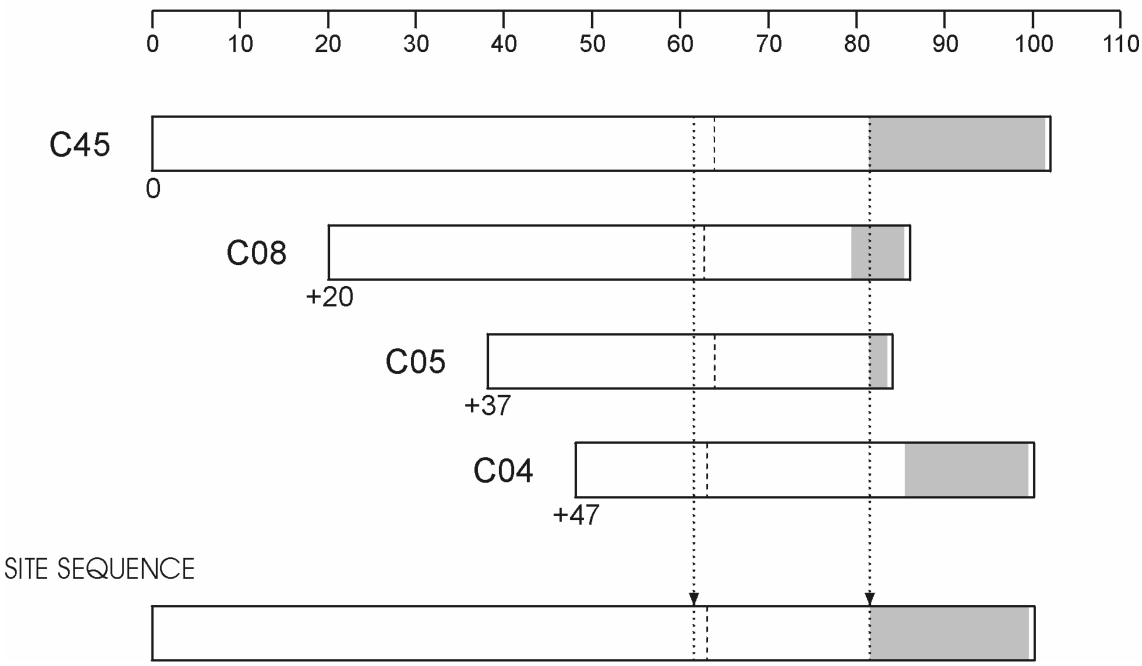


Figure 5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

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.

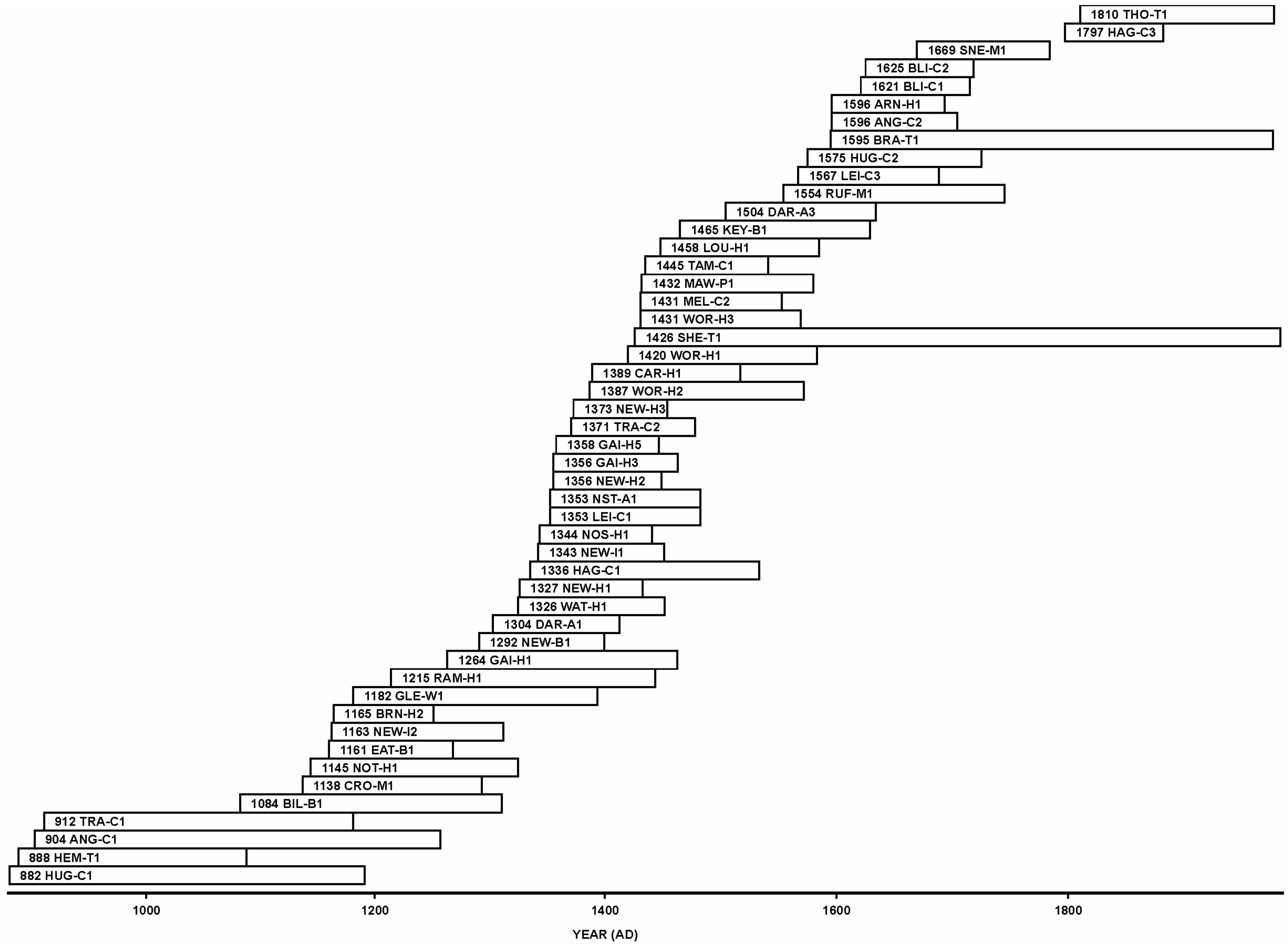
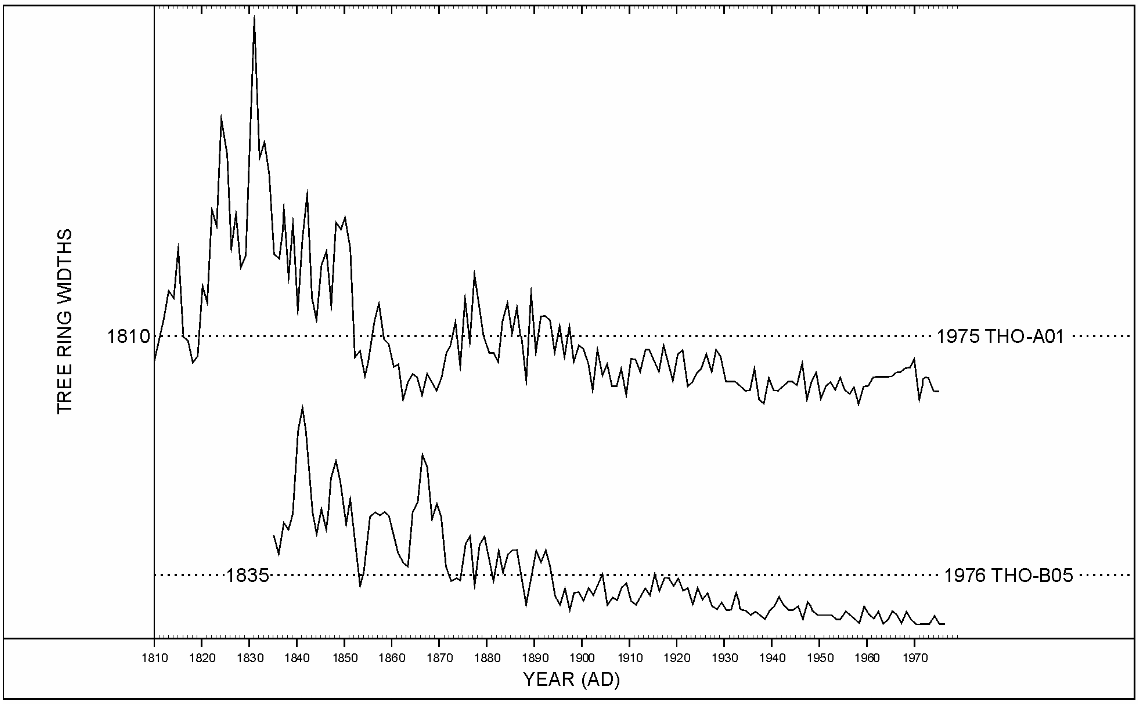


Figure 6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

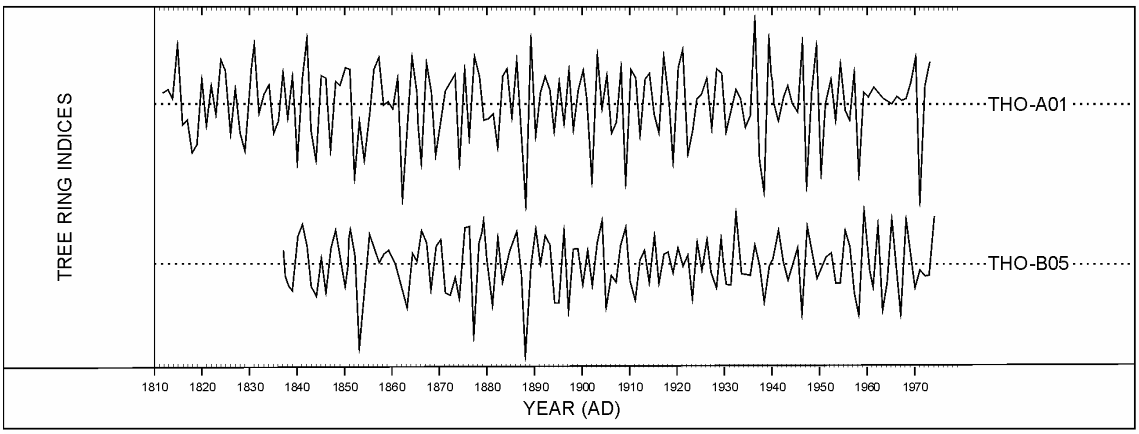


Figure 7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young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

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

REFERENCES

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

English Heritage, 1998 *Dendrochronology; Guidelines on Producing and Interpreting Dendrochronological Dates*, London

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

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

Laxton, R R, and Litton, C D, 1988 *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, AD 1158 to 1540, *Medieval Archaeol*, **33**, 90–8

Laxon, R R, Litton, C D, and Howard, R E, 2001 *Timber; Dendrochronology of Roof Timbers at Lincoln Cathedral*, English Heritage Research Transactions, **7**

Litton, C D, and Zainodin, H J, 1991 Statistical models of Dendrochronology, *J Archaeol Sci*, **18**, 29–40

Miles, D W H, 1997 The interpretation, presentation and use of tree-ring dates, *Vernacular Architecture*, **28**, 40–56

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

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