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Summary

Analysis was undertaken on 55 samples taken from timbers of the south, east and north-range roofs, from floor beams of the ground and first-floor frames, and from two stud posts in the east-range attic, resulting in the construction and dating of two site sequences.

The first contains 29 samples and spans the period AD 1380-1559. The second contains 16 samples and spans the period AD 1534-1725.

The earliest timbers in the north-range roof are dated to AD 1559. Also dated to the mid-sixteenth century are roof timbers and the stud posts in the east range (AD 1544-69), although this roof also shows evidence for repair in the first half of the eighteenth century. The south-range roof contains timbers felled in AD 1725.

Timbers were also dated in the ground and first-floor frames in the south and east ranges. Four elements in the south-range ground and first-floor frames were dated to the late-seventeenth or early-eighteenth centuries, though these frames also contained material dating to the mid-sixteenth century (AD 1547-72). Floor timbers of the ground-floor frame in the east range were also dated to AD 1547-72.

Keywords

Dendrochronology
Standing Building

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Introduction

Poltimore House is situated just to the north of Exeter (Fig 1; SX 9678 9635), and was the residence of the Bampfylde family (Lords Poltimore, after AD 1831). Thought to originate in the late-sixteenth century, this building has been extensively extended and remodelled in the late-seventeenth, nineteenth, and twentieth centuries until it now almost completely fills an internal courtyard (Figs 2-4). In recent years this building has been used as a private hospital.

The oldest, surviving part of the building is the L-shaped portion formed by the east wing and the three-gabled eastern part of the north wing (Fig 5), along with the polygonal stair turret (Fig 6). The presence of this stair turret suggests an originally quadrangular plan for the building, although there is no other architectural or documentary evidence for this. It is unknown as to whether the two wings belong to the same construction programme but both are thought to date to the end of the sixteenth century.

The next building period is thought to have occurred in about AD 1700 with the construction of the south front. This has been attributed variously to Sir Coplestone Bampfylde (2nd Bart; Images of England List Description) who died in AD 1691 or Sir Coplestone Bampfylde (3rd Bart; Fortescue Foulkes, nd) who died in AD 1727. It is of 11 bays, of which the central three project slightly. (Figs 7 and 8). The east wing is also believed to have been remodelled at this time. That work was carried out in the late-seventeenth century is further evidenced by the inscription of a stone gate pier at the main entrance to the estate of the date AD 1681. The original entrance has been obscured by a single-storey porch with Doric columns which was added in about AD 1831.

The date of the west wing, which closed the court, is difficult to judge on architectural features but is thought to be AD 1800.

The Laboratory would like to thank Alan Payne of the Friends of Poltimore House for his advice and assistance in arranging access. Christine Locatelli of The University of Sheffield Dendrochronology Laboratory provided the photographs and the building plans were drawn by Louis Hawkins, Architect.

Sampling and analysis by tree-ring dating was funded by English Heritage to inform conservation and restoration plans being produced for the building.

Sampling

Fifty-five core samples were taken from roof, stud posts, and floor timbers at Poltimore House. Each sample was given the code POL-B (for Poltimore) and numbered 01-55. Samples were taken from the south-range roof (POL-B01-12), the east-range roof timbers and two studs from the attic (POL-B13-28), the north range roof (POL-B29-40), the first-floor frame (POL-B41-49), and the ground-floor frame (POL-B50-55). When the west-range roof was inspected with a view to sampling, a substance that was thought likely to be asbestos was seen. In the interests of health and safety, it was felt that the quickest and easiest way to mitigate the problem would be to avoid the area until a full asbestos survey had been undertaken and any possible hazard removed. The position of all samples was noted at the time of sampling and has been marked on Figures 9-14. Further details relating to the samples can be found in Table 1. Trusses have been numbered north to south (east range roof) and east to west (north and south range roofs) as shown in Figures 9-11.

Analysis and Results

All 55 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. These samples were then compared with each other by the Litton/Zainodin grouping procedure (see appendix).

At a least value of *t*=4.5, 45 samples grouped, forming three site sequences. Firstly, 29 samples matched each other and were combined at the relevant offset positions to form POLBSQ01, a site sequence of 180 rings (Fig 15). 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 1380 and of its last measured ring is AD 1559. The evidence for this dating is given by the *t*-values in Table 2.

Two samples matched each other and were combined at the relevant offset positions to form POLBSQ02, a site sequence of 97 rings (Fig 16). This site sequence was then compared with the reference material where it was found to match at a first-ring date of AD 1564 and a last ring date of AD 1660. The evidence for this dating is given by the *t*-values in Table 3.

Finally, 14 samples matched each other and were combined at the relevant offset positions to form POLBSQ03, a site sequence of 192 rings (Fig 17). This site sequence was consistently dated against the reference material at a first-ring date of AD 1534 and a last measured ring date of AD 1725 (Table 4).

It was then ascertained that site sequence POLBSQ02 and POLBSQ03 matched each other at the expected offset at a value of *t*=4.1. Another site sequence was then constructed containing all 16 samples (Fig 18). This new site sequence, POLBSQ04, was matched at a first-ring date of AD 1534 and a last measured ring date of AD 1725. The evidence for this dating is given by the *t*-values in Table 5.

The remaining ten ungrouped samples were then compared individually against the reference material but no consistent match could be found and these samples remain undated.

Interpretation

Analysis of 55 samples taken from timbers at Poltimore House has resulted in the dating of two site sequences.

The first, POLBSQ01, of 180 rings, contains samples from the north and east-range roofs and from ground and first-floor joists, and spans the period AD 1380-1559. Ten of these samples are from the north-range roof. Of these, one (POL-B34) has complete sapwood and a last measured ring date of AD 1559, the felling date of the timber represented. Of the other nine, seven have the heartwood/sapwood boundary ring, which is broadly contemporary and suggestive of a single felling. The average of this is AD 1536, which allows an estimated felling date to be calculated for the seven timbers represented to within the range AD 1551-76, consistent with a felling of AD 1559. The other two north-range roof samples do not have the heartwood/sapwood boundary ring and so an estimated felling date cannot be calculated, except to say that with last measured ring dates of AD 1503 (POL-B35) and AD 1507 (POL-B37) this would be AD 1519 and AD 1523 at the earliest, respectively.

Twelve of the samples are taken from timbers of the east-range roof and the two stud posts in the east-range attic. Of these ten have the heartwood/sapwood boundary ring, which is broadly contemporary and therefore suggestive of a single felling. The average heartwood/sapwood boundary ring date for these ten samples is AD 1529, which calculates to an estimated felling date for the timbers represented to within the range AD 1544-69. The other two samples from the east range, both roof timbers (POL-B13 and POL-B19) do not have the heartwood/sapwood boundary ring, however, both have the last measured ring date of AD 1509, which means that at the earliest these two timbers would have been felled in AD 1525, making it possible that these two samples were also felled sometime within the range AD 1544-69.

Seven samples from the ground and first-floor frames were dated within this site sequence. Six of these samples, four from the south range and two from the east range, have the heartwood/sapwood boundary ring date, which is broadly contemporary. The average of this is AD 1532, which calculates to an estimated felling date range of AD 1547-72 for the six timbers represented. Sample POL-B43, from the first-floor frame of the east range does not have the heartwood/sapwood boundary ring and, therefore, other than an estimated earliest possible felling date of AD 1484 it is not possible to assign a felling date range to this timber.

The second site sequence, POLBSQ04, of 192 rings, contains 16 samples and spans the period AD 1534-1725. Eleven of the samples in this site sequence are from timbers of the south-range roof. One of these, POL-B07, has complete sapwood and the last measured ring date of AD 1725, the felling date of the timber represented. Six of the other south-range roof timbers in this sequence have the heartwood/sapwood boundary ring. In all six samples this is broadly contemporary and therefore, suggestive of a single felling. The average heartwood/sapwood boundary ring date of these six samples is AD

1705, which calculates to an estimated felling date within the range AD 1723-45 (allowing for sample POL-B12 having a last measured ring of AD 1722 without complete sapwood). This date range is consistent with these timbers also having been felled in AD 1725. The remaining four south-range roof samples in this site sequence do not have the heartwood/sapwood boundary ring, however with last measured ring dates ranging from AD 1662 (POL-B03) to AD 1698 (POL-B08) it is possible that these samples were also felled at the same time as the others.

Also contained within this site sequence are four samples taken from floor beams, three from the ground-floor frame of the south range, and one from the first-floor frame of the south range. Three of these have the heartwood/sapwood boundary ring. In the case of two of these (POL-B53 and POL-B54), this is broadly contemporary and suggestive of a single felling. The average heartwood/sapwood boundary ring of these two samples is AD 1656, which allows an estimated felling date to be calculated for the two timbers represented to within the range AD 1671-96. The third sample with the heartwood/sapwood boundary ring is POL-B49. The heartwood/sapwood boundary ring for this sample is AD 1684, slightly later than that of the other two samples. This gives an estimated felling date range for POL-B49 of AD 1699-1724. The third sample from the ground-floor frame, POL-B55, does not have the heartwood/sapwood boundary ring and, therefore, an estimated felling date range cannot be calculated for the timber it is taken from. However, with a last measured ring date of AD 1597 this is estimated to be AD 1613 at the earliest.

The final sample in site sequence POLBSQ04 is POL-B20, taken from the east range. The last measured ring on this sample is the heartwood/sapwood boundary ring. This is dated to AD 1701 which calculates to an estimated felling date range for the timber represented of AD 1716-41, consistent with a felling of AD 1725 with those timbers from the south-range roof.

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

Discussion

On stylistic grounds, the earliest part of the building was believed to be the L-shaped portion formed by the east wing and the eastern part of the north wing. This was thought to be sixteenth century with the surviving features suggesting a date nearer AD 1600 than AD 1550. Roof timbers and two stud posts from these two areas have been dated to AD 1559 (north wing) and AD 1544-69 (east wing), in fact nearer to AD 1550 than AD 1600. Without an absolute felling date for the east-range roof it is still uncertain as to whether these two parts of the building represent a single construction phase or two separate building phases, however, it is known that they both belong to the mid-sixteenth century.

The south front has been attributed to both Sir Coplestone Bampfylde (2nd bart; died AD 1691) and Sir Coplestone Bampfylde (3rd bart, died AD 1727). Roof timbers from this part of the building have been dated to AD 1725 and, therefore, this is now known to be the work of the 3rd bart. A single timber from the east range has been dated to AD 1716-41, supporting the suggestion that work in this part of the building was also being undertaken at this time.

Timbers from the ground and first-floor frames in the east and south ranges have been dated to the mid-sixteenth (AD 1547-72) and the late-seventeenth/early-eighteenth (AD 1671-96 and AD 1699-1724) centuries. In the case of those from the south range these must represent the secondary use of timbers, some of them probably from original construction timbers, as this range has been shown to be built with timbers felled in AD 1725.

The west range cannot be closely dated on architectural features but is thought to be *c* AD 1800. It is unfortunate that the possible presence of asbestos in this area meant sampling could not be undertaken at this time. If in the future, this material was found not to be asbestos or was removed and this part of the building made safe for sampling, it might be beneficial to return and sample timbers from its roof in order to clarify the development of Poltimore House.

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Table 1: Details of tree-ring samples from Poltimore House, Poltimore, Devon

Sample number	Sample location	Total rings	Sapwood rings*	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
South Range: roof						
POL-B01	South principal rafter, truss 1	87	14	1635	1707	1721
POL-B02	North principal rafter, truss 1	80	21	----	----	----
POL-B03	North principal rafter, truss 2	64	--	1599	----	1662
POL-B04	South lower purlin, trusses 3-4	116	h/s	1592	1707	1707
POL-B05	South mid purlin, trusses 4-5	137	--	1536	----	1672
POL-B06	North principal rafter, truss 8	64	17	1656	1702	1719
POL-B07	North lower purlin, trusses 8-9	94	23C	1632	1702	1725
POL-B08	South principal rafter, truss 9	100	--	1599	----	1698
POL-B09	North principal rafter, truss 9	123	h/s	1580	1702	1702
POL-B10	South principal rafter, truss 10	107	--	1580	----	1686
POL-B11	Collar, truss 10	101	h/s	1609	1709	1709
POL-B12	North wallplate, trusses 8-9	84	20	1639	1702	1722
East Range: roof and stud posts						
POL-B13	Main joist, truss 3	103	--	1407	----	1509
POL-B14	Main joist, truss 4	94	h/s	1424	1517	1517
POL-B15	Main joist, truss 5	128	h/s	1413	1540	1540
POL-B16	East common rafter 6, bay 4	67	h/s	1464	1530	1530
POL-B17	East common rafter 4, bay 4	73	h/s	1470	1542	1542
POL-B18	West lower purlin, trusses 1-2	73	h/s	1454	1526	1526
POL-B19	West lower purlin, trusses 3-4	95	--	1415	----	1509
POL-B20	East principal rafter, truss 6	88	h/s	1614	1701	1701
POL-B21	East upper purlin, trusses 6-south end	59	10	----	----	----
POL-B22	Collar, truss 3	90	h/s	1446	1535	1535
POL-B23	Collar, truss 4	99	h/s	----	----	----

POL-B24	East principal rafter, truss 3	106	h/s	1422	1527	1527
POL-B25	East lower purlin, trusses 2-3	69	h/s	----	----	----
POL-B26	East principal rafter, truss 4	71	h/s	1454	1524	1524
POL-B27	Stud post 3, bay 4	58	h/s	1472	1529	1529
POL-B28	Stud post 4, bay 4	68	h/s	1453	1520	1520
North Range: roof						
POL-B29	West purlin to east gable roof, (south)	144	h/s	1391	1534	1534
POL-B30	South queen post to west truss, east gable	145	h/s	1394	1538	1538
POL-B31	East purlin to west gable roof	117	h/s	1420	1536	1536
POL-B32	East principal rafter to west gable (south)	111	h/s	1425	1535	1535
POL-B33	East common rafter 1, west gable (south)	77	h/s	----	----	----
POL-B34	East purlin to east gable (south)	111	32C	1449	1527	1559
POL-B35	South principal rafter to east gable roof	115	--	1389	----	1503
POL-B36	South purlin, bay 2	134	h/s	1406	1539	1539
POL-B37	South principal rafter, truss 2	99	--	1409	----	1507
POL-B38	South purlin, trusses 1-2	132	h/s	1405	1536	1536
POL-B39	South queen post to truss 2	141	h/s	1393	1533	1533
POL-B40	South principal rafter, truss 1	62	h/s	----	----	----
East Range: First-floor frame						
POL-B41	Joist, room 50	168	21	1380	1526	1547
POL-B42	Joist, room 50	71	08	----	----	----
POL-B43	Joist, room 50	83	--	1386	----	1468
POL-B44	Common joist, room 48	127	h/s	----	----	----
POL-B45	Common joist, room 48	154	01	1383	1535	1536
POL-B46	Common joist, room 48	91	21C	----	----	----

South Range: First-floor frame						
POL-B47	Main joist, room 58 (east beam)	64	10	1491	1544	1554
POL-B48	Main joist, room 58 (west beam)	145	09	1390	1525	1534
POL-B49	Main joist, room 59h	66	h/s	1619	1684	1684
South Range: Ground-floor frame						
POL-B50	Main joist, room 4 (west)	112	h/s	1422	1533	1533
POL-B51	Main joist, room 4 (east)	70	h/s	----	----	----
POL-B52	Common joist 6, room 4	93	h/s	1435	1527	1527
POL-B53	Common joist, room 4	88	h/s	1564	1651	1651
POL-B54	Common joist, room 4	88	h/s	1573	1660	1660
POL-B55	Common joist, room 4	64	--	1534	----	1597

*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 POLBSQ01 and relevant reference chronologies when the first-ring date is AD 1380 and the last-ring date is AD 1559

Reference chronology	*t*-value	Span of chronology	Reference
England, London	6.3	AD 413-1728	Tyers and Groves 1999 unpubl
Southern England	5.3	AD 1083-1981	Bridge 1988
Kent	4.8	AD 1158-1540	Laxton and Litton 1989
Pye Corner, Moulsford, Oxon	6.7	AD 1340-1558	Alcock *et al* 1991
Wells Cathedral, E range roof C1 - 19	5.8	AD 1279-1451	Howard *et al* 2001
Lacock Abbey, Wilts	5.5	AD 1395-1546	Esling *et al* 1990
The Forge, Church St, E Hendred, Oxon	5.1	AD 1379-1521	Alcock *et al* 1989

Table 3: Results of the cross-matching of site sequence POLBSQ02 and relevant reference chronologies when the first-ring date is AD 1564 and the last-ring date is AD 1660

Reference chronology	*t*-value	Span of chronology	Reference
England	5.7	AD 401-1981	Baillie and Pilcher 1982 unpubl
England, London	5.1	AD 413-1728	Tyers and Groves 1999 unpubl
Stoneleigh Abbey	6.1	AD 1398-1658	Howard *et al* 2004 unpubl
Nevile Holt, Leicestershire	5.9	AD 1570-1638	Howard 2001 unpubl
Sinai House, Burton on Trent, Staffs (central range)	5.3	AD 1555-1665	Howard *et al* 1999
Staircase House, Stockport, Greater Manchester	4.9	AD 1069-1248	Howard *et al* 2003
Bolsover Castle (Riding House), Derbys	4.7	AD 1494-1744	Howard *et al* forthcoming

Table 4: Results of the cross-matching of site sequence POLBSQ03 and relevant reference chronologies when the first-ring date is AD 1534 and the last-ring date is AD 1725

Reference chronology	*t*-value	Span of chronology	Reference
England, London	7.4	AD 413-1728	Tyers and Groves 1999 unpubl
East Midlands	5.9	AD 882-1981	Laxton and Litton 1988
England	5.5	AD 401-1981	Baillie and Pilcher 1982 unpubl
Worcester Cathedral	6.7	AD 1484-1772	Arnold *et al* 2003a
Manor Ho, Templecombe, Somerset	6.2	AD 1486-1591	Howard *et al* 1997
South	6.0	AD 1458-1681	Howard 2002 unpubl
Hulme Hall, Allostock	5.6	AD 1574-1689	Arnold *et al* 2003b

Table 5: Results of the cross-matching of site sequence POLBSQ04 and relevant reference chronologies when the first-ring date is AD 1534 and the last-ring date is AD 1725

Reference chronology	*t*-value	Span of chronology	Reference
England, London	8.2	AD 413-1728	Tyers and Groves 1999 unpubl
East Midlands	6.6	AD 882-1981	Laxton and Litton 1988
England	6.3	AD 401-1981	Baillie and Pilcher 1982 unpubl
Worcester Cathedral	7.1	AD 1484-1772	Arnold *et al* 2003a
Manor Ho, Templecombe, Somerset	7.1	AD 1486-1591	Howard *et al* 1997
South	6.7	AD 1458-1681	Howard 2002 unpubl
Sutton Scarsdale manor, Derbys	5.9	AD 1520-1632	Howard *et al* 1997

Figure 1: Map to show the location of Poltimore House

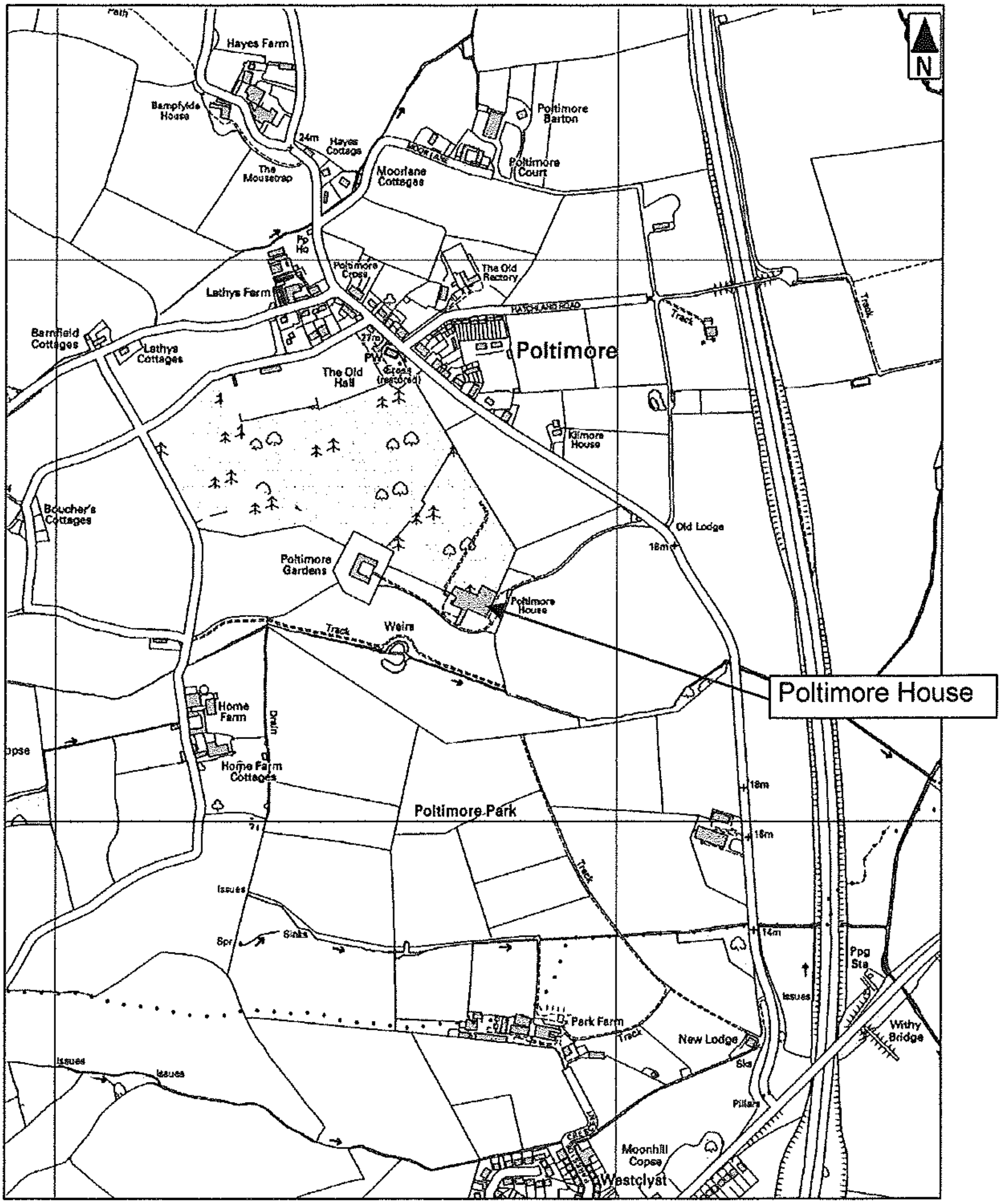


Figure 2: Ground-floor plan (Louis Hawkins, Architect)

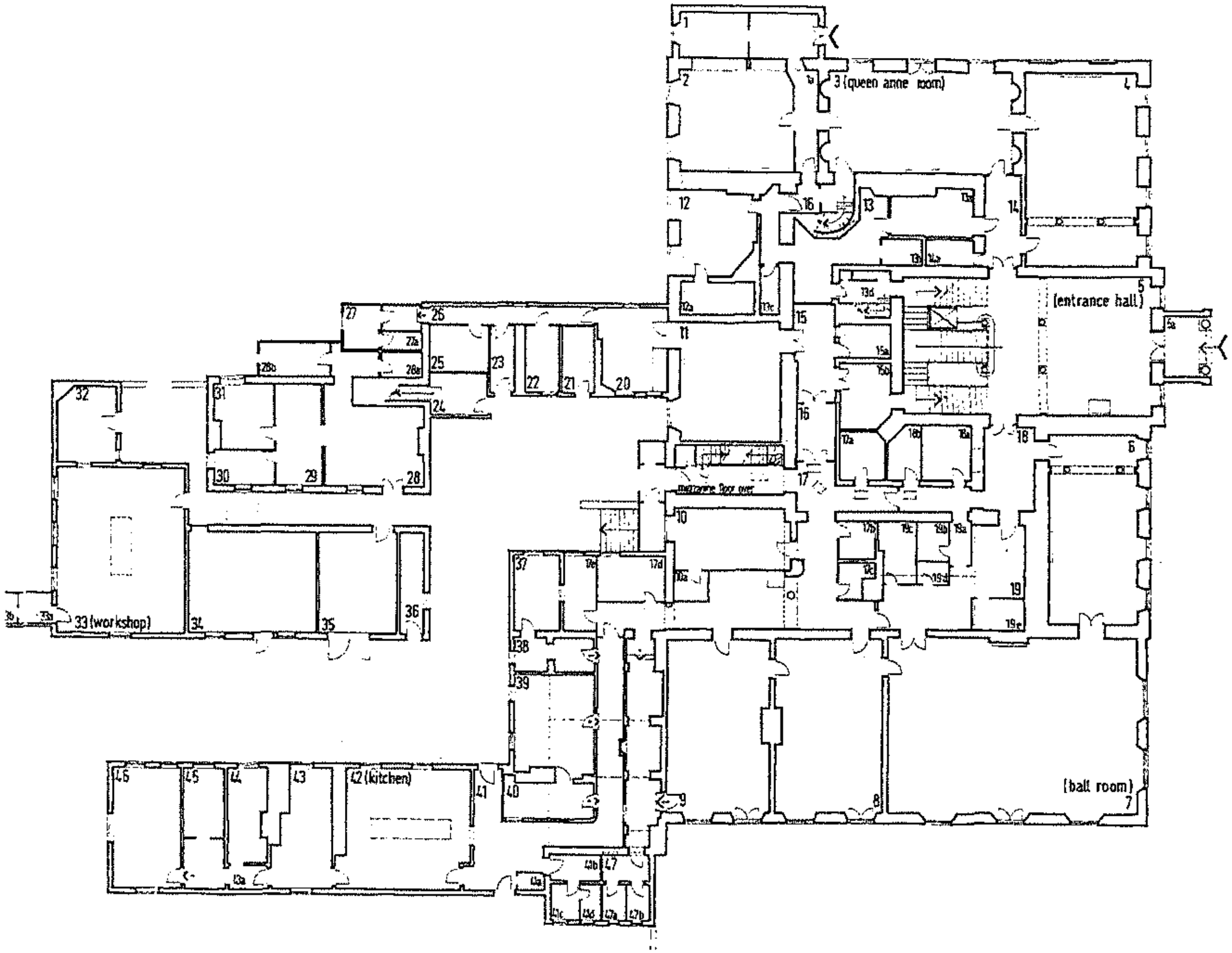


Figure 3: First-floor plan (Louis Hawkins, Architect)

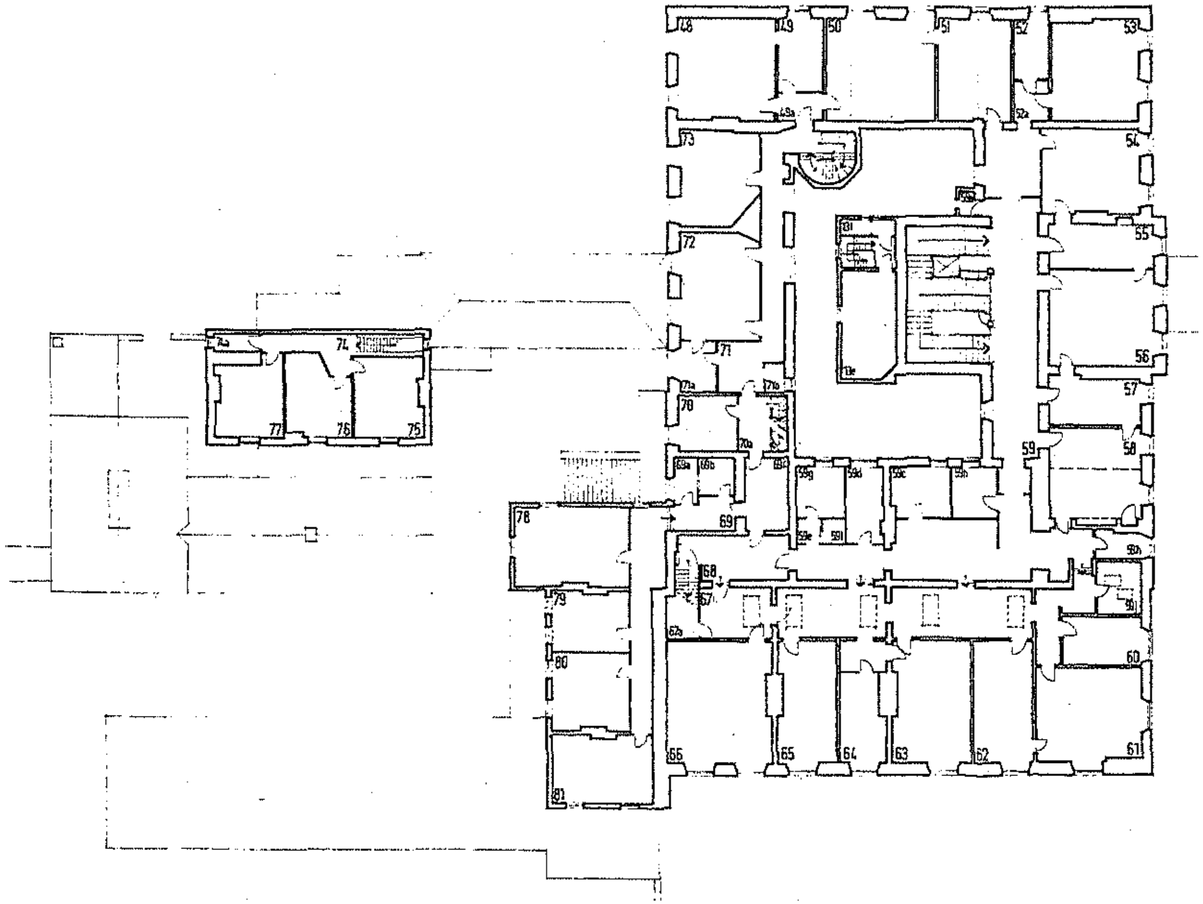


Figure 4: Second-floor plan (Louis Hawkins, Architect)

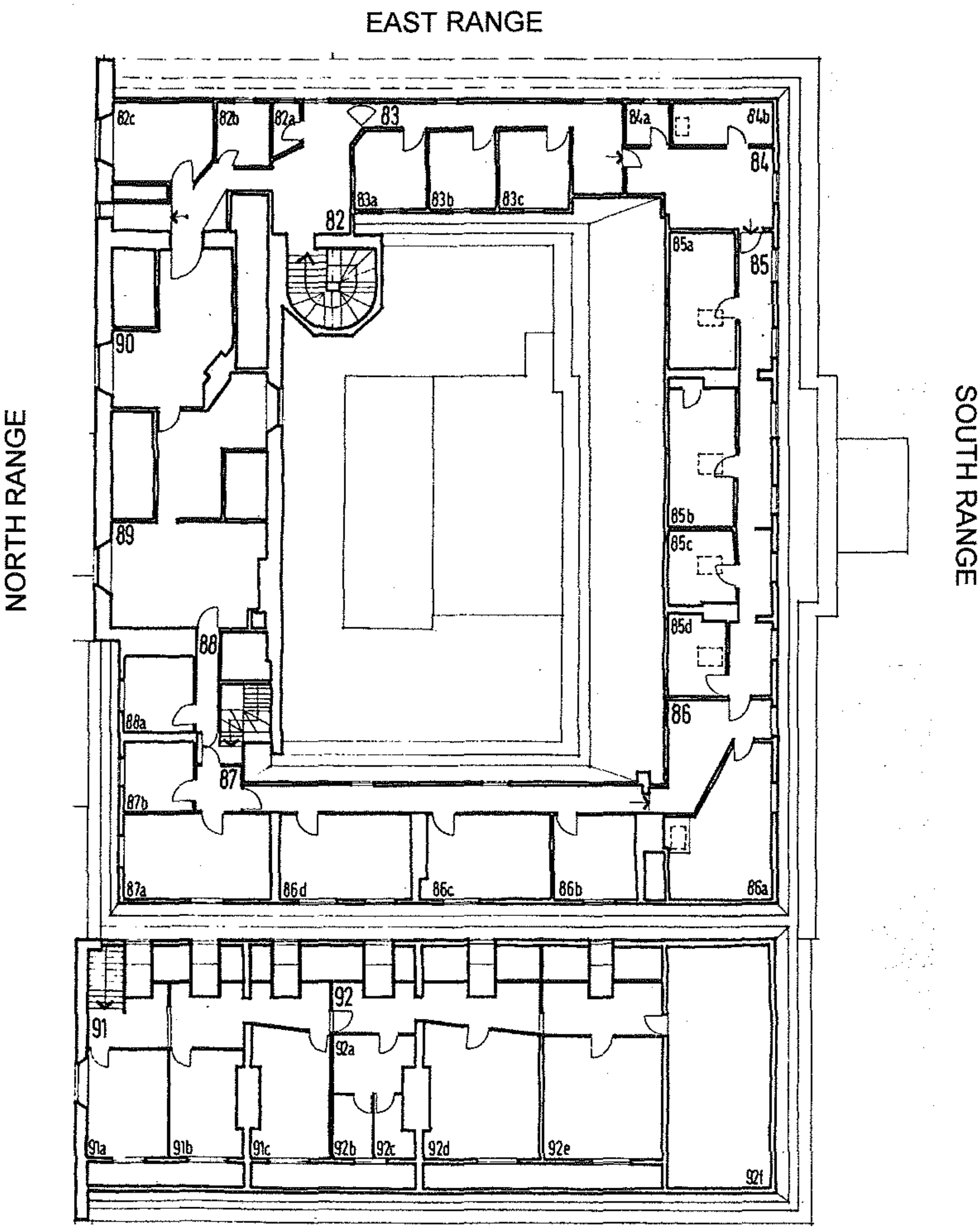


Figure 5: The rear (or north) wing (Christine Locatelli)

Figure 6: The polygonal stair turret, from the internal courtyard (Christine Locatelli)

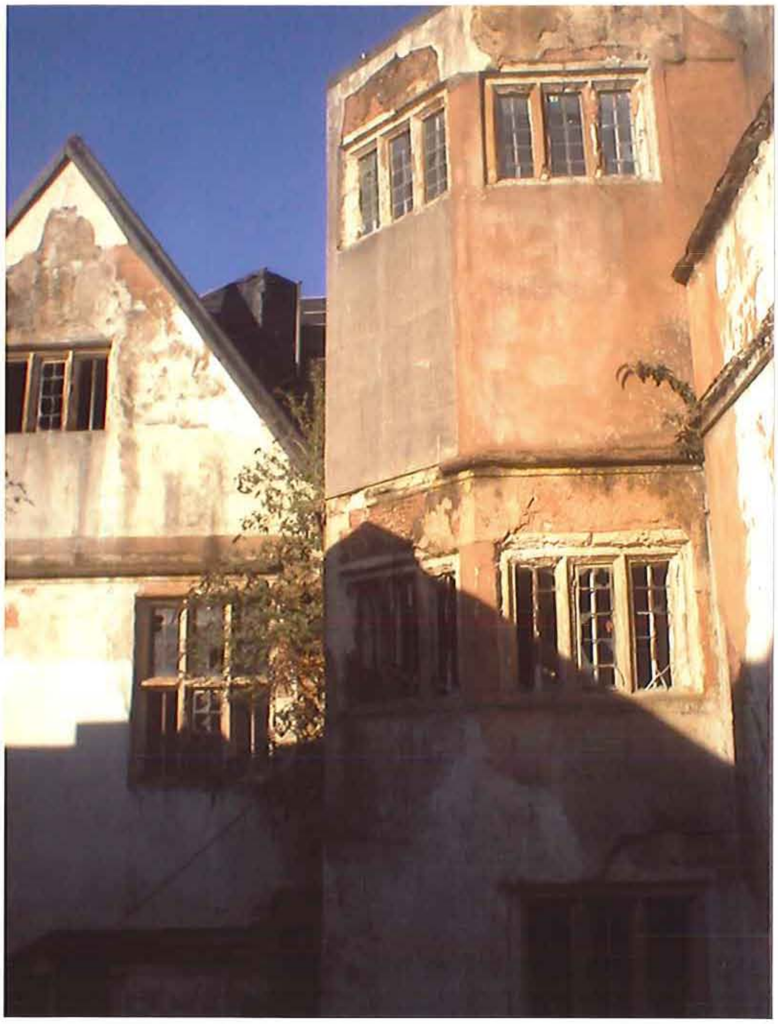


Figure 7: The south front (Christine Locatelli)

Figure 8: South range roof, truss 4 (Christine Locatelli)

Figure 9: South range, second-floor plan, showing truss numbering and location of samples POL-B01-12 (Louis Hawkins, Architect)

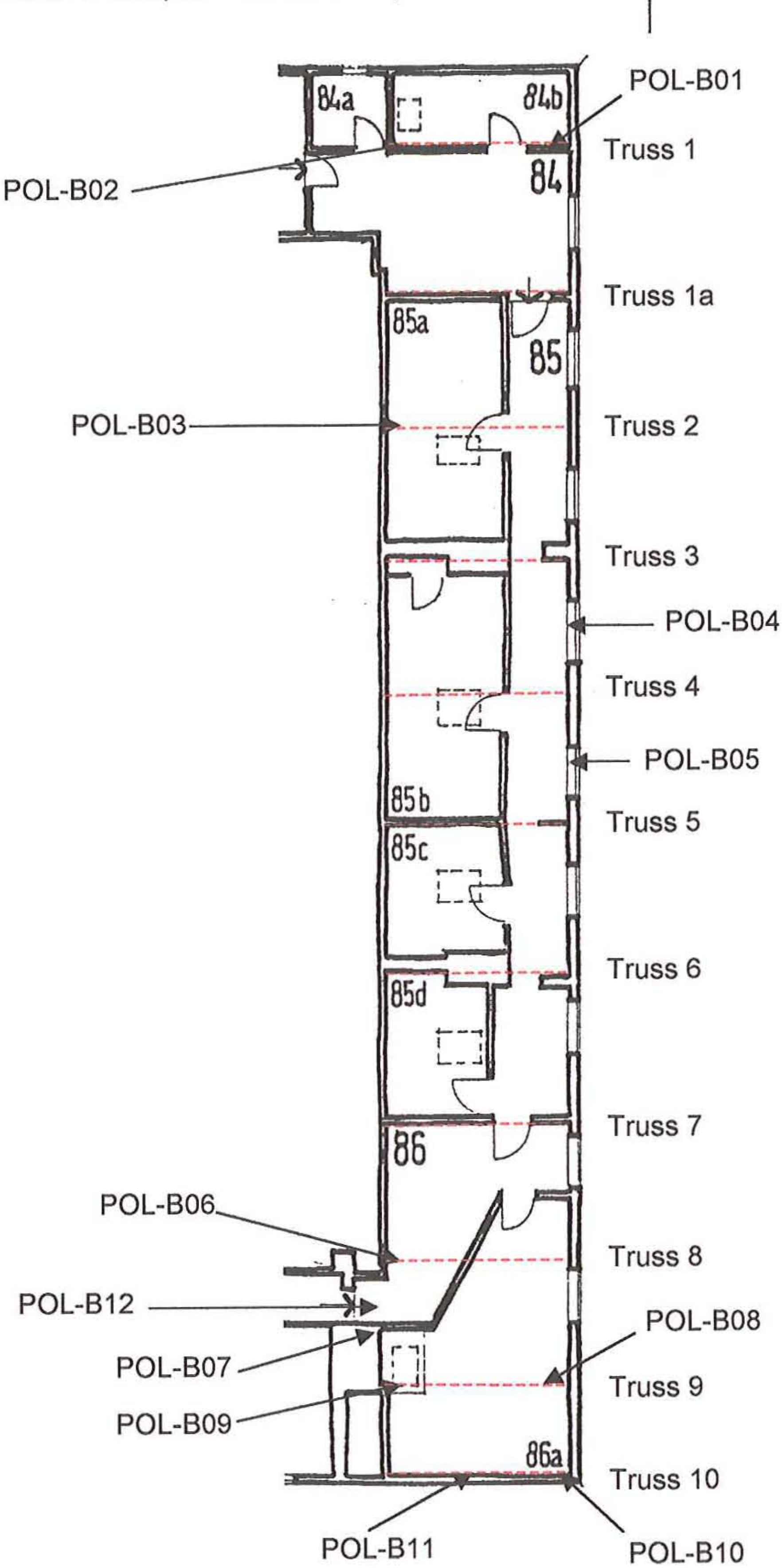


Figure 10: East range, second-floor plan, showing truss numbering and the location of samples POL-B13-28 (Louis Hawkins, Architect)

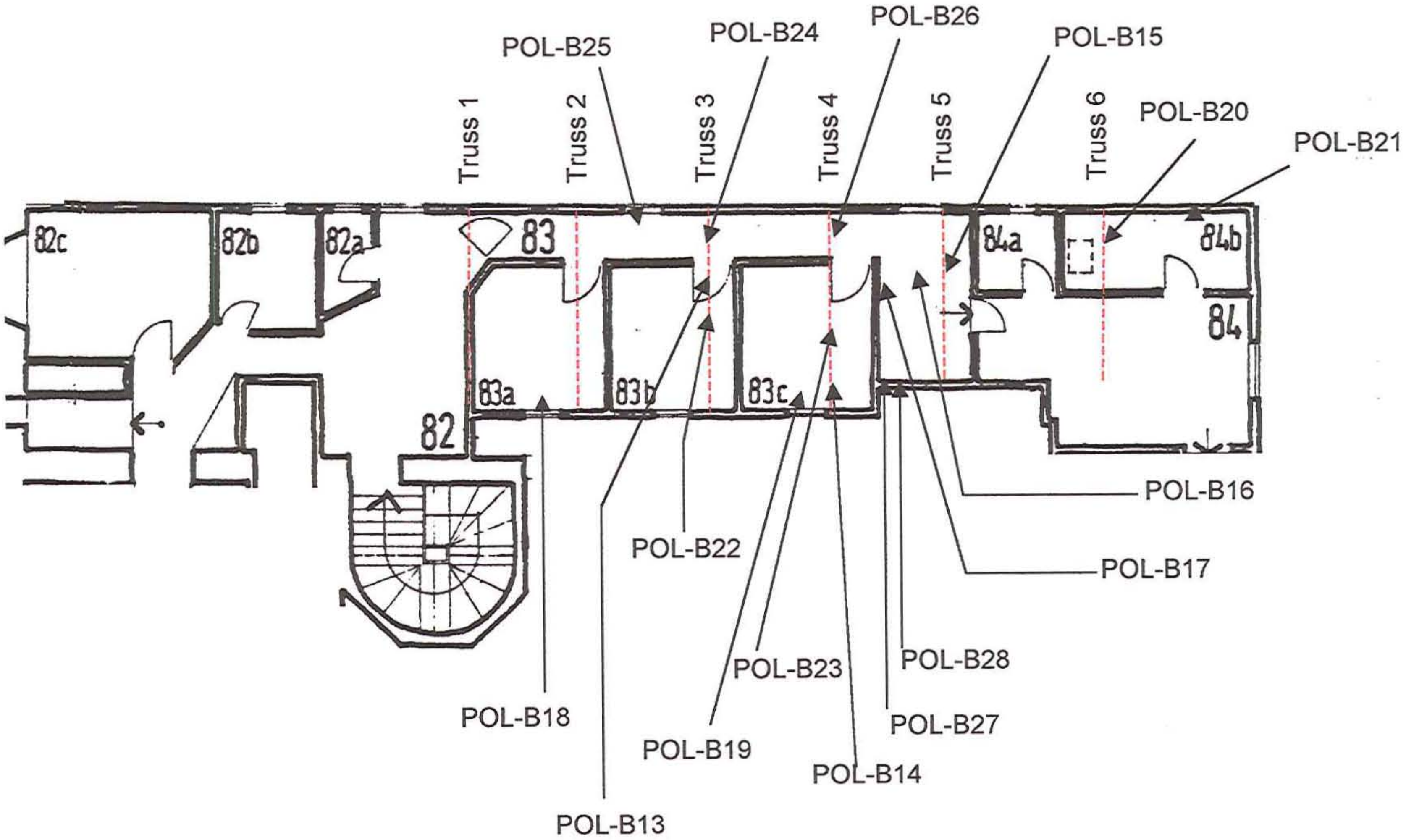


Figure 11: North range, second-floor plan, showing truss numbering and the location of samples POL-B29-40 (Louis Hawkins, Architect)

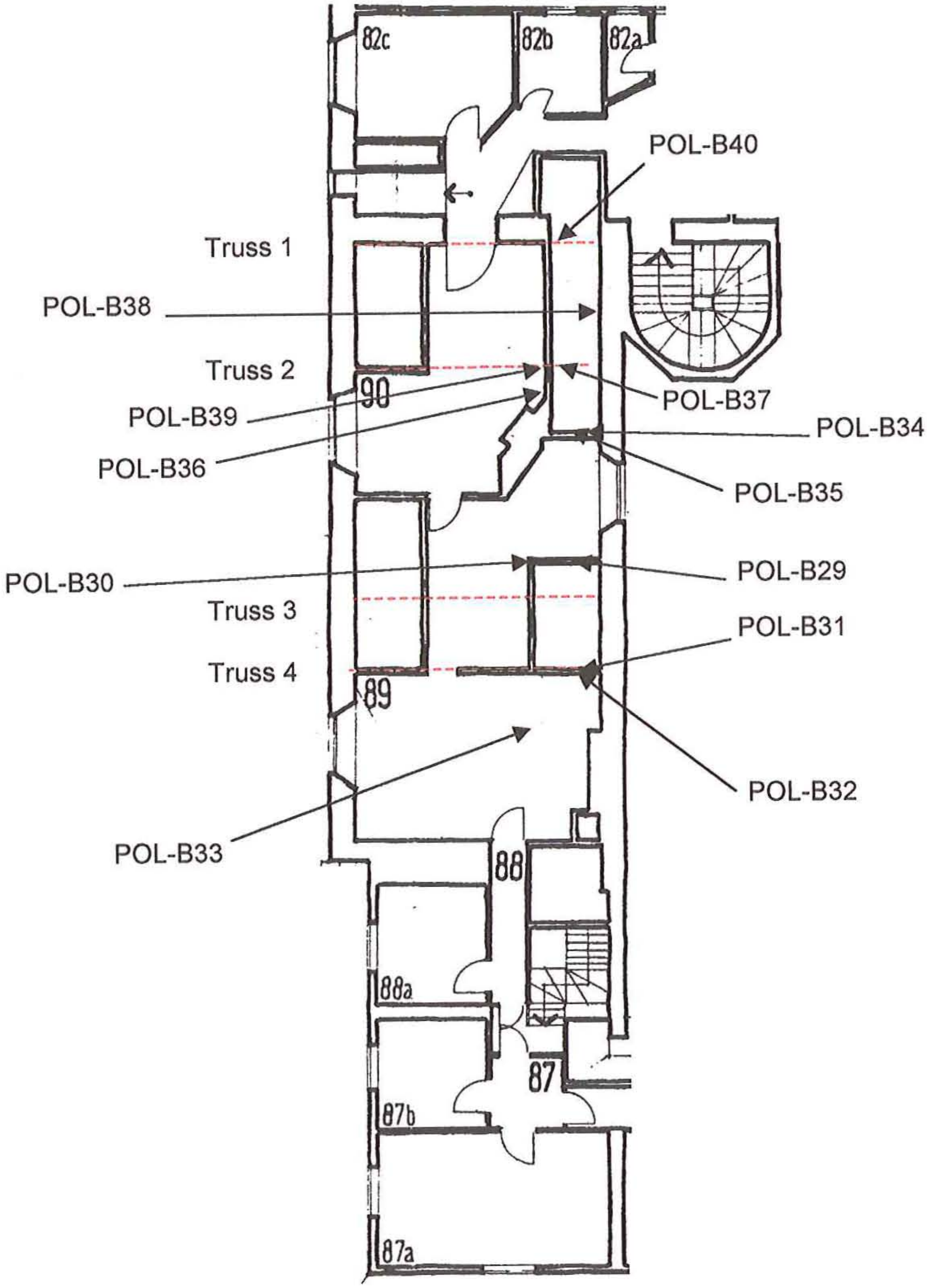


Figure 12: First-floor plan, showing the location of samples POL-B41-46 (Louis Hawkins, Architect)

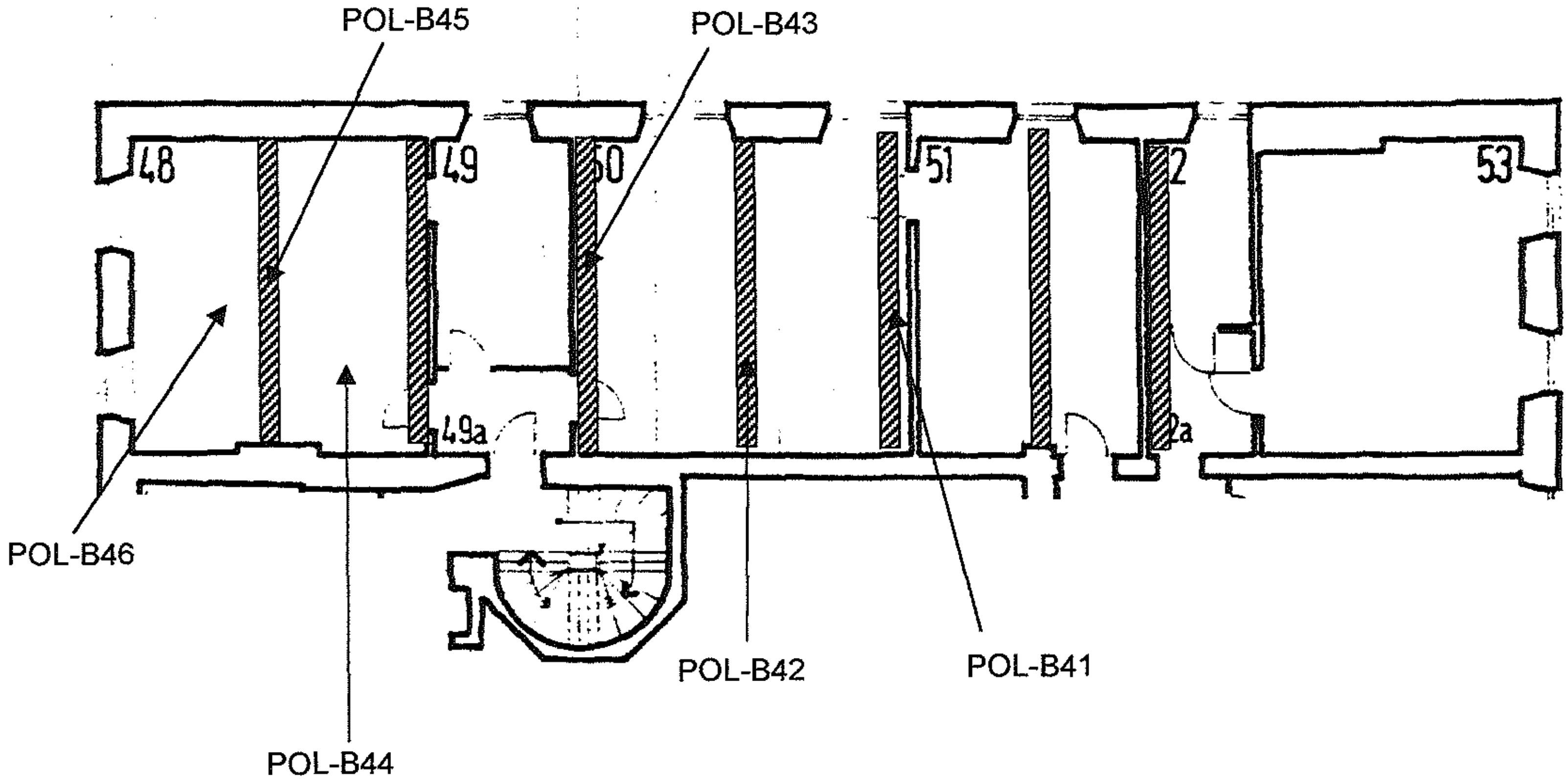


Figure 13: South range, first-floor plan, showing the location of samples POL-B47-49 (Louis Hawkins, Architect)

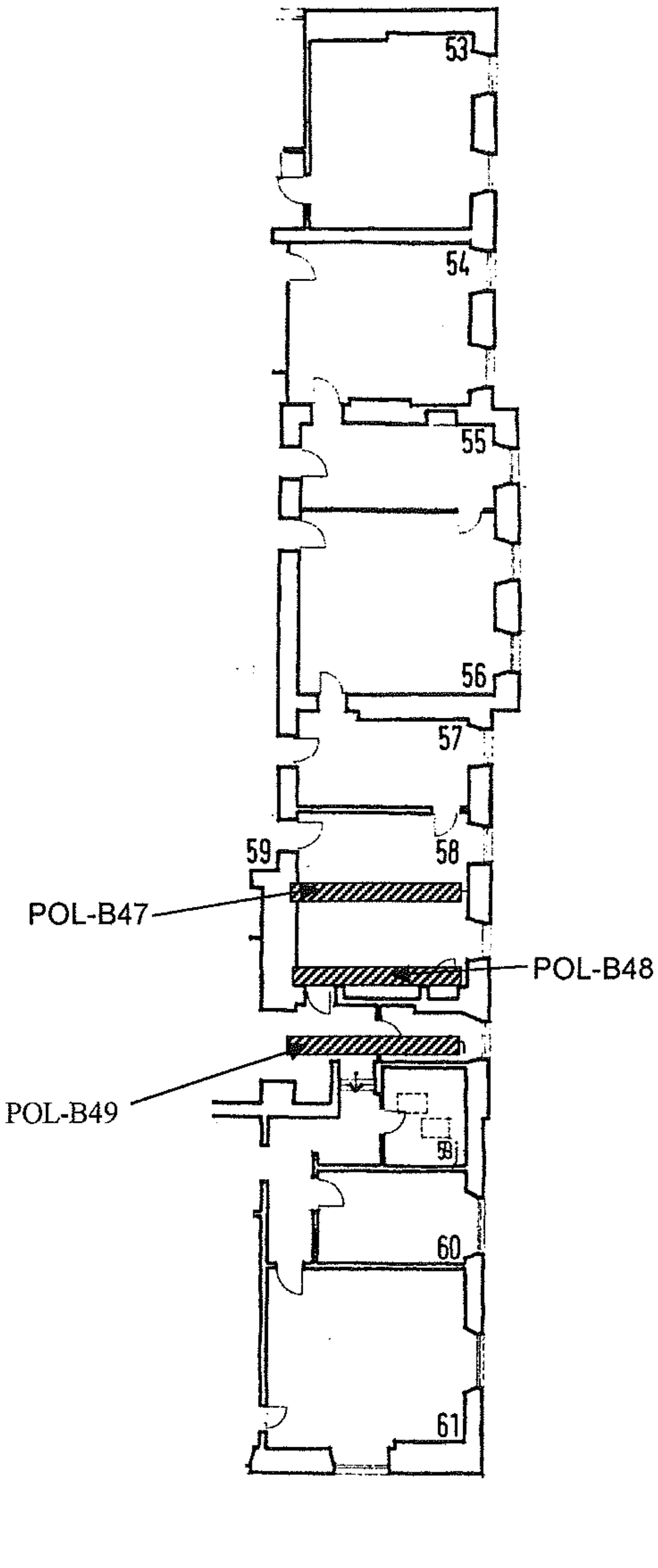


Figure 14: South range, ground-floor plan (room 4), showing the location of samples POL-B50-55 (Louis Hawkins, Architect)

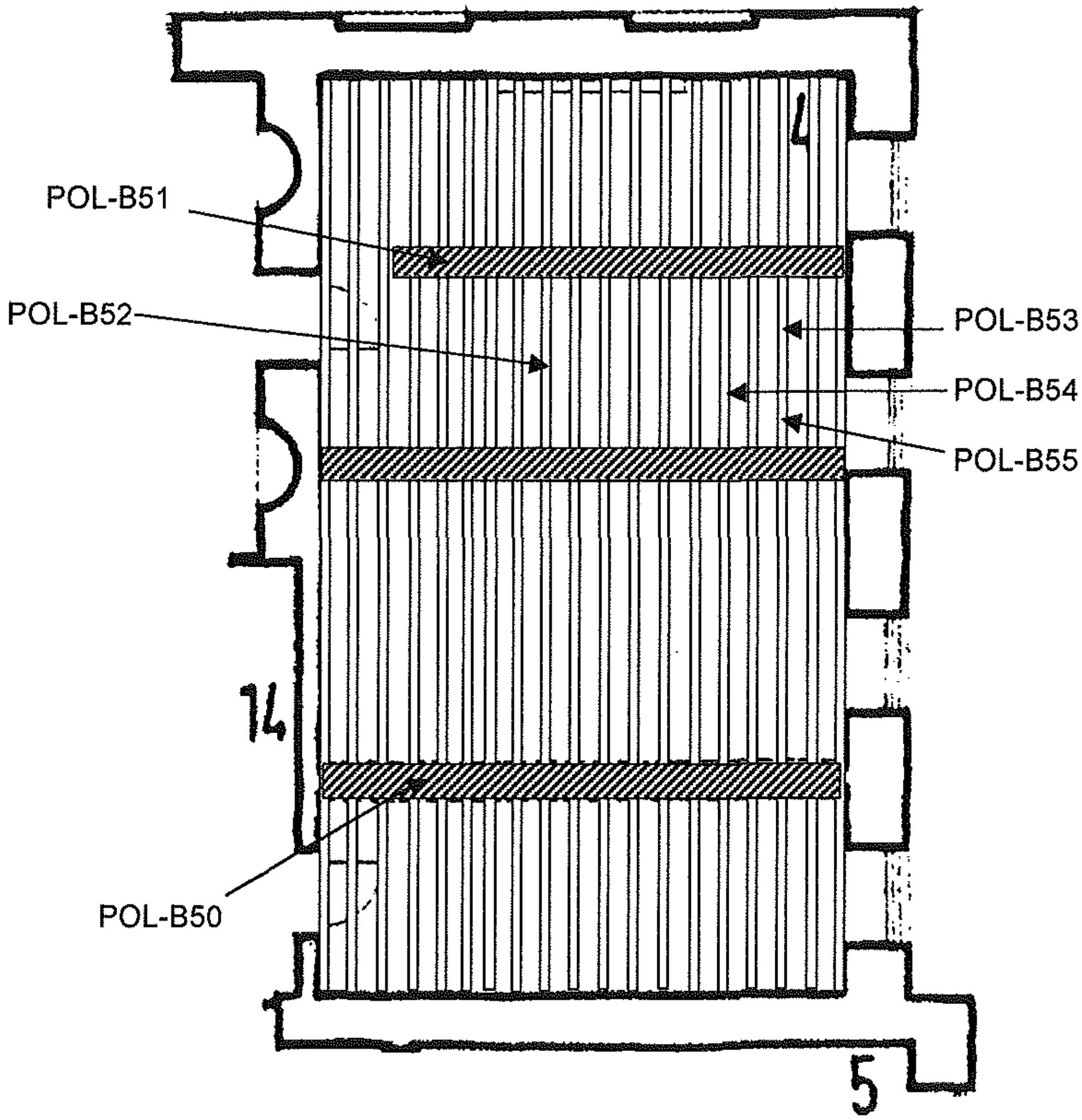
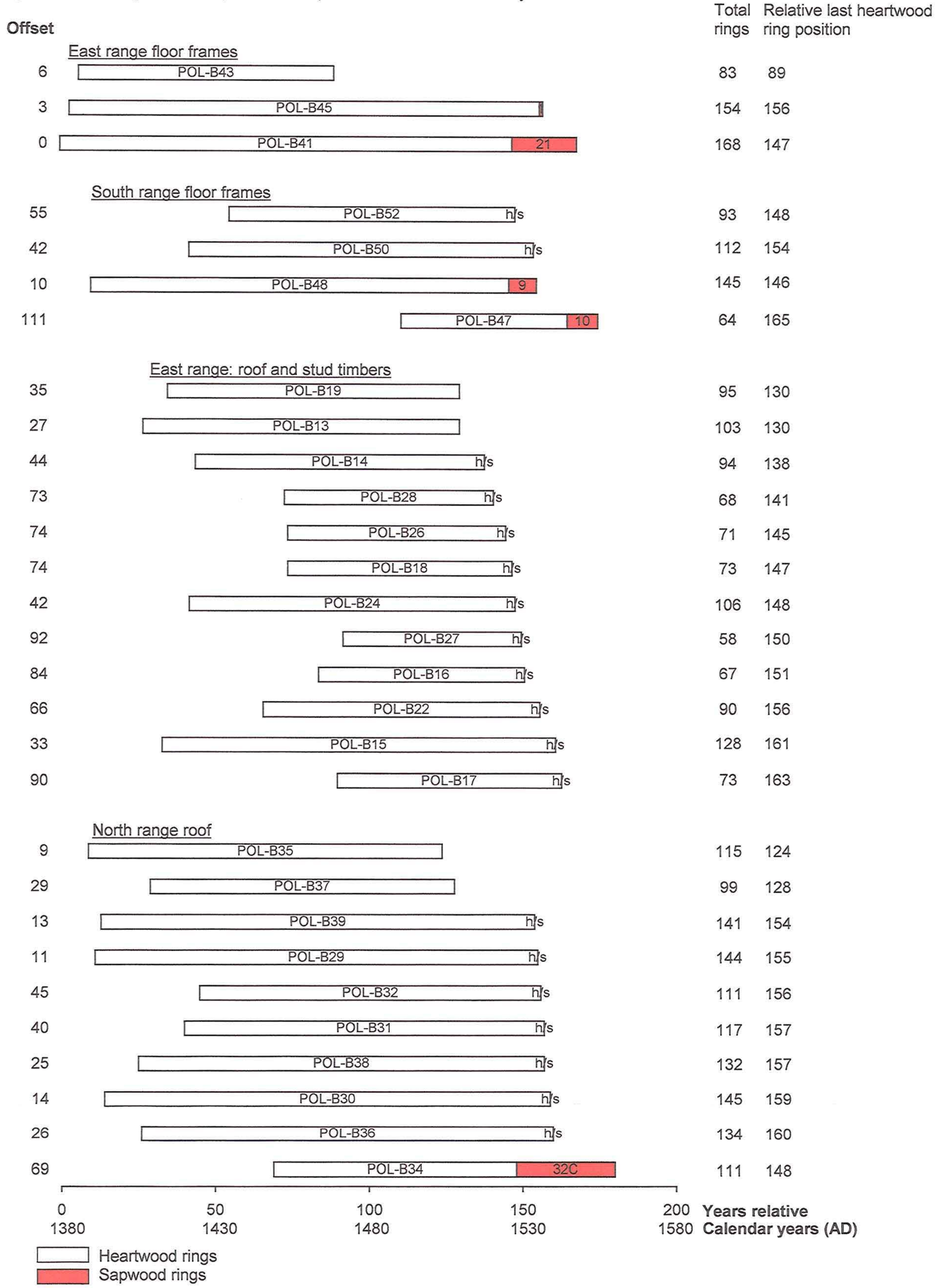
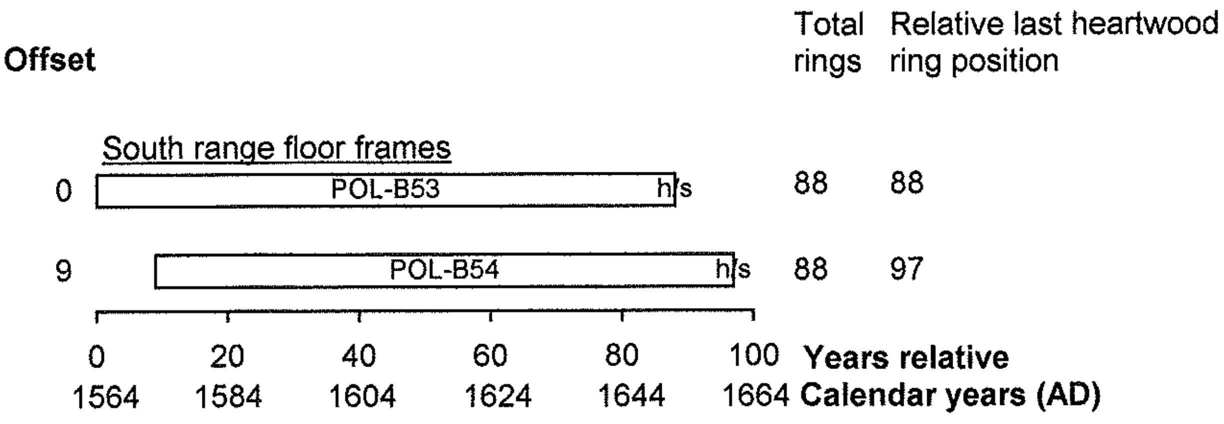


Figure 15: Bar diagram of sample in site sequence POLBSQ01 sorted by area



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

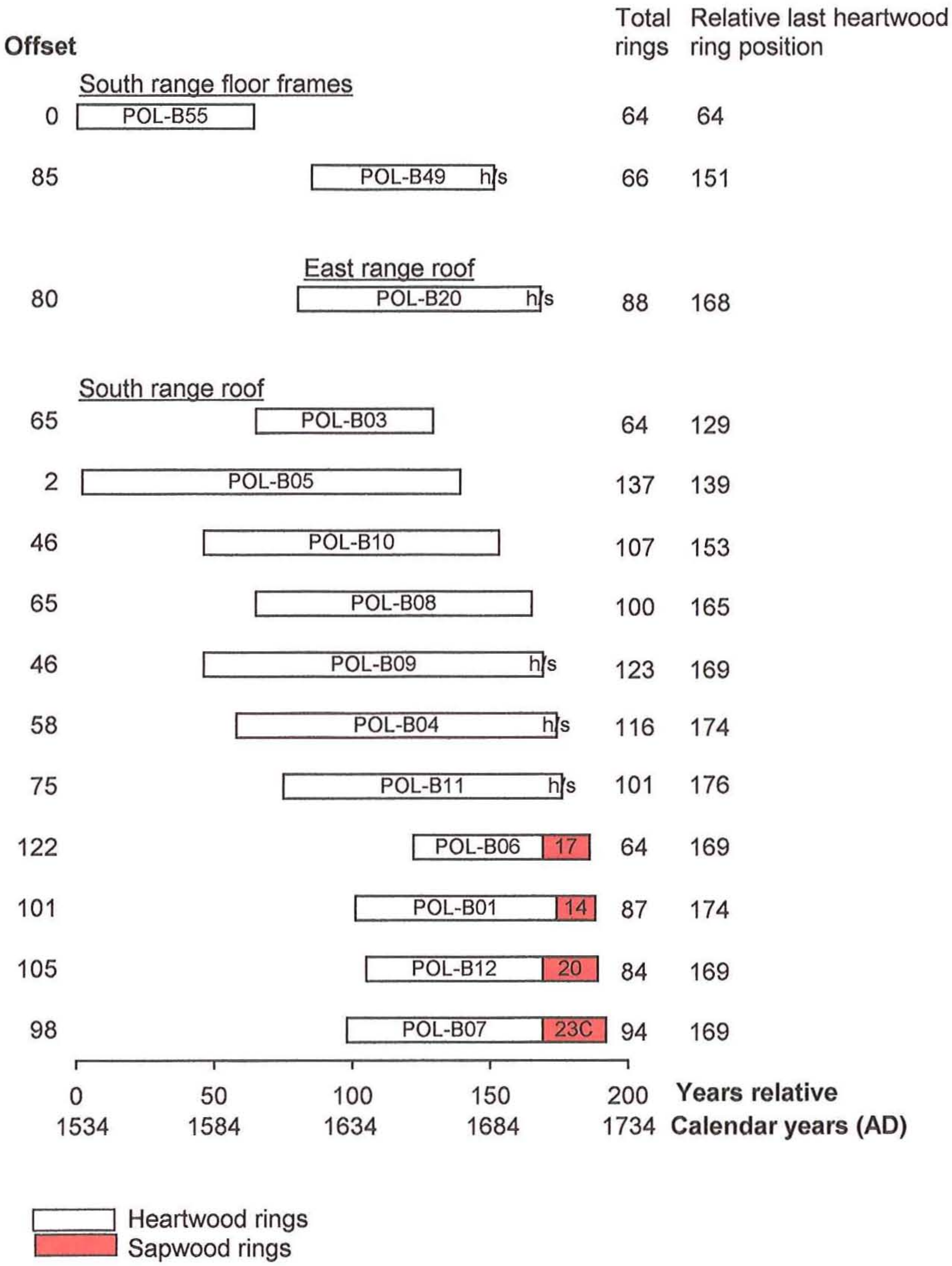
Figure 16: Bar diagram of samples in site sequence POLBSQ02 sorted by area



Heartwood rings

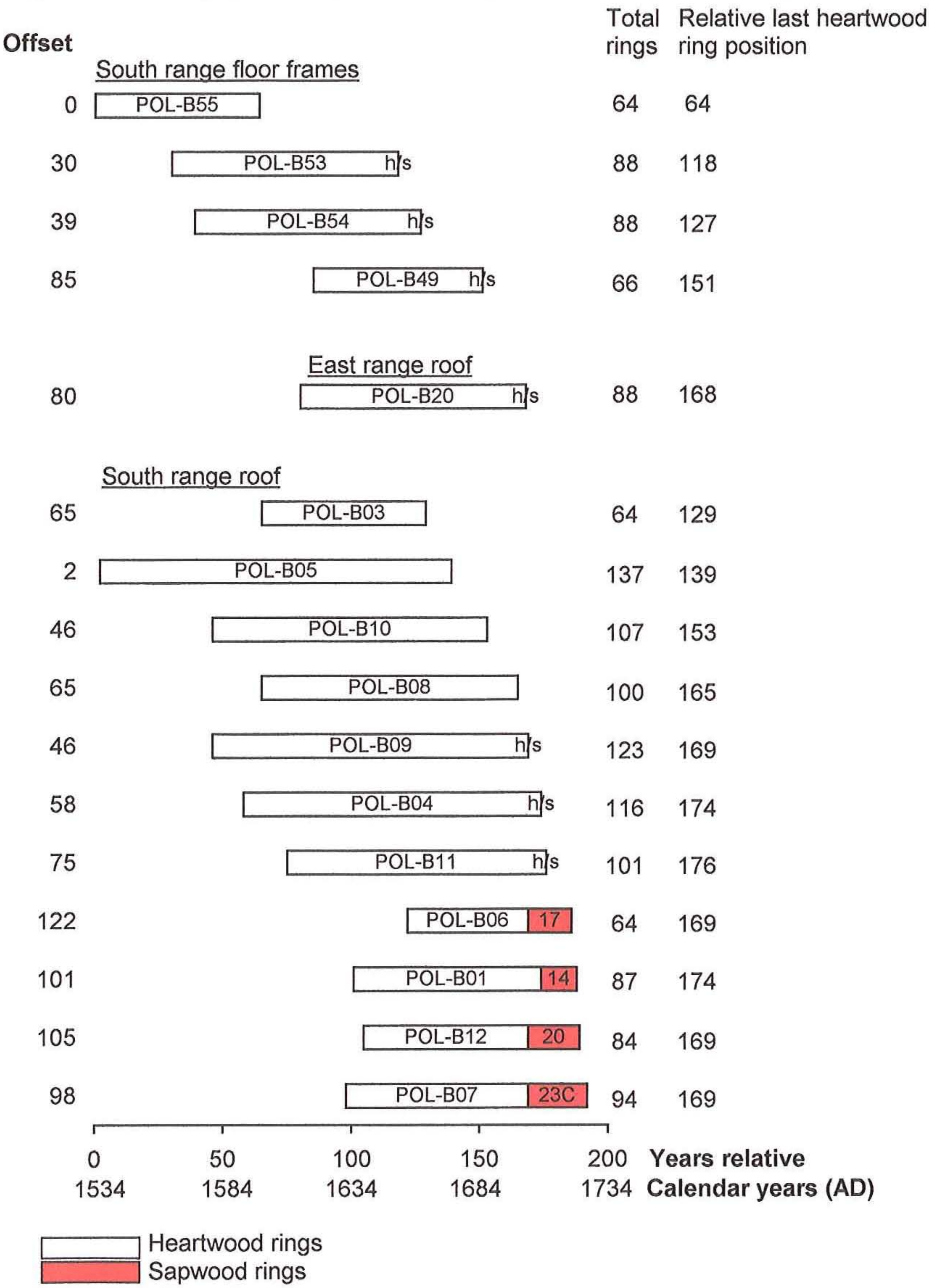
h/s = the heartwood/sapwood boundary is the last measured ring.

Figure 17: Bar diagram of samples in site sequence POLBSQ03 sorted by area



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

Figure 18: Bar diagram of samples in site sequence POLBSQ04 sorted by area



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

Data of measured samples – measurements in 0.01mm units

POL-B01A 87
210 198 214 195 141 139 142 158 258 232 313 302 195 321 342 309 202 191 213 212
294 266 322 222 139 249 279 227 240 213 188 192 140 253 186 237 247 261 331 293
242 225 243 228 156 197 171 232 168 220 198 249 150 132 179 210 115 102 157 167
185 194 135 195 215 178 116 101 132 107 90 76 145 142 155 140 164 156 203 131
160 164 145 132 101 103 136
POL-B01B 87
161 194 208 196 145 137 151 148 258 209 301 310 188 342 358 281 195 188 211 214
288 273 328 234 195 243 270 235 234 203 196 190 135 253 186 227 236 263 336 276
255 242 241 223 147 203 166 227 169 230 196 224 160 132 185 223 94 122 168 161
178 200 134 200 200 175 117 93 137 94 98 69 153 153 160 146 155 174 184 147
164 155 149 128 109 113 131
POL-B02A 80
244 134 141 142 174 214 136 157 113 169 231 191 138 119 141 85 134 98 152 86
61 82 67 70 131 145 151 132 180 194 135 71 69 74 85 99 165 142 163 53
70 57 76 142 186 142 127 205 87 128 89 111 195 183 163 138 84 84 114 183
84 130 171 173 293 159 176 143 235 174 189 174 150 118 159 152 175 178 121 171
POL-B02B 80
265 140 130 124 182 229 128 136 116 202 224 189 131 118 127 86 133 80 175 81
64 80 70 69 138 139 150 130 180 187 140 85 84 80 85 115 179 139 161 52
70 59 77 130 189 148 119 211 92 125 98 115 184 189 160 127 82 100 105 169
67 140 171 159 318 128 176 155 252 178 179 168 155 128 168 157 174 187 118 148
POL-B03A 64
282 325 312 315 303 312 245 279 162 101 143 129 179 251 240 211 75 53 73 110
112 168 196 160 169 192 328 216 231 296 285 254 316 307 345 209 228 252 320 329
352 247 152 247 221 147 185 261 189 203 161 179 219 261 305 307 248 230 286 208
160 251 272 254
POL-B03B 64
251 320 360 282 318 345 213 291 155 108 143 137 173 216 251 200 82 47 68 99
112 172 212 203 168 200 311 241 249 250 246 267 331 319 355 209 225 251 309 338
353 257 167 241 230 131 183 260 195 197 163 186 219 259 278 299 246 227 278 207
166 254 264 259
POL-B04A 116
165 172 151 194 206 151 107 205 184 155 121 123 91 82 156 147 158 136 114 125
86 148 94 114 109 124 149 93 81 122 115 135 122 122 73 84 104 145 140 89
119 82 71 109 56 130 123 101 163 146 124 148 126 139 183 126 129 98 132 133
92 74 81 101 87 98 154 88 135 85 93 171 122 142 124 111 137 115 164 111
180 174 163 169 151 198 160 158 196 132 219 169 165 143 177 208 157 164 163 126
103 175 91 161 170 124 133 94 101 76 86 103 116 68 81 96
POL-B04B 116
126 164 172 202 198 154 141 216 160 151 127 116 105 96 145 143 163 129 128 136
73 146 103 116 97 131 106 90 83 133 117 143 114 109 83 86 99 127 144 110
129 93 83 102 60 156 121 105 153 164 126 157 119 133 186 125 125 100 135 131
106 75 71 105 88 120 120 103 127 84 89 190 101 138 124 122 113 121 168 106
176 177 152 172 153 199 163 134 217 111 226 170 162 152 193 193 144 148 139 131
119 162 90 152 174 128 122 97 98 81 84 116 102 78 66 122

POL-B05A 137
122 142 139 182 147 174 135 116 108 126 89 115 155 230 140 185 154 129 164 108
91 105 125 102 84 79 103 77 132 121 78 97 83 107 114 98 91 90 126 123
82 112 143 138 216 92 141 121 147 122 150 133 138 140 105 137 123 161 189 203
173 133 131 159 125 128 115 109 125 84 165 155 165 152 131 133 94 180 149 141
102 157 155 111 122 188 155 136 105 106 78 84 103 128 121 104 100 79 77 61
42 103 91 91 113 121 96 90 88 83 81 51 59 63 79 78 64 54 48 53
62 61 71 57 71 45 47 104 84 107 88 77 110 91 132 169 222
POL-B05B 137
101 137 134 189 141 162 141 113 115 107 114 123 191 224 133 180 146 126 164 137
88 106 124 95 93 74 107 79 135 113 78 85 76 96 126 97 89 94 127 116
91 107 139 145 216 102 127 134 156 127 144 139 136 151 98 140 132 162 189 207
187 134 131 164 121 139 115 99 121 83 137 155 154 159 123 137 91 175 135 157
107 150 144 116 139 183 162 122 126 94 83 93 105 122 129 103 110 84 70 85
56 107 99 88 122 130 100 93 84 91 86 51 62 72 78 79 70 49 45 64
55 66 72 60 66 47 41 99 86 108 86 81 121 97 147 166 206
POL-B06A 64
194 306 302 274 408 390 469 335 266 286 294 282 301 369 350 365 363 362 214 225
193 308 274 318 293 256 246 194 171 166 249 205 177 225 245 190 137 158 153 173
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112 121 134 121
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172 295 260 303 289 256 233 202 185 162 258 201 184 230 240 204 129 140 156 157
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110 123 142 107
POL-B07A 94
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141 167 97 76 110 89 138 131 83 95 129 99 173 125
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136 172 97 77 111 88 133 130 85 82 133 108 169 121
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221 241 217 239 177 169 175 217 167 168 184 173 158 158 118 112 119 162 155 160
POL-B08B 100
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225 237 217 251 186 170 173 219 185 179 184 185 162 157 119 95 118 165 157 182

POL-B09A 123
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POL-B10A 107
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POL-B12A 84
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86 89 166 125

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68 99 169 150
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198 127 113 95 102 114 148 127 142 144 142 77 99
POL-B18B 73
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POL-B19B 95
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143 166 110 125 110 95 114 145 149 173 117 111 87 140 167
POL-B20A 88
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147 171 270 213 212 198 221 133
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216 254 217 338 235 132 200 194 152 257 184 256 294 191 277 259 311 207 203 185
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150 174 249 186 225 202 226 149

POL-B21A 59
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286 265 263 222 171 139 142 102 93 108 112 118 123 124 176 180 145 195 126
POL-B21B 59
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306 267 272 225 170 147 130 105 97 104 115 118 132 129 152 192 125 193 164
POL-B22A 90
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POL-B22B 90
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POL-B23A 99
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174 188 194 159 83 69 79 73 94 90 167 120 116 132 140 143 94 61 58 75
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119 121 104 107 154 180 182 154 178 139 144 113 150 194 144 94 120 135 186 193
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86 81 79 71 83 98 93 75 54 111 115 81 115 104 98 93 105 123 100 104
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POL-B24B 106
161 187 189 164 90 64 83 66 84 93 160 121 127 125 157 133 88 68 64 77
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232 192 224 191 221 148 150 161 177 157 120 95 144 116 98 116 74 62 84 69
85 75 71 75 67 99 73 80 57 119 112 92 108 110 95 103 103 118 100 96
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POL-B25A 69
158 224 226 200 235 226 206 127 128 196 232 145 173 200 263 186 115 56 132 116
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POL-B25B 69
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POL-B26A 71
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87 45 63 73

POL-B29B 144
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POL-B32A 111
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51 99 108 94 94 124 123 68 60 48 57

POL-B32B 111
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141 112 126 146 132 215 152 101 176 143 168 170 181 153 105 113 116
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93 106 105 80 59 47 94 82 82 69 57 60 90 60 74 63 59 63 61 57
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125 108 76 116 59 154 113 168 82 123 126 80 81 78 122 122 78 131 141 159
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POL-B36A 134
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POL-B49A 66
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APPENDIX

Tree-Ring Dating

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

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

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

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

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

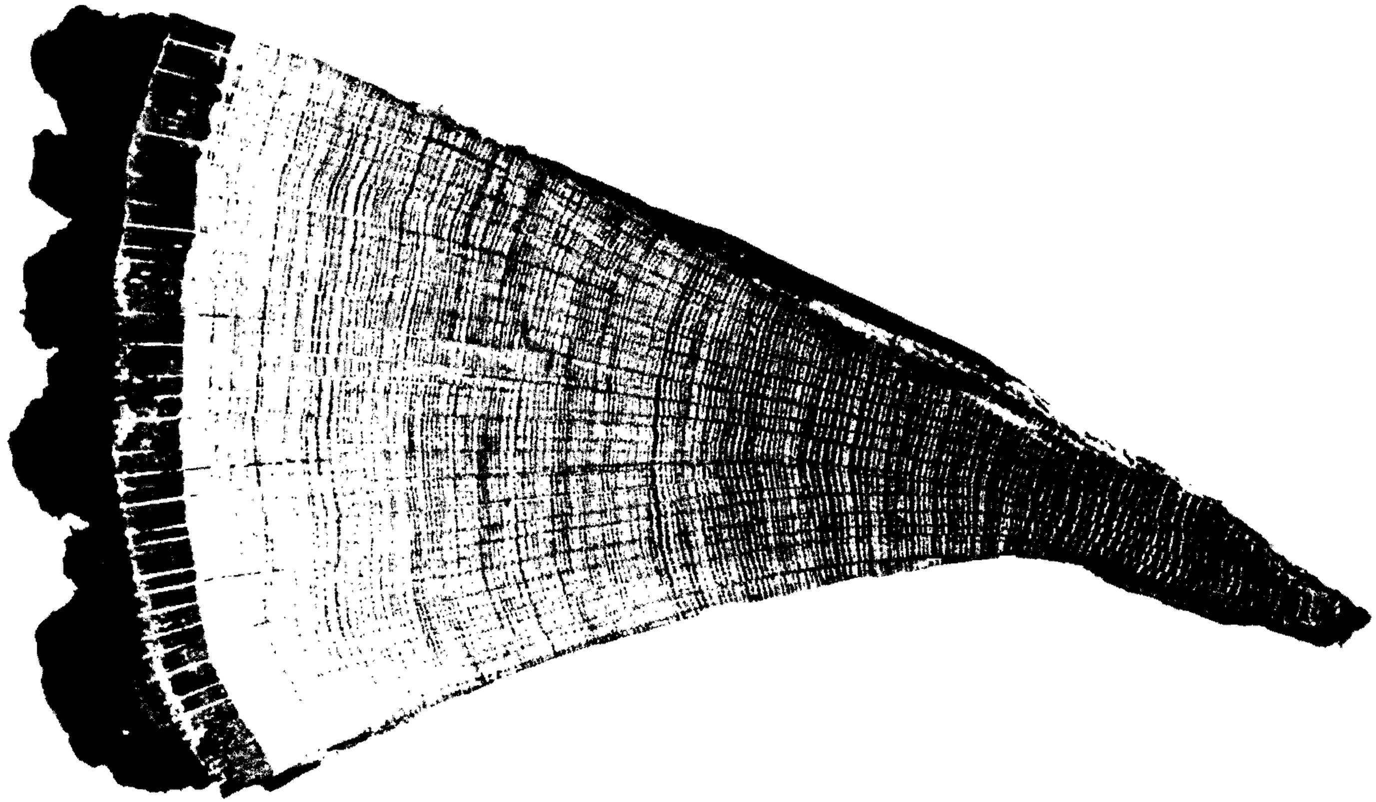


Fig 1. A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can determined by counting back from the outside ring, which grew in 1976.

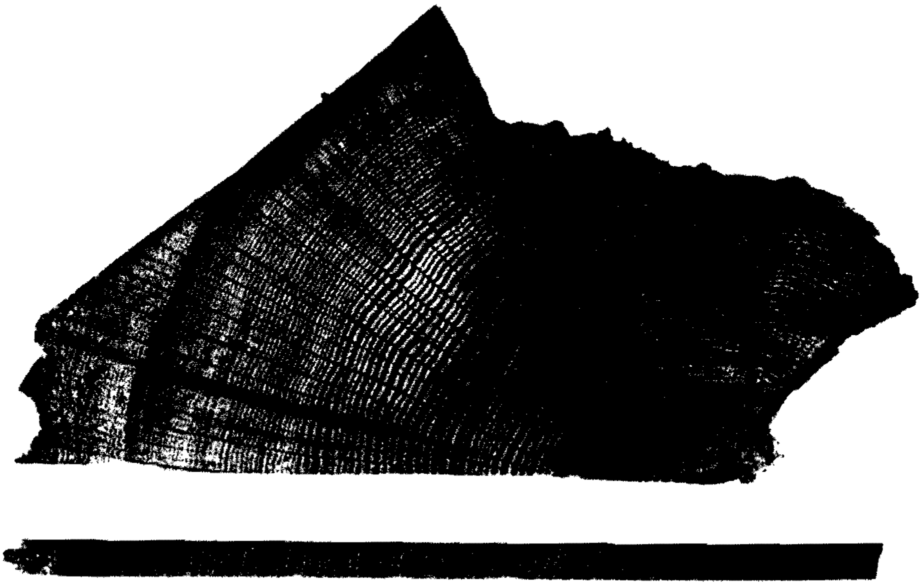


Fig 2. Cross-section of a rafter showing the presence of sapwood rings in the left hand corner, the arrow is pointing to the heartwood/sapwood boundary (H/S). Also a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil.

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

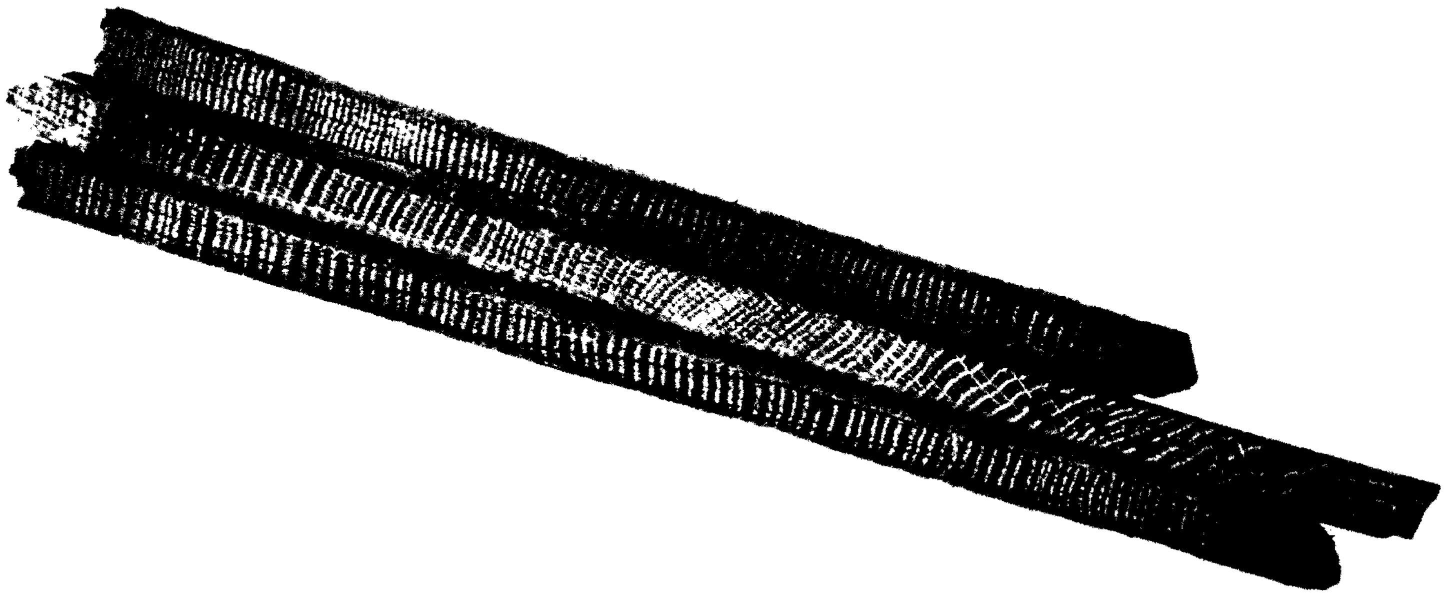


Fig 4. Three cores from timbers in a building. They come from trees growing at the same time. Notice that, although the sequences of widths look similar, they are not identical. This is typical.

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

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

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

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

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

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

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

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

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

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

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

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

	C45	C08	C05	C04
C45		+20	+37	+47
C08	5.6		+17	+27
C05	5.2	10.4		+10
C04	5.9	3.7	5.1	

Bar Diagram

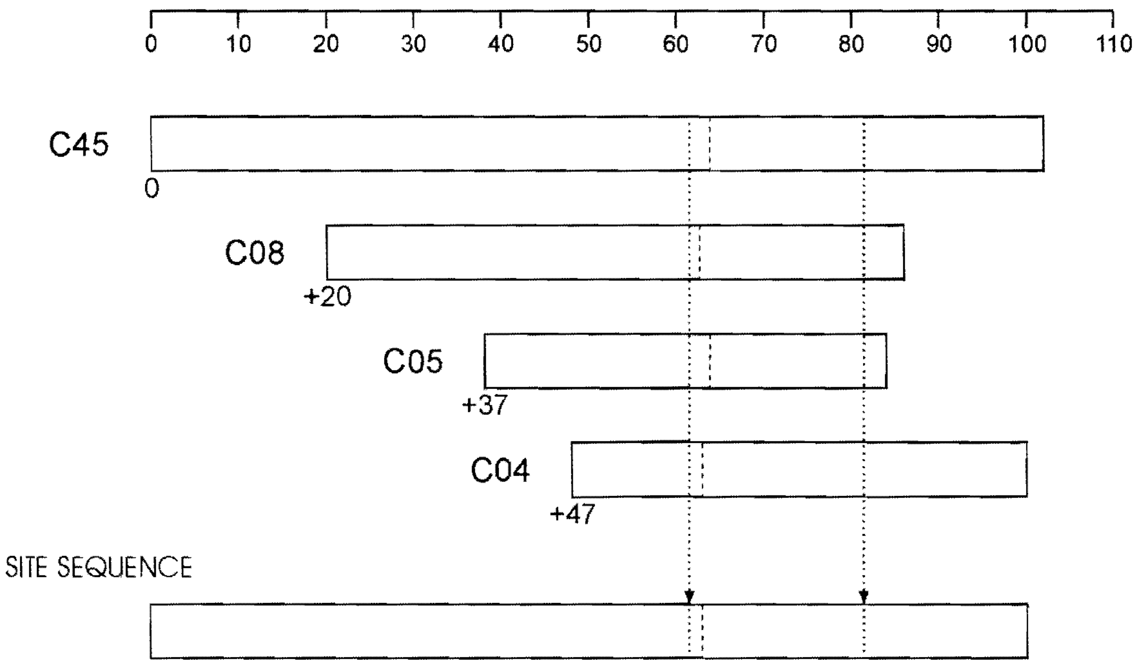


Fig 5. Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

The *bar diagram* represents these sequences without the rings themselves. The length of the bar is proportional to the number of rings in the sequence. Here the four sequences are set at relative positions (*offsets*) to each other at which they have maximum correlation as measured by the *t*-values.

The *t*-value/offset matrix contains the maximum *t*-values below the diagonal and the offsets above it. Thus, the maximum *t*-value between C08 and C45 occurs at the offset of +20 rings and the *t*-value is then 5.6.

The *site sequence* is composed of the average of the corresponding widths, as illustrated with one width.

have taken place between AD 1512 and 1515, which is much more precise than without this extra information.

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

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

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

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

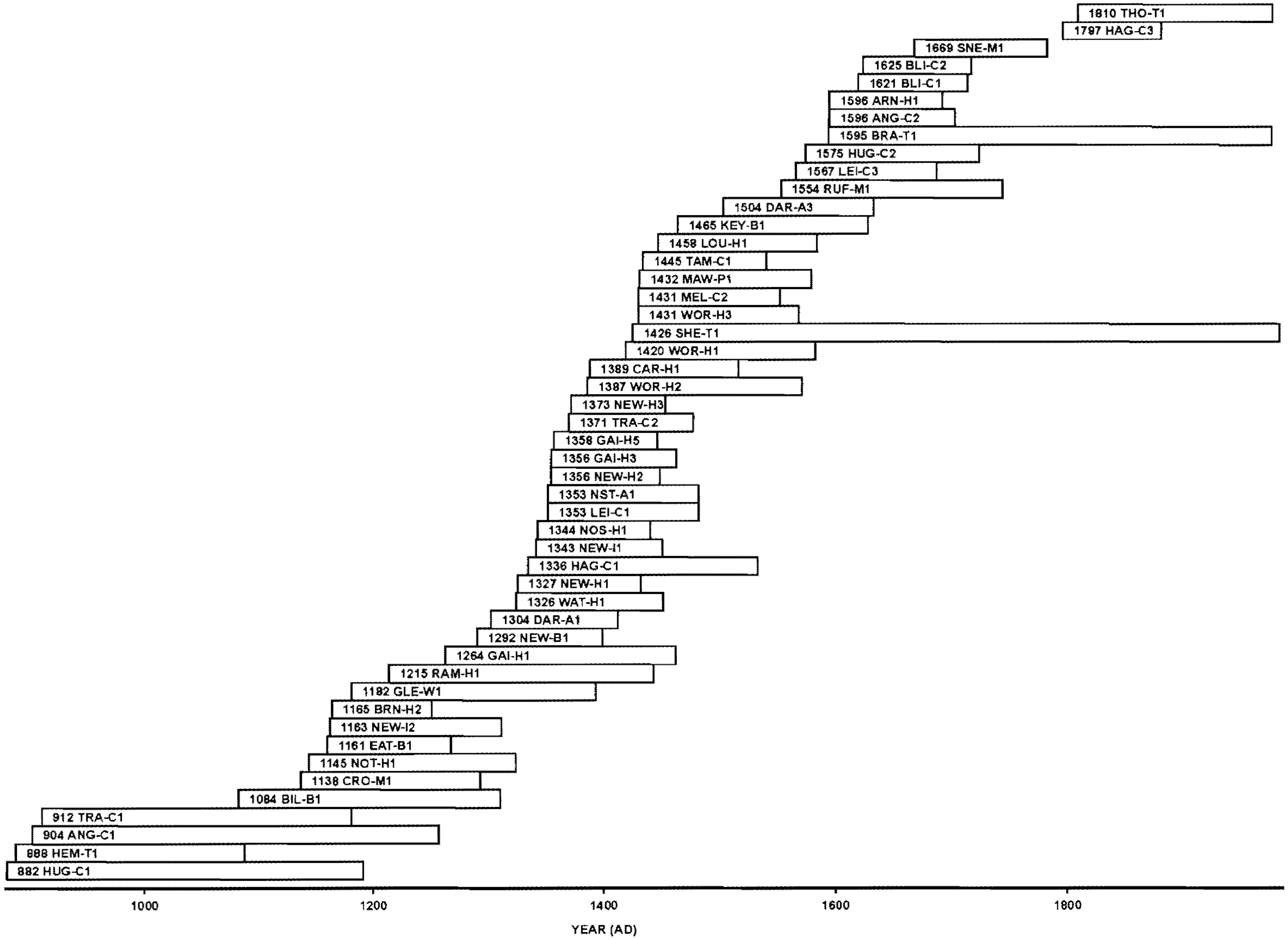
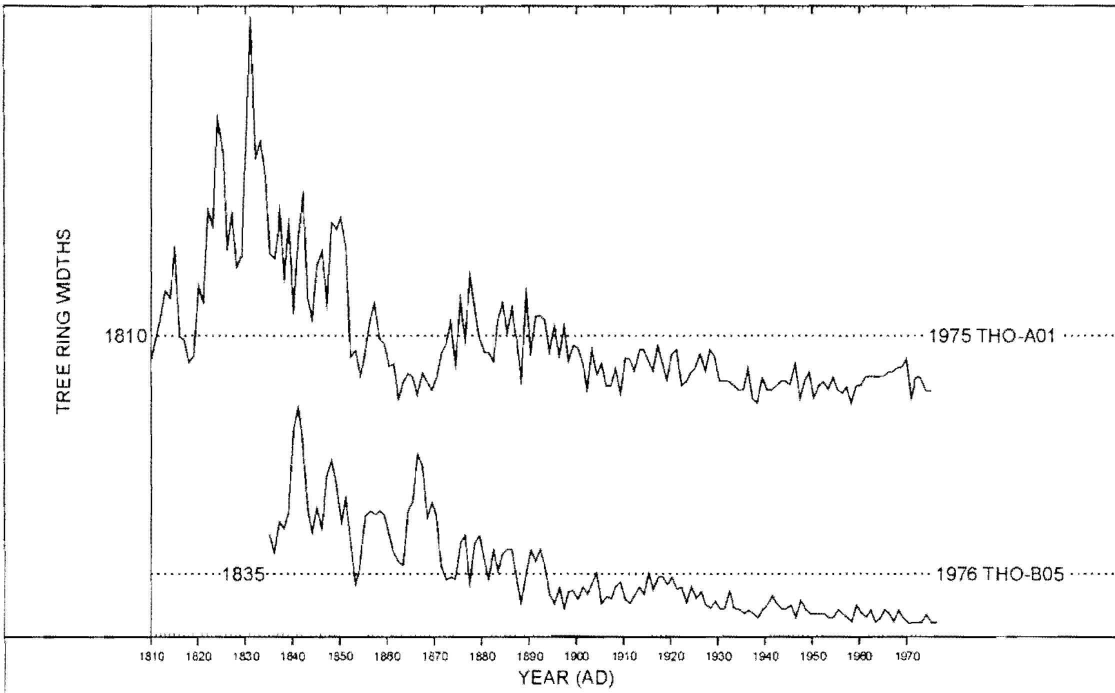


Fig. 6 Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

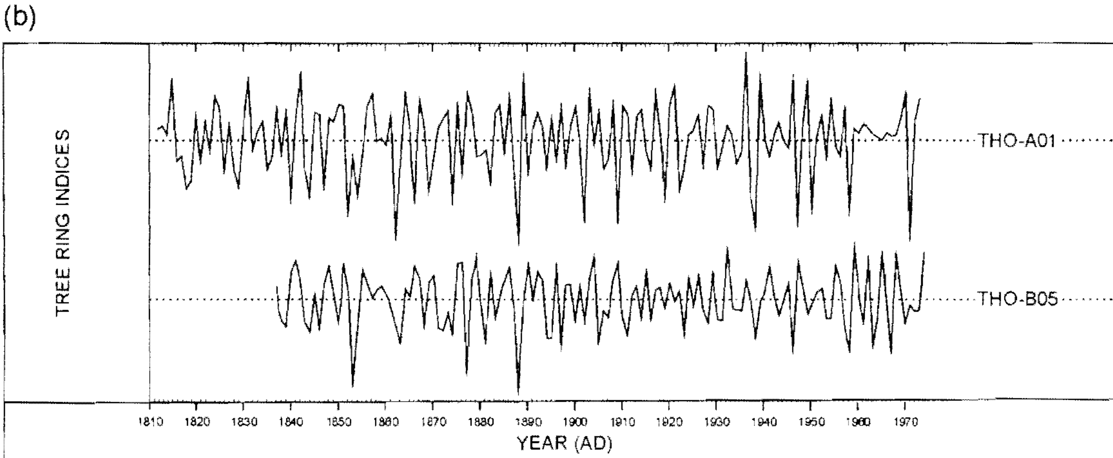


Fig 7. (a) The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young tree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

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

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