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PRIDHAMSLEIGH MANOR AND FARM, STAVERTON, NEAR ASHBURTON, DEVON
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

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SUMMARY
Analysis by dendrochronology of 14 out of 31 samples obtained from the roof (17 samples having been rejected as unsuitable) has produced a single site chronology, comprising three samples, having an overall length of 138 rings. These rings are dated as spanning the years AD 1420–1557.
One of the dated samples has an estimated felling date in the range AD 1516–41. The felling date range of the other two samples cannot be determined, but one is unlikely to be before AD 1558, and the other unlikely to be before AD 1572.
A further single sample has been dated individually, the timber represented having an estimated felling date in the range AD 1631–56.
It would thus appear that while one timber was felled in the early- to mid-sixteenth century, others were probably felled in the early- to mid-seventeenth century.

CONTRIBUTORS
Alison Arnold and Robert Howard

ACKNOWLEDGEMENTS
The Laboratory would like to take this opportunity to thank the owner of Pridhamsleigh Manor, Mrs Sally Spreadbury for her enthusiasm and interest in this programme of tree-ring analysis and for her particular hospitality during sampling. We would also like to thank Simon Chalk, owner of Pridhamsleigh Farm, for his help and interest in this programme. Finally, the Laboratory would like to thank John Allan and Richard Parker of Exeter Archaeology for their help and advice on the interpretation of the building, and for the extensive use of their notes in the introduction, and their plans and drawings elsewhere in this report.

ARCHIVE LOCATION
Devon Historic Environment Record
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DATE OF INVESTIGATION
2006–8

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INTRODUCTION

Pridhamsleigh is a former manor house in the parish of Staverton, near Ashburton, in Devon (Figs 1–3; SX 749 677). The group of buildings is large and complex (see site plan Fig 4). In its present state it is not immediately apparent that in the seventeenth and early-eighteenth centuries this was an extremely grand courtyard mansion of a wealthy family, with a richly carved Classical entrance porch and costly armorial window glass, and with luxurious household goods such as Ming porcelain. At present it is divided into two properties: a tall west range known as Pridhamsleigh Manor (Fig 5), and a south range with attendant agricultural buildings known simply as Pridhamsleigh, or sometimes Pridhamsleigh Farm. The farmhouse is Grade-II* listed and, as a consequence of its recent neglect, is being placed on the English Heritage Buildings at Risk register. It has also been the subject of an archaeological assessment by Exeter Archaeology, from which the introduction and building description is taken directly (Allan 2004).

Pridhamsleigh is first recorded (by the name Leigh, simply meaning a wood) in a boundary dispute of AD 1219. A tithe payment was recorded on the property in AD 1281, when the family name Proudhomme (proud man), which gave the site the first part of the place-name, is first recorded. It was valued at the sum of 10s in the taxation of Pope Nicholas of *c.* AD 1291. John Proudhomme is listed in the returns for Staverton in the Lay Subsidy of AD 1332; he was assessed at 2s 6d, the same valuation as five other leading men in the parish, exceeded by just one other, who paid 3s 4d. In AD 1343 John de Prodhome was granted the right for mass to be celebrated at the manor at a portable altar (not a chapel). There was therefore a substantial farmhouse at Pridhamsleigh by the late-thirteenth and early-fourteenth centuries.

The fortunes of Pridhamsleigh changed dramatically in the early-seventeenth century, when it was acquired by the Gould family. The first record of the family's association with the site appears to be an indenture of AD 1609, which mentions Edward Gould. He was evidently responsible for a grand building programme at Pridhamsleigh. A crucial document in understanding the house is the inventory prepared upon the death of Edward in AD 1627, which lists all the rooms of the house, with their contents, the farm equipment and animals, and all Edward's other possessions.

The inventory appears to record the house in its fully developed form, showing that the body of the house surviving today had already been built. The inclusion of a new chamber, listed among the entries for the kitchen, buttery, and their attendant rooms, indicates that building works had recently been completed. The survival of an inventory of this date, alongside a house which has experienced comparatively little subsequent change, is a great rarity in the south-western counties, since the principal collections of such records were destroyed in the Exeter Blitz of AD 1942. A drawing showing the proposed stages of development of Pridhamsleigh is given in Figure 6.

BUILDING DESCRIPTION

Pridhamsleigh farm

The farmhouse, a two-storey stone-built range with a slate roof and much slate cladding, occupies the southern side of the upper courtyard. The south front faces a small formal garden on two levels; this arrangement is likely to belong to the seventeenth century. The north front, facing the courtyard, is dominated by a large projecting chimneystack. This is certainly bonded into the adjacent walls, showing that it is contemporary with them. The adjacent walling incorporates the openings of the ground-floor and first-floor windows. This is a crucial point, showing that the hall was built from the first with a fireplace and with first-floor chambers, in the manner of an Elizabethan or early Stuart house, rather than the earlier medieval form of hall, which was open from ground to roof.

The principal ground-floor room of the farm range, now subdivided into two small rooms, was clearly the hall of the seventeenth-century house. This room retains parts of an unusual late-seventeenth or early eighteenth-century decorated plaster ceiling: two wreaths at the corners of the room, angled towards its centre and fragments of the cornice. The central motif of the ceiling has been lost, as have the corresponding two wreaths to the east. The former cross-passage survives at the western end, separated by a solid stone wall from a central room.

At the opposite (eastern) end of the hall is now a small room holding a late-nineteenth century copper boiler and a modern lavatory. It is clear that this space was designed to accommodate a large framed staircase, serving both the chambers above the hall range and those in the east range (now the cider house) of the early-seventeenth century house. The blocked entrance from this stair into the chamber above the east wing (now the cider house) is still evident, and one of its windows survives; the scar of its window in the south wall can be seen at the back of a modern hen coop. The first floor of the staircase block dates only from the conversion of *c* AD 1860 and is of poor quality.

From the kitchen, modern stairs lead up to a first-floor landing (formerly half a bedroom) with a blocked fireplace in the gable-end wall. Its age is unknown. Running along the north wall of the range is a corridor, leading to two chambers. The chamber to the west, over the cross-passage, has an original seventeenth-century floor below broad boards of eighteenth- or nineteenth-century date.

The cider house

The cider house projects northward from the hall range. It is a structure of two main phases: a primary room forming the southern half of the range, displaying features of the early-seventeenth century, and a secondary remodelling as a cider house in *c* AD 1860, which entailed the rebuilding of the northern end of the room.

Around AD 1860 this range was partially dismantled and remodelled as a cider house. The roof was dismantled and the walls reduced by a few courses. A new roof was provided in the same style as those of the shippons, dated AD 1860.

Pridhamsleigh Manor

Pridhamsleigh Manor ('the Manor'), or west range, lies outside the Exeter Archaeology survey but a brief description of it is needed to make any sense of this complex of buildings. Within its northern end is a huge chimneystack serving five fireplaces on three floors. The very large and plain fireplace in the ground-floor room (its lintel with a moulding corresponding to those elsewhere in the house) leaves little doubt that this is almost certainly the kitchen. This part of the house therefore seems to have been the service end and is attributable to the main building phase of the house.

A large room at the south end of the ground floor, with a good granite fireplace, may have been a parlour or dining room. At the centre of the ground floor is a delightful panelled room of *c* AD 1700, with a shell niche in one wall and large raised-field panelling above a dado rail. The adjacent staircase, with some surviving heavy turned balusters, appears to be contemporary. Above are three first-floor chambers, with two further chambers on the second floor, in the gables at each end of the range. Here there are three pieces of evidence that the wing was built in two distinct phases. First, a roof-line, indicating that this range was formerly lower, can be seen in the chimneystack within the second-floor chamber at the southern end of the range. Above the roof-line on the chimneystack there survives an area of external slate-hanging, now incongruously placed within the chamber, showing that this has been raised one storey. Second, a small window, clearly intended to look out of the house, is now embedded between two first-floor chambers here. Third, a butt joint is visible at first-floor level between the southern and central rooms of the range on the front of the house.

SAMPLING

Sampling and analysis by tree-ring dating of a number of timbers in the Pridhamsleigh complex were requested by Francis Kelly, Historic Buildings Inspector at English Heritage's Bristol office. In particular, these timbers formed the roof of the former hall range (now known as the farmhouse), the roof of the cider house, plus the roof and various ceiling beams and lintels of the Manor range. The purpose of this programme of work was to inform a programme of repairs and to establish that the remaining timbers were primary and original. In addition, it was hoped that the data obtained during this analysis would contribute to the further development of local reference material for the late-sixteenth / early-seventeenth century, a period which is not especially well-represented in this area.

Thus, from the timbers available, a total of 31 samples was obtained by coring. Each sample was given the code PRD-A (for Pridhamsleigh, site 'A') and numbered 01–31. Six samples, PRD-A01–06, were obtained from the roof and attic floor timbers of the former hall range, with five samples, PRD-A07–11, being obtained from the cider house. From the Manor range itself, five samples, PRD-A12–16, were taken from roof timbers, with the remaining 15 samples, PRD-A17–31, being taken from the ceiling joists of the ground- and first-floor rooms and from certain door lintels.

Although more timbers were accessible in the areas of interest, it was seen that these were derived from particularly fast-grown trees which were unlikely to provide samples with sufficient rings, ie, a minimum of 54, for reliable dating. Given the state of quite a number of the accessible timbers, some covered in bird droppings, others stained and varnished, it was not possible, before sampling, to determine reliably whether or not they had sufficient rings. These unassessable timbers were cored anyway, in the hope that they would produce adequate samples, to ensure that sampling was as extensive as possible within each area under investigation,

The positions of these samples were marked on sketch plans made at the time of sampling, before being transferred to survey drawings made and provided by John Allan of Exeter Archaeology. These are reproduced here as Figure 7a–e. Details of the samples are given in Table 1. In this Table the timbers have been located and numbered following the schema on the plans provided.

ANALYSIS AND RESULTS

Each of the 31 samples obtained was prepared by sanding and polishing. It was seen at this point that 17 samples, more than half those obtained, had less than 54 rings, the minimum generally required for reliable dating, and these samples were rejected from this programme of analysis.

The annual growth rings of the remaining 14 samples were, however, measured, the data of these measurements being given at the end of this report. The data of these 14 samples were then compared with each other by the Litton/Zainodin grouping procedure (see appendix), allowing a single group comprising three samples to be formed, cross-matching with each other as shown in the bar diagram, Figure 8.

The three cross-matching samples were combined at their respective off-sets to form site chronology PRDASQ01, this having an overall length of 138 rings. This site chronology was compared to a number of relevant reference chronologies for oak, this indicating a consistent cross-match with a number of these when the date of the first ring is AD 1420 and the date of the last ring is AD 1557. The evidence for this dating is given in the *t*-values of Table 2.

Site chronology PRDASQ01 was compared with the 11 remaining measured but ungrouped samples, but there was no further satisfactory cross-matching. These 11 ungrouped samples were then compared individually with a full range of reference chronologies for oak, this indicating a cross-match and date for only one further sample, PRD-A12, giving it a first ring date of AD 1507 and a last ring date of AD 1616. The evidence for this dating is given in the *t*-values of Table 3.

DISCUSSION AND CONCLUSION

Analysis by dendrochronology of 14 out of 31 samples from this site has produced a single dated site chronology, PRDASQ01, comprising three samples, its 138 rings dated as spanning the years AD 1420–1557. None of the samples in this site chronology retains complete sapwood, and thus the precise felling date of the timbers represented cannot be determined with reliability. Indeed, only one of the dated samples, PRD-A09, retains the heartwood/sapwood boundary, ie, only the sapwood rings are missing, this boundary ring being dated to AD 1501. Allowing a 95% probability limit of 15–40 sapwood rings that the tree might have had would give the timber an estimated felling date in the range AD 1516–41.

The other two samples in the dated site chronology do not retain the heartwood/sapwood boundary and thus felling date ranges for these timbers cannot be given. However, the felling date for sample PRD-A01 (which, although it has a last measured ring date of AD 1523, has approximately a further 20 unmeasurable rings, and thus a probable last ring date of *c* AD 1543) is unlikely to be before AD 1558. Sample PRD-A08 was probably not felled before AD 1572, this date again based on a 95% probability limit of a minimum of 15 sapwood rings that the tree might have had.

A further single sample, PRD-A12, has been dated individually with a last measured, heartwood/sapwood boundary ring, date of AD 1616. Using the same sapwood estimate as above, ie, 15–40 rings, would give the timber represented an estimated felling date in the range AD 1631–56.

Thus, sadly, for the moment, tree-ring dating has provided little help with refining the dating and sequential development of Pridhamsleigh Manor and Farm as deduced from the documentary sources. It does show, however, that at least one timber, a principal rafter of the cider house range, represented by sample PRD-A09, is likely to have been felled in the early- to mid-sixteenth century. A second timber, a principal rafter of the Manor house, represented by sample PRD-A12, is likely to have been felled in the early- to mid-seventeenth century, perhaps representing a main building phase known to have been undertaken about this time. The two other dated timbers, a principal rafter from the former hall range and a second principal rafter from the cider-house roof, are very broadly coeval, both having been felled no earlier than the latter half of the sixteenth century. The results therefore suggesting that the cider-house roof contains timbers from a least two different periods of felling.

Ten measured samples remain ungrouped and undated, despite, as can be seen from Table 1, most of them having sufficient, and sometimes high, numbers of rings. Whilst having such a high proportion of ungrouped and undated samples is slightly unusual, it is not unknown in tree-ring analysis, particularly from sites in south-west England. A number of factors may have come together at Pridhamsleigh to account for this phenomenon.

Whilst in theory cores from 31 timbers should provide sufficient samples to date a single-phase site, or a series of phases spanning a relatively short period of time, even if the site is made up of a number of component parts, 14 samples, the number with sufficient rings, is perhaps too few. It is possible, for example, that although the timbers used throughout Pridhamsleigh are in fact mostly of early-seventeenth century date, they have come from varied woodland sources, affected by different growing conditions, and thus have sufficiently different growth patterns to preclude cross-matching. This effect could be further exacerbated by some of the timbers being of slightly different dates, perhaps felled at different times as work on this fairly large-scale project progressed. Such differences in date can, when working with timbers with relatively short ring sequences, hamper cross-matching as the potential overlaps between rings sequences will be less than is required for reliable statistical comparison. This has the effect of making the samples 'singletons', which are generally more difficult to date than groups of well-replicated samples even when they are sequences of good length.

It is also possible that the lack of cross-matching and dating might be caused by the reuse of older material, as may potentially be implied by the early-mid sixteenth-century timber represented by sample PRD-A09. The use of timbers of various different dates might again have the effect of making some of them singletons.

At least some of the 14 measured samples, and some of rejected samples, have disturbed growth patterns, which will again hamper cross-matching and dating. For example, PRD-A06 suffers a growth suppression event that it does not recover from (Fig 9) while PRD-A14 has two clear growth suppression events from which it does recover its previous growth rate; sample PRD-A28 shows erratic growth in the latter half of its ring sequence. These growth disturbances may be the result of anthropogenic or environmental effects, or a combination of the two. Causal factors include management regimes or at least some form of human intervention, such as pollarding or shredding, possible responses to localised environmental effects, such as flooding, or more generalised environmental effects in the form of severe weather conditions, such as drought, long hard winters, or late frosts.

An additional factor potentially adversely affecting successful dating of the Pridhamsleigh timbers is likely to be associated with the apparent need for a more localised network of reference data for this area, as previously highlighted by Groves (2005). It is possible that as further sites of a similar date to that expected for much of the Pridhamsleigh material are analysed it may be become possible to date additional timbers from this site. However the disparate nature of the timbers analysed from Pridhamsleigh means that it is unlikely that any additional dendrochronological dating will be capable of providing detailed dating evidence to elucidate the development of this complex group of buildings.

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TABLES

Table 1: Details of tree-ring samples from Pridhamsleigh Manor and Farm, Staverton, near Ashburton, Devon

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
	Hall range (now the farmhouse)					
PRD-A01	South principal truss 5	80+20 nm	no h/s	AD 1444	------	AD 1523 (AD 1543)
PRD-A02	South principal truss 3	59	no h/s	------	------	------
PRD-A03	Floor joist 4 from east	nm	---	------	------	------
PRD-A04	Floor joist 6	nm	---	------	------	------
PRD-A05	Floor joist 7	nm	---	------	------	------
PRD-A06	Floor joist 11	76	h/s	------	------	------
	Cider house					
PRD-A07	East principal rafter, truss 3	nm	---	------	------	------
PRD-A08	West principal rafter, truss 3	127	no h/s	AD 1431	------	AD 1557
PRD-A09	West principal rafter, truss 4	82	h/s	AD 1420	AD 1501	AD 1501
PRD-A10	Ground-floor ceiling beam north	93	43C	------	------	------
PRD-A11	Ground-floor ceiling beam south	86	16C	------	------	------
	Pridhamsleigh Manor – attic rooms					
PRD-A12	North principal rafter, truss 1	110	h/s	AD 1507	AD 1616	AD 1616
PRD-A13	South principal rafter, truss 1	nm	---	------	------	------
PRD-A14	East principal rafter, truss 5	84	h/s	------	------	------
PRD-A15	South principal rafter, truss 7	nm	---	------	------	------
PRD-A16	East purlin, truss 4 – 6	76	h/s	------	------	------

Table 1: continued

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
	Pridhamsleigh Manor – bedroom 1					
PRD-A17	Ceiling joist 3 (from east)	nm	---	------	------	------
PRD-A18	Ceiling joist 5	74	h/s	------	------	------
PRD-A19	Ceiling joist 8	nm	---	------	------	------
PRD-A20	Ceiling joist 9	58	h/s	------	------	------
PRD-A21	Alcove lintel 1 (outer or south)	nm	---	------	------	------
PRD-A22	Alcove lintel 2 (middle)	nm	---	------	------	------
PRD-A23	Door lintel to bedroom 1	64	h/s	------	------	------
	Pridhamsleigh Manor – bedroom 2					
PRD-A24	Ceiling joist 2 (from north)	nm	---	------	------	------
PRD-A25	Ceiling joist 3	nm	---	------	------	------
PRD-A26	Ceiling joist 6	nm	---	------	------	------
PRD-A27	Ceiling joist 7	nm	---	------	------	------
PRD-A28	Door lintel to bedroom 2	nm	---	------	------	------
	Pridhamsleigh Manor – lounge					
PRD-A29	Ceiling joist 3 (from east)	56	4	------	------	------
PRD-A30	Ceiling joist 5	nm	---	------	------	------
PRD-A31	Ceiling joist 7	nm	---	------	------	------

*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 chronology PRDASQ01 and relevant reference chronologies when first ring date is AD 1420 and last ring date is AD 1557

Reference chronology	Span of chronology	*t*-value	
Church of St Ildierna, Lansallos, Cornwall	AD 1355–1514	7.3	(Arnold and Howard 2006)
Warleigh House, Tamerton Foliot, Devon	AD 1367–1539	6.9	(Howard *et al* 2006)
The Guildhall, Worcester	AD 1361–1609	6.8	(Arnold *et al* 2006)
St Briavel's Castle, Glos	AD 1362–1636	6.6	(Howard *et al* 1999)
Holy Cross church, Crediton, Devon	AD 1317–1536	6.3	(Tyers 2004)
The Gildhouse, Poundstock, Cornwall	AD 1405–1543	6.2	(Arnold and Howard 2007)
Wales and West Midlands	AD 1341–1636	5.4	(Siebenlist-Kerner 1978)
Naas House, Lydney, Glos	AD 1373–1568	5.4	(Howard *et al* 1998a)

Table 3: Results of the cross-matching of site chronology PRD-A12 and relevant reference chronologies when first ring date is AD 1507 and last ring date is AD 1616

Reference chronology	Span of chronology	*t*-value	
Upwich, Droitwich, Worcestershire	AD 1454–1651	5.9	(Groves and Hillam 1997)
Wales and West Midlands	AD 1341–1636	5.8	(Siebenlist-Kerner 1978)
26 Westgate Street, Gloucester	AD 1399–1622	5.6	(Howard *et al* 1998b)
Worcester Cathedral, Worcester	AD 1484–1772	5.6	(Arnold *et al* 2003)
Naas House, Lydney, Glos	AD 1373–1568	5.5	(Howard *et al* 1998a)
St Briavel's Castle, Glos	AD 1362–1636	5.3	(Howard *et al* 1999)
Godolphin House, Godolphin Cross, Cornwall	AD 1376–1620	5.1	(Tyers and Tyers forthcoming)
Penrhos Court, Kington, Herefordshire	AD 1420–1571	5.0	(Tyers 1998)

FIGURES

Figure 1: map showing the location of Pridhamsleigh, Devon

Figure 2: map showing the location of Pridhamsleigh Manor and Farm

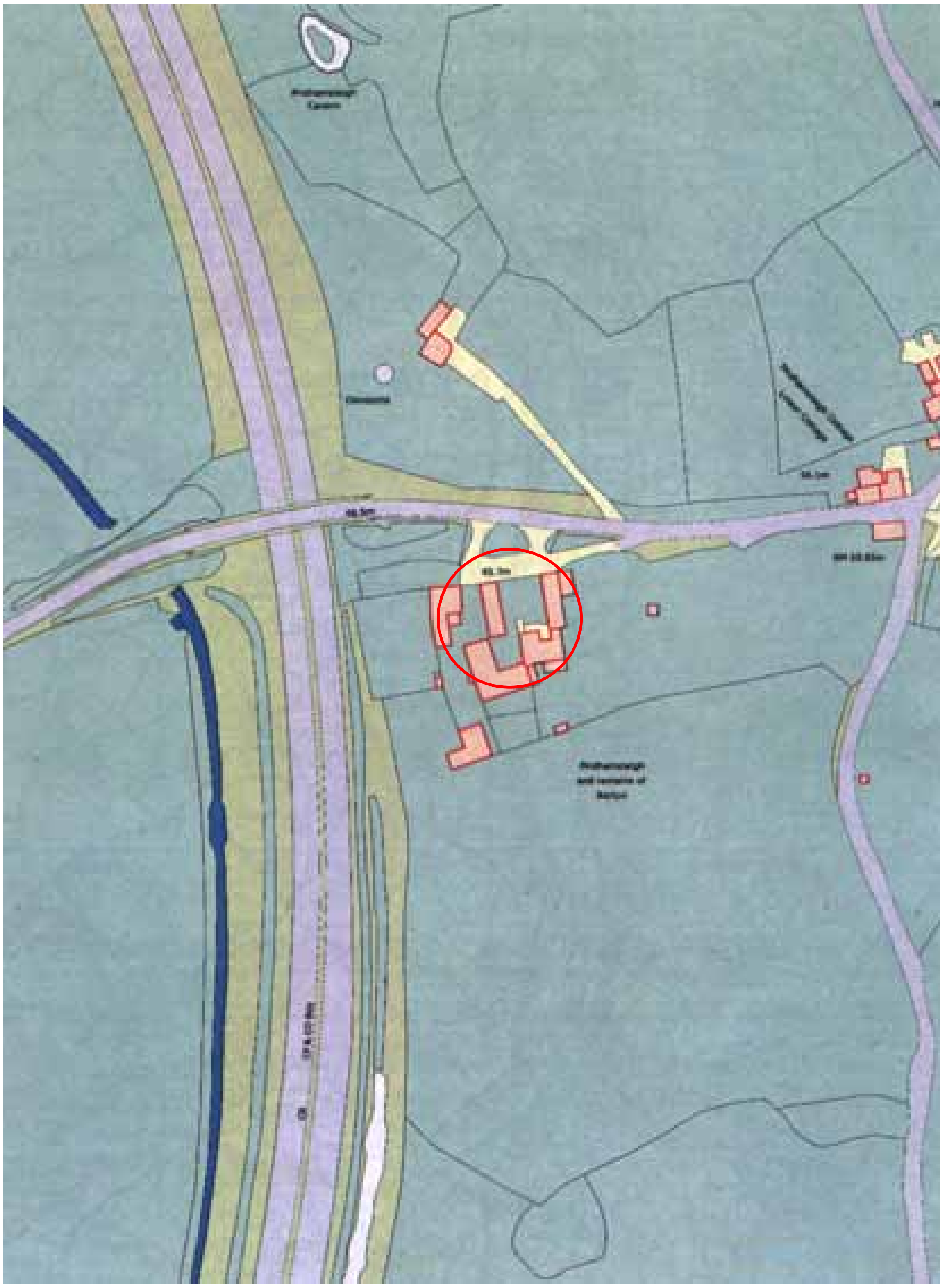


Figure 3: map showing the buildings of Pridhamsleigh Manor and Farm (based on the Ordnance Survey map with permission of the Controller of Her Majesty's Stationery Office, ©Crown Copyright)

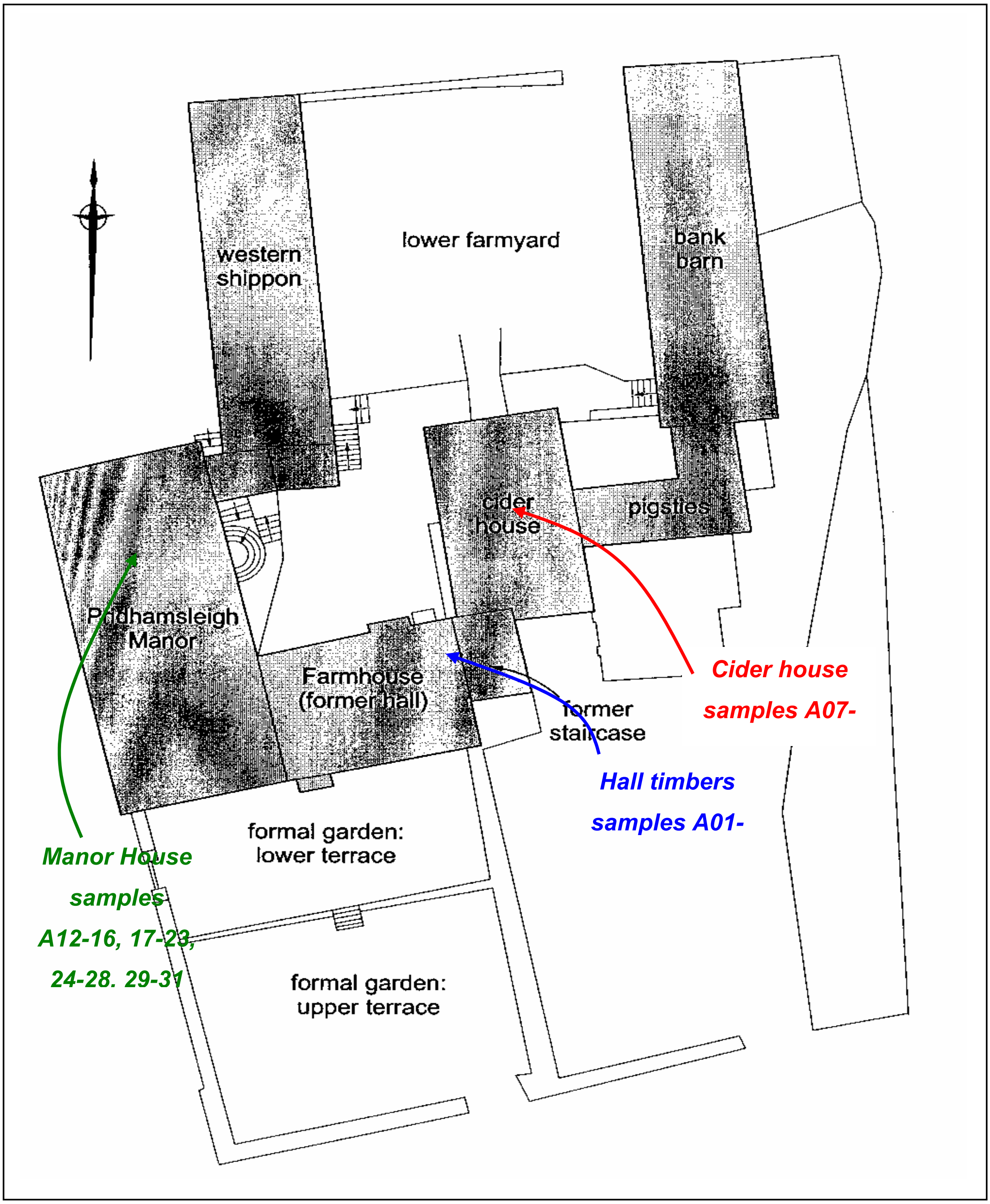


Figure 4: Plan of Pridhamsleigh to show location and arrangement of specific buildings

(based on a survey by Ford Gilpin Riley 2004)

Figure 5: View of Pridhamsleigh Manor from the south west

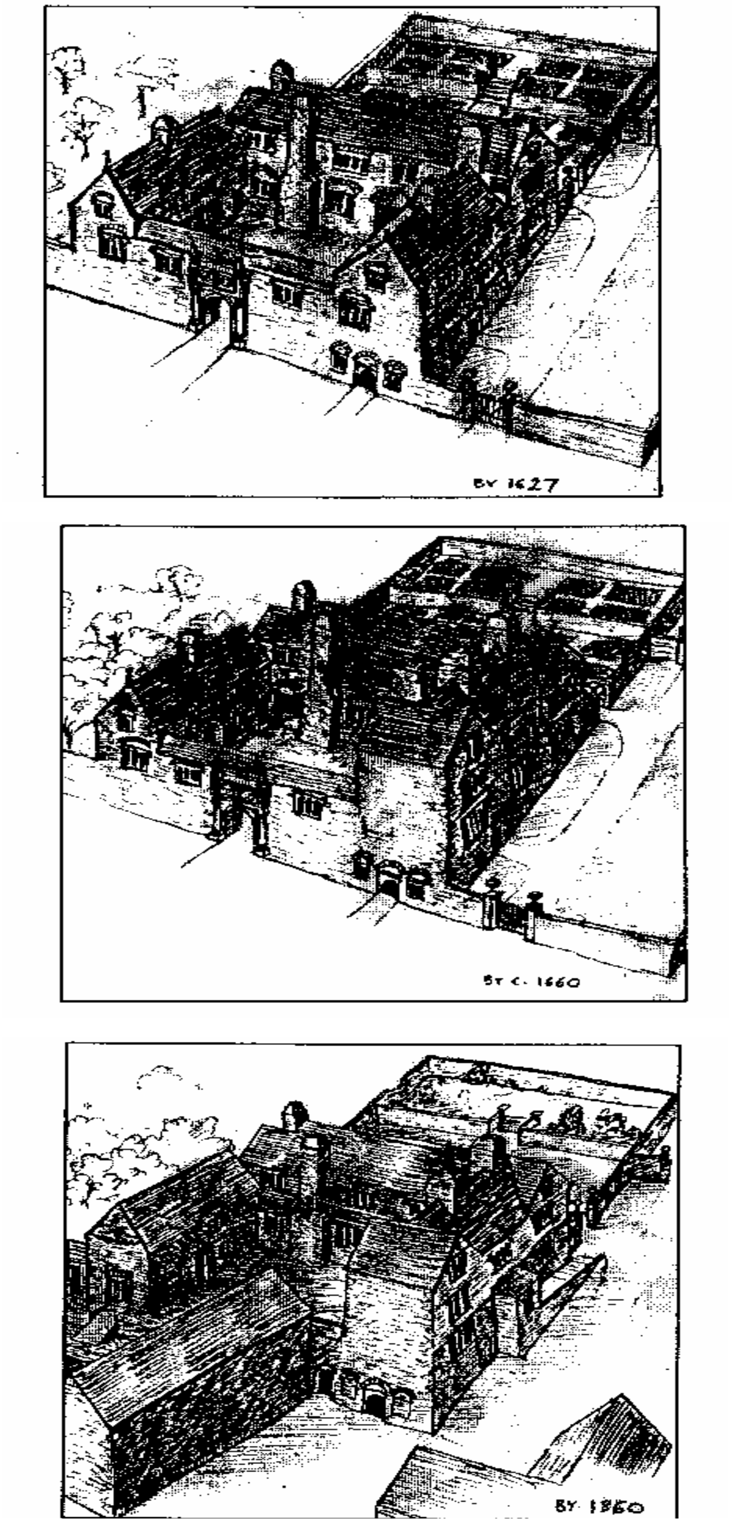


Figure 6: Reconstructions of Pridhamsleigh at different dates

(after Richard Parker, Exeter Archaeology)

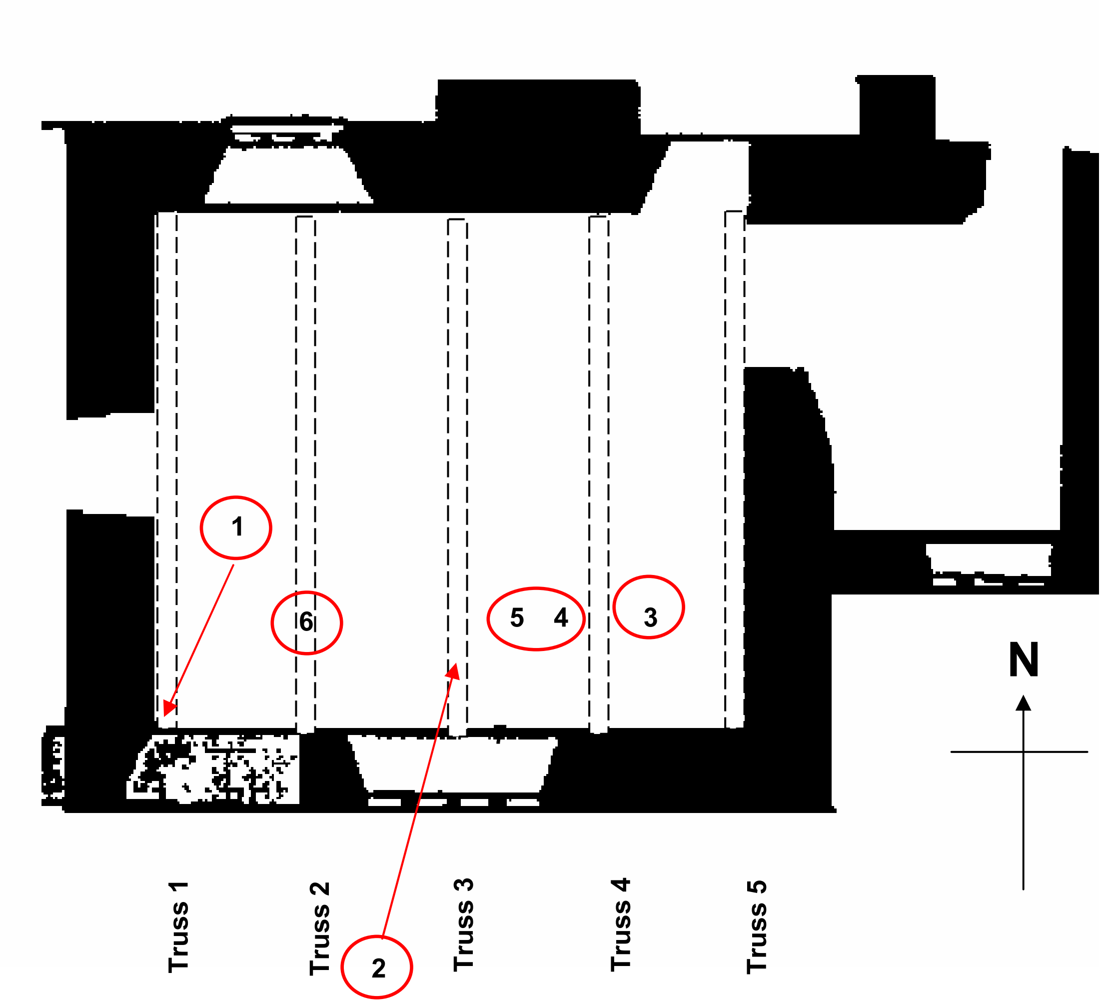


Figure 7a: The former Hall range (now the farm house); plan to show approximate location of sampled timbers

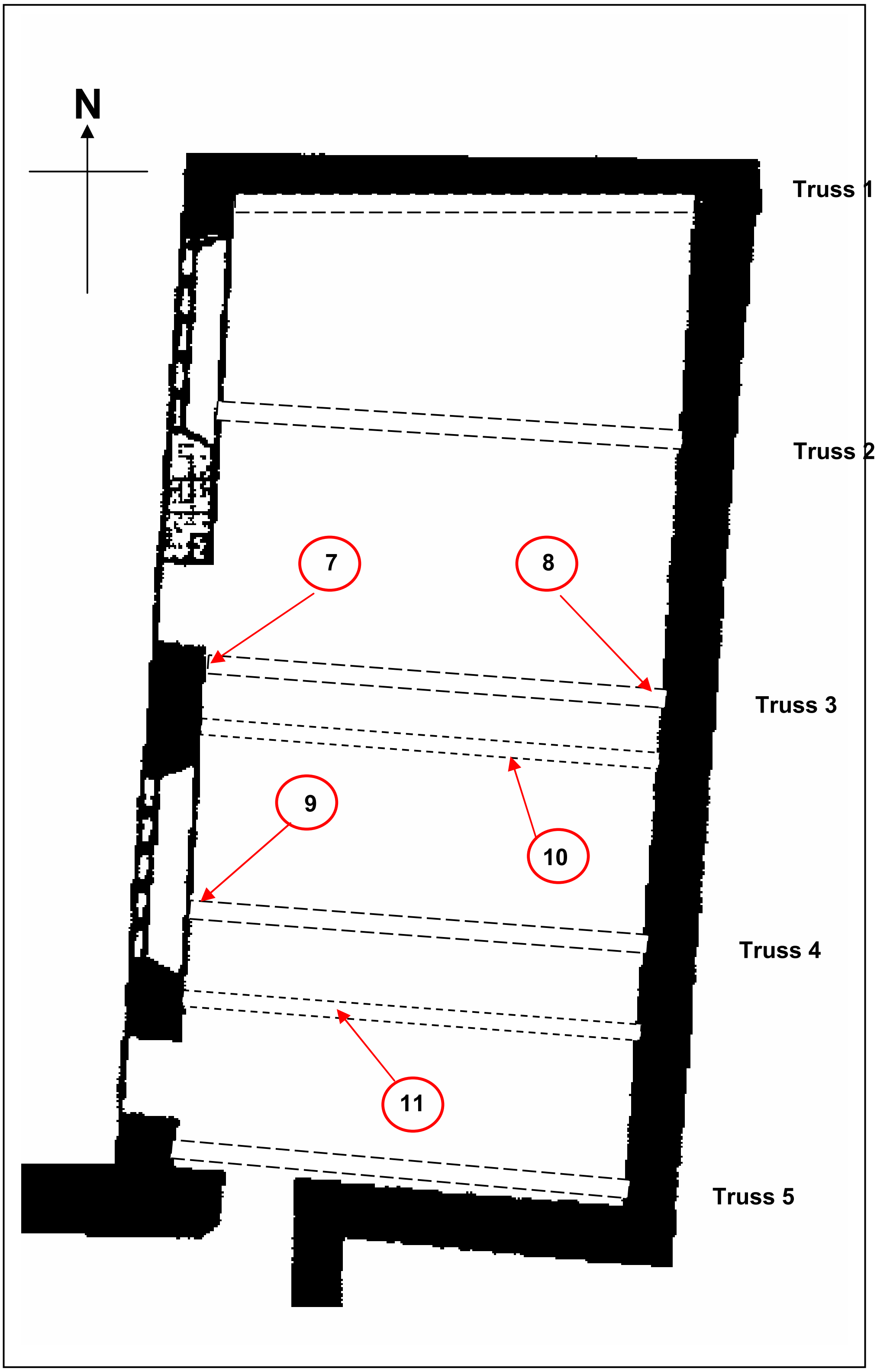


Figure 7b: The cider house; plan to show approximate location of sampled timbers

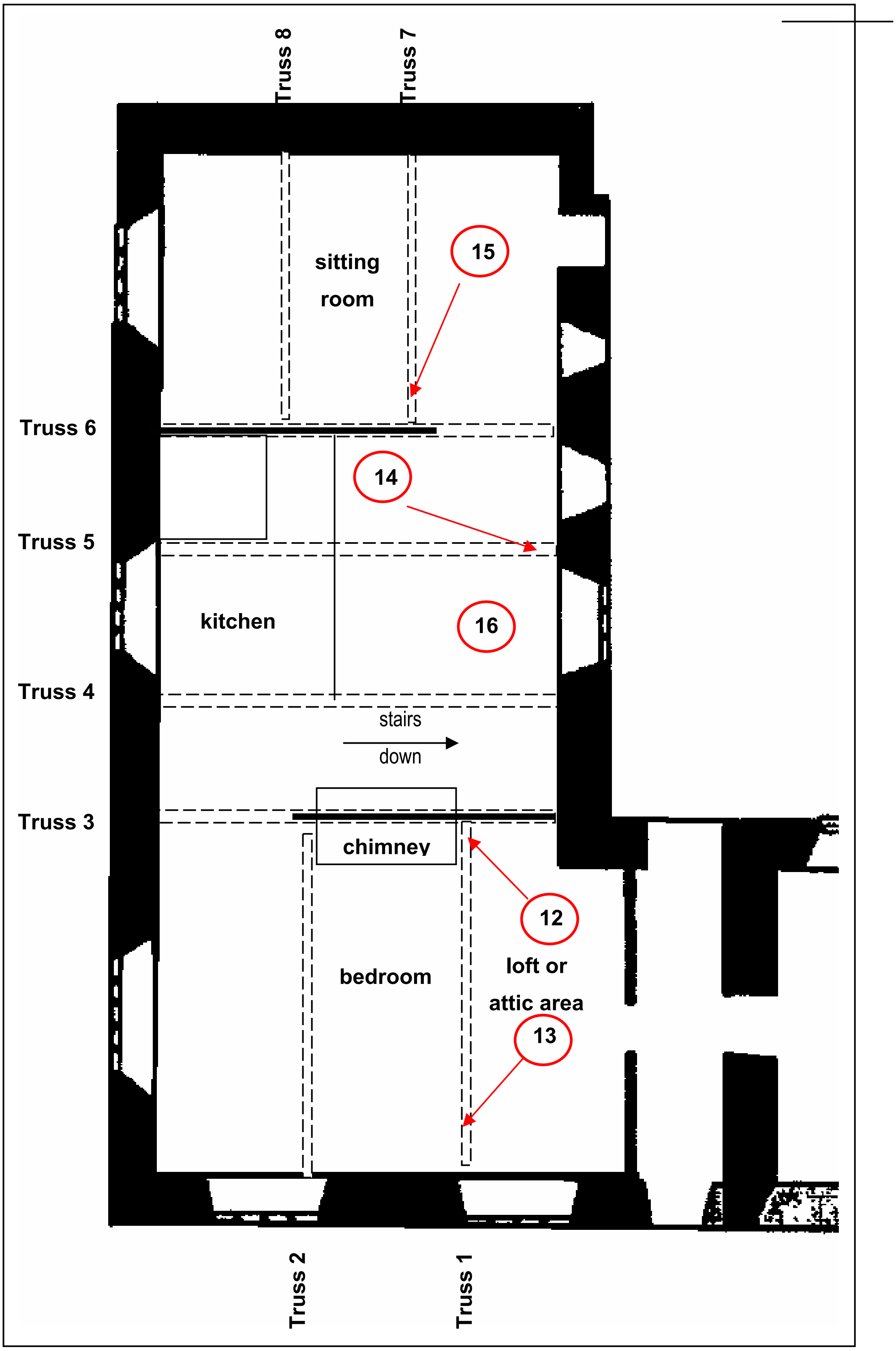


Figure 7c: Pridhamsleigh manor (top floor level); plan to show approximate location of sampled timbers

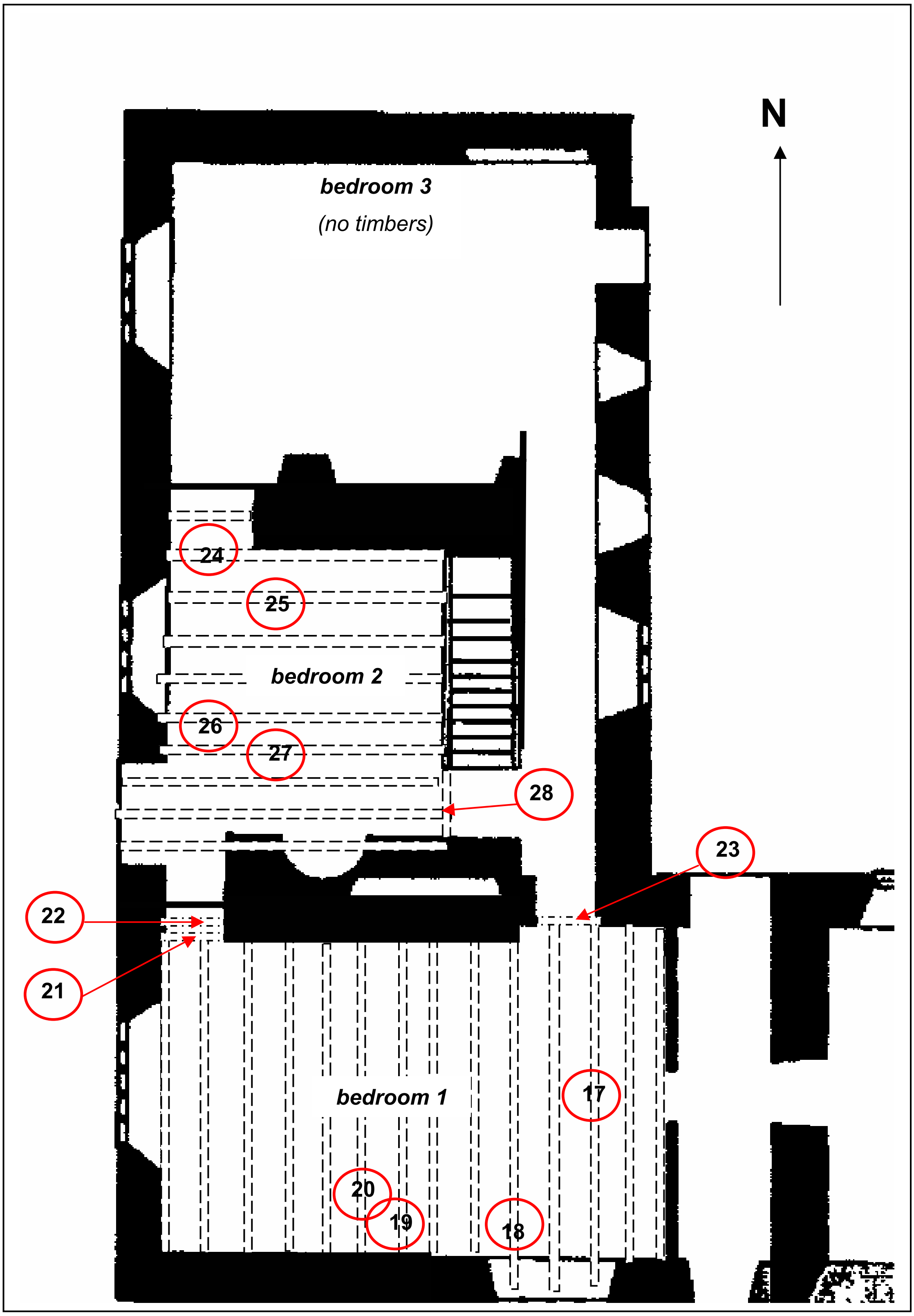


Figure 7d: Farmhouse, first-floor rooms to show approximate location of sampled timbers

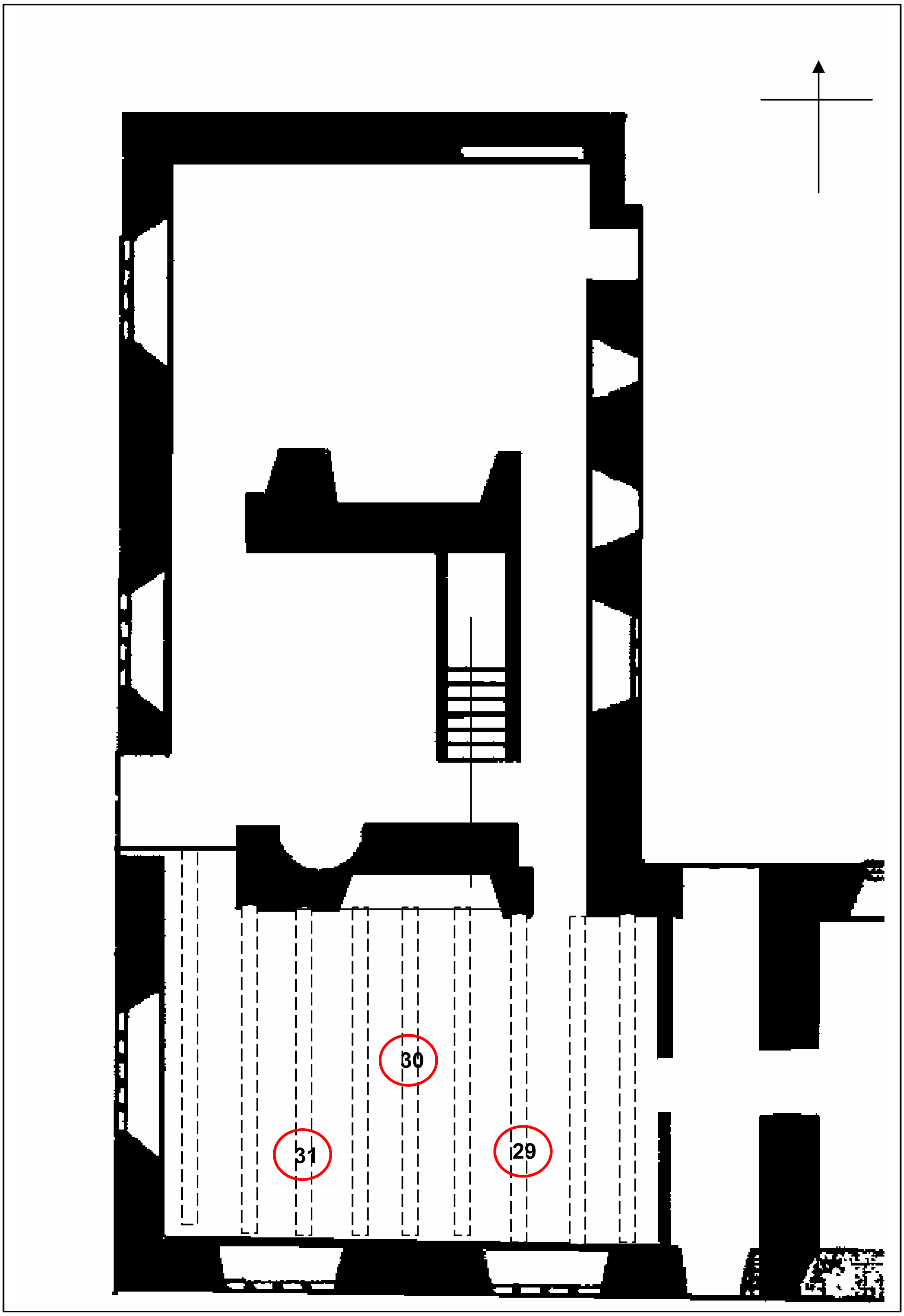


Figure 7e: Pridhamsleigh manor; ground-floor rooms to show approximate location of sampled timbers

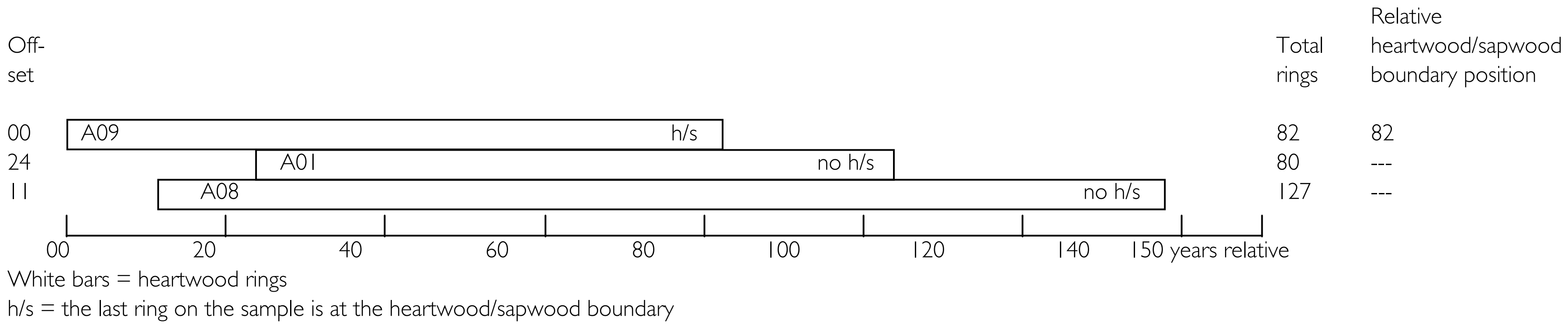


Figure 8: Bar diagram of the samples in site chronology PRDASQ01

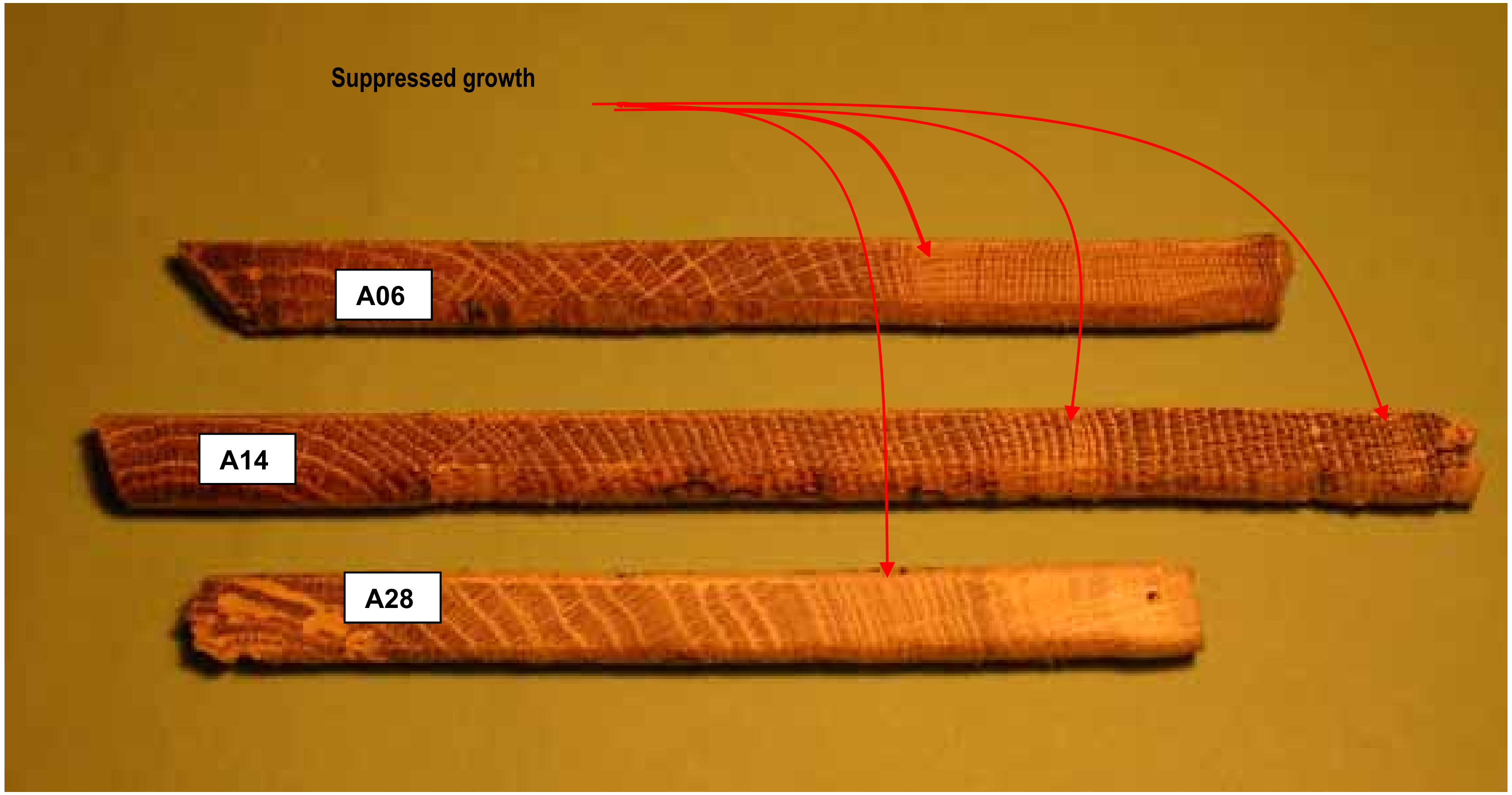


Figure 9: Example of cores showing ring patterns: PRD-A06 (top) showing wide early-rings, followed by sudden narrowing from which growth does not recover; PRD-A14 (middle) has two periods of disturbance from which the tree does recover its previous growth rate. Sample PRD-A28 (bottom), which is unmeasured, shows growth disturbance in the latter half of its ring sequence.

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units

PRD-A01A 80
250 235 249 225 237 199 134 183 88 108 165 119 211 183 227 177 208 181 124 170
99 149 187 133 177 170 225 160 121 135 75 122 119 97 92 91 98 106 126 126
111 148 150 147 150 110 113 120 75 82 104 103 164 98 78 69 85 65 76 69
46 51 58 38 49 84 55 47 79 84 95 99 73 67 58 63 64 94 74 55
PRD-A01B 80
257 194 231 200 211 171 135 148 110 113 161 123 221 182 239 167 204 194 136 164
108 150 187 159 206 195 235 155 126 111 71 114 121 114 94 99 91 116 112 123
124 126 135 139 139 94 116 112 71 91 97 104 166 106 77 83 74 66 66 77
34 45 64 38 40 86 51 49 80 84 103 97 80 69 50 67 50 87 84 54
PRD-A02A 59
608 616 505 637 423 582 365 211 152 154 247 249 428 470 434 496 407 351 330 222
259 444 222 306 293 414 440 402 476 472 612 314 409 365 283 365 270 373 387 303
143 212 228 249 351 214 170 224 296 352 213 155 161 154 137 150 176 137 174
PRD-A02B 59
623 647 532 651 410 589 377 213 156 145 228 247 429 469 448 481 404 380 312 246
267 425 228 291 299 415 444 378 485 479 616 311 407 358 297 371 270 331 405 289
170 196 227 234 334 235 166 233 272 359 233 142 175 125 142 156 178 134 173
PRD-A06A 76
448 466 381 180 307 253 293 333 339 411 327 372 338 369 307 210 164 140 158 94
122 73 45 46 55 57 61 72 50 63 54 83 80 94 140 86 109 78 118 112
118 127 106 114 111 103 103 70 89 78 121 98 102 103 98 96 78 91 84 87
101 97 93 93 85 85 100 73 119 106 128 95 95 115 93 102
PRD-A06B 76
411 450 354 179 274 254 290 335 362 404 322 399 334 365 311 231 218 147 181 96
115 59 45 60 59 69 62 69 51 62 53 82 84 73 133 89 101 82 108 109
119 125 97 122 107 110 89 75 86 91 117 110 107 101 102 92 82 84 114 86
105 106 86 100 76 97 84 85 110 110 127 97 103 93 96 108
PRD-A08A 127
400 379 270 309 204 340 225 133 370 431 377 149 461 283 231 186 242 456 285 134
158 138 145 268 124 226 200 203 198 252 152 144 150 95 166 369 258 275 147 171
124 96 121 103 179 122 91 83 102 104 151 156 173 119 136 123 99 64 80 53
61 49 71 79 74 111 88 67 71 63 61 44 56 67 71 61 78 28 64 72
61 76 48 71 32 34 25 19 21 30 36 53 48 48 97 77 83 70 47 33
33 22 26 32 30 32 40 42 70 73 50 47 37 57 37 38 40 38 43 47
76 43 64 77 79 57 69
PRD-A08B 127
400 391 261 272 198 343 215 134 383 439 395 142 452 310 216 191 238 442 291 137
170 133 141 294 120 238 193 178 196 238 173 133 156 104 162 368 236 294 164 179
110 100 116 96 196 131 98 73 106 104 150 163 164 115 131 119 100 70 86 57
66 51 58 68 86 106 92 58 80 65 55 47 44 66 65 67 86 32 47 55
56 61 52 68 29 25 31 32 33 26 28 47 46 59 82 89 73 76 44 35
27 27 26 33 29 31 49 63 60 70 61 42 41 59 34 34 39 38 44 50
68 44 64 72 80 54 72
PRD-A09A 82
288 264 138 274 310 223 511 468 451 269 421 358 543 210 405 372 381 456 257 231
284 289 157 183 272 209 232 167 232 212 143 170 117 116 217 110 236 190 227 191
250 201 135 180 97 155 202 199 234 175 175 117 143 108 91 133 114 121 92 119
158 146 196 195 186 185 285 257 277 234 149 215 132 127 161 181 241 213 111 125
134 151

PRD-A09B 82
311 263 135 284 310 223 512 461 430 280 393 381 530 207 416 355 388 462 269 221
291 285 146 205 248 214 232 175 241 198 151 164 107 122 222 115 228 193 228 191
248 181 141 164 89 149 222 205 217 173 188 110 135 109 89 126 120 121 78 131
159 143 184 216 166 195 286 246 252 226 147 222 125 128 154 173 251 221 117 111
138 151
PRD-A10A 93
196 322 287 361 173 199 256 182 202 228 239 175 190 235 185 281 266 178 133 216
241 145 107 118 81 117 155 155 148 99 97 80 135 92 81 86 95 78 77 83
103 84 56 62 122 98 119 92 96 89 48 55 51 35 44 59 61 50 55 79
47 106 74 97 71 135 72 95 88 119 116 71 75 90 60 64 119 38 73 59
89 73 52 61 58 56 73 64 55 97 53 66 71
PRD-A10B 93
203 322 289 295 181 206 246 196 205 250 246 171 182 243 190 286 248 184 135 207
250 148 128 120 83 102 179 140 135 105 104 73 142 100 70 91 79 91 61 105
96 84 60 66 122 92 112 107 63 97 54 37 65 29 41 50 62 57 80 62
37 122 91 83 73 136 78 102 94 114 120 76 72 88 63 64 121 37 79 61
78 79 59 50 56 60 67 70 58 95 54 58 69
PRD-A11A 86
200 141 160 154 176 114 149 194 265 382 316 255 300 324 276 253 188 256 244 167
155 175 163 224 189 193 164 121 158 203 220 124 147 159 147 164 192 341 208 232
283 258 268 208 155 146 126 130 201 216 182 193 169 195 221 199 174 233 292 164
149 208 258 215 164 148 276 195 180 446 269 254 171 178 148 162 112 104 113 211
169 189 204 242 132 185
PRD-A11B 86
193 141 156 156 175 111 156 184 360 366 306 245 305 314 281 262 191 261 239 174
156 171 181 217 182 236 168 116 159 207 221 122 133 169 159 162 196 321 222 222
259 258 244 217 160 133 131 130 183 215 186 180 182 209 221 180 187 230 271 149
163 192 256 214 177 133 266 195 163 428 301 228 202 166 134 161 106 112 105 186
171 185 209 238 127 180
PRD-A12A 110
59 58 91 75 82 82 93 95 95 71 63 63 70 57 92 96 45 37 34 41
50 43 42 42 51 49 80 57 54 59 47 53 74 85 75 78 84 87 76 72
77 77 71 65 86 62 94 66 69 55 52 59 84 97 97 138 75 113 107 96
88 64 115 86 113 84 104 96 62 51 69 73 74 122 85 91 63 81 97 81
102 107 111 72 98 77 92 97 124 155 90 90 67 52 55 39 58 63 50 76
73 66 59 49 50 28 74 46 64 65
PRD-A12B 110
68 48 89 78 82 85 84 98 87 80 60 65 60 59 96 91 53 29 32 36
50 51 37 39 63 57 62 50 53 51 49 65 69 100 87 78 84 95 67 82
67 72 83 64 90 53 88 75 67 54 60 63 77 103 92 151 83 116 118 93
83 70 118 93 100 84 105 102 54 66 83 67 79 123 82 82 67 82 97 76
106 102 119 67 98 85 94 101 117 153 94 80 78 57 52 44 62 61 51 75
67 63 55 54 46 50 55 41 53 73
PRD-A14A 84
400 309 254 176 214 224 242 161 159 125 164 261 268 231 227 263 263 178 211 157
212 151 185 188 192 161 175 188 151 162 148 166 150 165 173 211 174 229 229 199
134 147 163 147 188 164 180 93 52 72 85 142 209 201 285 200 241 187 151 144
200 189 145 194 163 129 140 140 189 185 186 150 124 116 99 53 63 94 100 131
142 149 184 151
PRD-A14B 84
507 303 255 164 206 229 252 164 163 101 163 255 255 241 222 258 268 172 239 153
221 134 178 179 177 173 172 185 160 178 171 172 147 159 155 208 173 212 260 200
133 162 142 161 178 161 186 104 52 77 84 134 214 207 292 213 256 186 151 164
193 182 143 188 148 140 135 139 177 205 200 146 125 113 88 37 64 77 90 150

142 145 160 149
PRD-A16A 76
183 309 116 183 169 141 141 106 131 96 82 107 72 70 94 93 70 96 92 116
90 71 65 90 76 104 78 123 71 118 104 88 87 78 72 64 45 40 64 48
39 58 66 54 39 54 66 52 58 46 71 68 60 58 76 50 102 96 92 135
149 106 83 73 90 125 97 143 133 138 139 118 127 136 169 217
PRD-A16B 76
183 308 118 171 171 124 151 106 136 103 84 102 83 65 99 83 96 92 112 98
111 79 83 95 76 101 91 93 75 102 99 91 79 78 68 71 51 49 39 41
43 58 62 56 48 47 65 55 53 69 69 69 69 68 97 57 99 95 98 126
128 96 100 65 91 132 86 136 130 133 159 116 134 137 154 215
PRD-A18A 74
38 37 35 58 24 89 60 70 70 84 101 99 105 134 91 67 39 42 64 75
134 126 149 125 139 110 118 117 67 118 104 84 51 58 95 90 97 90 104 123
90 55 55 70 49 72 74 84 111 117 82 98 60 103 133 120 124 113 76 51
36 32 64 35 69 63 58 51 50 53 58 53 67 61
PRD-A18B 74
33 40 36 55 31 80 61 68 76 84 101 92 106 133 97 72 37 48 58 74
139 115 157 124 140 103 137 103 68 115 113 81 53 56 97 81 89 104 106 130
97 57 54 61 60 57 93 89 101 118 84 95 63 99 129 123 120 108 74 48
34 41 57 40 62 64 65 45 49 53 60 56 59 62
PRD-A20A 58
289 90 123 103 128 230 229 309 246 265 209 128 129 176 184 198 126 196 227 205
145 220 194 142 152 121 114 95 89 74 89 106 97 88 87 73 106 72 87 77
93 99 88 101 85 53 74 56 94 94 84 88 90 78 67 76 62 78
PRD-A20B 58
275 91 113 96 132 230 224 303 246 275 191 134 140 165 192 197 138 190 213 204
144 222 185 137 164 123 113 91 90 84 94 100 102 81 96 72 96 83 77 79
84 106 86 94 87 56 69 69 86 106 72 98 83 81 63 80 65 83
PRD-A23A 64
234 474 394 134 174 171 115 339 189 84 59 75 58 37 56 90 183 183 113 134
90 83 133 126 550 219 147 150 233 123 121 141 234 114 138 140 166 239 181 188
133 134 276 180 250 177 91 33 53 65 50 60 66 115 99 101 149 136 136 148
141 105 90 110
PRD-A23B 64
227 478 409 131 188 170 115 357 183 74 62 83 44 34 59 79 184 196 117 130
83 100 161 102 535 262 137 147 270 126 110 155 232 117 132 144 168 237 186 184
129 143 285 185 234 167 95 38 46 67 51 55 64 103 98 98 143 127 172 139
135 104 86 114
PRD-A29A 56
131 192 91 127 157 285 673 332 268 327 280 158 207 197 178 245 179 194 236 317
299 190 233 198 303 252 200 288 227 164 210 308 256 361 371 379 390 343 299 332
287 298 279 325 234 251 294 234 298 298 247 332 313 308 273 332
PRD-A29B 56
133 216 96 126 144 307 665 336 264 328 260 169 197 198 200 258 203 194 248 316
254 209 252 216 274 263 213 302 230 170 203 299 303 356 346 383 411 389 310 300
290 314 259 329 234 261 280 253 290 295 248 319 308 305 261 326

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 A1 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 A1, 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 A2 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 8–10 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 A2; it is about 150mm long and 10mm 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 A1: 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 A2: Cross-section of a rafter, showing sapwood rings in the left-hand corner, the arrow points to the heartwood/sapwood boundary (H/S); and a core with sapwood; again the arrow is pointing to the H/S. The core is about the size of a pencil

Figure A3: 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 A4: 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 A2. 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 A3).

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 A4). 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 A5 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 A5. 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 A5 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 straightforward 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 (or the last full year before felling, if it was felled in the first three months of the following calendar year, 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 A2, 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 region 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 A2 was taken still had complete sapwood but that some of the soft sapwood rings were lost in coring. By measuring into the timber the depth of sapwood lost, say 20mm, 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; Miles 1997, 50–5). Hence, provided that 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, fig 8; 34–5, where 'associated groups of fellings' are discussed in detail). However, if there is any evidence of storage 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 Figure A6 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 Figure A6. 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 Figure A7. 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

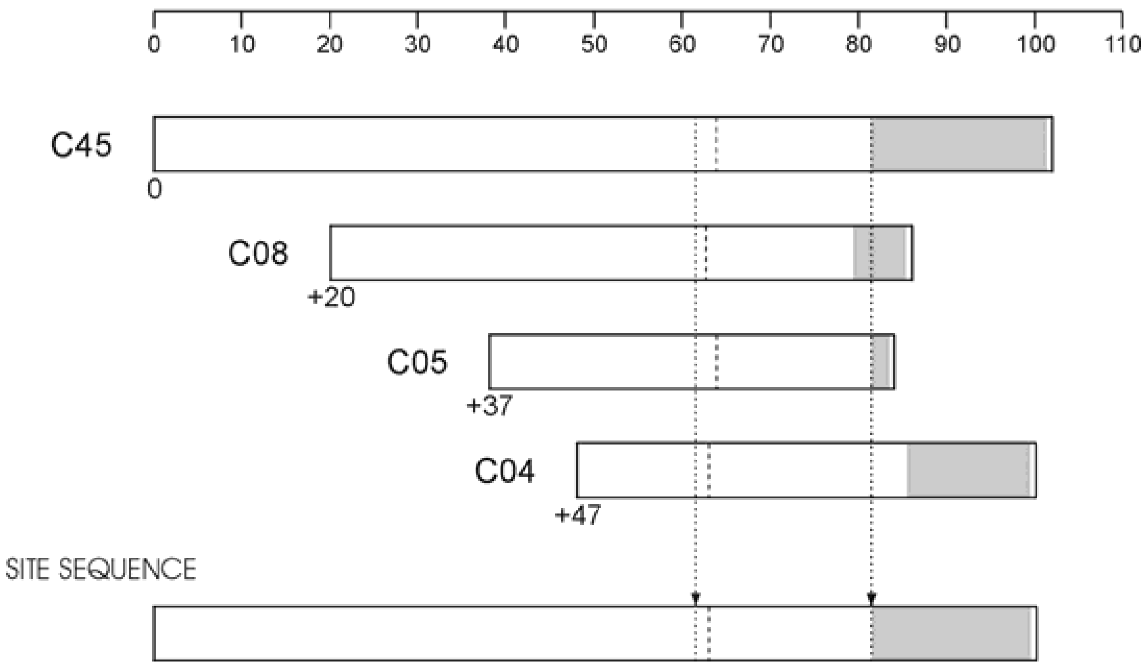


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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

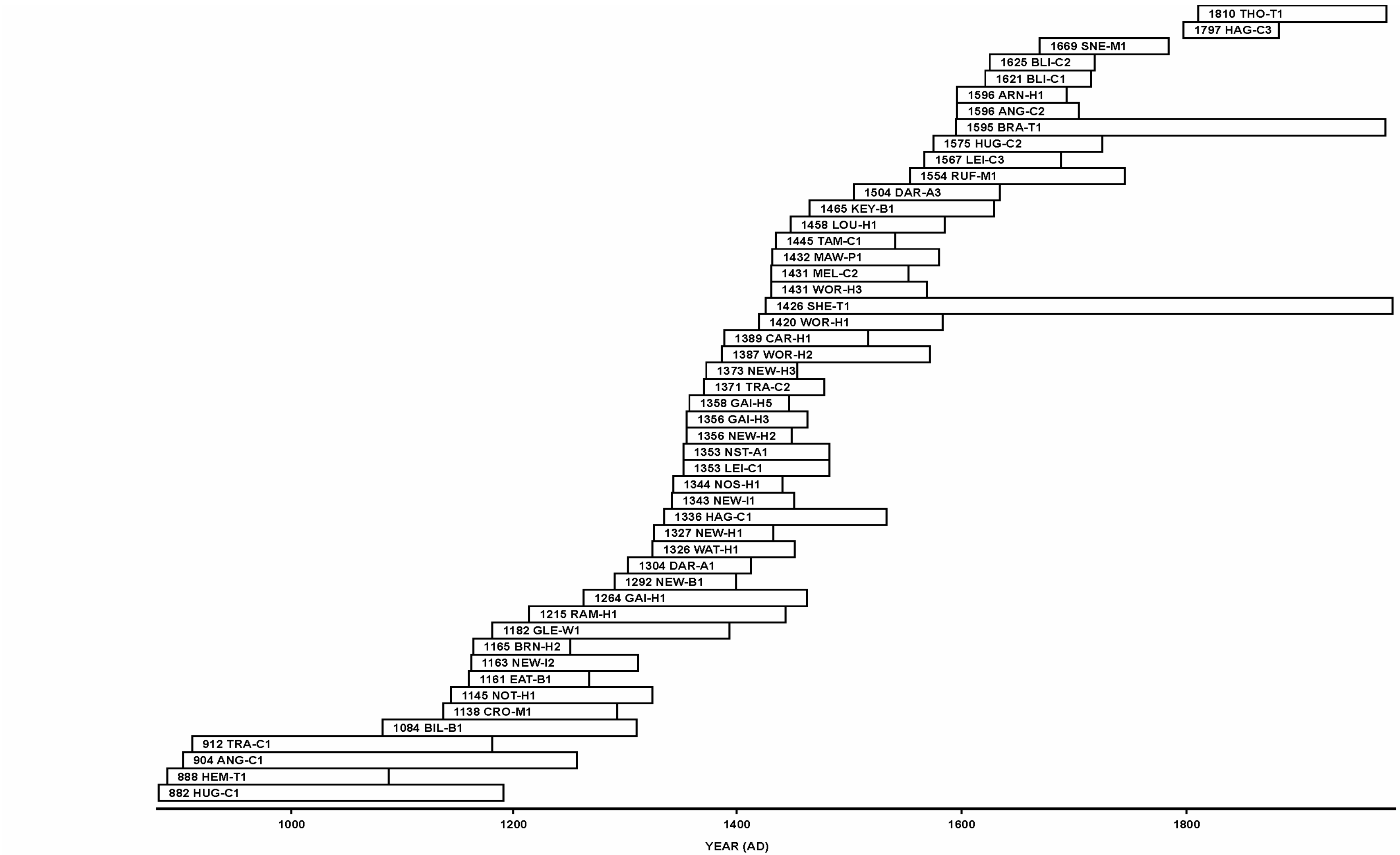
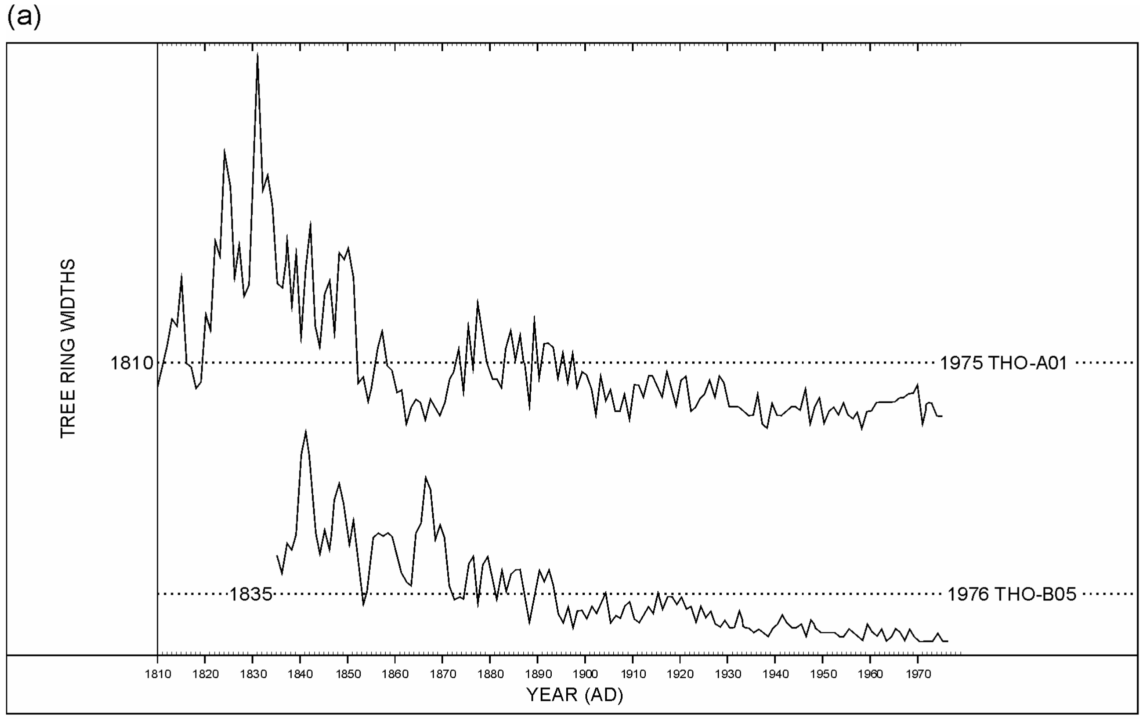


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87



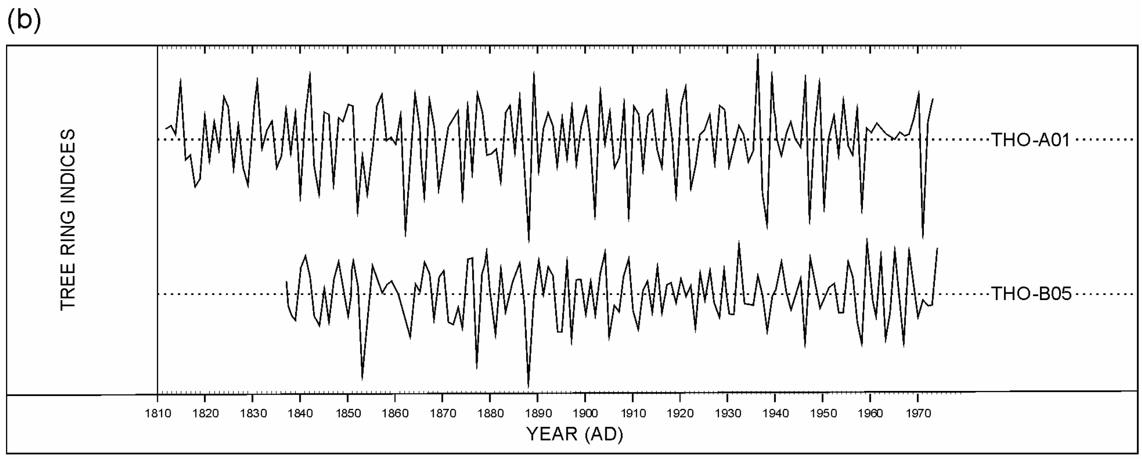


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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 A7 (b): The Baillie-Pilcher indices of the above widths

The growth trends have been removed completely

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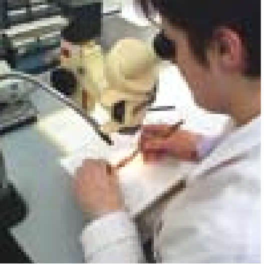
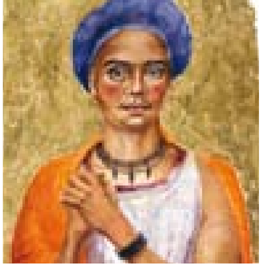



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