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CROMWELL COTTAGE, CROMWELL LANE, TILE HILL, COVENTRY
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

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Research Department Report Series 92/2007

Cromwell Cottage, Cromwell Lane, Tile Hill, Coventry
Tree-Ring Analysis of Timbers

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Summary

Prior to tree-ring analysis being undertaken, this building was thought to have its origins in the late-sixteenth century, but with much of the present internal arrangement and the Timber-Framed Range roof dating to the late-seventeenth century.

Within the Stone Range, the ground-floor ceiling structure was considered primary or early; its timbers have been dated to AD 1552–77. The first-floor timber-framed partition and ceiling structure were thought to be late-seventeenth century in date. Timbers of the former have been dated to AD 1547–72 and the latter to AD 1548–73.

Within the Timber-Framed Range, timbers of the external framing have been dated to AD 1550–75 and a possibly primary first-floor partition to AD 1575. The timbers of the ground-floor internal partition have been dated to AD 1572–97. This partition was thought to have been inserted, under a ceiling beam which has now been dated to AD 1555–80.

The double-pile Stone Range roof and the Timber-Framed Range roof are constructed from timber felled in AD 1560–75.

These results indicate one or more periods of felling, and hence building activity, in the second half of the sixteenth century. No timbers have been identified that represent building activity in the seventeenth century.

Keywords

Dendrochronology
Standing Building

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Introduction

The Grade-II listed Cromwell Cottage is located at Tile Hill, about 6km to the west of Coventry (Figs 1–3; SP 275 774). Thought to date from the late-sixteenth century and to have been extended in the early seventeenth century, it has been known as Cromwell Cottage from at least the 1930s. The house can be divided into two basic components, a Stone Range and a Timber-Framed Range.

The Stone Range

This part of the building is a rectangular two-storey block that is thought to have once continued further to the south, based on the obvious difference in character of the south wall to the others and the clear construction break between it and the west and east walls. Additionally, internally at the southern end of the west wall can clearly be seen the northern jamb of a doorway further demonstrating that this wall once continued further south. The present ground-floor layout is likely to be of relatively recent date, with none of the extant partition walls believed to be primary. This layout consists of entrance hall, one large and irregular room to the south, and a closet in the north-west with a type of baffle entry. There is an internally projecting brick chimneystack at the western end, bisected by a modern partition (Fig 4).

The large southern room has exposed ceiling beams, consisting of a large east-west beam, two shorter beams which run between this and the north wall, a third shorter beam running southwards towards the south wall, and a series of substantial, stop-chamfered common joists. In the soffit of the main beam are a number of redundant mortices and stave holes indicating the existence of a framed partition beneath it. Study of these empty mortices demonstrate the existence of a doorway which would have lined up with the narrowed doorway in the north wall of the range, making it likely that rather than simply being a reused timber, this beam is part of the primary fabric of the range.

The first floor is divided into two rooms, accessed through a lobby entrance off the stair landing, the eastern room being slightly larger than the western (Fig 5). The timber-framed partition between the two rooms appears to be of one piece, but is thought to be inserted. It is two panels high with a blocked primary doorway, under a segmental head, in the centre and an inserted doorway at the north end (Fig 6). The wallplate of this partition supports the ends of the plain but again substantial ceiling joists.

This range has a plain-tiled roof of double-pile structure, of one bay long (Figs 7 and 8). Its twin gables have no obvious relationship with the brickwork of the southern wall upon which they sit. Both of these southern trusses share a tiebeam and consist of principal rafters, a collar, and two queen struts, running from tie to collar (Fig 7). The trusses at the northern end of this roof are of a different design but again share a substantial tiebeam. These trusses have principal rafters and a pair of raking struts. There is a single tier of purlins to each slope, stiffened by windbraces. From the design of the southern trusses they would appear to have been intended to be external which suggests this roof is not primary to the range because, as mentioned above, the building previously continued further south.

The Timber-Framed Range

Initially this range seems to clearly post-date the Stone Range, utilising as it does the northern wall of that building as its own southern wall. However, the southern post in the framing of the east elevation has a pegged mortice, indicating a continuation of at least the eastern frame of the Timber-Framed Range southwards, suggesting that it may actually pre-date the Stone Range. At ground-floor level this part of the building is divided into two rooms, with the eastern one being the larger of the two (Fig 4). These two rooms are separated by a timber-framed partition, at the northern end of which is an early doorway opening which has since been blocked and replaced by an inserted doorway at the southern end (Fig 9). The frame is located on an assumed 'bay division', but has clearly been inserted under a former bridging beam, as the tops of the studs have been half-lapped into it on the western side. Further evidence of this frame's secondary status is that it runs into the earlier doorway through the north wall of the Stone Range, which had to be narrowed as a result.

Within the east room is a large fireplace, in the north-eastern corner of which are traces of a bread oven. The fireplace is spanned by a large timber lintel which may have been reset or reused in the past. The room is spanned by a north-south chamfered beam and has chamfered and stopped common ceiling joists. The western joists are tenoned into what is now the wallplate of the cross frame, which would have originally been another large ceiling beam, implying that the ground floor was once a three bay single space.

At first-floor level the stair and landing are located between the wall of the Stone Range and an inserted partition just to the north of the axial beam. The landing provides access to a small room at the south-west of this range and the main room to the north-east which leads to the third room (Fig 5). This room is divided from the south-west room by an inserted partition and the main room by a potentially primary cross-frame. This latter frame consists of two rows of broad panels. A modern doorway has been cut through the north end and an earlier one at the south end for the present corridor (Fig 10).

The roof structure of this range of the building is plain gabled and plain tiled and of two structural bays. The gable trusses are of different design with the front, or east, truss consisting of tiebeam, principal rafters, two queen struts, and a high collar, and the rear, or western, truss, consisting of tiebeam, principal rafters, three queen struts from tie to a collar, and two further queen struts from collar to principals. These latter struts are linked by a short horizontal beam which may be the lintel of a blocked attic window (Fig 11). The intermediate truss consists of tiebeam, principal rafters, and a pair of raking queen struts allowing free access through the truss. The trusses have two tiers of trenched, simple chamfered purlins, stiffened by crude straight wind-braces. There is evidence of reuse in the form of redundant mortices amongst some of the timbers of this roof. The present roof is not thought to be primary to this part of the building.

Suggested Phasing: Late sixteenth/Early-seventeenth century

With contradictory evidence it is unclear as to whether the Stone Range pre- or post-dates the Timber Range, and this building is obviously a very complex structure. However, it is suggested that the Stone Range began life as a two-storey building, which would originally have extended further south. The northern portion had a cross-passage, with doorways in the west and east walls, flanked on the south side by an apparently primary timber-framed partition with doorway through it, opposite another doorway in the north wall. The large room to the south of the partition may have been the hall. There are no indications of primary partitions at first-floor level so this may have been one large chamber. There are suggestions the building also continued northwards in the form of the doorway at this level in the north wall. The present roof is not necessarily the original one.

If the above interpretation is accurate then it would be expected that to the north of the cross-passage would be a service range and it is possible that the present Timber-Framed Range replaced or did indeed itself fulfil this function. The wall framing of the Timber-Framed Range is thought to be earlier than its extant roof, and datable to this late-sixteenth or early-seventeenth century phase.

Later-seventeenth century

This period is thought to be one of great change for both parts of the building. It is suggested that it was during this time that the original roof of the Timber-Framed Range was replaced with the present one and much of the internal partitioning in this part of the building was inserted. It is also suggested that this period sees the rebuilding of the south wall of the Stone Range, the insertion of the partition at first-floor level, and possibly the removal of the original partition at ground-floor level.

To the present day

Little is thought to have then changed with the property after the seventeenth century until the late twentieth and early twenty-first centuries, when considerable alterations were undertaken both internally and externally.

Aims and Objectives

Sampling and analysis by tree-ring dating were commissioned and funded by English Heritage. Nicholas Molyneux, Historic Buildings Inspector at their Birmingham Office requested the work to inform recording and repair of this Building at Risk.

It was hoped that by sampling the original timber-framing in the Timber-framed range it would be possible to provide a construction date for this part of the building and potentially establish whether it was likely to pre- or post-date the Stone Range. Neither of the roofs of the two ranges are believed to be the original structures, so producing dates for their timbers would allow us to determine when these re-roofings occurred. Sampling of the internal features of both ranges, ceilings, partitions, lintels, etc, might identify any survival of the original layout and also the date of modifications to the internal structure.

Acknowledgements

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Sampling

A total of 91 oak core samples was taken from timbers at this building. Each sample was given the code COV-B (for Coventry, site 'B') and numbered 01–91. Samples were taken in the Stone Range from the ground-floor ceiling (COV-B01–08 and COV-B11–12), the first-floor ceiling (COV-B13–22), two window lintels (COV-B09 and COV-B23) a door lintel (COV-B10), a first-floor timber-framed partition (COV-B24–9), and the east and west roofs (COV-B30–52). A number of the timbers, such as the principal rafters, in the east roof were seen to be very wide-ringed, and so were not sampled. In the Timber-Framed Range samples were taken from the main structural framing (COV-B53–61), three ceiling beams (COV-B62, COV-B66, and COV-B70), a first-floor timber-framed partition (COV-B63–5), the ground-floor fireplace lintel (COV-B67), the ground-floor timber-framed partition (COV-B68–9 and COV-B71–2), and roof (COV-B73–91). The positions of samples were noted at the time of sampling and have been marked on Figures 4, 5, and 12–22. Further details relating to the samples can be found in Table 1. Roof trusses and ceiling joists have been numbered from north to south (Stone Range) and east to west (Timber-Framed Range).

Analysis and Results

At this stage it was noticed that 28 of the samples had too few rings to make secure dating a possibility, and these samples were rejected prior to measurement. These 28 samples are spread amongst several of the sampled areas, with the greatest proportion being from the Stone Range. The remaining 63 samples were prepared by sanding and polishing and their growth-ring widths measured; the data of these measurements are given at the end of the report. All samples were compared with each other by the Litton/Zainodin grouping procedure (see appendix), resulting in 54 samples forming three groups.

Firstly, 50 samples matched and were combined at the relevant offset position to form COVBSQ01, a site sequence of 231 rings (Fig 23). This site sequence was then compared with a large number of relevant reference chronologies for oak where it was found to match at a first-ring date of AD 1345 and a last-ring date of AD 1575. The evidence for this dating is given by the *t*-values in Table 2.

Two samples matched and were combined at the relevant offset position to form COVBSQ02, a site sequence of 59 rings (Fig 23). This site sequence was compared against the reference chronologies for oak where it was found to span the period AD 1500–58. The evidence for this dating is given by the *t*-values in Table 3. Although COVBSQ01 and COVBSQ02 overlap in date, there is no cross-matching between the two site sequences.

Finally, two samples grouped and were combined to form COVBSQ03, a site sequence of 107 rings (Fig 24). Attempts to date this site sequence by comparing it against the relevant reference chronologies were unsuccessful and it remains undated.

Attempts to date the remaining ungrouped samples by individually comparing them against the reference chronologies proved unsuccessful, and these are also undated.

Interpretation

Analysis of 63 samples taken from timbers at this house has resulted in the construction of three site sequences, two of which have been dated. Site sequence COVBSQ01, contains 50 samples, from both ranges of the building, and spans the period AD 1345–1575. Site sequence COVBSQ02 contains two samples, both from the Timber-Framed Range, and spans the period AD 1500–58. For the purpose of clarity, each group of timbers has been dealt with separately according to area (Fig 25).

Stone Range, ground-floor ceiling

Four of these samples have been dated, three of which have the heartwood/sapwood boundary ring. In all three cases this is broadly contemporary and suggestive of a single felling. The average of these is AD 1537, allowing an estimated felling date to be calculated for the three timbers represented to within the range AD 1552–77. The fourth sample (COV-B06) does not have the heartwood/ sapwood boundary ring, but, with a last measured ring date of AD 1510, this would be estimated to be AD 1526 at the earliest, not precluding this sample also having been felled in AD 1552–77.

Stone Range, first-floor ceiling

Only three samples taken from this structure have been successfully dated and of these only one (COV-B20) has the heartwood/sapwood boundary ring. This is AD 1533, which allows an estimated felling date to be calculated for the timber represented to within the range AD 1548–73. The other two have last measured ring dates of AD 1431 (COV-B15) and AD 1526 (COV-B21) which means they would be estimated to have been felled at the earliest in AD 1447 and AD 1542, respectively.

Stone Range, first-floor timber-framed partition

Three of the samples from the timbers of the first-floor partition have been dated. Of these, only sample COV-B27 has the heartwood/sapwood boundary ring date (AD 1532), which allows an estimated felling date range to be calculated for the timber represented of AD 1547–72. The other two samples do not have the heartwood/sapwood boundary ring and so estimated felling dates cannot be calculated, except to say that with last-measured ring dates of AD 1482 (COV-B29) and AD 1505 (COV-B25) these would be at the earliest AD 1498 and AD 1521, respectively.

Stone Range, east roof

Six samples have been dated from the east roof, three of which have the heartwood/sapwood boundary ring date. In all three cases, this is broadly contemporary and suggestive of a single felling. The average of these is AD 1533, which allows an estimated felling date to be calculated for the three timbers represented to within the range AD 1560–1573. This allows for sample COV-B39 having a last measured ring date of AD 1559, with incomplete sapwood. The other three dated samples from this part of the roof do not have the heartwood/sapwood boundary ring and so estimated felling dates cannot be calculated, except to say that with last measured ring dates ranging from AD 1455 (COV-B38) to AD 1518 (COV-B35), it is possible that these three timbers were also felled in AD 1560–73.

Stone Range, west roof

Eleven samples from this part of the roof were successfully dated. Seven of these have the heartwood/sapwood boundary ring date, which is broadly contemporary and suggestive of a single felling. The average of these is AD 1531, allowing an estimated felling date to be calculated for the ten timbers represented to within the range AD 1546–71. The other dated samples do not have the heartwood/sapwood boundary ring date and so estimated felling dates cannot be calculated, except to say that with last-measured ring dates ranging from AD 1442 (COV-B49) and AD 1529 (COV-B40), it is possible that these timbers were also felled in AD 1546–71.

Timber-Framed Range, structure

Four of the timbers of the main timber framing have been successfully dated, only one of which (COV-B59) has the heartwood/sapwood boundary ring. This is AD 1535, allowing an estimated felling date of AD 1550–75 to be calculated for the timber represented. Estimated felling dates cannot be calculated for the other three dated samples, except to say that with last-measured ring dates ranging from AD 1497 (COV-B60) to AD 1533 (COV-B58), it is not impossible that these samples were also felled in AD 1550–75.

Timber-Framed Range, ground-floor timber-framed partition

Two timbers from this ground-floor partition have been dated. Both of these samples have the heartwood/sapwood boundary ring date, the average of which is AD 1557, allowing an estimated felling date to be calculated for the two timbers represented of AD 1572–97.

Timber-Framed Range, first-floor timber-framed partition

All three of the samples taken from this structure have been successfully dated. One of these, COV-B63, has complete sapwood and the last-measured ring date of AD 1575, the felling date of the timber represented. The other two samples, COV-B64 and COV-B65, both have the heartwood/ sapwood boundary ring, whose date is consistent with these having also been felled in AD 1575.

Timber-Framed Range, ceiling beam

The sampled ceiling beam under which the ground-floor frame was thought to have been inserted has been successfully dated. The last measured ring on this sample (COV-B70) is the heartwood/ sapwood boundary, the date of which (AD 1540) allows an estimated felling date to be calculated for the timber represented to within the range AD 1555–80.

Timber-Framed Range, roof

Fifteen of the timbers taken from this roof have been dated, nine of which have the heartwood/ sapwood boundary ring date. These are all broadly contemporary and so suggestive of a single felling. The average heartwood/sapwood boundary ring date for these nine is AD 1538, giving an estimated felling date range for the nine timbers represented of AD 1553–78. The other six samples do not have the heartwood/sapwood boundary ring and so estimated felling dates cannot be calculated, except to say that with last-measured ring dates ranging from AD 1480 (COV-B88) to AD 1516 (COV-B91), it is possible that these samples were also felled in AD 1553–78.

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

Discussion

Prior to tree-ring analysis being undertaken at Cromwell Cottage, the building was thought to have its origins in the late-sixteenth century, but there was a degree of confusion regarding the dating of and relationship between the two parts, the Stone Range and the Timber-Framed Range. Little of the original internal layout was thought to survive in either part of the building, although a first-floor timber-framed partition within the Timber-Framed Range was believed to be primary or at least a very early insertion. Additionally, evidence for an earlier, no longer extant, partition within the ground floor of the Stone Range was provided by the main east-west ceiling beam, which has a series of empty mortices. By association with this beam, the rest of this ceiling structure would be likely to be of the same early phase in the building's history. The ground-floor timber-framed partition within the Timber-Framed Range and the first-floor timber-framed partition within the Stone Range are both considered inserted, possibly in the latter part of the seventeenth century. The first-floor ceiling in the Stone Range is not morticed into, but rather rests on top of this latter partition, suggesting it is slightly later than it. Neither the double-pile roof over the Stone Range nor the one over the Timber-Framed Range were believed to be the original structures, with the latter thought to be a re-roofing of the second half of the seventeenth century.

Obviously, it is not possible to use dendrochronology to provide a construction date for the stone structure of the Stone Range. However, the main east-west ground-floor ceiling beam and associated common joists were thought to be primary, or to belong to an early phase, and these have now been dated to a felling of AD 1552–77. Also now dated to the second half of the sixteenth century are some timbers associated with the external timber framing of the Timber-Framed Range, one to a felling date range of AD 1550–75 and a further three to *termini post quem* which make it possible they were also felled in the second half of the sixteenth century. Unfortunately, none of the sampled corner posts of the Timber-Framed Range's structure has been successfully dated, despite two of them cross-matching to form the site sequence COVBSQ03.

Although not considered primary, the double-pile roof over the Stone Range was thought to belong to an early part of the building's history, whereas the roof over the Timber-Framed Range was thought to be a re-roofing of the second half of the seventeenth century. The tree ring dating has now shown the roofs over both parts of the building to be broadly contemporary, with the timbers of the roof over the Stone Range being dated to AD 1560–73 (east roof) and AD 1546–71 (west roof), and that over the Timber-Framed Range to AD 1553–78. Moreover, the level of cross-matching seen between the timbers in both parts of the Stone Range roof and in the Timber-Framed Range roof is such to strongly suggest that the entire roof structure of the building, ie, that over the Stone Range and the Timber-Framed Range, is of the same date and constructed from a coherent group of timbers. There is even evidence of same-tree matching between roofs, with COV-B39 from the east roof matching COV-B43 from the west roof at a value of t=15.6, and COV-B50 of the west roof of the Stone Range matching COV-B82 of the Timber-Framed Range roof at t=15.4. It is therefore reasonable to provide a felling date range that covers the timbers of both ranges' roofs. Looking at the heartwood/sapwood boundary ring dates of all roof timbers, and allowing for the last measured ring date of sample COV-B39 being AD 1559 with incomplete sapwood, this gives an estimated felling date range for the timbers used in the construction of the roof as a whole of AD 1560–75.

Two internal timber-framed partitions were sampled in the Timber-Framed Range. The first-floor frame was considered primary, whilst the ground-floor one was thought to have been inserted, possibly in the later-seventeenth century. The only dated sample retaining complete sapwood at this building was taken from the first-floor partition, and this has a felling date of AD 1575, with two further timbers from this frame also thought likely to have been felled in AD 1575, confirming the early date assigned to this partition. However, rather than being significantly later, two timbers from the ground-floor partition have been dated to AD 1572–97, a felling date range that allows for these timbers to have also been felled in AD 1575. This latter partition was thought to have been inserted under a ceiling beam and so was expected to be somewhat later than the beam. This ceiling beam is now known to have the similar, albeit slightly earlier, felling date range of AD 1555–80.

The level of cross-matching between the timbers of this first-floor timber-framed partition and from the main structural framing of the Timber-Framed Range also suggest the use of a strong coherent group of timbers. As noted above, the timbers of the partition have been dated to AD 1575 and those of the main structural framing to AD 1550–75, a date range consistent with felling in AD 1575.

The timber-framed partition on the first-floor of the Stone Range was thought to be an insertion of the second half of the seventeenth century, but has in fact been shown to be constructed from timber felled in AD 1547–72. With the ceiling joists of the first floor resting on the top of this partition, it was thought likely that this ceiling structure was later than the frame, but the ceiling timbers have now been dated to the very similar felling date range of AD 1548–73.

As stated above, the level of cross-matching between timbers suggests that the roofs of the Stone Range and the Timber-Framed Range are contemporary, and also that the timbers of the main structural framing of the Timber-Framed Range and those of a first-floor partition within it are also of the same date. Indeed, all areas sampled and dated within both ranges have produced similar and mostly overlapping felling date ranges, making it possible that all timbers in this building were felled at the same time. However, with the lack of precise felling dates, it is not possible to confirm or refute this, and it is also possible that these felling date ranges from both ranges represent a series of discrete felling periods.

The lack of bark edge has meant that it has not been possible to establish the precise chronological development of the two ranges of this house, nor to demonstrate absolutely whether the Stone or Timber-Framed Range came first. However, somewhat unexpectedly, the dendrochronology has shown that the timber utilised in both ranges of this structure is all broadly coeval and dates to the second half of the sixteenth century, demonstrating intense building activity at this time.

Conclusion

It was thought that the origins of Cromwell Cottage were in the late-sixteenth century, but that much of the present layout dated to the later-seventeenth century. The results have indeed provided valuable evidence to support the late-sixteenth century date attributed to the building, but have not identified any timbers from the seventeenth century. Instead, timbers throughout both ranges have been dated to a series of overlapping felling date ranges, which are restricted to the second half of the sixteenth century. This demonstrates a period of great building activity within the house at this time, but whether this is a single intensive building period or a series of different building periods spanning a few decades cannot be proven. The complex nature of the structural evidence at this building had proved an obstacle to gaining a comprehensive understanding of its development. It is to be hoped that these dendrochronological results, in conjunction with further analysis of the structural evidence by building archaeologists, may lead to a greater understanding this interesting building.

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Table 1: Details of tree-ring samples from Cromwell Cottage, Tile Hill, Coventry

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
STONE RANGE						
Ground-floor ceiling						
COV-B01	North-south main beam	122	--	----	----	----
COV-B02	East-west main beam	118	h/s	1421	1538	1538
COV-B03	Joist 1 (east side)	55	h/s	----	----	----
COV-B04	Joist 1 (west side)	55	h/s	1483	1537	1537
COV-B05	Joist 2 (east side)	60	01	1479	1537	1538
COV-B06	Joist 2 (west side)	54	--	1457	----	1510
COV-B07	Joist 3 (east side)	NM	--	----	----	----
COV-B08	Joist 3 (west side)	NM	--	----	----	----
COV-B11	North-south beam (east) – hallway	NM	--	----	----	----
COV-B12	North-south beam (west) – hallway	78	h/s	----	----	----
Lintels						
COV-B09	Ground-floor window lintel – main room, west wall	69	11	----	----	----
COV-B23	First-floor window lintel – west room, west wall	NM	--	----	----	----
COV-B10	Ground-floor door lintel – hallway	92	h/s	----	----	----
First-floor ceiling						
COV-B13	North-south main beam	NM	--	----	----	----
COV-B14	Joist 1 – east room	NM	--	----	----	----
COV-B15	Joist 3 – east room	54	--	1378	----	1431
COV-B16	Joist 4 – east room	NM	--	----	----	----
COV-B17	Joist 6 – east room	NM	--	----	----	----
COV-B18	Joist 2 – west room	NM	--	----	----	----
COV-B19	Joist 3 – west room	NM	--	----	----	----
COV-B20	Joist 4 – west room	95	05	1444	1533	1538
COV-B21	Joist 5 – west room	129	--	1398	----	1526
COV-B22	Joist 6 – west room	77	h/s	----	----	----

First-floor timber-framed partition						
COV-B24	South stud	NM	--	----	----	----
COV-B25	Stud/door jamb	51	--	1455	----	1505
COV-B26	Mid stud	NM	--	----	----	----
COV-B27	South rail	127	h/s	1406	1532	1532
COV-B28	Top rail	NM	--	----	----	----
COV-B29	North rail	55	--	1428	----	1482
East roof						
COV-B30	Tiebeam, truss 1	167	h/s	1364	1530	1530
COV-B31	West common rafter 1	NM	--	----	----	----
COV-B32	West common rafter 3	NM	--	----	----	----
COV-B33	East common rafter 5	106	--	1390	----	1495
COV-B34	West common rafter 5	NM	--	----	----	----
COV-B35	East common rafter 8	140	--	1379	----	1518
COV-B36	East common rafter 10	NM	--	----	----	----
COV-B37	East valley rafter	134	h/s	1404	1537	1537
COV-B38	West stub purlin	101	--	1355	----	1455
COV-B39	East strut, truss 1	155	28	1405	1531	1559
West roof						
COV-B40	East principal rafter, truss 1	138	--	1392	----	1529
COV-B41	West principal rafter, truss 1	162	h/s	1368	1529	1529
COV-B42	East principal rafter, truss 2	125	h/s	1404	1528	1528
COV-B43	West principal rafter, truss 2	157	h/s	1370	1526	1526
COV-B44	West common rafter 1	93	h/s	1442	1534	1534
COV-B45	East common rafter 2	NM	--	----	----	----
COV-B46	East common rafter 4	NM	--	----	----	----
COV-B47	East common rafter 5	137	--	1345	----	1481
COV-B48	West common rafter 5	137	h/s	1403	1539	1539
COV-B49	West common rafter 7	63	--	1380	----	1442
COV-B50	East common rafter 8	132	h/s	1407	1538	1538
COV-B51	West common rafter 8	128	h/s	1397	1524	1524
COV-B52	West brace, truss 2	133	--	1386	----	1518

TIMBER-FRAMED RANGE						
Main structure						
COV-B53	North-east corner post	107	--	----	----	----
COV-B54	South-east corner post	63	h/s	----	----	----
COV-B55	North-west corner post	56	--	----	----	----
COV-B56	East wall, south main stud	59	--	----	----	----
COV-B57	North wall, west lower stud	154	--	1354	----	1507
COV-B58	North wall, west lower main rail	79	--	1455	----	1533
COV-B59	East wall, lower rail	154	h/s	1382	1535	1535
COV-B60	North wall, upper west rail	106	--	1392	----	1497
COV-B61	Wallplate/original tiebeam	NM	--	----	----	----
First-floor timber-framed partition						
COV-B63	North stud	130	27C	1446	1548	1575
COV-B64	South stud	160	h/s	1383	1542	1542
COV-B65	South mid rail	150	h/s	1407	1556	1556
Ground-floor framing						
COV-B68	North cross rail	58	h/s	1500	1557	1557
COV-B69	South cross rail	58	02	1501	1556	1558
COV-B71	North stud	NM	--	----	----	----
COV-B72	Mid stud	NM	--	----	----	----
Ceiling beams						
COV-B62	North-south central bridging beam	NM	--	----	----	----
COV-B66	Ceiling beam	NM	--	----	----	----
COV-B70	Ceiling beam (used as top of timber-framed partition)	105	h/s	1436	1540	1540
Lintel						
COV-B67	Fireplace lintel – main room, north wall	70	--	----	----	----
Roof						
COV-B73	North upper queen strut, truss 3	124	09	1428	1542	1551
COV-B74	North queen strut, truss 2	NM	--	----	----	----
COV-B75	South queen strut, truss 2	113	h/s	1429	1541	1541
COV-B76	North upper purlin, bay 1	155	h/s	1383	1537	1537

COV-B77	North lower purlin, bay 2	NM	--	----	----	----
COV-B78	South upper purlin, bay 1	168	h/s	1362	1529	1529
COV-B79	Brace, south principal rafter, truss 1 to upper purlin	72	h/s	1466	1537	1537
COV-B80	Brace, north principal rafter, truss 2 to lower east purlin	129	--	1387	----	1515
COV-B81	Brace, north principal rafter, truss 3 to lower purlin	78	--	1438	----	1515
COV-B82	Brace, south principal rafter, truss 3 to upper purlin	96	--	1404	----	1499
COV-B83	North rafter 5, bay 1	NM	--	----	----	----
COV-B84	North rafter 8, bay 1	112	h/s	1426	1537	1537
COV-B85	North rafter 6, bay 1	98	h/s	1444	1541	1541
COV-B86	North rafter 5, bay 2	NM	--	----	----	----
COV-B87	North rafter 6, bay 2	80	--	1430	----	1509
COV-B88	North rafter 1, bay 1	88	--	1393	----	1480
COV-B89	South rafter 5, bay 1	121	h/s	1418	1538	1538
COV-B90	South rafter 7, bay 1	108	h/s	1433	1540	1540
COV-B91	South rafter 6, bay 2	95	--	1422	----	1516

Table 2: Results of the cross-matching of site sequence COVBSQ01 and relevant reference chronologies when the first-ring date is AD 1345 and the last-ring date is AD 1575

Reference chronology	*t*-value	Span of chronology	Reference
East Midlands	7.7	AD 882–1981	Laxton and Litton 1988
Stoneleigh Abbey, Stoneleigh, Warwicks	10.3	AD 1398–1658	Howard et al 2000
Lord Leicester's Stables, Kenilworth Castle, Warwicks	8.2	AD 1354–1532	Arnold *et al* 2006
Lower Bean Hall, Bradley Green, Feckenham, Worcs	7.3	AD 1419–1565	Arnold and Howard 2005 unpubl
Cuttlepoole Farm, Knowl, Sutton Coldfield, Leics	6.6	AD 1337–1478	Howard *et al* 1993
Lord Leicester's Stables, Kenilworth Castle, Warwicks	6.6	AD 1482–1599	Arnold *et al* 2006
Tusmoore Park, Oxon	6.2	AD 1359–1545	Howard *et al* 1992

Table 3: Results of the cross-matching of site sequence COVBSQ02 and relevant reference chronologies when the first-ring date is AD 1500 and the last-ring date is AD 1558

Reference chronology	*t*-value	Span of chronology	Reference
Wales and West Midlands	5.3	AD 1341–1636	Siebenlist-Kerner 1978
Hill House, Dagger Lane, W Bromwich	7.2	AD 1484–1584	Esling *et al* 1990
Worcs Cath, composite of all samples	5.9	AD 1484–1772	Arnold *et al* 2003
Finchale Priory Barn, Brasside, Durham	5.7	AD 1449–1677	Arnold *et al* 2002
Barn, Abbey Fields, Kenilworth, Warwicks	4.8	AD 1427–1573	Howard 2002 unpubl
Sharpcliffe Hall, Sharpcliffe, Staffs	4.7	AD 1466–1647	Arnold and Howard 2007 unpubl
Meeting House Cottage, Carlton in Lindrick, Notts	4.5	AD 1502–1651	Arnold *et al* 2003 unpubl
5–7 Regent Street, Hinckley, Leics	4.5	AD 1502–1624	Howard 2000 unpubl

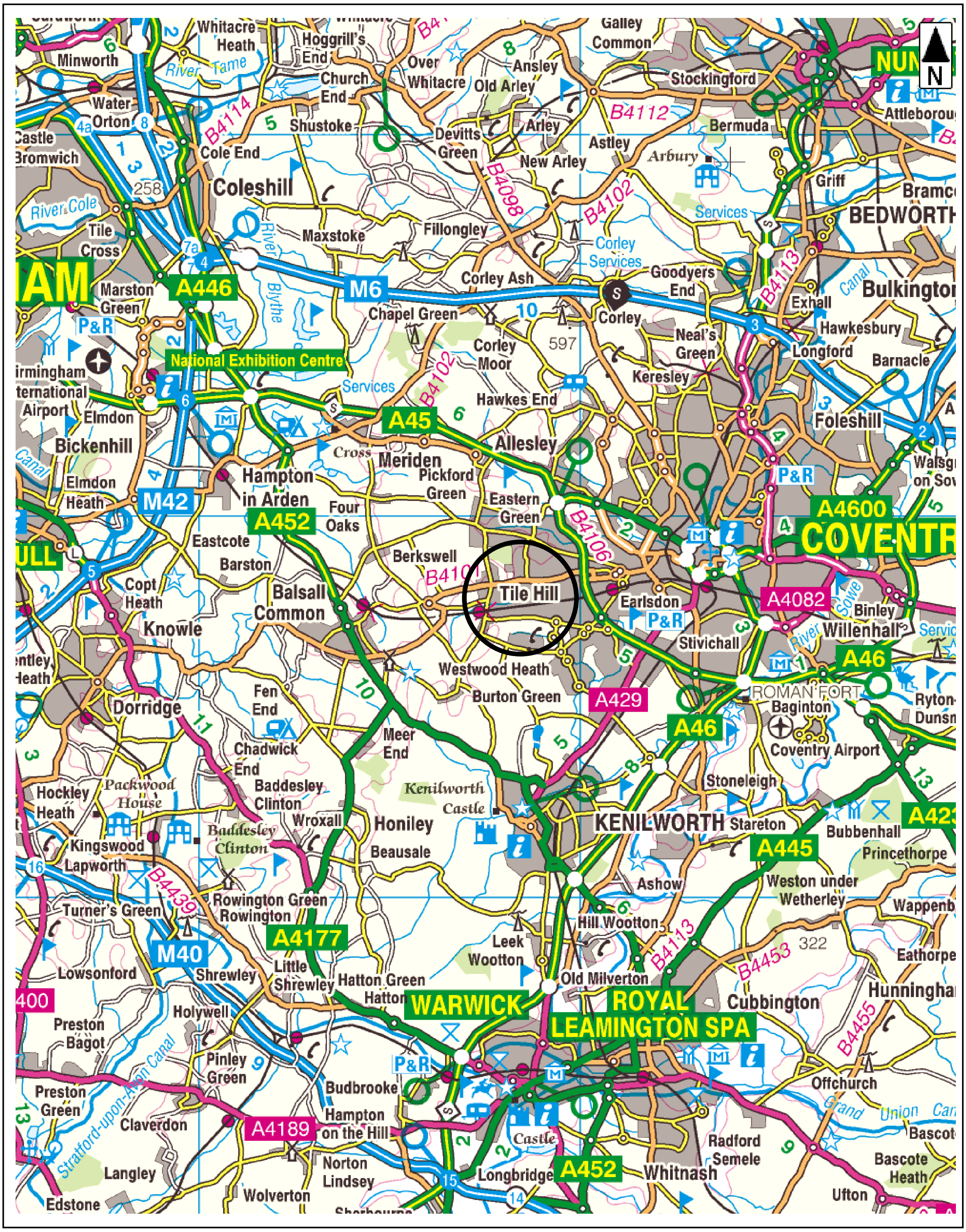

Figure 1: General location of Tile Hill, Coventry

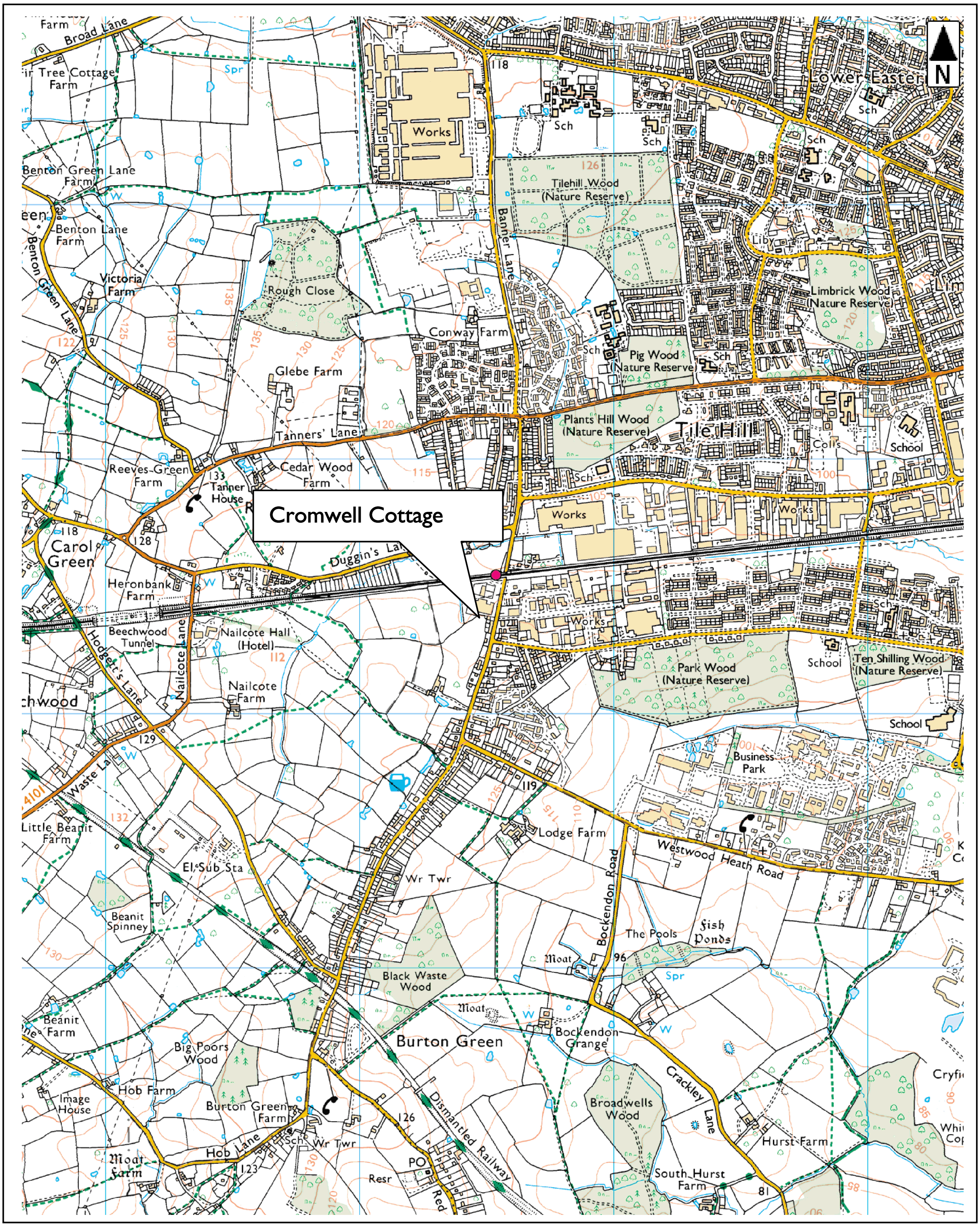

Figure 2: Map to show the general location of Cromwell Cottage

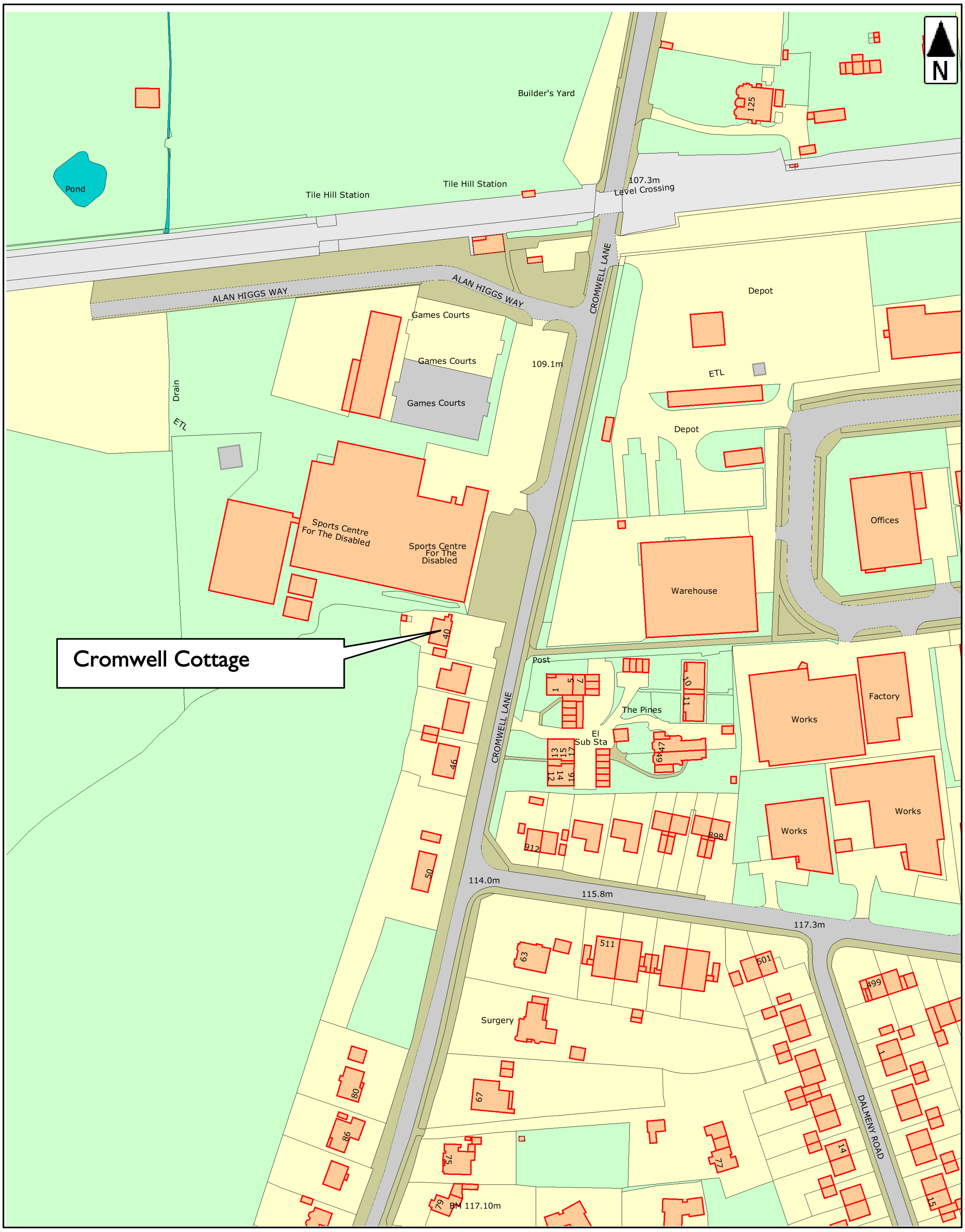

Figure 3: Map to show the location of Cromwell Cottage

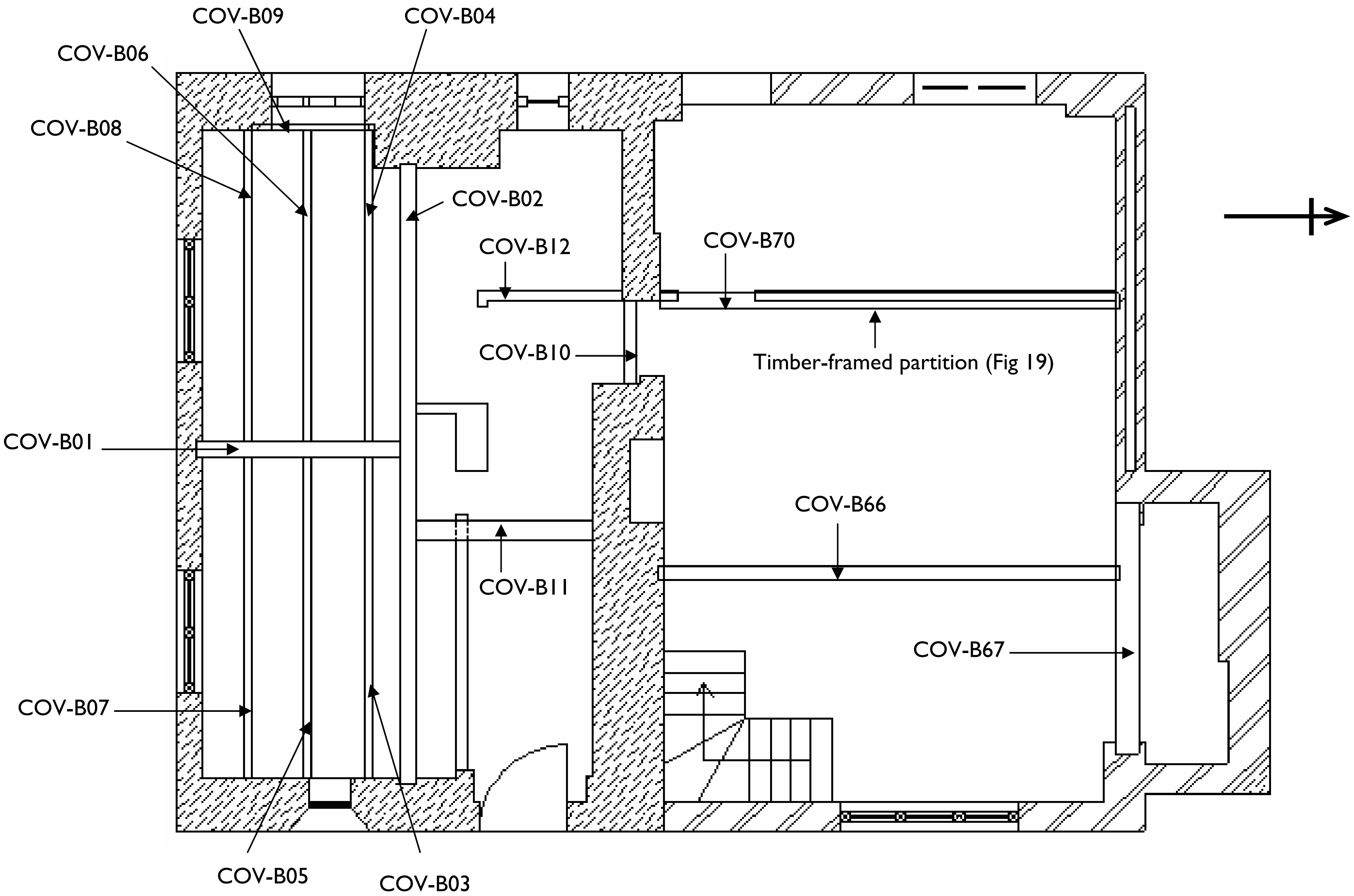

Figure 4: Cromwell Cottage; ground-floor plan, showing the location of samples COV-B01–12 and COV-B66, COV-B67, and COV-B70 (Frank W Haywood & Associates)

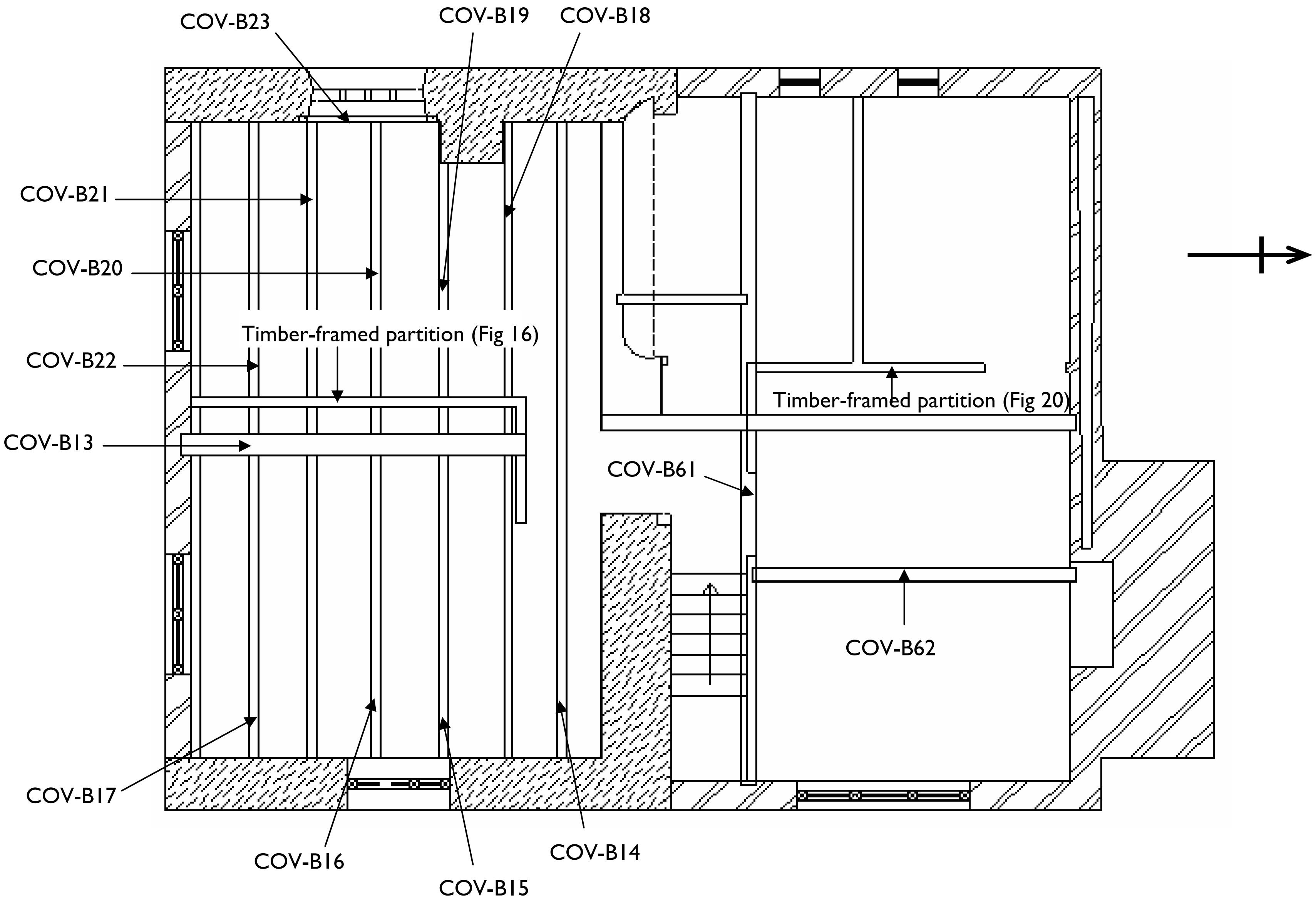

Figure 5: Cromwell Cottage; first-floor plan, showing the location of samples COV-B13–23, COV-B61, and COV-B62 (Frank W Haywood & Associates)

Figure 6: Stone Range, first-floor framing

Figure 7: Stone Range, east roof, south gable truss

Figure 8: Stone Range, west roof (from the north)

Figure 9: Timber-Framed Range, ground-floor framing

Figure 10: Timber-Framed Range, first-floor framing

Figure 11: Timber-Framed Range, west gable

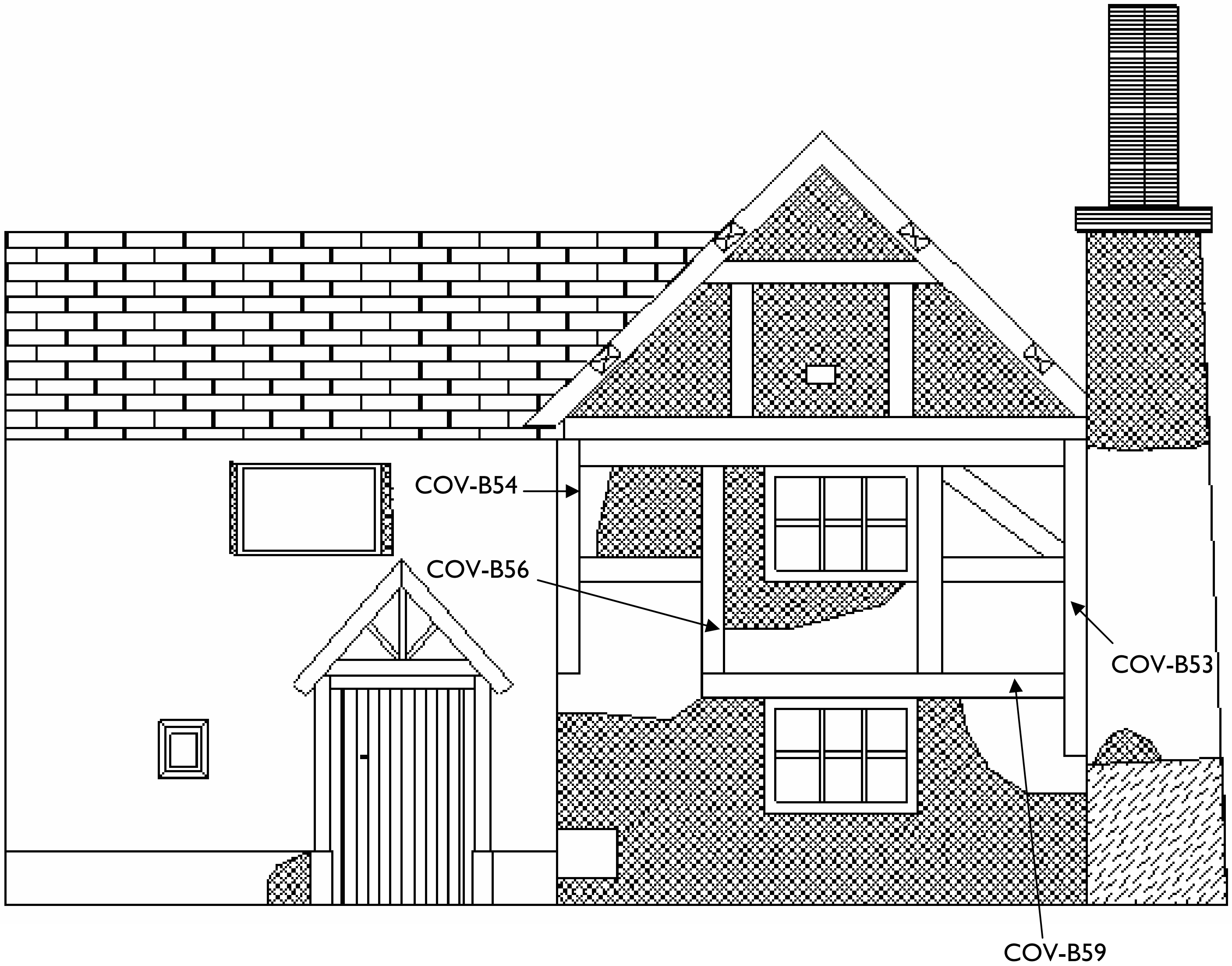

Figure 12: Cromwell Cottage; east elevation, showing the location of samples COV-B53, COV-B54, COV-B56, and COV-B59 (Frank W Haywood & Associates)

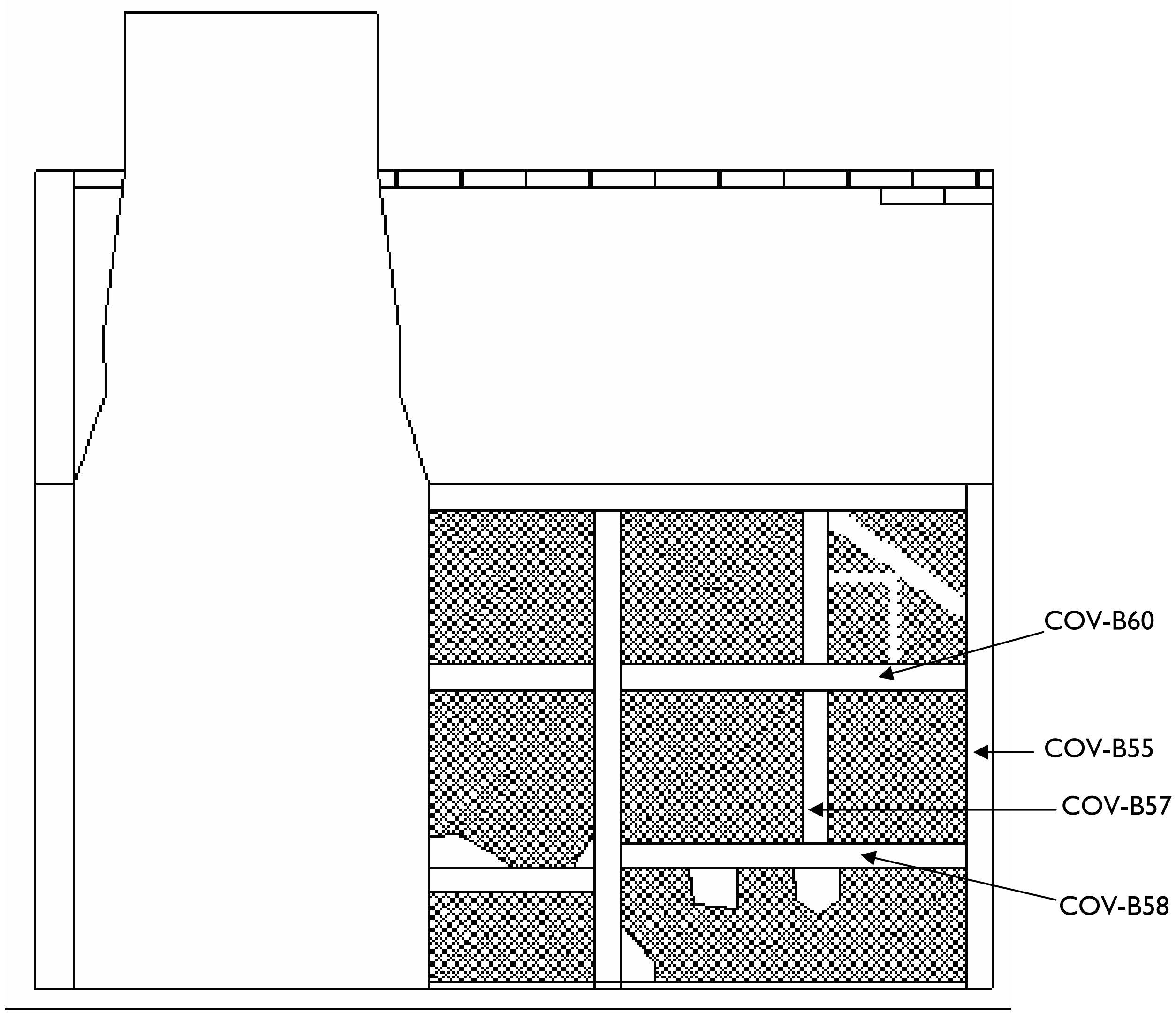

Figure 13: Cromwell Cottage; north elevation, showing the location of samples COV-B55, COV-B57, COV-B58, and COV-B60 (Frank W Haywood & Associates)

Figure 14: Cromwell Cottage, west elevation, showing the location of sample COV-B73 (Frank W Haywood & Associates)

Figure 15: Cromwell Cottage, south elevation (Frank W Haywood & Associates)

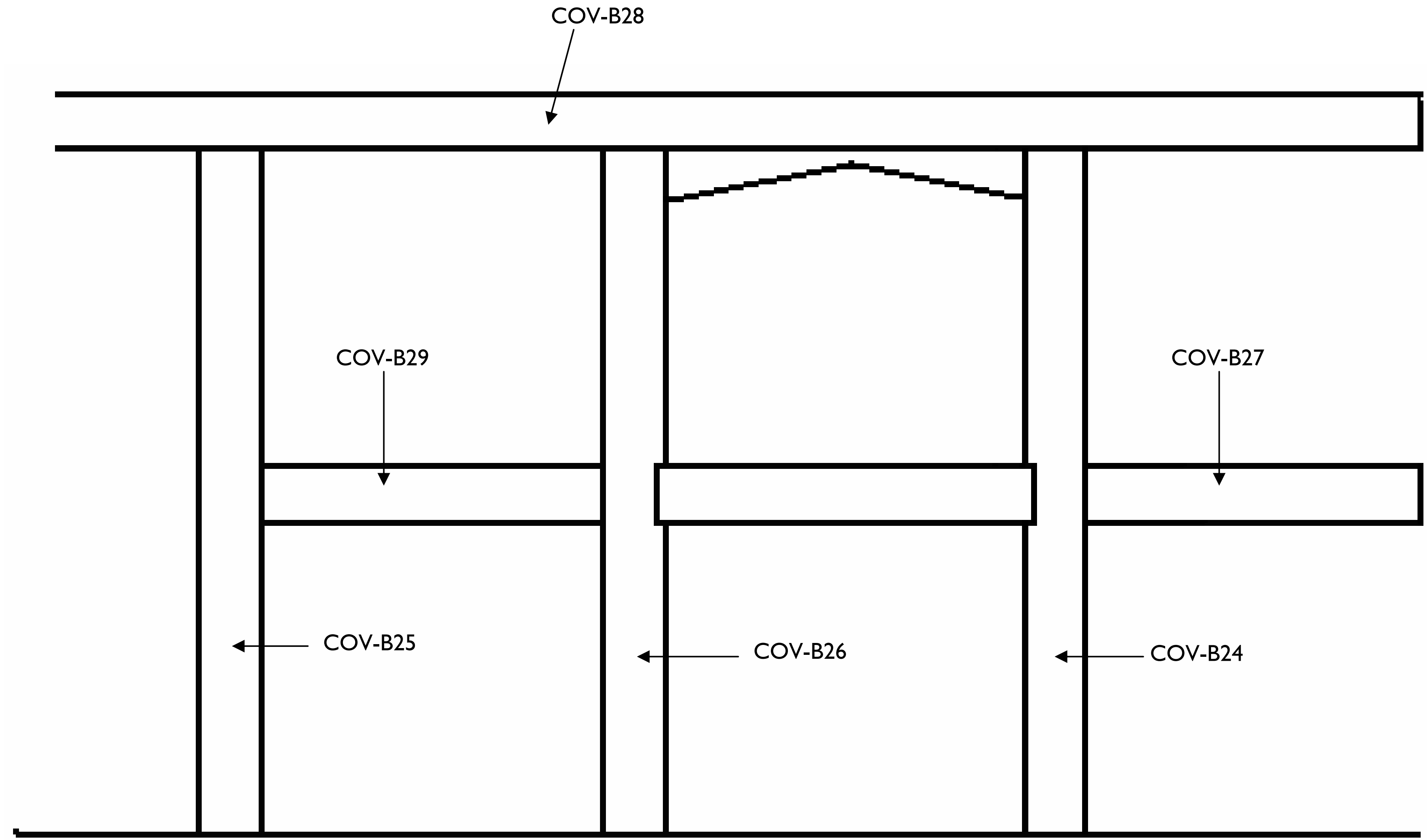

Figure 16: Stone Range, sketch of first-floor timber-framed partition (from the west), showing the location of samples COV-B24–9

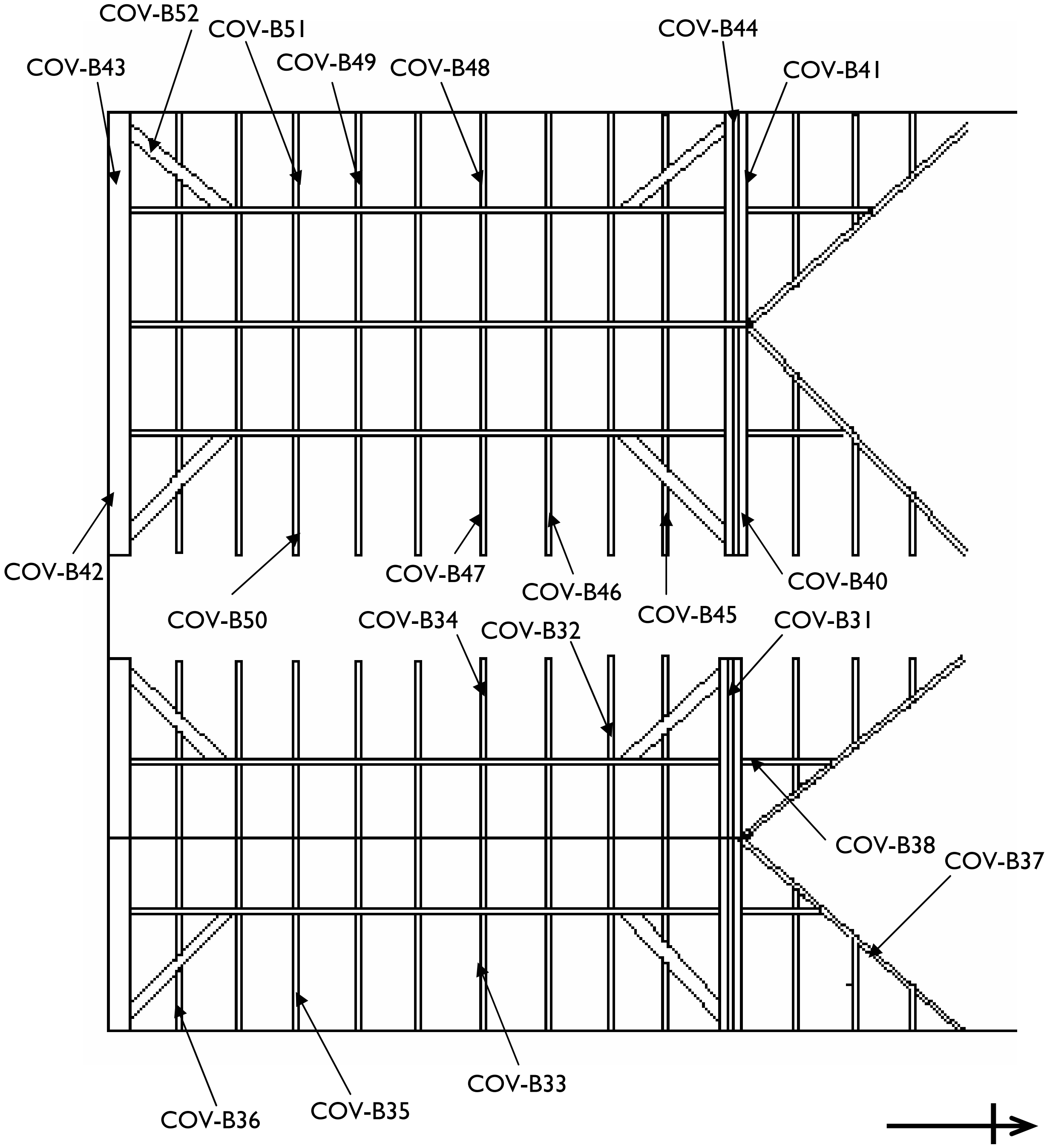

Figure 17: Stone Range; sketch plan of the roof, showing the location of samples COV-B31–8, COV-B40, COV-B42, COV-B45–7, and COV-B50

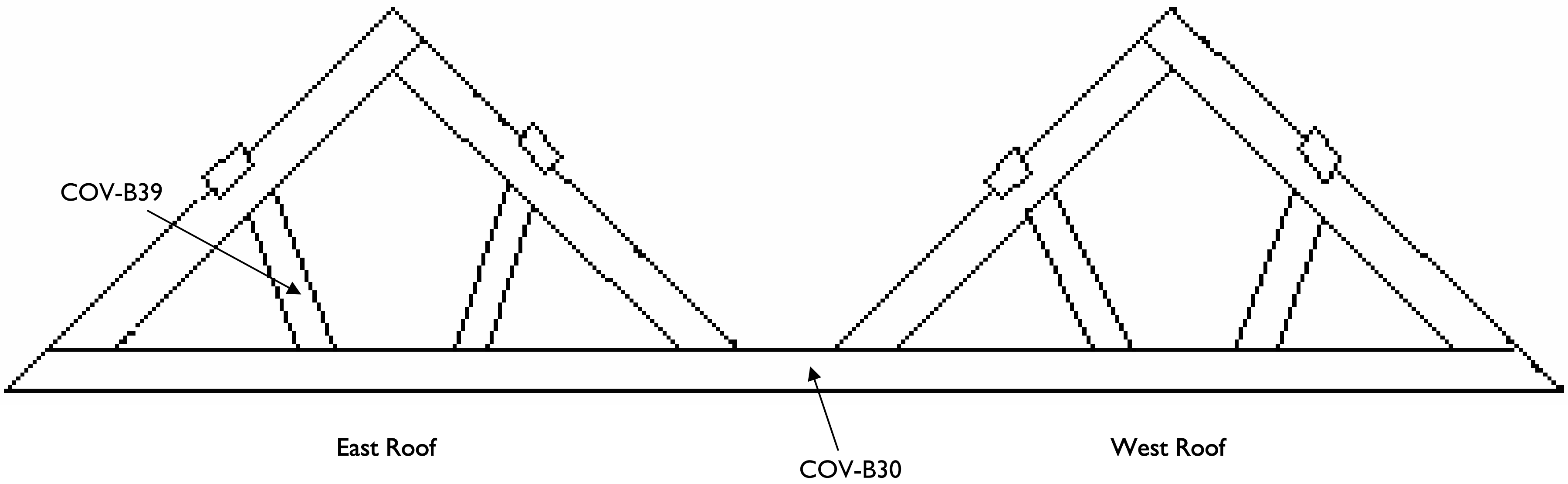

Figure 18: Stone Range, sketch of truss 2 (north face), showing the location of samples COV-B30 and COV-B39

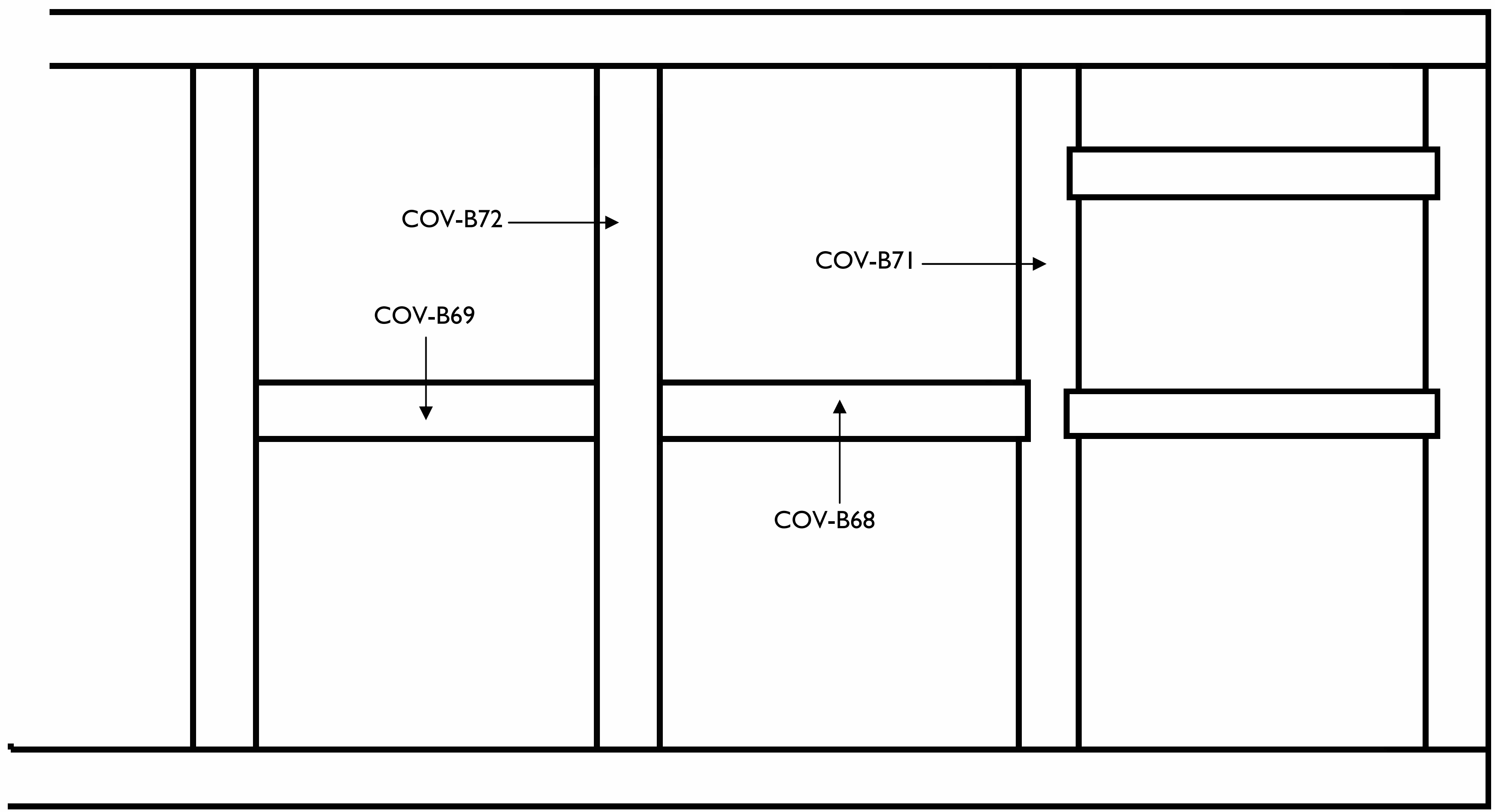

Figure 19: Timber-Framed Range, sketch of ground-floor timber-framed partition (from the east), showing the location of samples COV-B68, COV-B69, COV-B71, and COV-B72

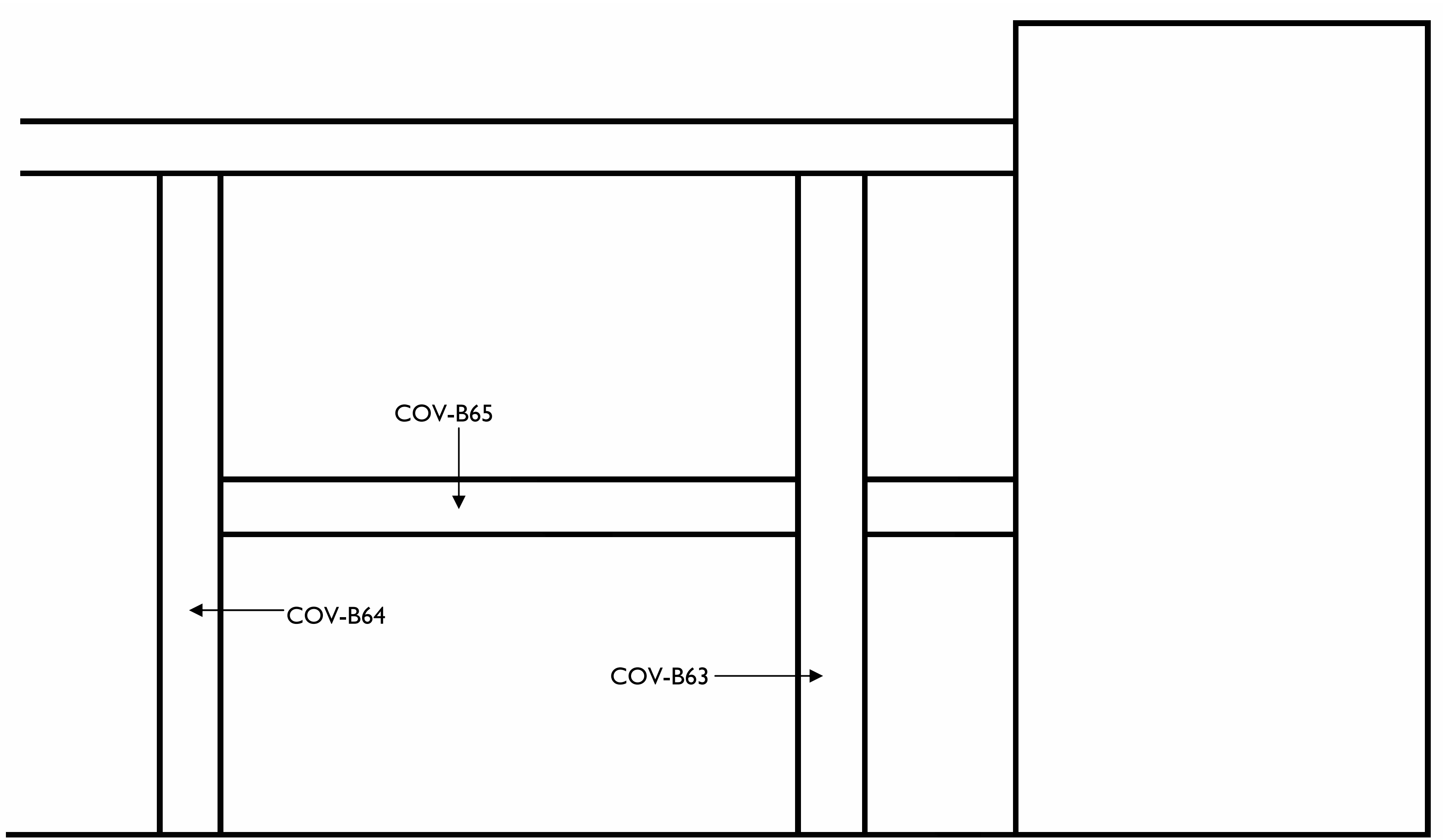

Figure 20: Timber-Framed Range, sketch of first-floor timber-framed partition, showing the location of samples COV-B63–5

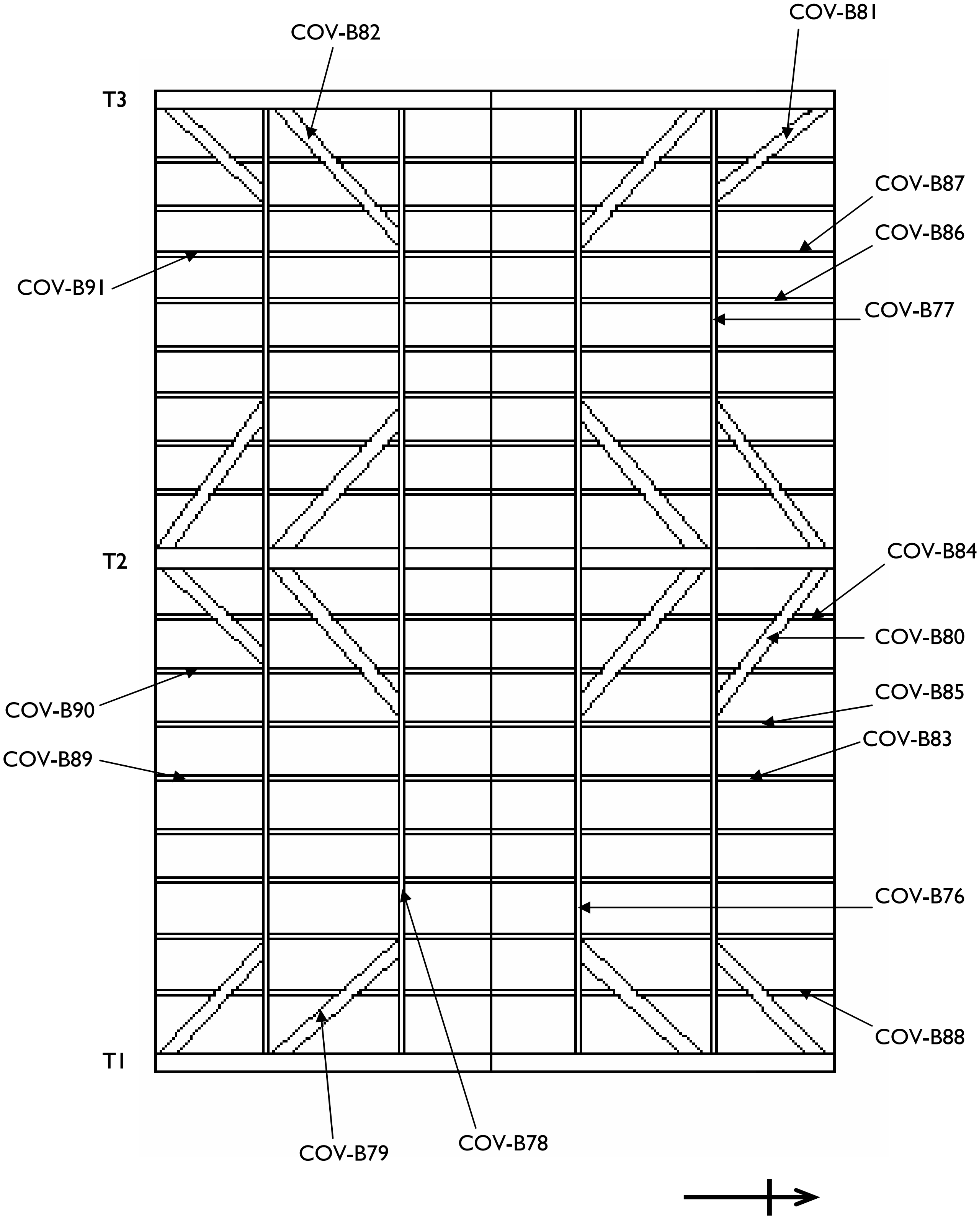

Figure 21: Timber-Framed Range, sketch plan of roof, showing the location of samples COV-B76–91

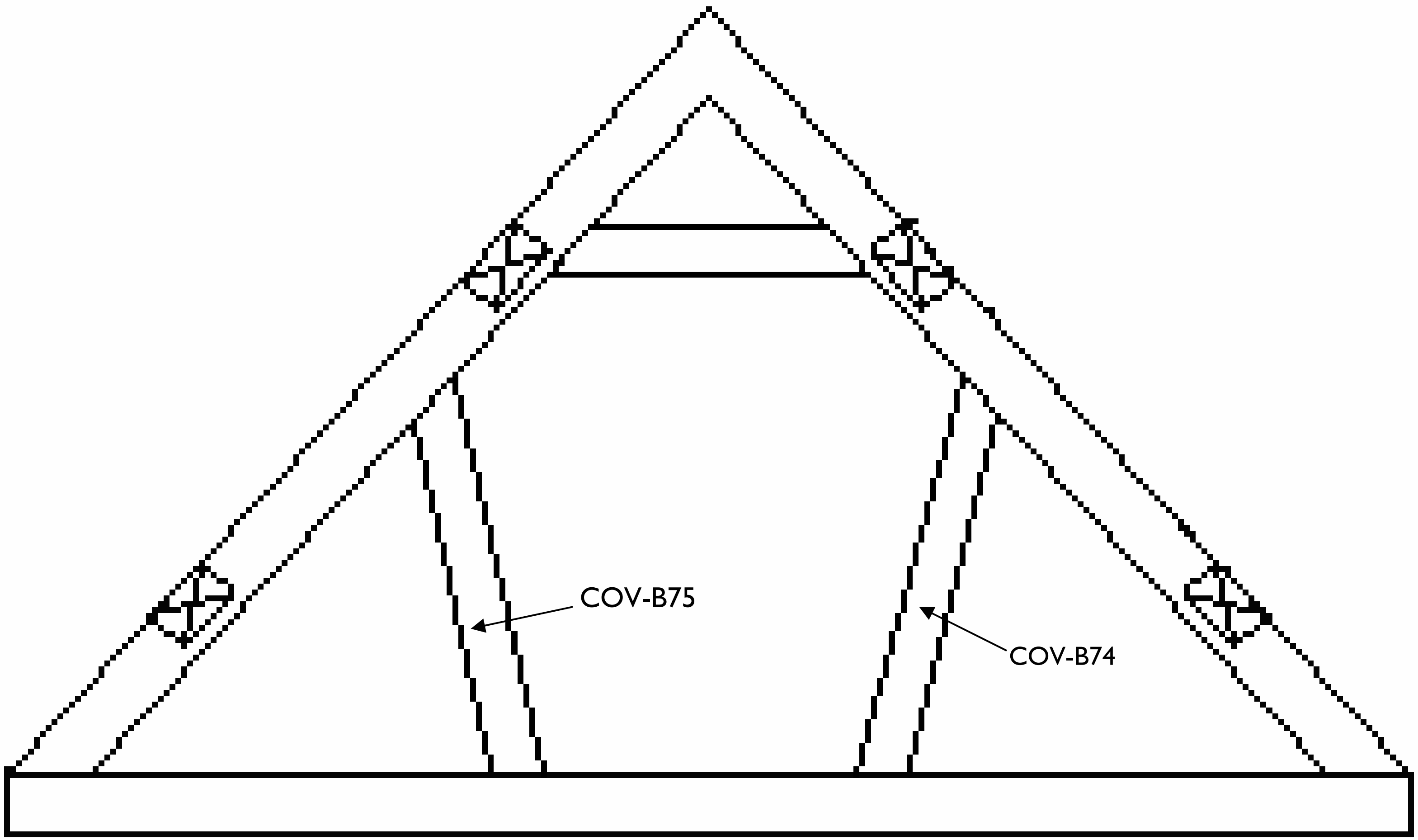

Figure 22: Timber-Framed Range, sketch of truss 2 (east face), showing the location of samples COV-B74 and COV-B75

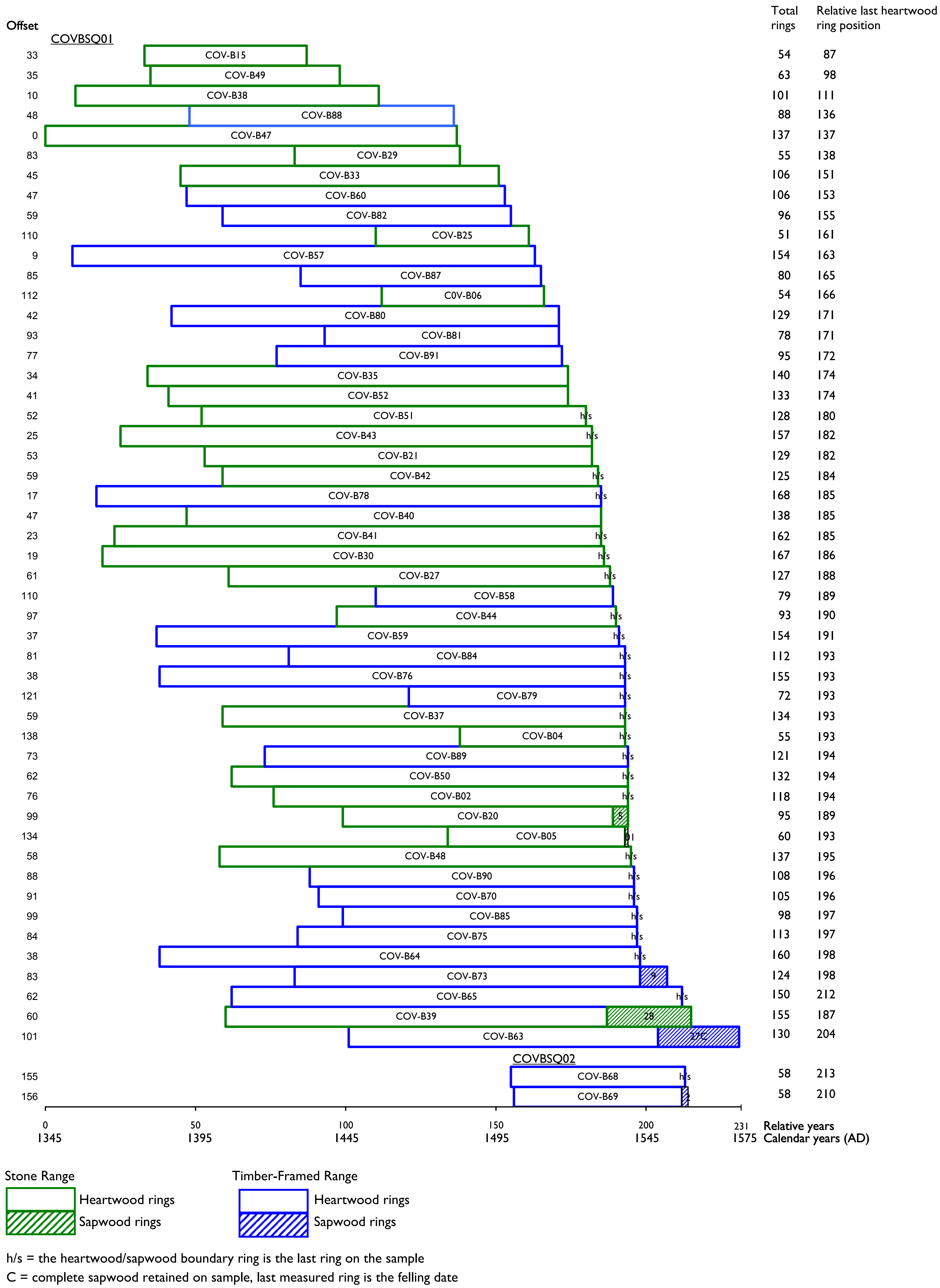

Figure 23: Bar diagram of samples in site sequences COVBSQ01 and COVBSQ02

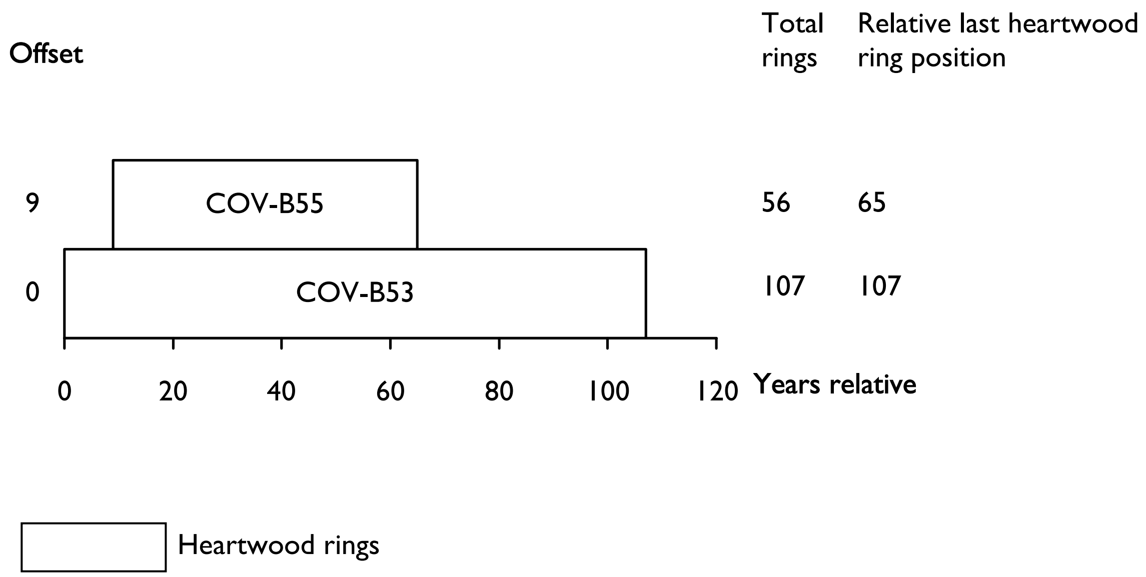

Figure 24: Bar diagram of samples in undated site sequence COVBSQ03

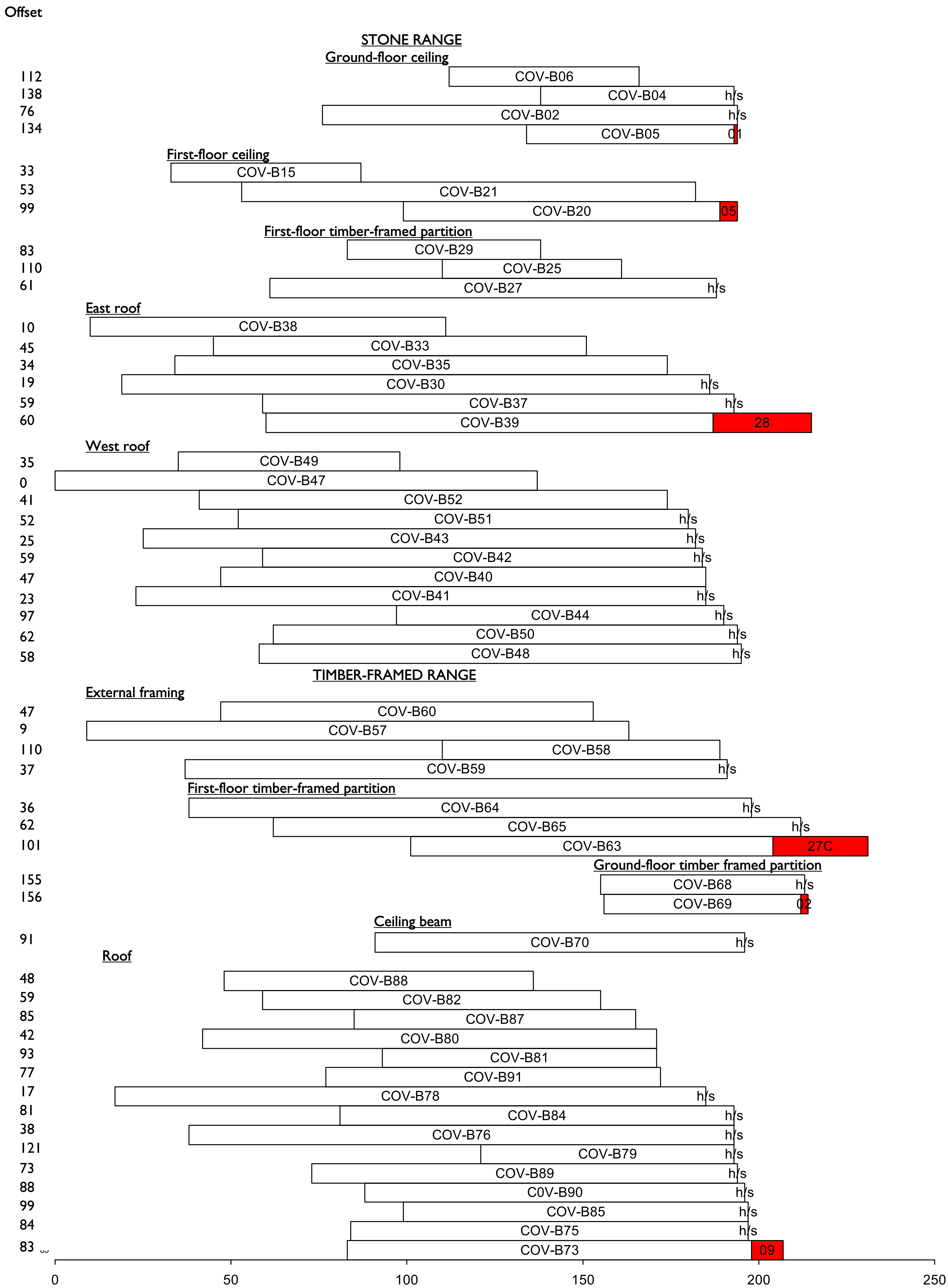

Figure 25: Bar diagram of samples in dated site sequences COVBSQ01 and COVBSQ02, sorted by area

Data of measured samples – measurements in 0.01mm units

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COV-B01A 122
  52  46  63  60 119 108  93  52  88 150 124 163  45  91 136 132 237 426 301 273
 349 293 217 282 335 371 394 359 511 515 393 283 311 377 423 257 302 381 468 354
 491 443 409 259 338 303 474 284 398 440 421 364 513 515 660 750 561 502 557 469
 572 388 327 339 314 219  74  52  36  39  44  57  59 101  81  97 166 191 257 287
 274 271 209 123 279 313 339 349 225 209 208 197 289  74  98  56  68  70  65  85
  83 147 212 176 171 108 174 204 145 270 401 323 315 190 169 216 310 273 259 193
 190 194
COV-B01B 122
  48  51  61  50 107 120  95  62  80 147 130 154  48  92 132 132 243 431 294 270
 354 292 222 271 333 384 394 362 505 519 363 289 303 365 433 257 298 379 467 358
 486 438 411 260 317 322 453 290 389 456 408 385 498 527 647 740 549 510 576 453
 568 397 335 349 310 237  61  64  40  31  37  63  63  96  83  94 170 187 260 285
 273 273 206 123 281 315 341 344 226 213 208 202 284  74  98  62  59  68  72  75
  83 154 209 174 168 106 173 195 148 273 399 305 329 162 195 215 307 284 251 204
 150 205
COV-B02A 118
 118 125 109 119  96  77  79 109 111  88 109  91  80  61  76  47  79  77  61 131
 119 119  86 118 101 116  94  54  76  62 101  96  98  68  94 105 105  96 132 133
 158 122 145 116  50  77  65  78 109  68  89  99  80  64  59  55  52  76  51  78
  85  70  89  51  67  63  57  63  61  92  58  67  57  66  97  79  71  57  57  77
 102  75  90  63  54  64  96  99 144 113 126 149 127  76  63  73  76 132 130 110
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COV-B02B 118
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 124 119  85 120 106 109  97  51  76  65  94 105  90  79  91  98 110 112 120 125
 173 122 146 127  58  85  66  83 107  77  82 111  81  69  51  66  53  85  46  84
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  78 119  67 141  92  90 151 138 127 103 117  95 116 100 144 163 146 136
COV-B03A 55
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 169 200 204 173 122 102 106 184 199 263 208 200 192 196 204 216 251 205 163 218
 193 202 145 139 156 195 142 177 185 175 125 194 139 110 168
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 190 250 302 184 253 353 269 282 238 192 193 287 371 479 170  85  39  52  71  96
 172 177 217 166 116 103 106 168 178 268 221 202 197 192 221 209 261 218 161 204
 184 194 152 126 175 189 143 162 183 177 129 199 130 114 167
COV-B04A 55
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 158 226 219 271 283 198 163 160 196 118  81  83  71  65  97
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 129 163 209 189 206 241 286 242 178 177 269 343 388 440 408 367 339 310 350 502
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 123 163 203 185 206 238 286 236 167 177 256 339 401 437 410 366 360 321 361 493
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 169 184 135 132 210 275 278 300 256 189 134 170 133 146 152 185 176 156 213 176
 161 129 147 184 155 189 174 207 190
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COV-B09B 69
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 153 144 127 152 174 130 146 131  99 100 164 111
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 157 143 128 156 171 122 154 125 100 106 150 107
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 244 253 275 403 346 369 380 318 298 328 264 343 210 144 178 191 166 155 161 145
 138 143 149 168 171 195 155 166 139 167 205 171 123 120 101  99 101 120 171 229
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COV-B12B 78
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 237 287 264 385 355 370 373 320 317 329 268 348 222 148 176 195 175 164 154 153
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 242 166 118  95 100 151 167 174 225 204 217 137  96 134 184 227 201 183
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 261 259 207 204 213 265 200 128 161 155 230 211 220 215 210 174 233 233  79  45
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COV-B15B 54
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 252 266 208 202 212 270 199 130 165 152 234 213 222 210 217 170 230 236  81  47
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  72 108 124 205 149 131 134  87  98 121 132 144 169 186 180 159 158 139 238 192
 173 144  76  63 100 141 162 210 160  86 128 174 149 166 261 188 187 167
COV-B82A 96
 114 136 104 133  91 121 118  68  50  51  69 123  59  57  91  91  91 103  96  94
 102  77  55  54 106  86  55  59  53  39  49  67  53  51  39  57 102  77  78  44
  60  50  42  48  47  57  90  63  55  69  44  49  44  82  58  58  87  77  60  65
  37  64  56  45  89  47  38  86  79  72  39  55  97  59  62  54  68 107  88  76
  37  49  76  80  77  78  91  75  71  81  79  73  91  77  60  65
COV-B82B 96
 126 134 104 132  96 115 105  85  45  47  74 112  65  54  96  82  94 100  98  82
  96  76  64  42  99  82  53  63  52  39  44  71  53  38  48  62 106  77  74  39
  56  50  38  54  33  55  90  59  56  70  38  61  56  62  56  69  76  82  56  68
  37  61  57  57  68  46  39  89  73  71  46  58  95  56  65  57  64  99  93  64
  46  50  72  77  82  66 101  70  72  70  88  72  85  69  62  63
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COV-B84A 112
76 77 87 100 113 100 120 83 70 81 65 72 59 48 79 101 83 114 110 86
72 60 59 48 45 52 47 62 50 67 78 66 64 59 64 63 72 84 61 89
84 97 94 77 69 83 70 83 92 117 102 126 95 91 110 122 101 91 73 75
91 87 80 94 117 64 80 98 124 102 99 107 76 76 74 66 58 79 91 102
108 116 117 132 108 107 126 119 85 78 82 88 104 142 75 75 76 73 63 66
74 74 75 86 55 86 67 78 65 87 96 70
COV-B84B 112
70 73 91 88 114 95 113 89 67 73 74 68 60 45 81 88 84 120 118 83
79 57 60 55 41 46 53 59 51 68 76 70 68 51 68 73 63 93 60 88
79 95 93 81 69 76 82 71 100 118 102 127 86 99 101 114 107 95 79 66
107 78 86 88 121 62 81 91 126 106 94 118 67 84 73 66 56 78 96 95
120 126 102 131 105 109 125 117 79 81 86 75 110 144 75 77 68 75 65 59
84 70 65 86 64 80 75 67 61 103 92 76
COV-B85A 98
96 101 88 77 88 66 74 84 90 93 84 101 110 90 106 88 103 111 93 110
72 92 79 89 63 53 55 59 63 88 88 134 111 122 87 99 107 125 89 89
65 71 93 83 72 90 91 56 73 84 110 85 105 94 64 74 66 57 44 63
75 85 85 110 100 94 108 104 114 92 85 78 86 80 93 131 60 80 66 67
77 66 74 77 82 81 57 78 67 60 68 124 93 69 97 82 99 88
COV-B85B 98
95 108 84 78 83 69 66 85 90 91 88 101 115 91 101 92 104 107 96 115
71 86 86 71 77 53 47 73 53 91 88 138 110 112 99 96 110 124 82 86
69 70 99 73 76 85 103 46 76 91 113 77 111 94 67 68 68 58 39 69
67 81 90 101 98 101 99 108 102 104 84 83 84 78 79 128 63 81 58 72
73 67 76 73 86 80 56 90 64 62 64 123 79 75 95 86 97 95
COV-B87A 80
61 71 101 85 65 78 67 56 65 52 79 104 94 120 133 100 67 90 79 74
83 111 86 101 87 94 121 116 98 95 87 93 81 108 66 85 82 66 87 73
51 79 61 93 110 128 122 111 96 122 105 138 82 99 62 72 74 83 72 101
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COV-B87B 80
87 66 114 80 57 74 58 65 70 48 78 104 92 112 129 87 74 78 94 73
77 101 93 104 79 109 114 112 97 97 97 96 82 103 65 82 80 72 82 92
57 92 54 95 106 121 123 101 102 104 103 140 80 98 61 67 82 82 75 92
100 59 60 80 102 79 105 74 64 60 59 59 45 56 65 76 91 102 92 80
COV-B88A 88
126 98 60 178 186 175 188 132 173 125 171 170 172 157 148 111 145 112 130 75
71 55 102 57 54 86 71 71 109 108 143 85 78 60 49 88 78 83 71 108
66 53 67 57 63 51 43 65 87 83 93 126 69 67 60 63 74 61 65 82
81 66 93 110 98 105 83 114 116 89 105 76 96 106 98 94 60 54 86 75
82 88 94 108 92 85 85 81
COV-B88B 88
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72 49 69 62 54 51 54 66 77 83 95 120 78 62 60 70 63 66 71 72
87 58 104 101 105 107 78 119 103 98 105 74 96 103 100 94 60 50 88 77
75 87 95 112 95 81 92 97
COV-B89A 121
96 82 78 113 109 137 150 110 74 55 91 77 101 93 105 91 71 69 69 61
55 56 84 95 96 113 103 83 74 78 68 73 72 92 88 89 91 92 106 100
97 108 119 108 112 128 76 104 104 97 92 89 54 74 64 81 117 130 127 122
113 115 135 150 117 90 53 57 64 55 62 81 95 45 66 75 80 85 120 98
60 66 74 64 61 77 59 93 86 94 123 138 153 154 166 170 107 104 92 80
113 146 94 67 72 66 59 53 64 69 81 80 57 76 58 51 55 86 82 84
117
COV-B89B 121
88 82 78 110 106 139 147 121 73 50 93 77 105 91 105 87 67 64 68 63
50 62 74 96 100 132 118 71 75 75 70 74 68 86 91 87 99 90 97 106
107 112 117 104 105 134 73 109 96 99 100 85 58 76 61 85 113 126 133 118
123 124 132 145 112 91 49 55 60 64 61 83 85 36 63 81 80 78 126 92
58 57 58 72 55 67 74 91 104 103 106 159 145 146 163 172 108 104 87 71
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98

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COV-B90A 108
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  88  86  84 117 105  94  87 108 105 103 127  83  99 117  97 111  68  59  88  69
  88 120 124 122 124 117 110 115 149  91 117  69  70  65 112  68  93  85  34  67
  71  84  78 110  84  71  49  62  74  76  69  77  56 128 121 145 130 145 123 148
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  72  90 129 128 117 142 113 116
COV-B90B 108
  76  95  72  66  90  58  56  79 119 101 126 177  93  70  75  93  75  86  83  88
  92  82  87 119  96 101  67 128 110  98 131  78 101 120  95 108  69  62  88  60
  91 124 121 119 129 112 117 113 150  94 120  73  71  67  88  67  94  96  38  66
  72  86  69 132  86  60  55  62  65  82  72  69  71 104 116 118 153 134 128 128
 104  93  71 101  80 114 149 115  75  89  88  75  86  90 108  89 126  68 155 108
  72  93 123 121 124 138 119 118
COV-B91A 95
 104 143 128  96  92  69 101  88  99  93 120 111  86  84  70  84  62  55  90 105
  92 108  99 115  65  96  71  85  74  84  76  99  82  99  99  94  95 101 111 117
 104 110  81  94 105  87 105  86  57  67  68  86 104 107 100 109  99 104  99 113
  61  89  52  66  84  73  61  70  99  40  65  86  93  79  95  80  51  73  63  48
  30  59  67  62  77  90  81  88  97  88 110  91  73  67  92
COV-B91B 95
  98 140 128 102  84  73  96  99  93 104 122 101  97  73  73  85  61  62  82 101
  89 112  94 118  71  91  85  74  76  83  78  99  80  97 103  89 103  92 116 120
 106 118  68 104  97  95  99  88  52  71  67  84 107 104 100 119  88 105 103 112
  66  81  64  58  86  67  55  82  93  45  59  86  91  76  95  84  51  76  56  50
  32  58  65  68  72 102  80  88  87  94 106  97  67  78  84
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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 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 8–10 samples per phase are usually taken. Sometimes we take many more, especially if the construction is complicated. One reason for taking so many samples is that, in general, some will fail to give a date. There may be many reasons why a particular sequence of ring widths from a sample of timber fails to give a date even though others from the same building do. For example, a particular tree may have grown in an odd ecological niche, so odd indeed that the widths of its rings were determined by factors other than the local climate! In such circumstances it will be impossible to date a timber from this tree using the master sequence whose widths, we can assume, were predominantly determined by the local climate at the time.

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

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

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

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

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

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

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

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

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

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

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

   The straightforward method of cross-matching several sample sequences with each other one at a time is called the 'maximal *t*-value' method. The actual method of cross-matching a group of sequences of ring-widths used in the Laboratory involves grouping and averaging the ring-width sequences and is called the 'Litton-Zainodin Grouping Procedure'. It is a modification of the 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 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 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 2 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 2cm, 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 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 Figure 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 Figure 7. Here ring-widths are plotted vertically, one for each year of growth. In the upper sequence of (a), the generally large early growth after 1810 is very apparent as is the smaller later growth from about 1900 onwards when the tree is maturing. A similar phenomenon can be observed in the lower sequence of (a) starting in 1835. In both the widths are also changing rapidly from year to year. The peaks are the wide rings and the troughs are the narrow rings corresponding to good and poor growing seasons, respectively. The two corresponding sequence of Baillie-Pilcher indices are plotted in (b) where the differences in the immature and mature growths have been removed and only the rapidly changing peaks and troughs remain, that are associated with the common climatic signal. This makes cross-matching easier.

t-value/offset Matrix

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

Bar Diagram

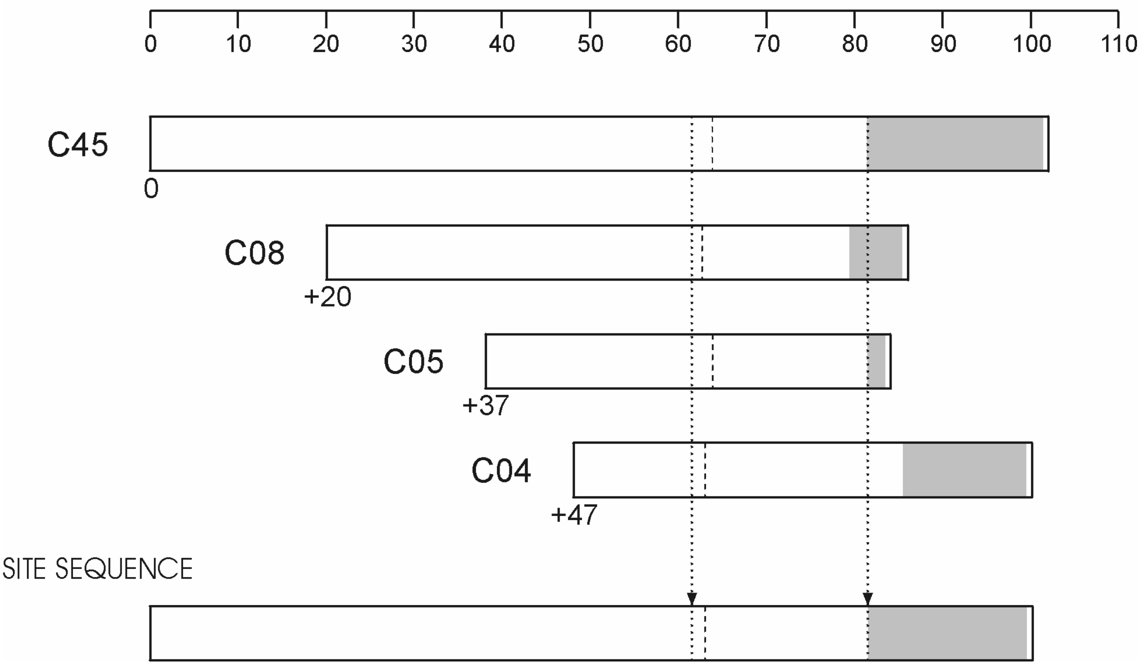


Figure 5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them.

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

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

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

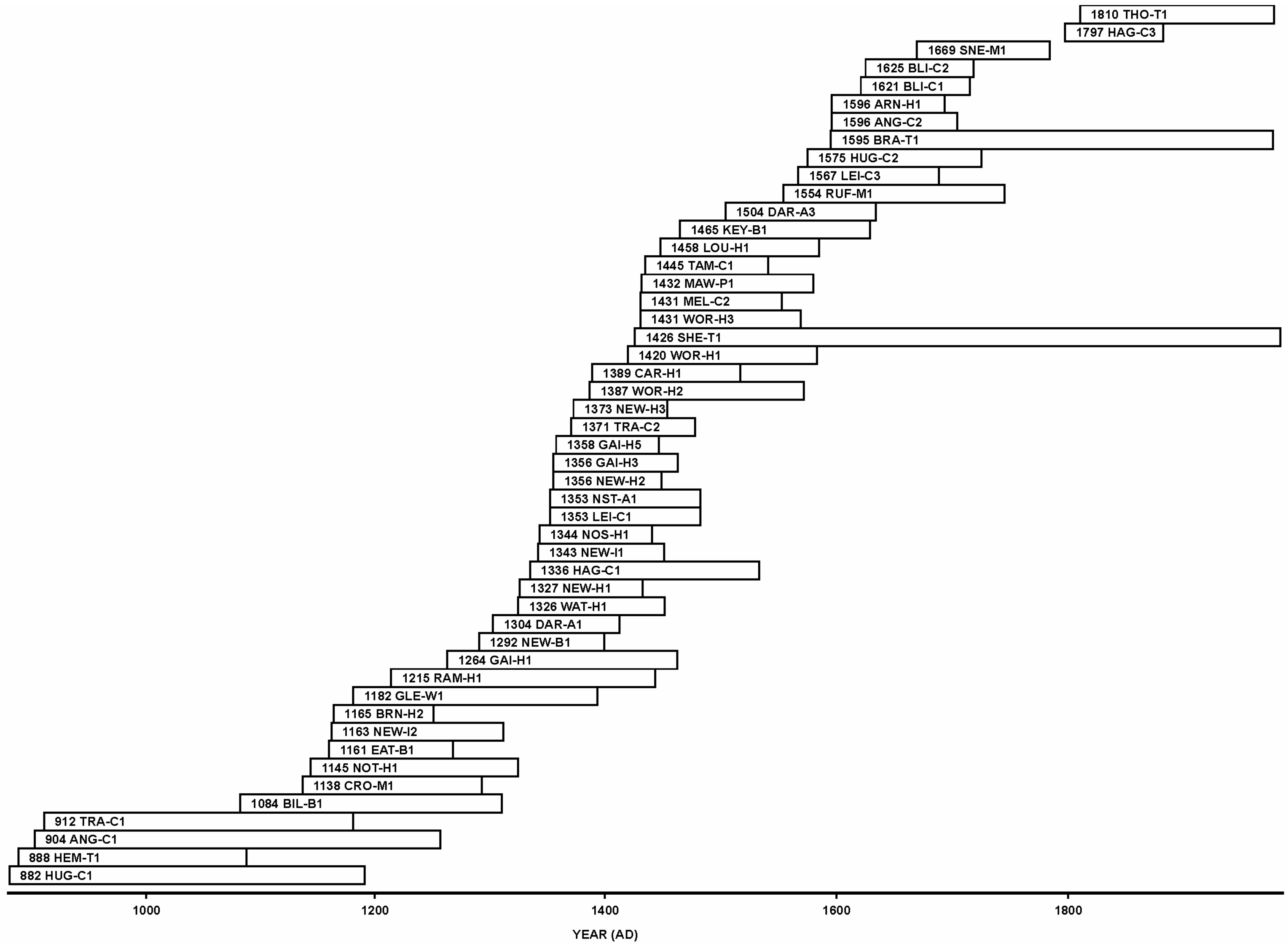
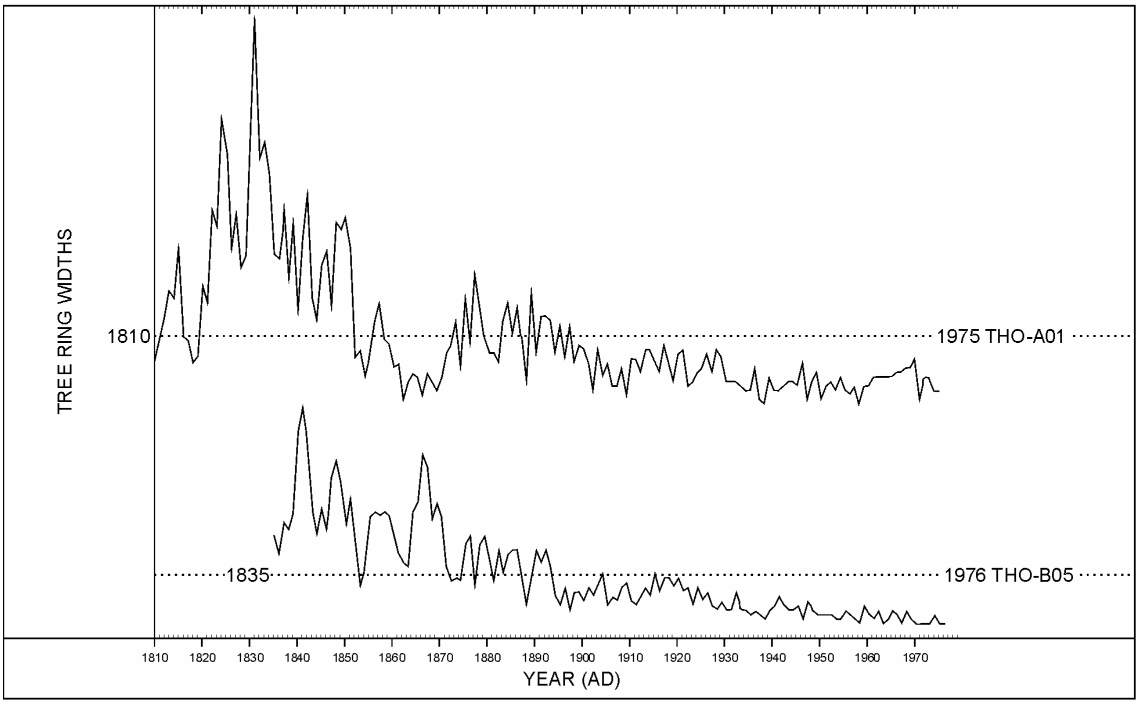


Figure 6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

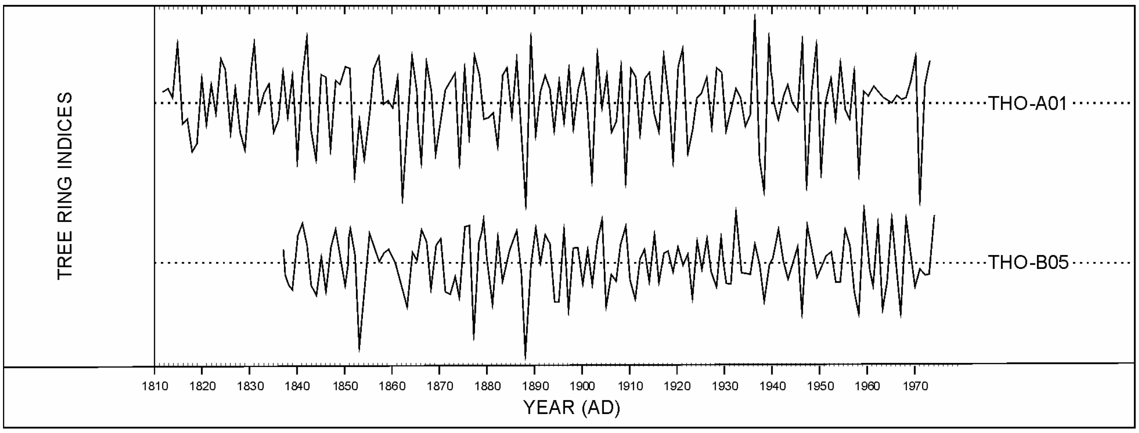


Figure 7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known. Here the ring widths are plotted vertically, one for each year, so that peaks represent wide rings and troughs narrow ones. Notice the growth-trends in each; on average the earlier rings of the young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

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

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