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CANONS GARTH, HELMSLEY, NORTH YORKSHIRE
TREE-RING ANALYSIS OF TIMBERS

SCIENTIFIC DATING REPORT

Alison Arnold and Robert Howard

INTERVENTION
AND ANALYSIS

ENGLISH HERITAGE

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SUMMARY

Analysis of 60 of the 65 samples taken from various parts of this building has resulted in the construction and dating of two site sequences. Site sequence HELMSQ01 contains 11 samples and spans the period AD 1198–1283 whilst HELMSQ02 contains 42 samples and spans the period AD 1381–1668.

The earliest group of timbers identified were those used in the construction of the roof of the hall house, felled in AD 1283. The inserted first-floor frame in this part of the building contains timbers felled in AD 1622–39, and at least two potentially reused joists felled in AD 1546–71. The roof of the south-west wing utilises timber felled in AD 1551–71. The roof over the west wing is constructed from timber felled in AD 1622, whilst the first-floor frame in this part of the house utilises timber felled in AD 1614–39 and AD 1668. Also, located in this wing is a ground-floor fireplace bresummer felled in AD 1629 and a series of floorboards on the first floor with *terminus post quem* felling dates ranging from AD 1535 to AD 1577. A fireplace bresummer in the chapel dates to AD 1510–35 but is thought to be reused.

CONTRIBUTORS

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INTRODUCTION

The Grade II* listed Canons Garth lies just to the north-east of Helmsley Church, in the Ryedale district of North Yorkshire (Figs 1–3). At the core of the extant building is the original hall house, thought to have been of base-cruck construction, possibly with a cross-passageway in the western bay (Ryder 2012). To the west of this is a north-south orientated cross-wing which projects slightly to the north of the hall. This wing is believed to have contained the kitchen at ground-floor level. To the south are two projecting wings with the porch between. To the east of the hall is a short wing which houses a chapel on the ground floor (Fig 4).

Hall house

Roof

There are two surviving crown-post roof trusses over this part of the building. These trusses consist of two parallel 'tiebeams', principal rafters, crown post, passing braces, struts, and collars. Between these are common rafters, collars (with bracing between), and collar purlin (Fig 5). This roof is thought to represent one of the earliest surviving roof structures in the north of England and is believed to date to *c* AD 1300.

Smokehood

At first-floor level on the east side, is a very large chimney stack of squared limestone and a hearth with chamfered stone jambs, spanned by a heavy timber bresummer, cut into a flat arch. There are nine stud posts attached to the top of this bresummer (Fig 6). This structure is believed to be sixteenth century in date.

First-floor frame

The hall house is thought to have been floored at both first- and attic-floor level in the seventeenth century. Although the exposed attic floor appears to have been replaced, the exposed first-floor structure is historic, consisting of a single large, spine beam with simple stopped chamfers and smaller, squared common joists morticed in to either side (Fig 7). These joists may be reused. The main beam can be seen to interrupt one of the studs of the smokehood (Fig 6).

West wing

Roof

The stripping out of cupboards and partitions has exposed two trusses of this roof. The northernmost truss (truss 1) was obviously a closed truss as evidenced by the struts between crown post and principal rafters (Fig 8). There are purlins running between these trusses. Truss 2 does not have the struts and so was always an open truss. A third truss can be seen in the south gable wall. This roof is thought to be a sixteenth-century re-roofing.

First-floor frame

The first-floor frame consists of a chamfered north-south spine beam and a series of common joists. It can be seen that the timbers of this floor frame and the underside of the boards were coated with red ochre (Fig 9). The main beam has an empty mortice at its north end.

Floorboards

At first-floor level a large number of wide, oak boards of late-medieval or sub-medieval character survive (Fig 10). These are laid north-south and supported by the floor frame below.

Bresummer

To the north of the west wing at ground-floor level is a large fireplace which has a large timber lintel supported on timber posts, the eastern one of which looks relatively modern (Fig 11).

South-west wing

Roof

This wing is slightly lower and has three trusses, two to the gable ends and one visible in a first-floor bedroom. This middle truss consists of principal rafters, tiebeam, and post to the east side (Fig 12); a further truss can be seen in the south gable end. There is a single tier of purlins to each side. This wing is thought to be sixteenth century in date.

First-floor frame

A single east-west main floor beam is visible at ground-floor level (Fig 13)

Chapel

There is an old fireplace with chamfered jambs to the west wall of this room. Set into this are two lintels; the one to the back has possibly been reset as it has a large chamfer and concave stops towards the stack (Fig 14). The bedroom directly above the chapel also has a fireplace with chamfered stone jambs and a roughly cambered and chamfered lintel (Fig 15).

SAMPLING

Tree-ring dating was requested by Diane Green, English Heritage Inspector of Historic Buildings and Areas, to inform listed building consent and to better understand the chronological development and relationship between the various elements within this important building.

A total of 59 core samples were taken from timbers of the hall house, west wing, south-west wing, and chapel; the ring width sequences of six floorboards were directly measured using a graticule. Each sample was given the code HEL-M and numbered 1–65. The location of all samples was noted at the time of sampling and has been marked on Figures 16–24. Further details relating to the samples can be found in Table 1.

The stopped and chamfered doorframe of the porch was also of interest with respect to the overall development of the building. However, this was found to be wide ringed and of small scantling and, therefore, unsuitable for tree-ring dating.

ANALYSIS AND RESULTS

Five samples, four from the hall house (HEL-M12, HEL-M14, HEL-M24, and HEL-M25), and one from the south-west wing (HEL-M57) had too few rings for secure dating and so were rejected prior to measurement. The remaining 54 core samples were prepared by sanding and polishing and their growth-ring width measured. The data of these measurements, and those from the six floorboards, are given at the end of the report. All samples were then compared with each other by the Litton/Zainodin grouping programme (see Appendix).

Firstly, 11 samples taken from the hall house roof matched each other and were combined at the relevant offset positions to form HELMSQ01, a site sequence of 86 rings (Fig 25). This site sequence was compared against a series of relevant reference chronologies for oak where it was found to span the period AD 1198–1283. The evidence for this dating is given by the *t*-values in Table 2.

Forty-two samples, taken from all parts of the building, also grouped and these were combined at the relevant offset positions to form HELMSQ02, a site sequence of 288 rings (Fig 26). This site sequence was found to match consistently and securely at a first-ring date of AD 1381 and a last-measured ring date of AD 1668. Evidence for this dating is given by the *t*-values in Table 3.

Attempts to date the remaining ungrouped samples were unsuccessful and all remain undated.

INTERPRETATION

To aid interpretation the dated timbers from each area have been illustrated separately (Fig 27).

Hall house

Roof

Eleven of the samples taken from the roof over this part of the building have been successfully dated. Five of the dated samples have complete sapwood and the last-measured ring date of AD 1283, the felling date of the timbers represented. The other six dated roof samples from the hall house all have the heartwood/sapwood boundary ring, which in all cases is broadly contemporary and suggestive of a single felling. The average heartwood/sapwood boundary ring date is AD 1263, allowing an estimated felling date to be calculated for the six timbers represented of AD 1283–1303 (taking into account sample HEL-M07 having a last-measured ring date of AD 1282 with incomplete sapwood), consistent with these timbers also having been felled in AD 1283. Further supporting the suggestion of all timbers having been felled at the same time is the good level of matching seen between samples from this structure, with all grouping together at a value of *t*=5.0.

First-floor frame

Eight samples taken from first-floor ceiling joists have been successfully dated. Three of these have the heartwood/sapwood boundary ring, the dates of which suggest two separate fellings. Sample HEL-M15 has the earlier heartwood/sapwood boundary ring date of AD 1531 which allows an estimated felling date to be calculated for the timber represented to within the range AD 1546–71. Two other samples (HEL-M16 and HEL-M20) have later, similar heartwood/sapwood boundary ring dates, the average of which is AD 1599, giving an estimated felling date for the two timbers represented of AD 1622–39. This allows for sample HEL-M20 having the last-measured ring date of AD 1621 with incomplete sapwood.

Of the remaining five dated samples without the heartwood/sapwood boundary it can be seen that sample HEL-M17 matches HEL-M15 at the high value of *t*=12.1, a value which suggests both timbers were cut from the same tree and hence have the same felling (AD 1546–71).

With a last-measured heartwood ring date of AD 1544 it is possible that HEL-M19 was also felled in AD 1546–71 but this sample can be seen to match sample HEL-M21 at *t*=11.0, again a value high enough to suggest the same tree. With a last-measured heartwood ring date of AD 1586, HEL-M21 cannot have been felled in AD 1546–71 but could have been felled in AD 1622–39. The other two samples, HEL-M18 and HEL-M22, have last-measured heartwood ring dates which allow *terminus post quem* fellings to be calculated for them of AD 1566 and AD 1574 respectively, and, therefore, it possible that both of these timbers were also felled in AD 1622–39.

West wing

Roof

Fourteen of the samples taken from the roof of the West wing have been successfully dated. Two of these, HEL-M13 and HEL-M33, have complete sapwood and the last-measured ring date of AD 1622, the felling date of the timbers represented. Sample HEL-M37 matches sample HEL-M33 at the high value of *t*=14.0, with both beams almost certainly being cut from the same tree and hence having the same felling (AD 1622). Four other dated roof timbers have the heartwood/sapwood boundary ring date which is broadly contemporary and suggestive of a single felling. The average of these dates is AD 1594, allowing an estimated felling date to be calculated for the five timbers represented to within the range AD 1609–34, consistent with these timbers also having been felled in AD 1622. There are seven dated roof timbers without the heartwood/sapwood boundary ring dates, but with last-measured ring dates which range from AD 1512 (HEL-M35) to AD 1553 (HEL-M27). All seven of these could also have been felled in AD 1622. The overall good level of crossmatching seen between the samples from this roof adds further weight to the suggestion that all timbers were felled at the same time.

First-floor frame

Six of these beams have been dated. Sample HEL-M39, taken from the spine beam has complete sapwood and the last-measured ring date of AD 1668, the felling date of the timber represented. Sample HEL-M41, from a joist, has the heartwood/sapwood boundary ring date of AD 1599, allowing an estimated felling date to be calculated for the timber represented to within the range AD 1614–39.

Four other joist samples, without the heartwood/sapwood boundary ring date have last-measured ring dates ranging from AD 1529 (HEL-M43) to AD 1593 (HEL-M40) which means that the timbers represented could have been felled in either AD 1614–39, AD 1668, or represent a completely separate felling date. It can be seen that three of these samples (HEL-M42, HEL-M43, and HEL-M45) match well with samples taken from the west wing roof, felled in AD 1622, a date encompassed by the AD 1614–39 felling calculated for HEL-M41.

Floorboards

The growth patterns of five of the floorboards were successfully dated. None of these boards had the heartwood/sapwood boundary ring but have *terminus post quem* felling dates ranging from AD1535 (HEL-M49) to AD 1577 (HEL-M52). Samples HEL-M48 and HEL-M49 match each other at the high value of *t*=13.8 and are likely to have been cut from the same tree.

Bressumer

The sample taken from this timber has complete sapwood and the last-measured ring date of AD 1629, the felling date of the timber represented.

South-west wing

Roof

Seven of the samples taken from the timbers of the roof over this part of the building have been dated. Five of these samples have the heartwood/sapwood boundary ring, which is broadly contemporary and suggestive of a single felling. The average heartwood/sapwood boundary ring date is AD 1531, allowing an estimated felling date to be calculated for the five timbers represented to within the range AD 1551–71. This allows for sample HEL-M58 having the last-measured ring date of AD 1550 with incomplete sapwood.

The other two samples, without the heartwood/sapwood boundary ring date, have last-measured ring dates of AD 1470 (HEL-M54) and AD 1485 (HEL-M56), which makes it possible that they were also felled in AD 1551–71. Furthermore, one of these (HEL-M56) matches sample HEL-M55 (felled AD 1551–71) at the high value of *t*=9.1, adding weight to the suggestion that they were felled at the same time.

Chapel

Only one of the samples taken from the fireplace bresummers in the Chapel has been successfully dated. Sample HEL-M64, taken from the inner bresummer of the ground-floor fireplace has a last-measured ring date of AD 1495. The heartwood/sapwood boundary is the last ring on the sample giving an estimated felling date range for the timber represented to within the range AD 1510–35.

Felling date ranges have been calculated using the estimate that mature oak trees in this region have 15–40 sapwood rings.

DISCUSSION

The earliest timber identified by the tree-ring dating was that used in the hall house roof. The dendrochronological dating has shown that the timber utilised was felled in AD 1283, with construction likely to have occurred shortly after. This roof was thought to date to *c* AD 1300 and this has now been confirmed, furthermore, the date gained puts it firmly in the thirteenth century.

It had been suggested that the first- and attic-floor frames of the hall house were inserted in the seventeenth century. It had also been suggested that some of the common joists had possibly been reused (Ryder 2012). The majority of the dated joists from the first-floor frame have been dated AD 1622–39, however, at least two of the common joists are earlier, dating to AD 1546–71. These dates suggest the insertion of the first-floor frame in the first-half of the seventeenth century utilising some sixteenth-century timbers.

It is unfortunate that of those timbers associated with the smokehood, only the bresummer was found to be suitable for measurement and that this sample is undated. This feature was thought, on stylistic grounds, to be sixteenth century in date and at present this is the only dating evidence available. However, as noted in the introduction, one of the beams associated with the floor frame 'cuts' the smokehood meaning that the smokehood has to be earlier than the floor, now known to be constructed with timber felled in AD 1622–39.

Some of the walling of the west wing suggests that this part of the building is early, however, the present roof was thought to be a sixteenth-century re-roofing. The tree-ring dating has now demonstrated the roof is constructed from timber felled in AD 1622, therefore, putting construction in the early seventeenth century, somewhat later than previously believed. This roof may belong to the same programme of work as the insertion of the hall house first-floor frame (AD 1622–39).

Timbers have also been dated from the first-floor frame in the west wing. The main beam is now known to have been felled in AD 1668; however, a number of the joists are earlier, dating to AD 1614–39. It is usually assumed that main beams of floor frames are 'safer' in terms of interpretation due to the difficulty in replacing these large timbers. On these grounds, the dates would suggest the floor dates to AD 1668, but reuses timber of AD 1614–39. The other explanation would be that the floor dates to AD 1614–39 but was modified or repaired in AD 1668 when the main beam was replaced. It may be significant that only joists to the west of the main beam were suitable for tree-ring dating with the joists to the east of the main beam all being found to be unsuitable. A closer inspection of this floor by a buildings archaeologist may clarify the situation.

Potentially providing further support for this latter interpretation, the ground-floor fireplace bresummer in this wing was felled in AD 1629, and can therefore be seen to be broadly contemporary with the joists. The floorboards above have *terminus post quem* felling dates ranging from AD 1535 to AD 1577. Without the heartwood/sapwood boundary it is not possible to provide a closer felling date/range. However, it is reasonable to say that they are likely to be of the same date, indeed two of the boards are almost certainly from the same tree (as above), making them all datable to after AD 1577.

The south-west wing was thought to have been added in the sixteenth century and this has now been supported by the dendrochronology which has dated the roof to AD 1551–71. The first-floor frame main beam is unfortunately undated.

Only one of the fireplace bresummers in the Chapel has been dated to AD 1510–35. This beam was thought to be reused and is likely to have come from somewhere else in the building. Although earlier, this sample matches most highly with samples taken from the west wing roof (eg HEL-M26, t=8.2 and HEL-M36, t=8.3).

Apart from those timbers sampled in the hall house roof which form an earlier and discrete group, the matching between samples from both individual elements or wings and from different areas is very good and suggestive of the same or adjacent woodland sources being utilised.

The dendrochronology has confirmed the survival of an important and rare thirteenth-century crown-post roof at Canons Garth. Apart from this early survival and the sixteenth-century south-west wing roof, the majority of the timbers sampled appear to date to the first half of the seventeenth century. This period was obviously a time of substantial building activity with the insertion of the first-floor frame in the hall house, construction of the west wing roof, fireplace bresummer and possibly insertion of the floor, again in the west wing, all dating to this period.

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TABLES

Table 1: Details of tree-ring samples from Canons Garth, Helmsley, North Yorkshire

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
HALL HOUSE						
Roof						
HEL-M01	Tiebeam (upper), truss 1	60	26C	1224	1257	1283
HEL-M02	North passing shore, truss 1	68	22C	1216	1261	1283
HEL-M03	South strut, truss 1	71	21C	1213	1262	1283
HEL-M04	South passing shore, truss 1	82	22	1199	1258	1280
HEL-M05	North brace, frame 1	47	14	1230	1262	1276
HEL-M06	South brace, frame 1	61	24C	1223	1259	1283
HEL-M07	North strut, truss 2	85	09	1198	1273	1282
HEL-M08	South strut, truss 2	68	13C	1216	1270	1283
HEL-M09	South passing shore, truss 2	50	06	1222	1265	1271
HEL-M10	Tiebeam (upper), truss 2	47	h/s	1211	1257	1257
HEL-M11	North passing shore, truss 2	51	04	1217	1263	1267
HEL-M12	North principal rafter, truss 2	NM	--	----	----	----
First-floor frame						
HEL-M14	Spine beam	NM	--	----	----	----
HEL-M15	Joist 3, north	96	02	1438	1531	1533
HEL-M16	Joist 3, south	112	h/s	1484	1595	1595
HEL-M17	Joist 5, north	87	--	1423	----	1509
HEL-M18	Joist 5, south	89	--	1463	----	1551
HEL-M19	Joist 14, north	122	--	1423	----	1544
HEL-M20	Joist 4, south	190	19	1432	1602	1621
HEL-M21	Joist 13, north	155	--	1432	---	1586
HEL-M22	Joist 14, north	119	--	1441	----	1559
Smokehood						
HEL-M23	Bresummer	109	04	----	----	----

HEL-M24	Stud 1	NM	--	----	----	----
HEL-M25	Stud 3	NM	--	----	----	----
WEST WING						
Roof						
HEL-M13	North common rafter 4, bay 4	127	34C	1496	1588	1622
HEL-M26	East wallplate	187	h/s	1401	1587	1587
HEL-M27	Crown post, truss 1	83	--	1471	----	1553
HEL-M28	West principal rafter, truss 1	54	h/s	1540	1593	1593
HEL-M29	Tiebeam, truss 1	122	--	1415	----	1536
HEL-M30	East principal rafter, truss 1	133	--	1420	----	1552
HEL-M31	Tiebeam, truss 2	133	01	1463	1594	1595
HEL-M32	East principal rafter, truss 2	126	--	1389	----	1514
HEL-M33	West principal rafter, truss 2	129	26C	1494	1596	1622
HEL-M34	Crown post, truss 2	138	--	1381	----	1518
HEL-M35	East common rafter 8, bay 2	106	--	1407	----	1512
HEL-M36	East upper purlin	162	h/s	1442	1603	1603
HEL-M37	West upper purlin	152	h/s	1451	1602	1602
HEL-M38	East lower purlin	132	--	1408	----	1539
First-floor frame						
HEL-M39	Main spine beam	161	23C	1508	1645	1668
HEL-M40	Joist 11, west	88	--	1506	----	1593
HEL-M41	Joist 10,west	110	05	1495	1599	1604
HEL-M42	Joist 9, west	95	--	1442	----	1536
HEL-M43	Joist 8, west	83	--	1447	----	1529
HEL-M44	Joist 5, west	58	--	----	----	----
HEL-M45	Joist 4, west	84	--	1468	----	1551
Fireplace						
HEL-M46	Bressummer	129	26C	1501	1603	1629
HEL-M47	West post to bressummer	43	05	----	----	----
First-floor floorboards						
HEL-M48	Board 1	100	--	1430	----	1529
HEL-M49	Board 2	91	--	1430	----	1520

HEL-M50	Board 3	75	--	1450	----	1524
HEL-M51	Board 4	75	--	----	----	----
HEL-M52	Board 5	132	--	1431	----	1562
HEL-M53	Board 6	131	--	1425	----	1555
SOUTH-WEST WING						
Roof						
HEL-M54	East post	88	--	1382	----	1470
HEL-M55	East principal rafter	117	11	1431	1536	1547
HEL-M56	West principal rafter	73	--	1413	----	1485
HEL-M57	Tiebeam	NM	--	----	----	----
HEL-M58	East common rafter 1, bay 2	70	14	1481	1536	1550
HEL-M59	East common rafter 3, bay 2	68	11	1478	1534	1545
HEL-M60	West purlin	88	27	1458	1518	1545
HEL-M61	West common rafter 3, bay 2	65	13	1480	1531	1544
First-floor frame						
HEL-M62	Main spine beam	85	h/s	----	----	----
CHAPEL						
HEL-M63	First-floor fireplace bressummer	116	h/s	----	----	----
HEL-M64	Ground-floor fireplace bressummer (inner)	108	h/s	1388	1495	1495
HEL-M65	Ground-floor fireplace bressummer (outer)	94	h/s	----	----	----

*NM = not measured

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

C = complete sapwood retained on sample, last measured ring is the felling date

Table 2: Results of the cross-matching of site sequence HELMSQ01 and relevant reference chronologies when the first-ring date is AD 1198 and the last-measured ring date is AD 1283

Reference chronology	*t*-value	Span of chronology	Reference
64–72 Goodramgate, York	7.1	AD 1079–1315	Arnold and Howard 2012
Manor Farm,Scotton, Knaresborough	7.1	AD 1096–1342	Tyers 2001a
51/2 High Street, Burton-on-Trent, Staffordshire	6.2	AD 1156–1387	Howard *et al* 1997
St Lawrence, Rush Spencer, Staffordshire	6.1	AD 1034–1279	Howard *et al* 1998
Manor House, Abbey Green, Burton-on-Trent, Staffordshire	6.0	AD 1162–1339	Howard *et al* 1998 unpubl
New Baxtergate, Grimsby	6.0	AD 1148–1284	Groves 1992
St Mary, Stockport, Manchester	5.9	AD 1099–1293	Arnold and Howard 2011

Table 3: Results of the cross-matching of site sequence HELMSQ02 and relevant reference chronologies when the first-ring date is AD 1381 and the last-measured ring date is AD 1668

Reference chronology	*t*-value	Span of chronology	Reference
Harome Manor (Ryedale Museum), North Yorkshire	10.5	AD 1391–1569	Miles and Worthington 1999
Old Chapel, Sinnington, North Yorkshire	9.9	AD 1296–1516	Tyers 1999 and Tyers 2001c
Low Harperley Farmhouse, Wolsingham, County Durham	9.8	AD 1356–1604	Arnold *et al* 2006
Hallgarth Pittington, County Durham	9.8	AD 1336–1624	Howard *et al* 2002
Old Hall Farmhouse, Mayfield, Staffordshire	9.6	AD 1437–1622	Arnold and Howard 2006 unpubl
Headley Hall Barns, Bradford, West Yorkshire	9.4	AD 1381–1604	Tyers 2001b
The Old Hall, West Auckland, County Durham	9.1	AD 1437–1619	Hurford *et al* 2010

FIGURES

Figure 1: Map to show the general location of Helmsley, circled.

Figure 2: Map to show the location of Helmsley, circled.

Figure 3: Map to show the location of Canons Garth, hashed. © Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900

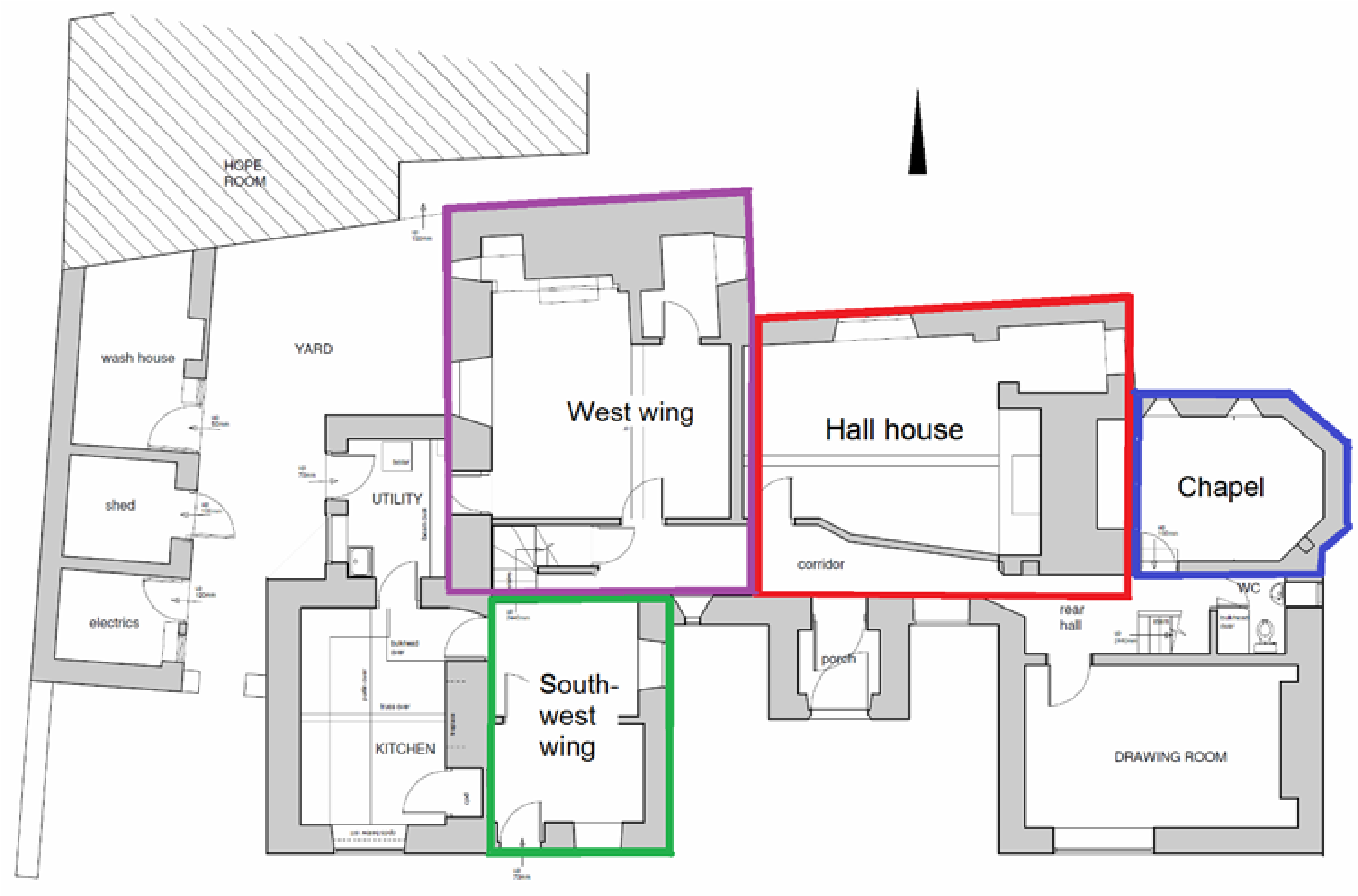

Figure 4: Plan of Canons Garth, showing the areas investigated (Malcolm Tempest Ltd)

Figure 5: Hall house, roof, truss 1, photograph taken from the west (Alison Arnold)

Figure 6: Hall house, smokehood (Alison Arnold)

Figure 7: Hall house, first-floor frame, photograph taken from the south (Alison Arnold)

Figure 8: West wing, roof, truss 1, photograph taken from the south (Alison Arnold)

Figure 9: West wing, first-floor frame, photograph taken from the west (Alison Arnold)

Figure 10: First-floor floorboards, photograph taken from the east (Alison Arnold)

Figure 11: West wing, ground-floor bresummer and posts, photograph taken from the south (Alison Arnold)

Figure 12: South-west wing, truss, photograph taken from the north (Alison Arnold)

Figure 13: South-west wing, ground-floor ceiling beam, photograph taken from the south (Alison Arnold)

Figure 14: Chapel, double lintel over ground-floor fireplace, with inner lintel chamfered and stopped towards stack, photograph taken from the south (Alison Arnold)

Figure 15: First-floor bedroom, fireplace lintel, photograph taken from the east (Alison Arnold)

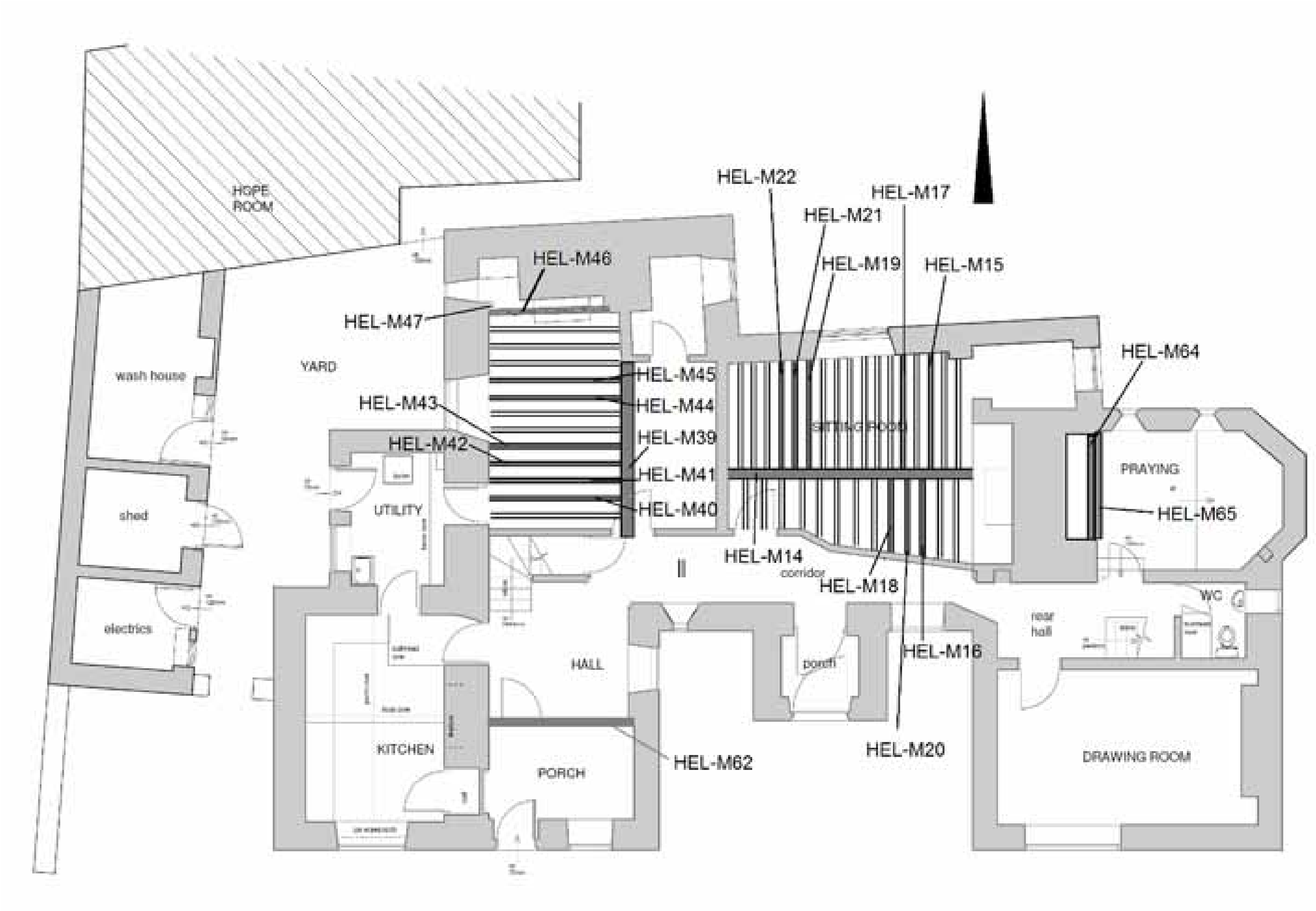

Figure 16: Ground-floor plan, showing the location of samples HEL-M14–22, HEL-M39–47, HEL-M62, and HEL-M64–5 (Malcolm Tempest Ltd)

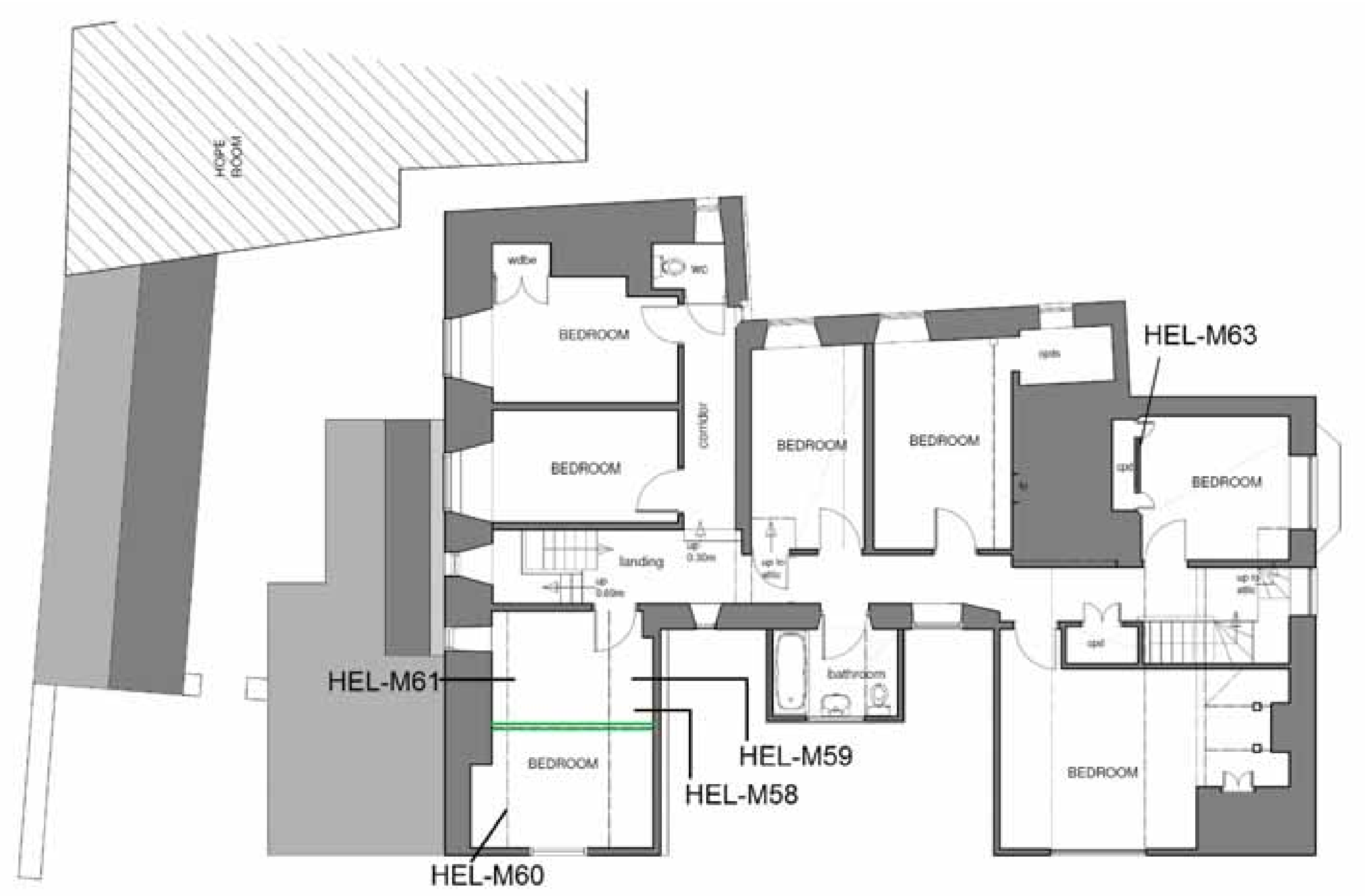

Figure 17: First-floor plan, showing the location of samples HEL-M58–61 and HEL-M63 (Malcolm Tempest)

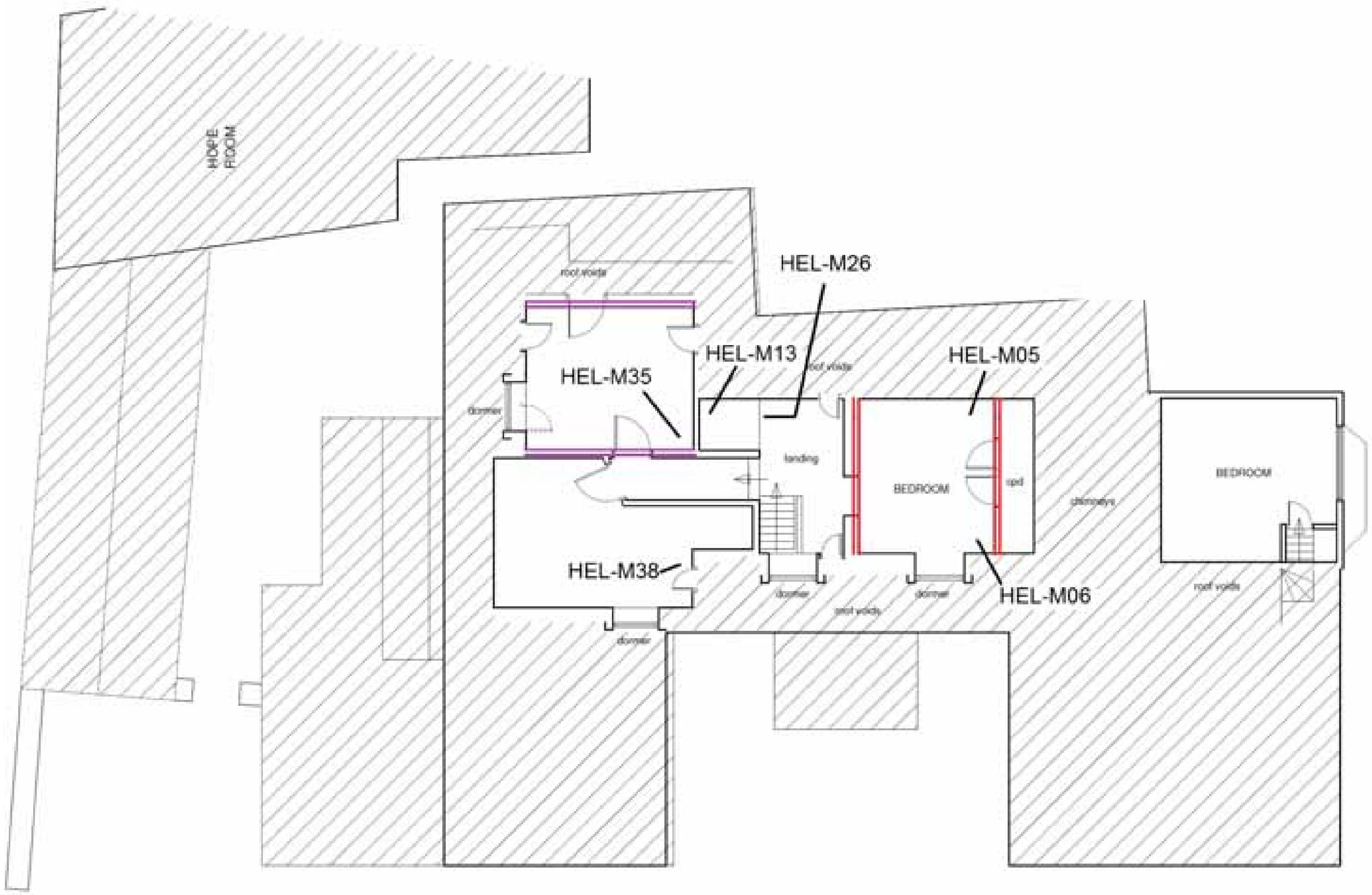

Figure 18: Attic plan, showing the location of samples HEL-M05–06, HEL-M13, HEL-M26, HEL-M35, and HEL-M38 (Malcolm Tempest Ltd)

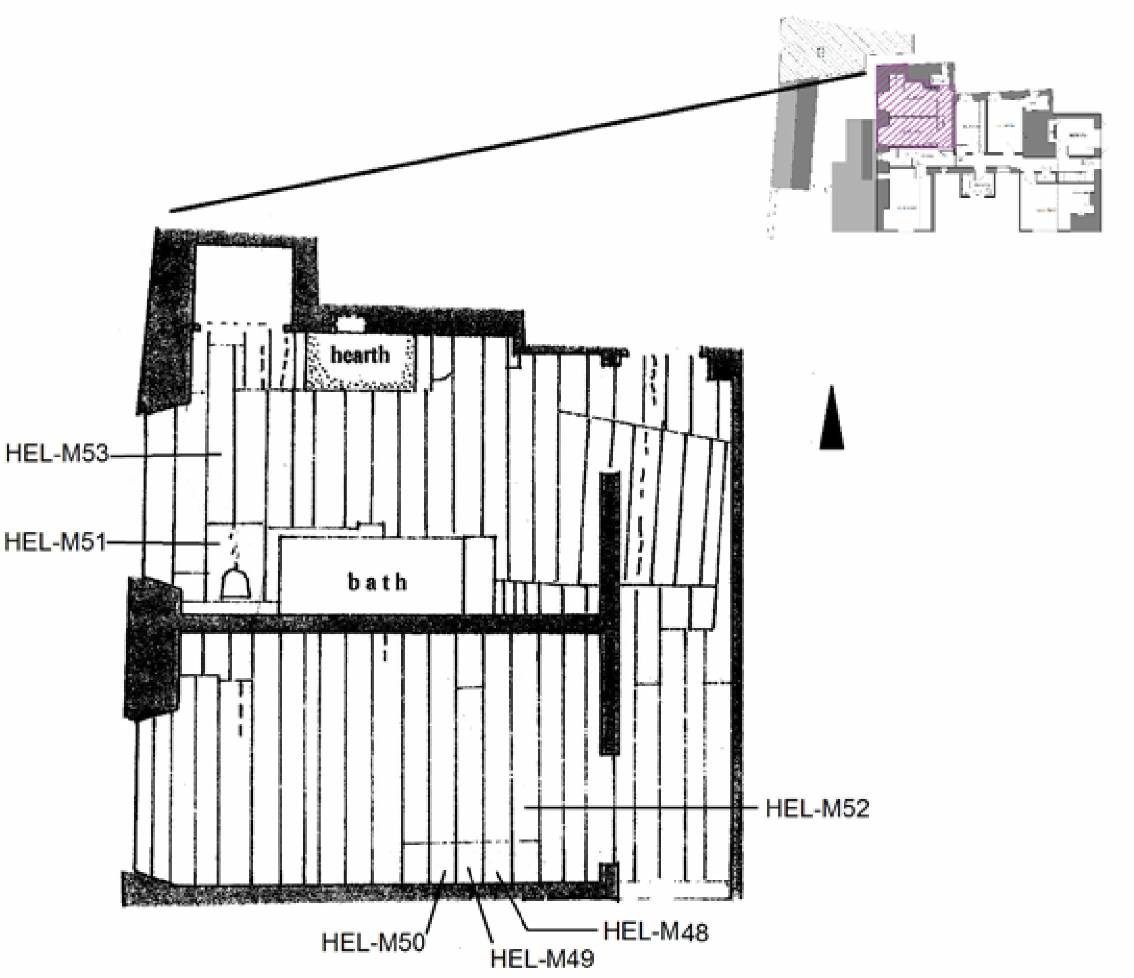

Figure 19: Plan of old flooring on the first floor, showing the location of samples HEL-M48–53 (Ryder 2012)

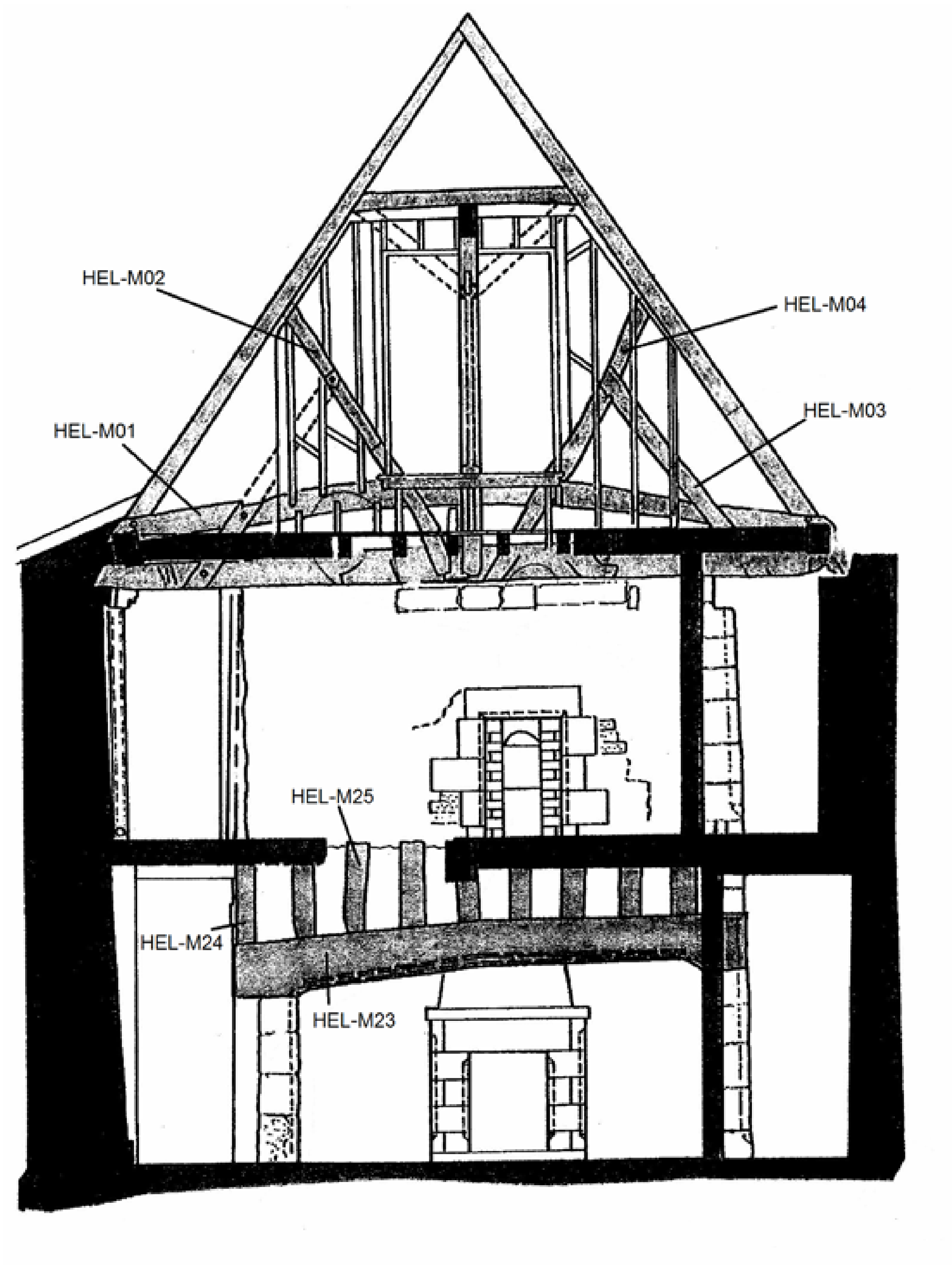

Figure 20: Section through house looking east, showing location of samples HEL-M01–04 and HEL-M23–5 (Ryder 2012)

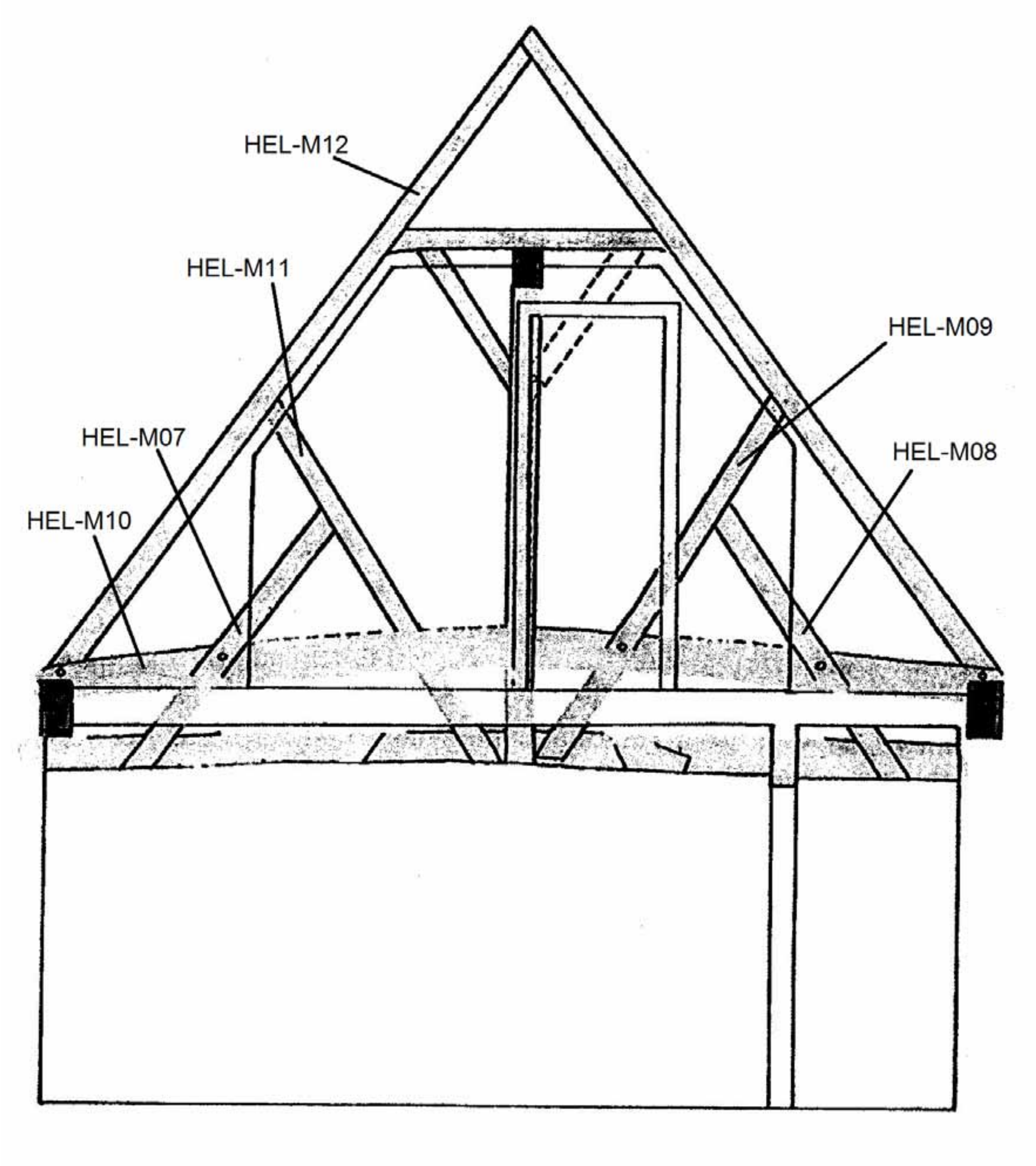

Figure 21: Hall house, truss 2, showing the location of samples HEL-M07–12 (Ryder 2012)

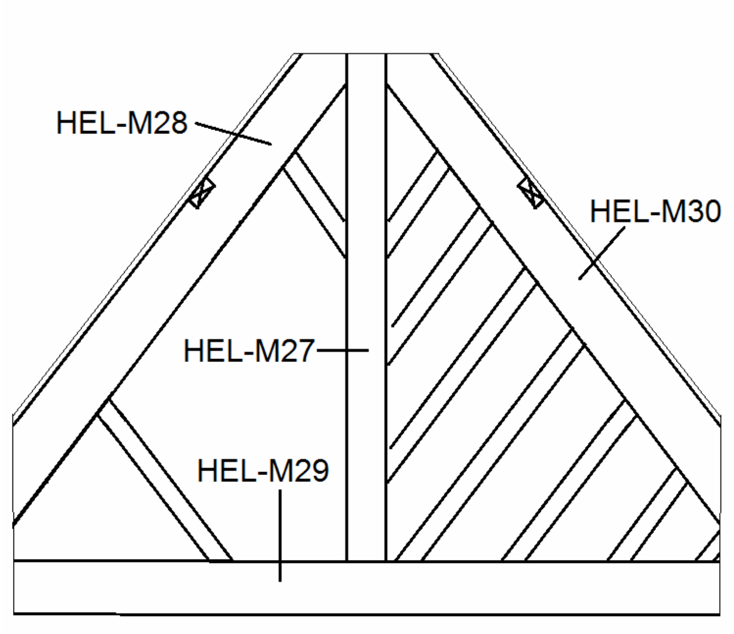

Figure 22: West wing, sketch of truss 1, showing the location of samples HEL-M27–30

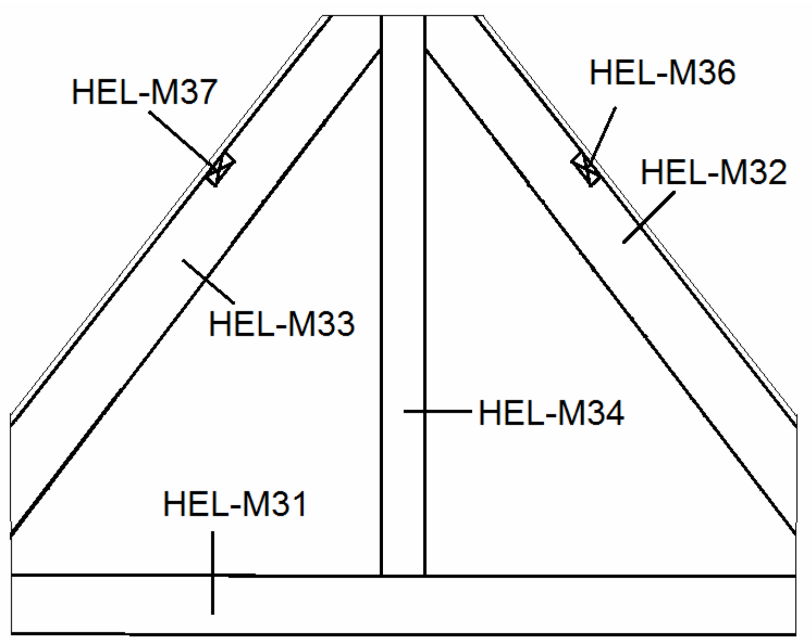

Figure 23: West wing, sketch of truss 2, showing the location of samples HEL-M31–4 and HEL-M36–7

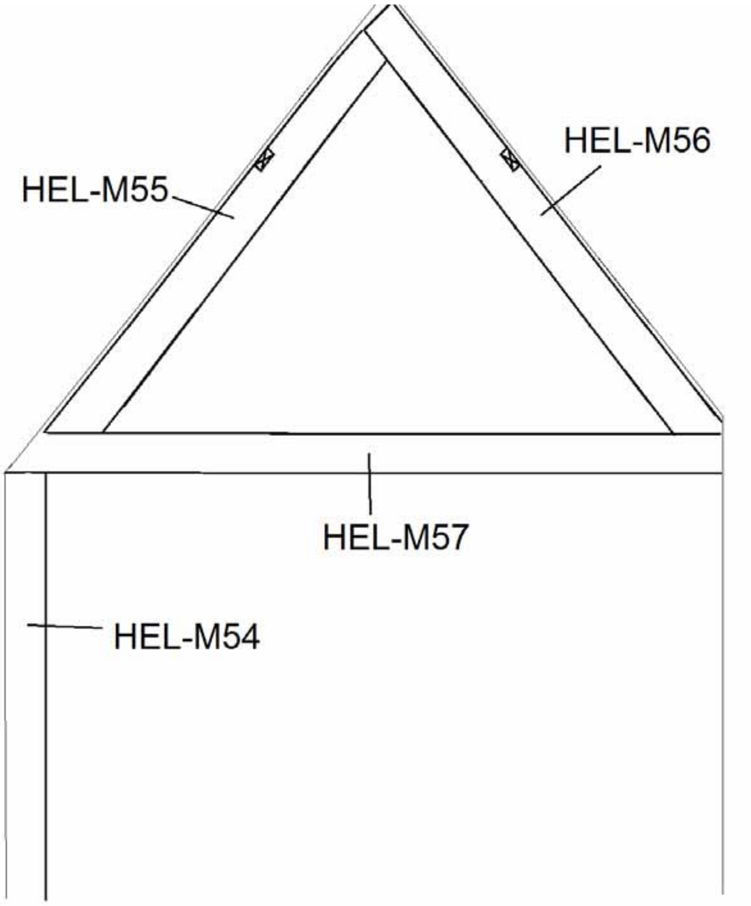

Figure 24: South-west wing, sketch of truss, showing the location of samples HEL-M54–7

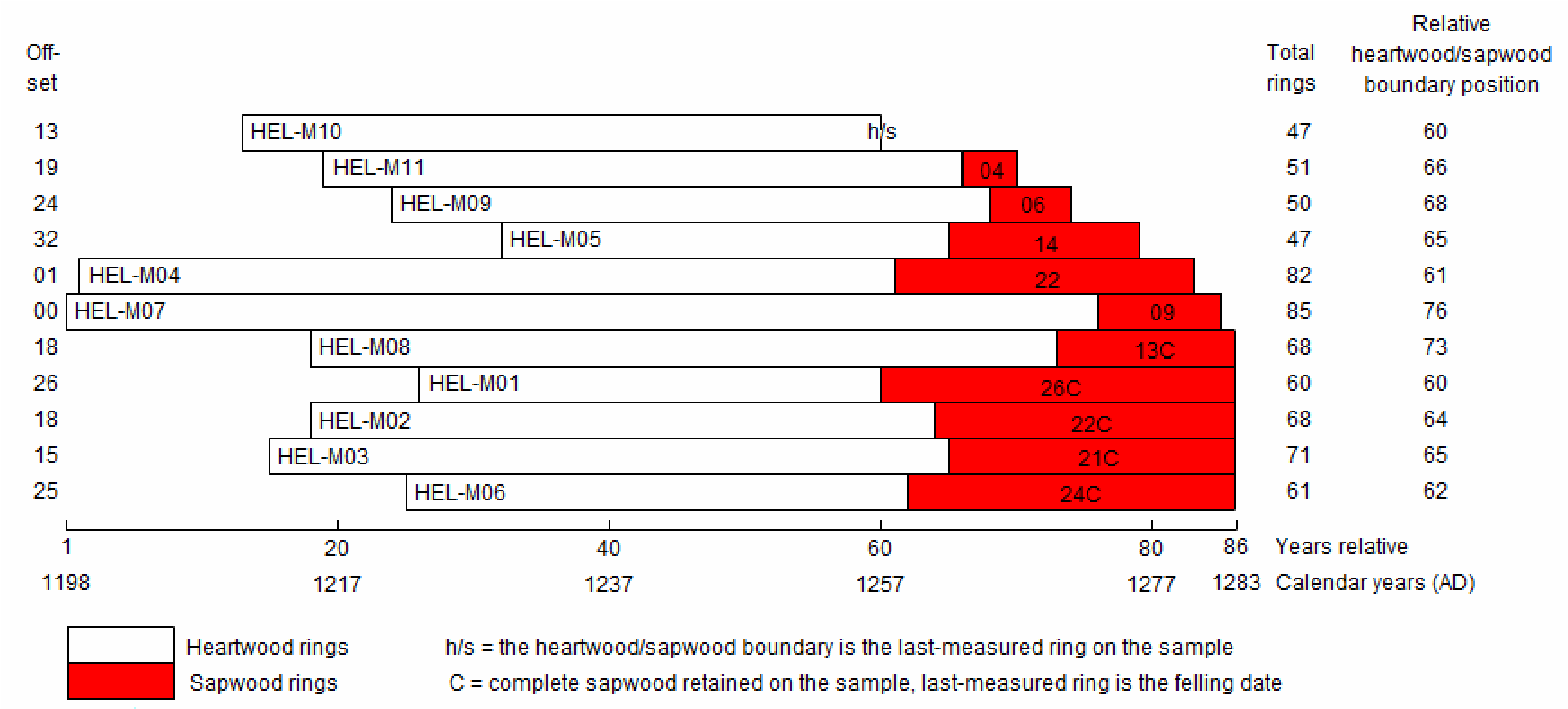

Figure 25: Bar diagram of samples in site sequence HELMSQ01

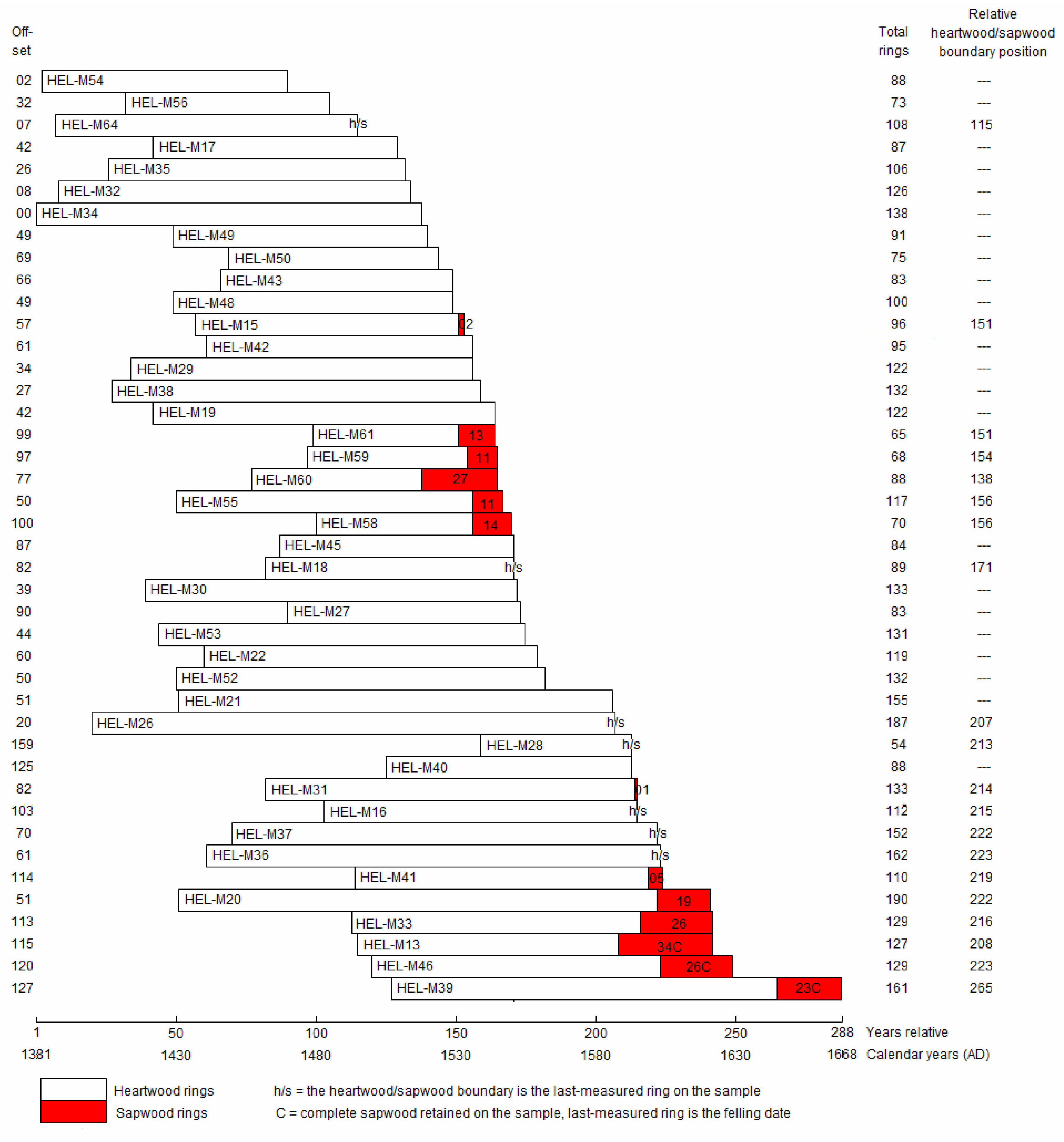

Figure 26: Bar diagram of samples in site sequence HELMSQ02

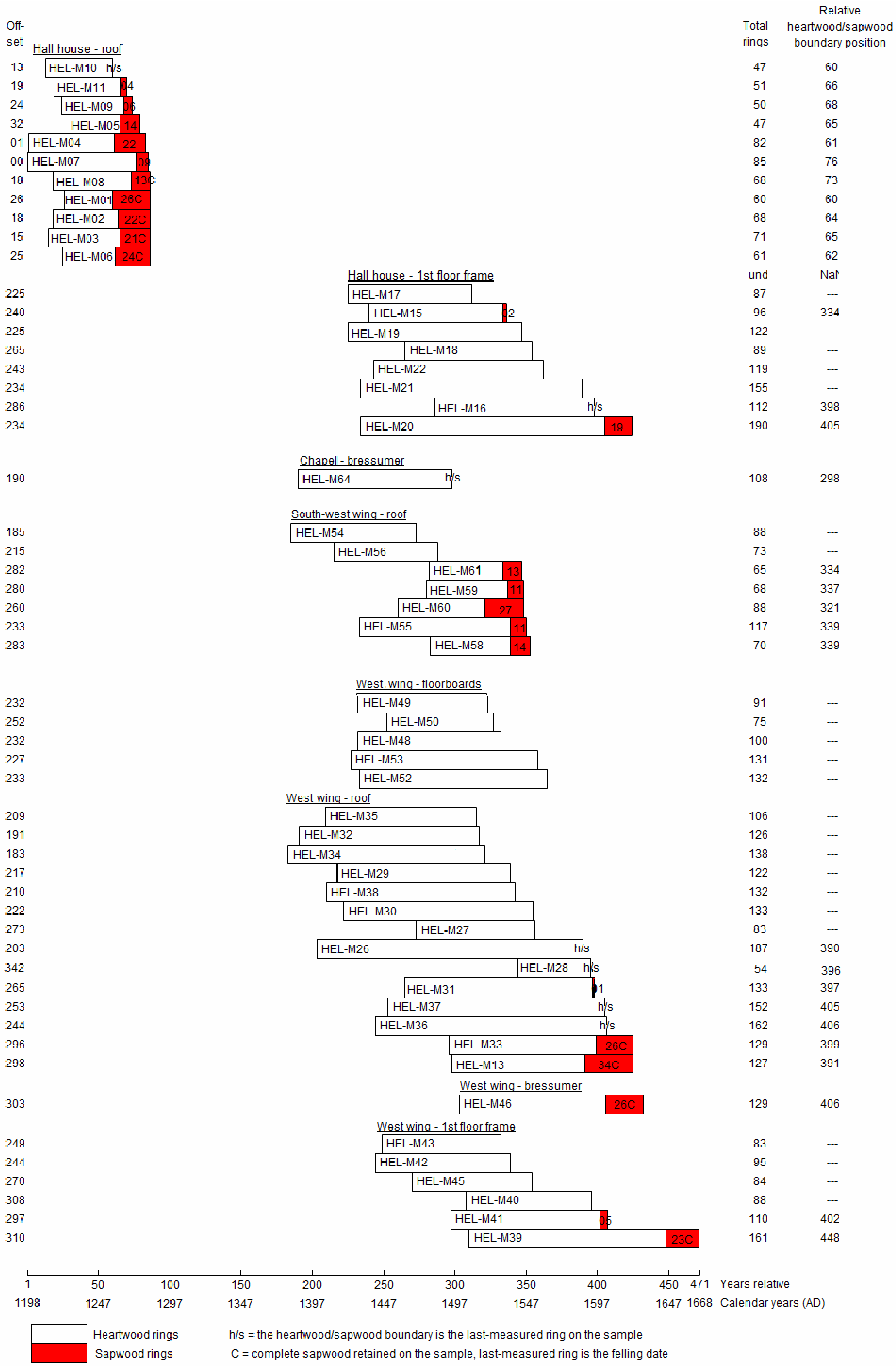

Figure 27: Bar diagram of all dated samples, sorted by area

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units with the exception of samples HEL-M48–53 which are in 0.1mm

HEL-M01A 60
292 300 310 261 297 256 216 190 201 126 209 264 140 220 185 260 197 112 88 128
155 120 152 205 126 79 121 155 86 106 184 161 129 153 134 144 122 76 130 95
90 152 170 116 130 108 117 128 117 125 108 102 201 208 123 134 150 196 149 100
HEL-M01B 60
291 292 311 258 293 263 215 187 197 132 206 263 144 221 188 251 197 117 83 131
161 128 150 208 131 77 121 154 88 108 178 156 139 148 135 144 119 78 129 110
84 143 171 115 127 108 118 127 137 122 91 105 206 200 130 127 149 196 142 108
HEL-M02A 68
220 215 180 204 197 225 183 165 174 85 80 82 133 123 118 95 127 116 115 169
121 144 134 179 167 142 132 107 168 200 169 184 151 138 159 206 155 153 209 196
148 133 139 176 183 131 142 120 86 119 101 130 147 141 102 125 88 104 67 65
79 113 69 89 108 129 125 73
HEL-M02B 68
225 214 176 196 192 219 190 164 173 95 72 92 130 119 123 95 122 116 119 164
118 141 140 179 168 137 128 110 169 192 162 183 155 145 155 202 163 153 204 207
151 132 129 176 188 132 144 124 77 127 94 134 143 139 104 125 91 98 72 66
84 109 70 89 110 122 130 58
HEL-M03A 71
197 237 284 247 371 317 326 383 355 364 330 329 264 193 215 176 167 164 138 155
136 142 171 186 217 193 204 193 155 79 107 104 106 132 119 90 82 107 99 87
76 97 95 119 149 136 170 175 142 179 122 92 109 92 96 98 95 99 94 81
98 60 64 84 69 68 60 82 103 95 48
HEL-M03B 71
194 233 288 244 367 324 332 376 358 360 336 327 271 192 209 179 170 163 137 157
132 146 170 181 218 198 207 198 158 81 107 102 109 135 120 90 85 104 99 88
74 95 99 119 149 139 172 173 138 178 124 100 109 88 91 110 94 98 87 75
94 53 70 74 62 63 64 86 85 110 72
HEL-M04A 60
351 231 231 191 215 183 140 162 107 103 156 173 122 86 87 112 89 102 101 84
98 120 117 99 111 99 135 101 102 122 108 80 69 82 55 78 75 63 71 64
86 53 54 45 45 73 64 86 93 64 42 45 65 63 56 116 79 60 72 69
HEL-M04B 68
86 103 91 104 114 64 96 108 93 101 88 94 113 94 82 110 104 77 64 83
57 60 69 51 66 57 74 63 44 37 47 69 57 84 88 54 49 43 70 60
56 120 77 69 76 81 81 70 60 74 72 63 76 60 59 73 65 54 89 67
69 73 82 129 124 90 102 112
HEL-M05A 47
180 140 113 85 126 165 144 223 225 303 274 253 283 223 226 245 273 314 144 94
104 148 133 114 144 151 110 140 98 104 133 95 86 110 91 91 85 98 122 125
106 113 110 95 61 62 76
HEL-M05B 47
177 139 116 78 122 162 141 223 215 291 275 254 274 225 227 238 270 309 145 88
90 152 145 110 136 138 107 155 117 101 135 84 82 114 92 105 80 103 117 128
125 111 115 103 54 72 80
HEL-M06A 61
190 197 227 164 119 173 154 143 113 157 95 80 119 104 122 114 201 140 263 200

167 257 298 315 375 263 168 110 118 118 162 243 205 155 269 260 237 221 157 138
118 111 120 129 137 127 107 85 111 111 87 75 64 78 112 81 73 75 84 59
57
HEL-M06B 61
187 198 235 172 146 177 160 148 114 149 102 81 122 107 130 115 192 136 250 224
192 281 290 314 382 246 179 125 140 125 159 251 205 153 257 278 241 223 134 125
106 102 120 138 129 153 111 89 111 112 91 85 67 84 103 83 70 77 76 65
53
HEL-M07A 85
273 412 237 210 222 310 166 166 217 111 144 166 160 121 66 87 85 165 189 321
233 275 277 228 191 198 199 207 113 112 151 132 80 63 73 58 69 106 66 115
63 103 79 53 40 47 69 48 65 103 74 63 58 57 48 58 82 67 76 94
105 127 161 120 109 103 80 81 68 69 79 87 75 87 98 119 76 107 198 227
152 125 229 208 156
HEL-M07B 85
288 410 242 217 193 317 167 164 243 120 142 160 157 108 58 86 84 156 180 296
252 279 279 218 190 218 195 208 118 120 155 129 80 57 82 53 68 91 72 108
70 97 75 52 47 48 65 52 59 106 77 61 45 66 72 41 78 61 69 92
114 121 162 118 113 102 80 84 69 63 82 91 74 82 91 103 79 103 196 228
147 127 232 214 158
HEL-M08A 68
167 225 152 223 218 160 240 236 292 332 147 150 204 152 132 84 108 69 111 193
125 200 132 184 122 63 89 72 126 98 121 200 126 110 120 119 103 123 148 124
86 171 144 183 248 197 177 217 194 207 209 161 175 170 163 208 183 123 95 123
250 268 195 215 323 346 205 107
HEL-M08B 68
171 229 144 218 208 151 237 249 273 330 144 148 196 157 136 76 117 67 113 188
130 181 113 185 109 77 77 71 133 117 141 207 120 110 120 119 102 128 148 120
89 172 151 182 242 198 174 214 193 199 215 151 165 143 159 216 192 122 96 121
249 293 201 218 325 333 208 123
HEL-M09A 50
263 382 263 260 197 185 256 303 246 190 210 204 239 370 237 368 265 301 240 197
166 200 245 204 259 262 204 127 117 124 116 170 239 209 191 236 180 213 186 153
227 242 134 195 149 275 224 205 153 195
HEL-M09B 50
298 409 264 256 189 175 228 307 272 147 201 207 259 388 239 387 241 309 241 188
173 194 232 214 238 287 192 127 89 150 123 161 244 205 195 247 198 219 194 158
229 250 129 195 147 284 294 249 148 201
HEL-M10A 47
138 148 284 191 328 210 452 178 284 326 300 345 362 428 300 231 198 242 256 231
160 196 101 200 201 145 250 163 181 88 65 67 66 89 86 76 77 52 42 36
39 51 63 108 87 74 94
HEL-M10B 47
142 157 281 206 331 207 457 178 285 324 302 346 362 426 303 234 201 240 253 228
162 189 105 196 207 120 241 166 182 90 69 63 60 90 83 78 75 53 44 32
42 53 59 107 91 69 97
HEL-M11A 51
147 158 185 181 236 270 327 235 189 165 156 227 220 195 139 155 128 144 212 156
251 209 271 206 177 129 211 188 193 227 260 172 117 115 157 143 164 222 252 243
283 238 219 189 200 226 232 168 176 147 119
HEL-M11B 51
144 154 177 189 237 262 323 237 192 163 161 242 216 202 145 153 143 140 184 166
238 202 268 214 184 139 192 191 185 215 262 159 119 115 164 133 163 227 242 239

279 230 227 186 199 237 232 155 199 162 132
HEL-M13A 127
164 115 60 62 76 82 128 115 117 151 130 135 129 154 96 119 92 127 142 125
154 132 89 100 95 124 117 84 81 59 60 64 56 76 65 87 101 84 80 100
115 92 65 120 171 152 99 104 77 94 87 52 58 47 55 85 68 85 58 81
40 49 62 73 74 94 57 85 89 54 62 63 71 77 85 75 73 85 56 41
66 71 67 79 103 72 58 53 59 85 100 86 66 83 63 48 57 69 70 94
66 75 71 52 58 72 60 74 81 89 64 76 76 84 83 73 71 51 61 55
42 57 83 64 77 86 77
HEL-M13B 127
154 122 52 65 76 82 119 119 133 157 134 136 132 151 95 128 84 126 145 139
149 144 113 107 104 132 123 96 83 62 62 59 61 71 63 91 97 89 76 104
102 103 63 117 147 172 91 108 86 94 91 47 51 54 60 84 73 77 59 77
46 45 61 73 70 94 63 78 91 49 56 62 60 75 82 85 71 84 50 47
65 63 58 85 99 66 53 43 62 73 95 78 66 83 64 46 53 68 78 89
71 76 70 54 61 68 61 71 83 79 76 70 80 81 89 71 63 64 54 53
43 58 72 75 66 87 73
HEL-M15A 96
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112 107 57 117 79 91 70 85 89 127 96 103 89 79 77 84 106 88 71 81
75 87 125 74 53 66 104 84 84 35 64 91 107 100 97 98 88 79 115 118
119 119 122 112 116 105 131 63 75 74 77 82 103 124 99 77
HEL-M15B 96
146 115 116 202 157 151 139 112 104 143 135 133 133 113 148 125 85 90 88 119
92 56 67 101 133 78 99 94 160 229 185 182 122 130 120 137 62 113 151 115
118 101 60 121 81 92 68 85 87 127 95 106 86 81 73 82 104 91 67 79
80 86 121 72 50 72 106 84 82 40 52 95 102 86 96 103 83 81 111 132
121 117 121 113 115 107 127 79 61 82 76 79 105 129 92 78
HEL-M16A 112
237 193 257 341 242 157 99 95 118 191 179 171 210 190 107 120 139 151 129 114
136 146 144 113 116 176 133 113 120 121 124 141 128 134 109 102 102 140 138 114
128 107 98 77 98 107 122 138 96 140 93 94 89 120 91 105 146 107 100 101
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69 65 76 78 78 97 92 138 90 108 58 63 48 58 74 73 81 84 79 55
86 114 80 65 67 69 63 46 45 52 61 66
HEL-M16B 112
251 195 255 312 241 158 101 92 126 192 171 174 210 182 119 117 139 148 128 118
133 158 139 108 104 190 129 112 124 117 121 147 130 130 106 102 106 135 126 108
128 108 93 80 97 110 122 143 93 140 96 94 89 117 90 104 149 111 94 107
106 108 123 66 77 83 104 169 137 134 115 142 75 82 97 129 99 120 122 100
74 62 75 82 73 99 93 136 97 100 62 63 50 60 74 73 82 78 79 61
87 108 82 65 72 73 58 46 46 48 65 66
HEL-M17A 87
216 220 202 156 164 189 312 232 245 236 200 210 200 145 182 155 82 92 165 165
202 134 93 104 133 132 177 175 133 159 134 113 111 112 121 89 60 75 108 110
86 117 117 187 206 157 141 163 171 140 151 100 131 168 144 116 103 75 109 75
90 74 107 117 117 92 102 113 100 118 109 136 119 103 96 91 101 145 71 58
103 127 107 132 65 96 153
HEL-M17B 87
241 223 195 160 152 189 295 230 247 237 205 219 188 140 174 162 86 96 169 161
211 141 91 105 134 130 174 173 131 169 135 107 118 115 125 89 62 73 106 109
89 112 116 191 203 159 142 167 169 163 151 93 132 173 144 113 105 72 112 71

92 74 109 117 117 92 104 117 102 123 103 140 124 97 102 90 91 145 67 64
109 131 109 127 65 104 153
HEL-M18A 89
71 107 87 104 135 118 114 129 101 63 52 47 59 80 70 60 47 54 36 52
65 59 71 73 99 73 63 68 46 50 61 54 58 60 65 55 50 71 78 53
68 77 95 108 60 55 73 62 46 56 93 86 72 73 81 42 51 65 90 105
103 134 61 69 77 76 87 63 42 69 62 54 75 77 82 57 94 103 77 69
82 75 64 74 41 42 36 35 58
HEL-M18B 89
96 104 84 105 123 116 113 129 93 63 59 28 67 91 71 63 50 45 43 52
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73 70 102 93 64 60 63 58 53 57 100 76 80 68 78 50 46 69 101 129
102 125 62 78 78 82 86 75 51 64 62 55 58 73 78 61 101 82 74 63
69 73 82 66 40 47 36 37 50
HEL-M19A 122
269 301 315 216 234 301 391 306 248 319 242 284 238 206 191 100 106 140 137 142
140 177 120 94 125 106 108 101 109 107 119 115 117 99 78 65 58 71 84 75
103 80 78 86 143 123 109 101 82 57 59 58 109 123 101 85 73 69 106 56
77 79 65 86 108 93 93 69 68 69 99 99 101 104 150 78 100 112 134 100
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78 70 58 49 52 49 53 65 50 50 50 54 52 57 50 38 62 60 41 61
62 60
HEL-M19B 122
278 303 316 212 235 303 406 301 255 314 247 283 230 210 183 128 109 137 145 142
148 178 114 95 121 118 110 101 110 111 113 118 116 96 80 71 54 74 69 78
106 84 85 83 141 121 107 107 77 59 69 55 123 116 108 95 66 82 101 62
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77 77 57 47 47 61 45 58 52 53 47 56 66 61 54 46 64 58 44 52
67 71
HEL-M20A 190
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53 45 27 30 37 56 76 50 70 67
HEL-M20B 190
106 110 92 103 80 56 52 38 39 79 71 87 76 91 55 57 67 55 69 64
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55 44 42 41 47 37 41 42 35 51 23 31 52 51 48 88 67 53 58 52
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64 70 53 73 71 49 49 59 63 67 46 54 56 61 46 46 33 31 61 66
67 64 63 65 54 47 72 60 38 56 58 70 51 39 41 41 40 48 72 44
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47 62 62 63 64 49 48 42 52 30 44 51 68 48 49 50 53 37 47 52
49 41 25 37 44 48 80 56 70 62
HEL-M21A 155

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81 95 96 104 85 87 83 102 131 111 128 145 121 103 123 149 125 115 127 94
86 63 54 64 80 88 71 65 70 76 63 52 65 56 56 79 67 73 60 42
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60 99 91 98 97 100 80 83 86 164 111 92 75 60 58 43 28 36 56 62
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79 86 49 39 52 55 62 55 77 90 85 79 109 115 200
HEL-M21B 155
214 182 175 146 119 122 95 72 109 132 104 120 121 76 74 84 85 84 83 85
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96 120 110 72 52 58 66 68 71 82 85 81 97 83 70 71 45 43 73 71
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82 111 105 119 83 80 50 35 35 52 52 62 67 39 94 59 42 35 83
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240 239 249 232 192 268 208 200 178 195 201 240 220 223 198 201 139 154 161 160
144 133 153 183 167 142 129 134 164 158 146 115 93 140 121 87 122 101 161 133
131 95 124 98 87 50 96 88 110 113 113 100 132 105 125 130 141 135 116 112
118 123 153 130 162 136 130 144 78 136 107 133 129 104 122 97 110 111 135 166
136 117 119 100 114 103 107 100 85
HEL-M23B 109
325 353 283 305 364 245 292 230 251 278 182 242 238 240 202 289 241 282 261 243
245 240 247 255 188 274 198 197 186 207 199 234 200 232 201 202 139 163 166 168
147 133 150 179 176 147 128 139 164 162 163 128 104 141 128 100 114 100 159 129
108 107 114 110 93 64 85 90 103 102 112 95 108 97 110 135 146 134 121 115
112 114 155 129 165 128 107 135 75 138 114 128 124 105 125 101 107 119 122 161
128 114 119 109 117 96 88 87 79
HEL-M26A 187
196 224 262 177 205 172 135 81 107 163 144 120 101 111 82 72 131 174 136 143
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HEL-M26B 187
187 221 254 190 210 174 97 88 107 168 144 124 97 97 92 73 135 174 130 138
136 86 123 124 117 60 83 122 189 157 167 168 122 116 74 44 120 77 48 101
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91 66 109 97 84 88 47 53 60 77 154 129 150 114 191 75 70 97 135 133
111 119 107 115 77 67 72 105 146 156 120 96 97 72 55 65 66 76 75 123
91 56 53 74 105 117 132
HEL-M27A 53
160 92 91 72 129 141 119 113 79 58 66 51 102 148 127 147 147 96 158 117
91 119 121 117 192 127 114 74 69 69 104 112 113 92 159 87 116 108 155 159
136 117 126 100 100 134 159 152 147 128 179 155 118
HEL-M27B 65
173 152 99 128 134 120 214 137 118 68 71 78 130 95 99 92 151 93 103 110
161 156 139 104 101 95 111 177 151 168 146 142 175 170 129 219 162 203 90 101
144 88 100 131 145 122 168 151 134 77 122 150 114 126 112 99 145 106 52 49
54 106 84 83 74
HEL-M28A 54
73 55 54 50 50 63 67 55 61 83 102 178 129 140 131 195 154 105 91 140
107 118 113 110 132 121 112 103 97 100 94 100 101 98 80 89 93 98 75 98
90 108 131 123 165 172 198 129 130 151 131 81 93 95
HEL-M28B 54
75 54 55 51 50 61 72 53 62 81 97 173 121 150 124 200 145 103 91 142
103 118 107 112 134 115 115 105 94 101 94 98 98 104 94 87 95 96 82 87
96 110 127 122 152 167 201 124 126 153 129 83 91 92
HEL-M29A 122
240 136 162 207 72 68 84 92 114 131 105 74 84 157 166 127 138 138 122 176
164 102 104 131 108 105 130 133 139 140 93 71 104 81 113 105 114 122 101 81
92 133 99 67 77 83 104 62 61 52 77 101 83 111 87 86 83 68 68 54
107 102 69 75 57 56 99 71 93 75 63 66 77 49 71 60 33 46 39 41
72 71 55 41 38 39 60 56 42 57 62 47 54 51 55 50 61 57 52 60
71 74 72 67 69 47 71 69 73 63 55 66 51 46 68 45 96 58 93 74
104 71
HEL-M29B 122
230 136 147 211 66 70 75 90 115 132 106 71 86 150 167 123 139 137 116 179
148 100 102 134 103 109 127 129 144 139 96 74 101 86 113 108 110 120 109 78
100 138 99 73 71 90 104 65 64 49 77 101 81 111 89 83 82 69 69 60
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70 75 53 44 37 42 59 57 42 47 65 44 43 51 49 58 62 54 43 58
71 73 72 63 64 53 67 70 62 63 58 64 42 54 67 42 90 56 97 90
101 84
HEL-M30A 133
240 279 257 265 212 239 173 213 207 229 159 168 296 185 207 158 183 180 163 130
147 129 101 98 122 102 79 113 119 119 90 110 101 89 100 79 77 73 84 63
71 83 68 90 59 84 78 86 84 78 81 80 61 54 33 59 82 62 58 45
44 72 60 63 64 67 75 89 72 65 67 57 58 81 68 57 63 68 58 64
67 71 62 49 55 50 81 58 77 73 56 60 55 70 52 46 53 47 56 52

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38 46 32 36 31 30 46 32 32 51 47 94 79
HEL-M30B 133
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HEL-M32A 126
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HEL-M42A 95
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68 71 80
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HEL-M47B 43
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109 103 127
HEL-M48A 100
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HEL-M50A 75
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HEL-M58B 70
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119 111 107 107 117 99 105 102 87 87 71 91 92 92 91 108 101 85 93 97
74 85 84 66 45 44 62 49 47 47 61 50 45 60 62 58 95 67 77 47
40 48 42 45 71 77 73 82 64 63 47 60 61 67 72 63 56 32 34 62
85 113 104 86 74 66 52 35 71 56 64 62 71 59
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239 218 200 179 216 163 181 200 166 183 168 151 146 122 137 119 112 121 111 150
124 111 111 114 112 101 103 104 94 86 83 85 98 89 100 91 107 77 97 96
74 81 77 48 44 46 58 54 44 53 55 50 50 61 61 59 93 68 75 49
39 48 38 48 76 72 81 79 66 61 45 60 61 67 77 66 51 34 38 59
78 115 110 93 67 63 48 34 67 63 65 56 72 76

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 1998). 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 complement 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

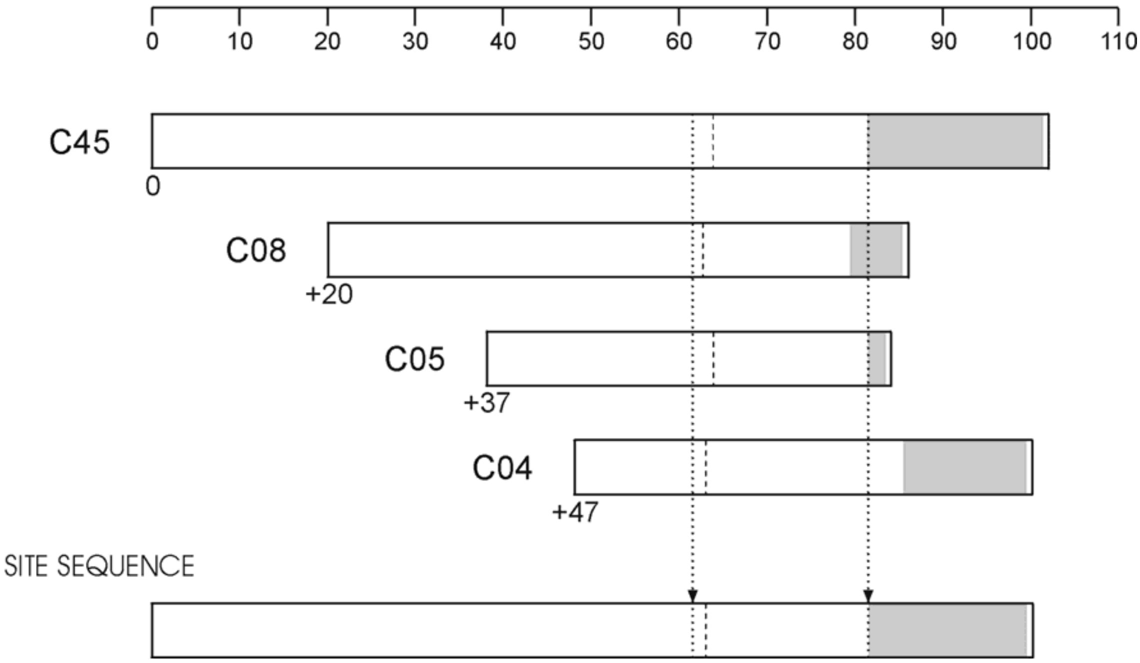


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

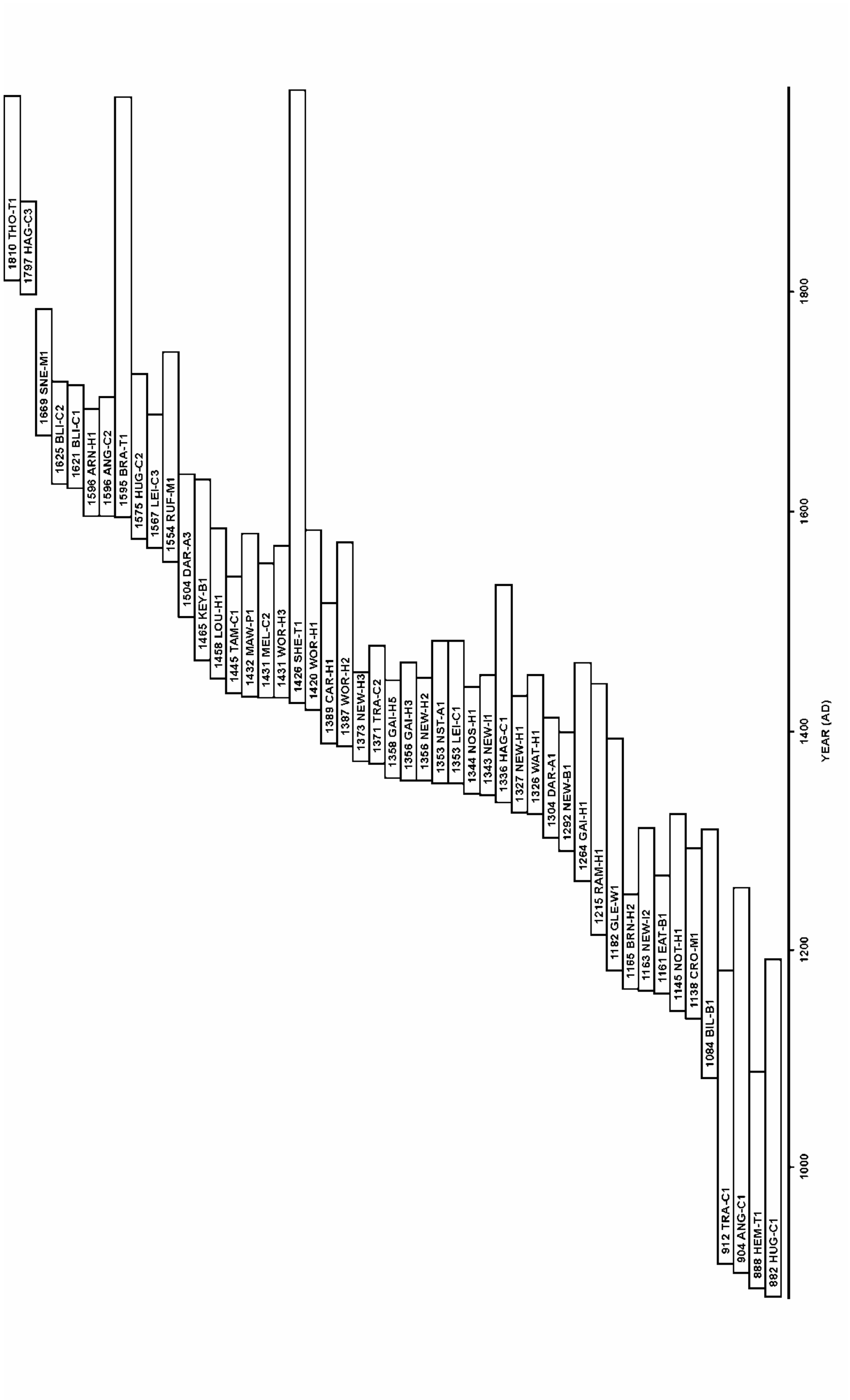
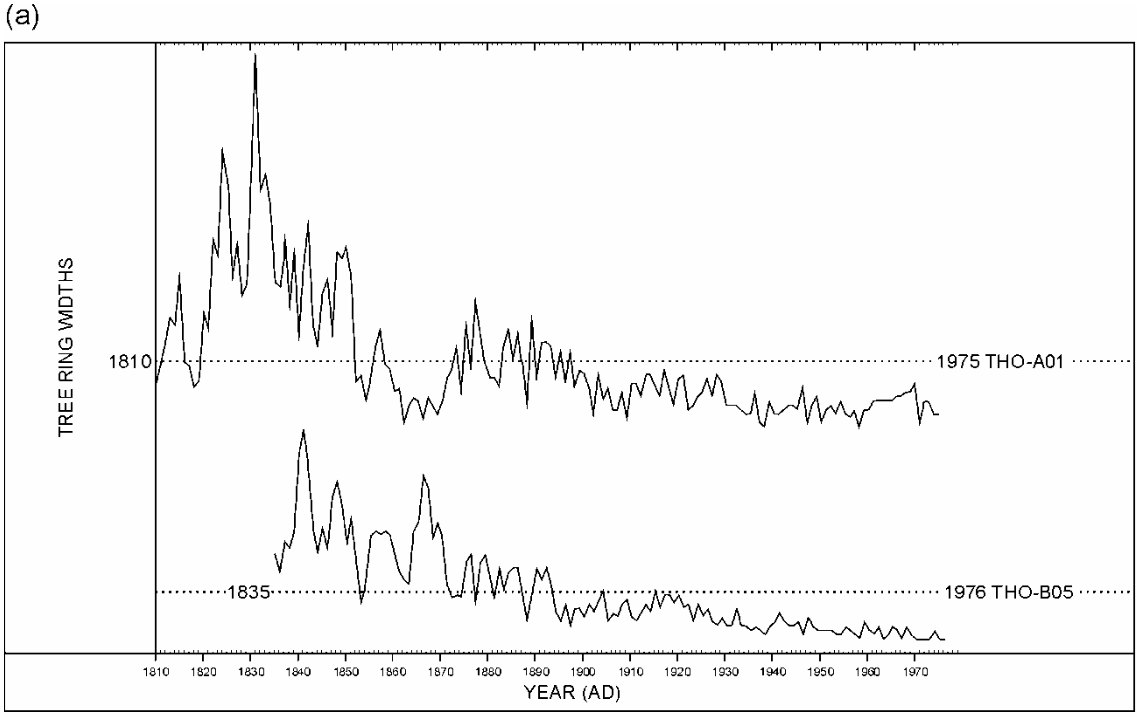


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87



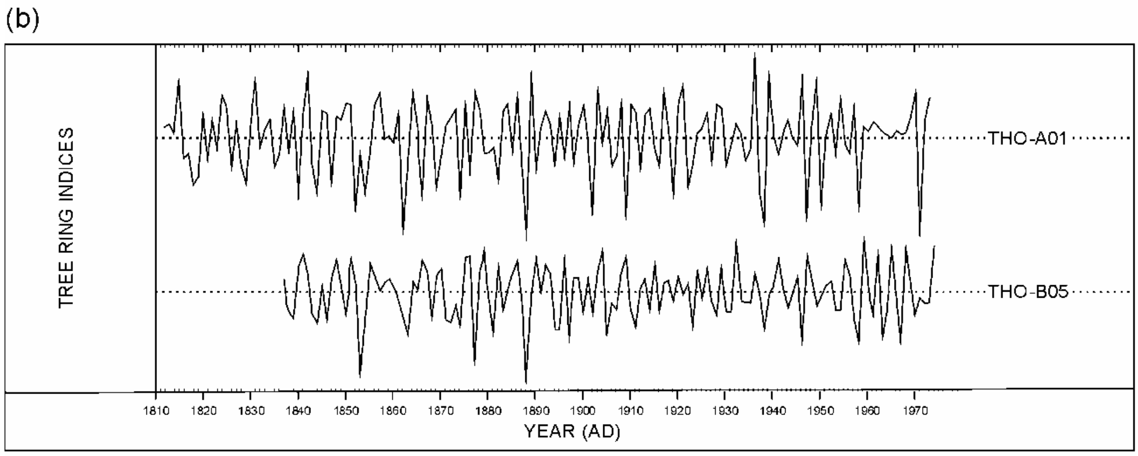


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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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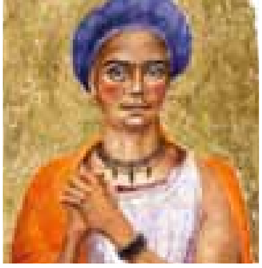


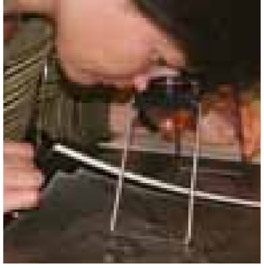


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