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The Abbot's Lodging and Corridor, Coggeshall Abbey, Essex

Tree-ring Analysis of Timbers

Alison Arnold and Robert Howard

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SUMMARY

Analysis undertaken on samples taken from various parts of this building has resulted in the successful dating of 40 timbers. The earliest timbers were identified within the Abbots Lodging where two roof timbers and a ground-floor ceiling joist were dated to AD 1363–88 and AD 1369–94, respectively. These timbers are thought to be reused.

The ground-floor ceiling of the Abbot's Lodging utilises timber felled in AD 1488, with construction thought to have followed shortly after. Potentially contemporary are a roof timber from the Abbot's Lodging with a *terminus post quem* date of AD 1487 and a roof timber from the Corridor dated to AD 1487–1512. Again, these are presumed to be reused.

The majority of the dated timbers of the Corridor roof were felled in AD 1549 although at least three (and probably four) are somewhat later, dating to AD 1567–92. Boards of a door in this part of the building have a *terminus post quem* felling date of AD 1527 and may be contemporary with the roof.

The majority of the Abbot's Lodging roof timbers date to the mid- to late-sixteenth century with at least two being felled in *c* AD 1571. A lintel dates to AD 1538–63.

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INTRODUCTION

The Scheduled Ancient Monument of Coggeshall Abbey is located between Colchester and Braintree in the County of Essex (Figs 1–3). The Abbey was founded in AD 1140 by King Stephen as a Savignac house but was later converted to the Cistercian order. Following its dissolution in AD 1538 the site continued as a farmstead and house.

Remains of the monastic buildings are to be found on the south side of the farmhouse where they survive mostly as foundations and buried remains. However, the eastern arm of the claustral range still stands and part of the infirmary has been incorporated within Abbey Farm. Surviving, is a vaulted corridor, which originally flanked the eastern dorter range of the cloister and the adjoining Abbot's Lodging (Fig 4). There is also a detached building a few metres south of the abbot's lodging called the Guesthouse and a monastic timber-framed building on the river bank is identified possibly as a boathouse. There are also two post-dissolution barns.

Abbot's Lodging

This rectangular building (Fig 4) is believed to have been an addition to the now demolished dorter range. It is thought that the ground floor would originally have been undivided with the exception of the easternmost bay, as evidenced by one of the bridging beams and a common joist having mortices for a stud partition. It was altered, probably post-dissolution, by dividing stud partitions, which formed three stables at the western end, a tack room, and two rooms used for storage at the eastern end. There are references to an abbot's lodging (and guest house) as early as AD 1194.

Roof

The roof over this building consists of five queen-post trusses with arch braces and clasped purlins (Fig 5). One of the queen posts is heavily weathered and is thought to be a reused medieval timber with moulded decoration. The present roof is believed to be a re-roofing of the late-sixteenth or seventeenth century.

Ground-floor ceiling

This extant ceiling structure consists of four large bridging joists with chamfered angles and step stops. These are supported by posts set against the walls; two of the northern ones are chamfered and have jowls whereas others are clearly reused. Between these main beams are a series of common joists, those in the two western bays mismatched and many showing signs of reuse, whilst those in the three eastern bays are larger and of a higher quality (Fig 6). Four of the existing common joists in the area previously partitioned off (above) are later insertions and are thought to fill the area once occupied by a stair. The use of soffit tenons with diminished haunches and the scribed carpenters' marks suggest construction *c* AD 1500–1600 (Andrews 2014). The absence of joist holes and offsets suggests that any earlier ceiling structure would also have been independently supported.

Corridor

Access between this vaulted passage (Fig 4) and the Abbot's Lodging is provided at both ground- and first-floor levels.

Roof

This roof consists of four principal rafters with tiebeam and collar trusses. There is a single tier of purlins to each slope with windbraces between these and the principal rafters (Fig 7). Some of the common rafters appear to be reused.

Door

To the west side at first-floor level is a three-plank door, thought to belong to the Tudor period (Fig 8).

SAMPLING

Tree-ring dating was requested by Deborah Priddy (Historic England Inspector of Ancient Monuments) to inform listed building consent for conversion of the Abbot's Lodging/Stables into residential accommodation.

A total of 55 core samples were taken from timbers of the roof and ground-floor ceiling of the Abbot's Lodging and the roof of the Corridor; the ring width sequences of the three boards making up the first-floor door in the Corridor were measured directly *in situ* using a graticule. Each core sample was given the code COG-A and numbered 1–55; the *in situ* measurements from the door were coded COG-D and numbered 01–03. The location of all samples was noted at the time of sampling and have been marked on Figures 8–10. Further details relating to the samples can be found in Table 1.

ANALYSIS AND RESULTS

Three samples, one from the Abbot's Lodging roof (COG-A27) and two from the ground-floor ceiling (COG-A50 and COG-A52) had too few rings for secure dating and so were rejected prior to measurement. The remaining 52 core samples were prepared by sanding and polishing and their growth-ring width measured; the data of these measurements, and those from the three door boards, 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, three samples, two from the Abbot's Lodging roof and one from the ground-floor ceiling, matched each other and were combined at the relevant offset positions to form COGASQ01, a site sequence of 130 rings (Fig 11). This site sequence was compared against a series of relevant reference chronologies for oak where it was found to span the period AD 1225–1354. The evidence for this dating is given in Table 2.

Thirty-seven samples, taken from all sampled areas, also grouped and these were combined at the relevant offset positions to form COGASQ02, a site sequence of 196 rings (Fig 12). This site sequence was found to match consistently and securely at a first-ring date of AD 1372 and a last-measured ring date of AD 1567. Evidence for this dating is given in Table 3.

Finally, seven samples (all from the Abbot's Lodging ground-floor ceiling) grouped and were combined at the relevant offset positions to form COGASQ03, a site sequence of 178 rings (Fig 13). Attempts to date this site sequence and the remaining ungrouped samples were unsuccessful and all remain undated.

INTERPRETATION

Tree-ring analysis has resulted in the successful dating of 40 samples. To aid interpretation samples will be discussed by area (Fig 14). All felling date ranges have been calculated using the estimate that mature oak trees in this region have 15–40 sapwood rings.

Abbot's Lodging

Roof

Sixteen of the samples taken from the timbers of the roof have been successfully dated. Two of these samples (COG-A21 and COG-A26) are substantially earlier than the rest of the timbers. These samples match at t=13.0, a value high enough to suggest that both timbers represented may have been cut from the same tree. The presence of the heartwood/sapwood boundary on sample COG-A21 dating to AD 1348 allows an estimated felling date of AD 1363–88 to be calculated for both timbers.

With the possible exception of COG-A28, the remaining timbers are clearly broadly coeval. Sample COG-A25 has a last-measured ring date of AD 1567. This sample was taken from a timber which had complete sapwood but *c* 3mm of the sapwood rings were lost during the sampling process. By estimating the number of rings likely to be present in the lost 3mm it can be seen that *c* 4 rings have been lost giving the timber represented a felling date of *c* AD 1571. Sample COG-A22 matches sample COG-A25 at a value (t=12.1) high enough to suggest that both timbers were cut from the same tree demonstrating sample COG-A22 must also have been felled in *c* AD 1571.

Ten of the other dated samples from the roof have the heartwood/sapwood boundary ring which varies from AD 1524 (COG-A33) to AD 1554 (COG-A36), a difference of 30 years, somewhat greater than one would expect from a group of timbers belonging to a single intensive period of felling. Using the estimate that 95% of mature oak trees in this region have between 15 and 40 sapwood rings it is possible to say that these ten timbers have estimated felling dates which range from AD 1539–64 (COG-A33) to AD 1569–94 (COG-A36) suggesting that more than one period of felling may be represented or that felling was undertaken over an extensive period of time.

The two remaining samples do not have the heartwood/sapwood boundary and so estimated felling dates cannot be calculated for them. With last-measured ring dates of AD 1487 (COG-A28) and AD 1549 (COG-A32), the timbers represented would have *terminus post quem* felling dates of AD 1487 and AD 1564, respectively.

Lintel

The sample taken from the lintel (COG-A35) has a heartwood/sapwood boundary ring date of AD 1523, giving an estimated felling date range for the timber represented of AD 1538–63.

Ground-floor ceiling

Six of the common joists of this structure have been successfully dated. Sample COG-A40 has a heartwood/sapwood boundary ring date of AD 1354, which is substantially earlier than the rest of the dated timbers. This allows an estimated felling date to be calculated for the timber represented to within the range AD 1369–94.

Sample COG-A49 has complete sapwood and the last-measured ring date of AD 1488, the felling date of the timber represented. The other four samples have broadly contemporary heartwood/sapwood boundary ring date. The average of which is AD 1472, allowing an estimated felling date to be calculated for the timbers represented to within the range AD 1487–1512, consistent with an AD 1488 felling date.

Corridor

Roof

Fourteen of the samples taken from this structure have been successfully dated and again, one of these is somewhat earlier than the rest of the timbers. Sample COG-A06 has the earliest heartwood/sapwood boundary ring date at AD 1472, giving an estimated felling date for the timber represented of AD 1487–1512.

Three of the samples have complete sapwood and the last-measured ring date of AD 1549, the felling date of the timbers represented. A fourth sample (COG-A12) has the last-measured ring date of AD 1543; this sample was taken from a timber with complete sapwood but *c* 5mm of these outer rings were lost during the sampling process. By noting how many rings are to be found in the last 5mm of this core it is possible to estimate that *c* 4 rings are missing, giving the timber represented a felling date of *c* AD 1547.

Five samples have similar heartwood/sapwood boundary ring dates, the average of which is AD 1524, giving an estimated felling date range for the timbers represented of AD 1539–64, consistent with a felling in the later AD 1540s. Furthermore, the level of matching seen between these samples and those known to have been felled in AD 1549 is particularly good (Table 4), with potential same tree matches noted between COG-A10, COG-A11, COG-A13, and COG-A15 (all common rafters), as with the Abbot's Lodging roof samples, suggesting a coherent group of timbers of a single programme of felling.

Three samples have somewhat later heartwood/sapwood boundary ring dates, the average of which are AD 1552, allowing an estimated felling date to be calculated for the three timbers represented of AD 1567–92.

The final dated sample (COG-A07) does not have the heartwood/sapwood boundary ring but with a last-measured ring date of AD 1543 the timber represented has a *terminus post quem* felling date of AD 1558 and so could also have been felled in AD 1567–92.

Door

Three of the boards making up this door have been dated. Unfortunately, none of these have the heartwood/sapwood boundary ring dates but bearing in mind the level at which these three samples match (Table 5) it is thought likely that all three boards may have been cut from a single tree, giving them all a *terminus post quem* for felling of AD 1527.

DISCUSSION

All of the dated timbers appear likely to have originated in relatively local woodlands as indicated by the high similarity shown by both dated site sequences (COGASQ01 and COGASQ02) to site reference chronologies from Essex and the surrounding counties (Tables 2 and 3).

The earliest timbers identified by the dendrochronology are found within the Abbot's Lodging where a ground-floor ceiling joist has been dated to AD 1369–94 and two roof timbers (both collars) to AD 1363–88 (Figs 11 and 14). All three of these timbers are thought to be reused in their current locations and indeed the joist is located in a part of the ceiling thought to have originally contained the staircase. Sample COG-A40 matches one of the early roof samples (COG-A21) particularly well (*t*=7.1) and, combined with the similarity in felling date ranges, it is possible that all three timbers may relate to the same earlier structure.

The remaining dated timbers of the ceiling structure of the Abbot's Lodging are now known to have been felled in AD 1488 (Figs 12 and 14), with construction of this ceiling thought likely to have occurred shortly after. This would make the ceiling slightly earlier than previously believed (*c* AD 1500–1600).

A single timber, a collar from the roof of the Corridor, dates to AD 1487–1512, making it potentially of the same date as the timbers of the ground-floor ceiling of the Abbot's Lodging (Figs 12 and 14). The majority of the dated timbers in this roof appear to have been felled in AD 1549. However, three, and probably four, other timbers are a little later with an estimated felling date range of AD 1567–92 and hence may be coeval with the *c* AD 1571 felling identified for the majority of the dated timbers from the roof of the Abbot's Lodging.

The three dated boards of the first-floor door in the Corridor are all thought to have been felled some time after AD 1527 (Figs 12 and 14). This makes it possible that the door relates to the same period as the roof of this part of the building (AD 1549). Alternatively, it may represent a totally different phase of work.

The extant roof over the Abbot's Lodging was thought to be a re-roofing of the late sixteenth or seventeenth century. One of the timbers from the roof appears likely to be either heavily trimmed or felled somewhat earlier than the majority of the timbers and subsequently reused. It has a *terminus post quem* felling of AD 1487 which raises the possibility that this timber is coeval with the ground-floor ceiling timbers (felled AD 1488) and the early timber in the Corridor roof (felled AD 1487–1512) (Figs 12 and 14). However, the majority of the timber utilised within this roof dates to the mid- to late-sixteenth century (Figs 12 and 14). At least two of these timbers are known to have been felled in *c* AD 1571, whilst the rest of this sixteenth-century timber has felling dates ranging from AD 1539–64 to AD 1569–94. It is possible that the majority of the timbers were felled in *c* AD 1571, particularly if some of those dated had more than the usual number of sapwood rings, but it is also possible that felling of the timbers occurred over an extended period of time perhaps in the AD 1560s and early AD 1570s. The alternative possibility is that some of the timbers used in the extant roof are slightly earlier and could actually be coeval with those from the Corridor roof felled in AD 1549.

The dated lintel in the Abbot's Lodging was felled in AD 1538–63, a felling date range which is very similar to that of the potentially slightly earlier timbers in the roof and again raises the possibility that it is coeval with the Corridor roof timbers felled in AD 1549.

It is, therefore, possible to suggest that there may only be four felling phases represented but that each of the areas analysed includes timbers representing more than one period of felling (Figs 11, 12, and 14). The felling phases being late-fourteenth century (Abbot's

Lodging roof and Abbot's Lodging ceiling), late AD 1480s (Abbot's Lodging ceiling, Abbot's Lodging roof, and Corridor roof), late AD 1540s (Corridor roof and Abbot's Lodging roof), and finally early AD 1570s (Abbot's Lodging roof and Corridor roof) with the Corridor door being potentially associated with either of the two sixteenth-century felling phases.

It is unfortunate that site sequence COGASQ03 could not be dated. It can be seen (Table 6) that the components of this site sequence match each other extremely well and are almost certainly cut from a single tree. This may be the reason for the lack of dating as, rather than trying to match an averaged growth pattern against the reference material, we are in effect trying to match the growth pattern of a single tree, which is always less likely to be successful.

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TABLES

Table 1: Details of tree-ring samples from The Abbot's Lodging and Corridor, Coggleshall Abbey, Essex

Sample number	Sample location	Total rings*	Sapwood rings**	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
Corridor						
COG-A01	Collar, truss 1 (from north)	104	h/s	1417	1520	1520
COG-A02	East wallplate, truss 1–2	110	h/s	1439	1548	1548
COG-A03	Tiebeam, truss 2	103	h/s	1449	1551	1551
COG-A04	West purlin, truss 2–3	98	h/s	1459	1556	1556
COG-A05	East purlin, truss 3–4	74	h/s	----	----	----
COG-A06	Collar, truss 4	101	h/s	1372	1472	1472
COG-A07	West principal rafter, truss 4	56	--	1488	----	1543
COG-A08	Lower middle stud post, truss 5	115	h/s	1409	1523	1523
COG-A09	Lower west stud post, truss 5	138	h/s	1388	1525	1525
COG-A10	East common rafter1, bay 1	141	23C	1409	1526	1549
COG-A11	West common rafter 1, bay 1	123	11	1414	1525	1536
COG-A12	West common rafter 4, bay 1	90	08c(+*c*4lost)	1454	1535	1543
COG-A13	East common rafter 3, bay 2	104	23C	1446	1526	1549
COG-A14	West common rafter 4, bay 2	59	h/s	1467	1525	1525
COG-A15	East common rafter 5, bay 2	128	23C	1422	1526	1549
First-floor ha-ha door to corridor						
COG-D01	Upper door, closing board	105	--	1380	----	1484
COG-D02	Upper door, middle board	95	--	1388	----	1482
COG-D03	Upper door, hanging board	123	--	1390	----	1512
Abbots Lodging						
Roof and lintel						
COG-A16	Tiebeam, truss 2	157	h/s	1385	1541	1541
COG-A17	Tiebeam, truss 3	149	h/s	----	----	----
COG-A18	Tiebeam, truss 4	83	h/s	----	----	----
COG-A19	Tiebeam, truss 5	83	h/s	1464	1546	1546

COG-A20	Tiebeam, truss 6	109	h/s	1433	1541	1541
COG-A21	Collar, truss 1	124	h/s	1225	1348	1348
COG-A22	Collar, truss 2	62	h/s	1495	1556	1556
COG-A23	Collar, truss 3	72	h/s	1471	1542	1542
COG-A24	Collar, truss 4	91	h/s	1444	1534	1534
COG-A25	Collar, truss 5	85	15+4lost	1483	1552	1567
COG-A26	Collar, truss 6	99	--	1229	----	1327
COG-A27	South queen strut, truss 3	NM	--	----	----	----
COG-A28	King stud, truss 6	95	--	1378	----	1472
COG-A29	North stud post, truss 6	107	h/s	1426	1532	1532
COG-A30	South stud post, truss 6	80	--	----	----	----
COG-A31	Lintel to east window	89	01	----	----	----
COG-A32	West windbrace, north principal rafter, truss 4	48	--	1502	----	1549
COG-A33	West windbrace, south principal rafter, truss 4	78	h/s	1447	1524	1524
COG-A34	East windbrace, north principal rafter, truss 6	55	h/s	1488	1542	1542
COG-A35	North window lintel	112	h/s	1412	1523	1523
COG-A36	North wall plate, truss 1–2	92	h/s	1463	1554	1554
COG-A37	North wall plate, truss 5–6	84	h/s	1447	1530	1530
Ground-floor ceiling						
COG-A38	Joist 3, bay 1	52	--	----	----	----
COG-A39	Joist 4, bay 1	134	01	----	----	----
COG-A40	Joist 6, bay 1	78	h/s	1277	1354	1354
COG-A41	Joist 9, bay 1	90	--	----	----	----
COG-A42	Joist 11, bay 1	47	--	----	----	----
COG-A43	Joist 12, bay 1	126	h/s	----	----	----
COG-A44	Joist 13, bay 1	45	h/s	1426	1470	1470
COG-A45	Joist 14, bay 1	85	--	----	----	----
COG-A46	Joist 15, bay 1	111	--	----	----	----
COG-A47	Joist 16, bay 1	110	h/s	----	----	----
COG-A48	North post supporting main beam 3	48	--	----	----	----
COG-A49	Joist 3, bay 2	46	14C	1443	1474	1488
COG-A50	Joist 5, bay 2	NM	--	----	----	----

COG-A51	Joist 7, bay 2	48	h/s	1423	1470	1470
COG-A52	Joist 9, bay 2	NM	--	----	----	----
COG-A53	Joist 10, bay 2	53	09	1432	1475	1484
COG-A54	Joist 11, bay 2	47	01	1427	1472	1473
COG-A55	Joist 15, bay 2	56	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 COGASQ01 and relevant reference chronologies when the first-ring date is AD 1225 and the last-measured ring date is AD 1354

Reference chronology	*t*-value	Span of chronology	Reference
Reading Waterfront, Berkshire	11.0	AD 1160–1407	Groves *et al* 1997
Chicksands Priory, Bedfordshire	9.8	AD 1200–1541	Howard *et al* 1998
St Laurence's Church, Blackmore, Essex	9.6	AD 1266–1399	Miles *et al* 2005
St Martin's Church, Colchester, Essex	9.4	AD 1218–1349	Tyers 1998
St George of England Church, Toddington, Bedfordshire	9.3	AD 1226–1392	Bridge 2001a
Normans Hall, Wakes Colne, Essex	8.6	AD 1229–1368	Tyers *et al* 2003
St Leonard's Church, Apethorpe, Northamptonshire	8.5	AD 1211–1403	Arnold and Howard 2008
St Thomas the Apostle Church, Navestock, Essex	8.4	AD 1201–1355	Tyers 1999a

Table 3: Results of the cross-matching of site sequence COGASQ02 and relevant reference chronologies when the first-ring date is AD 1372 and the last-measured ring date is AD 1567

Reference chronology	*t*-value	Span of chronology	Reference
Hays Wharf, Southwark, London	12.2	AD 1248–1647	Tyers 1996a; Tyers 1996b
Priory Barn, Little Wymondley, Bedfordshire	11.3	AD 1450–1540	Bridge 2001b
Chicksands Priory, Bedfordshire	10.7	AD 1200–1541	Howard *et al* 1998
Moyns Park, Birdbrook, Essex	10.2	AD 1450–1540	Tyers 1999b
Gosfield Hall, Essex	9.4	AD 1449–1537	Bridge 1998
Dannys House, West Sussex	9.1	AD 1389–1589	Miles *et al* 2010
Newnham Hall Farm – The Cottage	9.1	AD 1414–1551	Arnold and Howard 2006 unpubl
Lawns Farm, Great Leigh, Essex	8.8	AD 1377–1536	Miles *et al* 2004

Table 4: Matrix to show the level of t*-value matching and offsets between dated samples from the Corridor roof; values of* t*=10.0+ are likely to represent timbers cut from the same tree;* **- -** *indicates no overlap or a not statistically significant* t*-value between samples (*t*-values below, offsets above; ie the offsets between COG-A01 and COG-A03 is -32 years and the* t*-value between these ring series is 4.5)*

		1	2	3	4	5	6	7	8	9	10	11	12	13	14
COG-A01	1	***	-22	-32	-42	45	--	--	29	8	3	-37	-29	-50	-5
COG-A02	2	3.7	***	--	-20	--	-49	--	51	--	--	-15	-7	-28	
COG-A03	3	**4.5**	--	***	--	53	-39	40	--	40	35	-5	3	--	27
COG-A04	4	**4.6**	2.9	--	***	11	-29	50	71	50	--	5	13	-8	37
COG-A06	5	**4.7**	--	--	3.4	***	--	--	--	-37	-42	--	--	--	--
COG-A07	6	--	**5.0**	3.2	2.9	--	***	--	--	--	--	34	42	--	--
COG-A08	7	--	--	3.5	**6.2**	--	--	***	--	0	-5	-45	-37	-58	-13
COG-A09	8	**7.1**	3.2	--	**5.1**	--	--	--	***	-21	-26	-66	-58	-79	-34
COG-A10	9	**6.8**	--	3.8	**4.0**	3.7	--	**5.8**	**6.1**	***	-5	-45	-37	15	-13
COG-A11	10	**6.1**	--	2.8	--	3.7	--	**5.5**	**4.7**	**14.3**	***	-40	-32	--	-8
COG-A12	11	**7.6**	**5.8**	**4.5**	**6.2**	--	**5.4**	**5.5**	**5.0**	**4.5**	**4.2**	***	8	-13	32
COG-A13	12	**5.0**	2.8	3.6	**6.6**	--	2.8	**4.9**	**6.7**	**11.3**	**10.0**	**6.5**	***	-21	24
COG-A14	13	**5.5**	**6.1**	--	**4.8**	--	--	3.2	**4.6**	3.7	--	**7.0**	**4.0**	***	--
COG-A15	14	**5.5**	--	3.1	3.4	--	--	**5.0**	**6.1**	**11.3**	**13.1**	**5.4**	**11.4**	--	***

Table 5: Matrix to show the level of t-value matchingand offsets between samples from the Corridor door (t-values below; offsets above)

		1	2	3
COG-D01	1	***	-8	-10
COG-D02	2	9.8	***	-2
COG-D03	3	9.8	12.1	***

Table 6: Matrix to show the level of t-value matching and offsets between components of site sequence COGASQ03- indicates no overlap or a not statistically significant t-value between samples (t-values below; offsets above)

		1	2	3	4	5	6	7
COG-A38	1	***	--	-25	--	--	-15	--
COG-A39	2	--	***	19	-4	-5	29	-18
COG-A41	3	7.8	10.8	***	-23	-24	10	-37
COG-A43	4	--	13.7	14.3	***	-1	33	-14
COG-A45	5	--	12.1	12.7	15.1	***	34	-13
COG-A46	6	12.2	13.6	12.7	14.8	12.9	***	-47
COG-A47	7	--	13.7	10.2	14.1	8.2	10.5	***

FIGURES

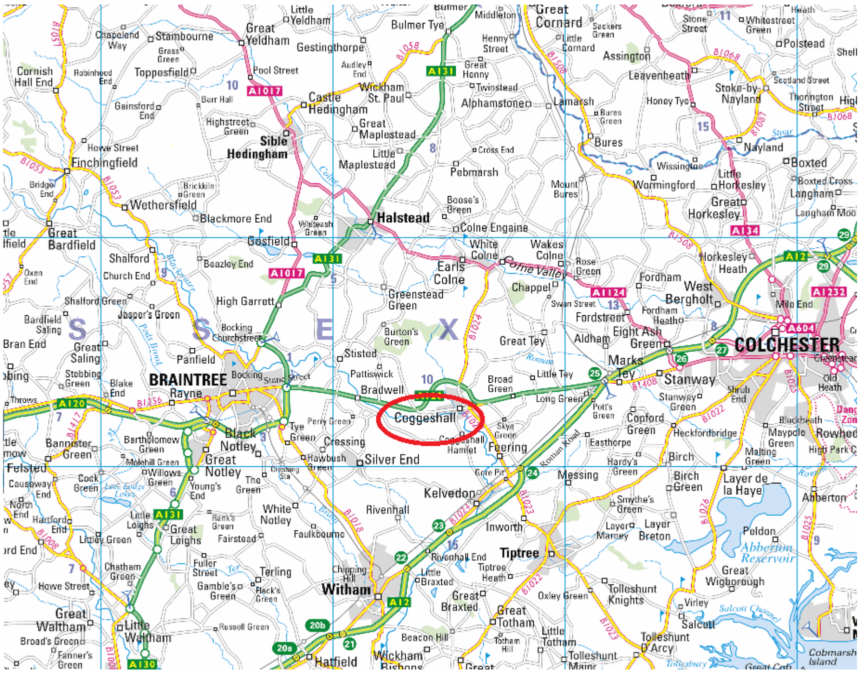

Figure 1: Map to show the general location of Coggeshall, circled. © Crown Copyright and database right 2015. All rights reserved. Ordnance Survey Licence number 100024900

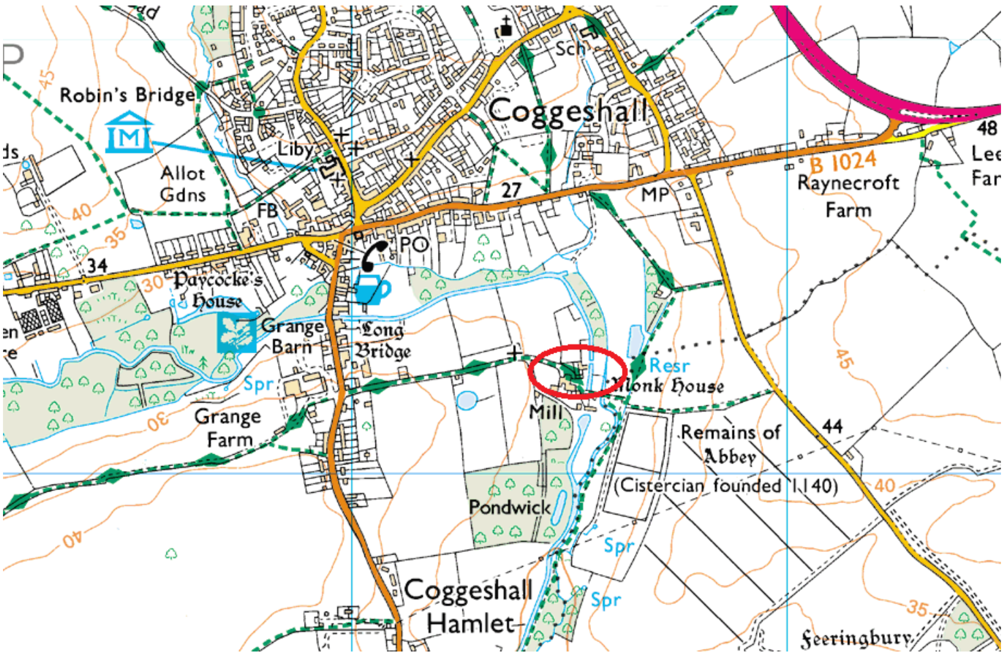

Figure 2: Map to show the location of Coggeshall Abbey, circled. © Crown Copyright and database right 2015. All rights reserved. Ordnance Survey Licence number 100024900

Figure 3: Map to show the location of the Abbot's Lodging and Corridor of Coggeshall Abbey.

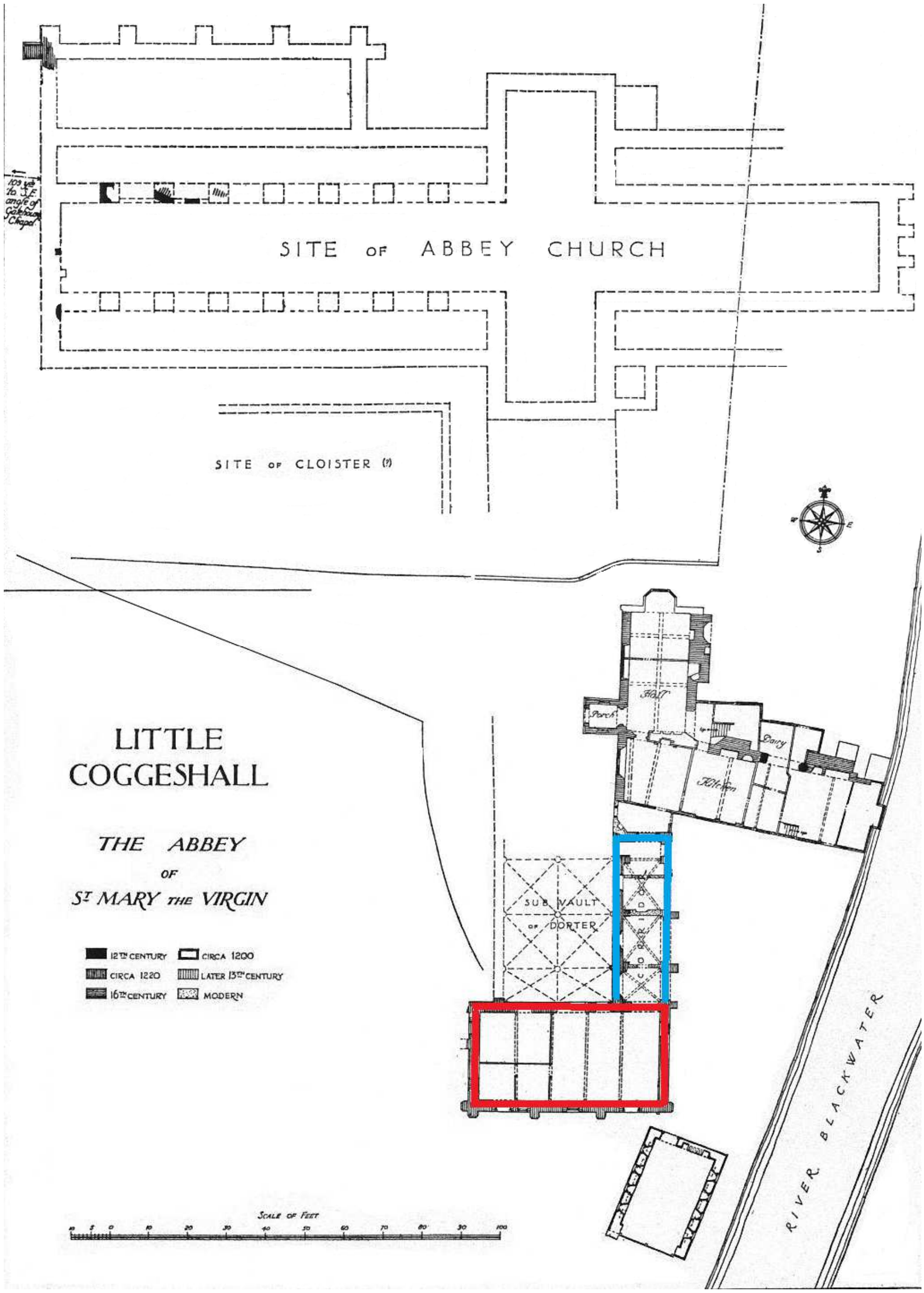

Figure 4: Plan of Coggeshall Abbey, with the Abbot's Lodging outlined in red and the Corridor in blue (RCHM 1922)

Figure 5: Abbot's Lodging roof, photograph taken from the north-west (Alison Arnold)

Figure 6: Abbot's Lodging ground-floor ceiling frame, photograph taken from the south-east (Alison Arnold)

Figure 7: Corridor roof, photograph taken from the south (Alison Arnold)

Figure 8: Corridor door, showing the location of samples COG-D01–03, photograph taken from the south (Alison Arnold)

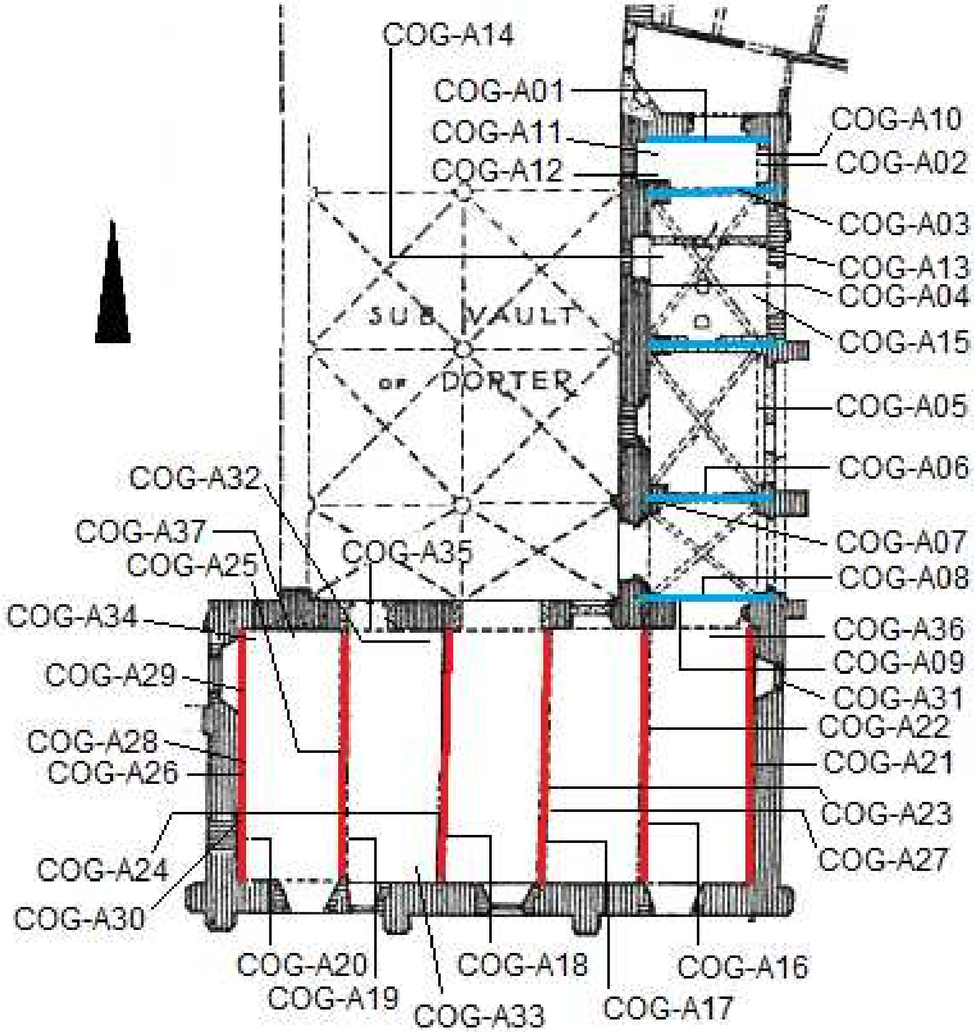

Figure 9: Plan, showing the location of samples COG-A01–15 and COG-A16–37 (after RCHM 1922)

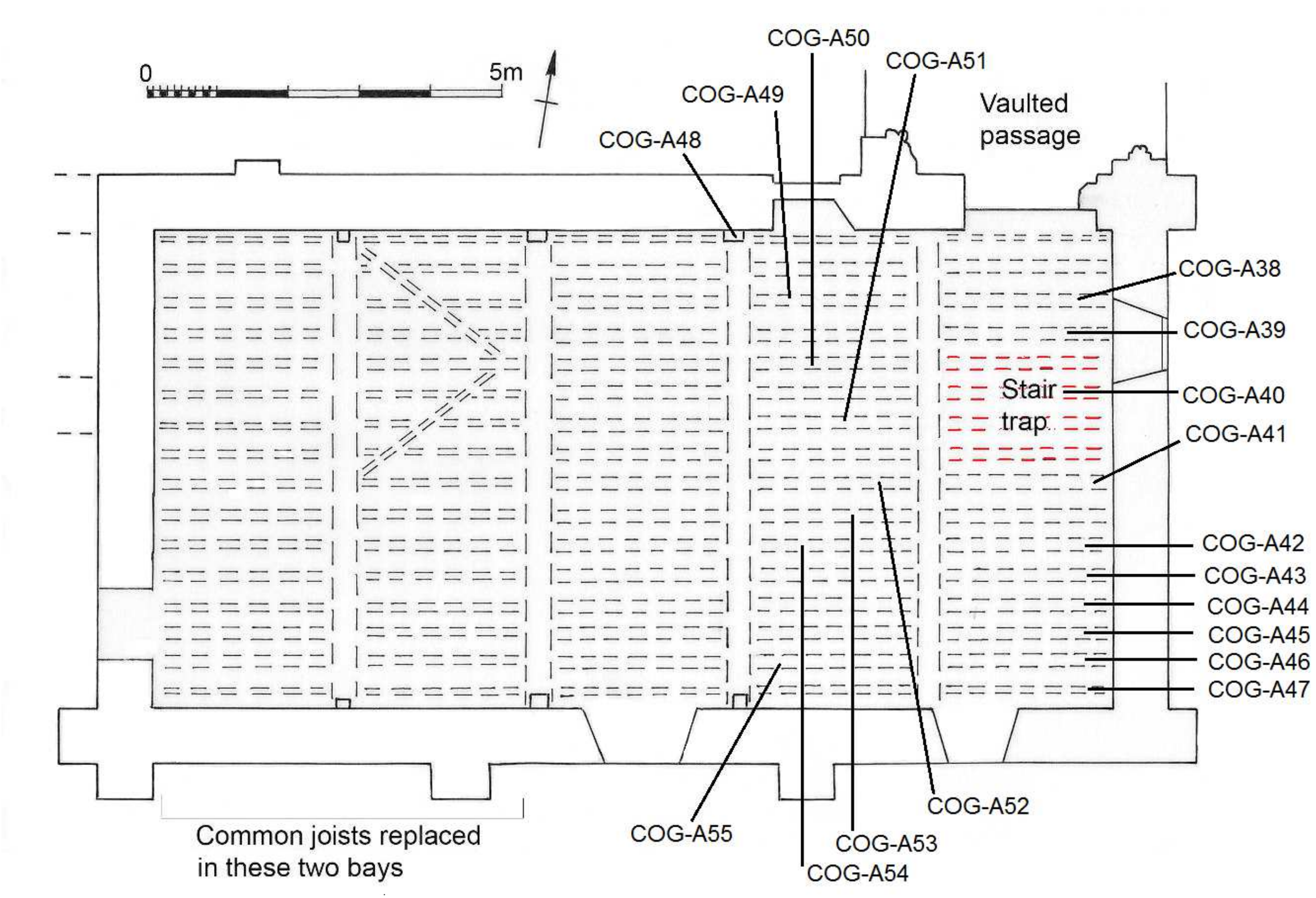

Figure 10: Abbot's Lodging plan showing the location of samples COG-38–55 (after Andrews 2014)

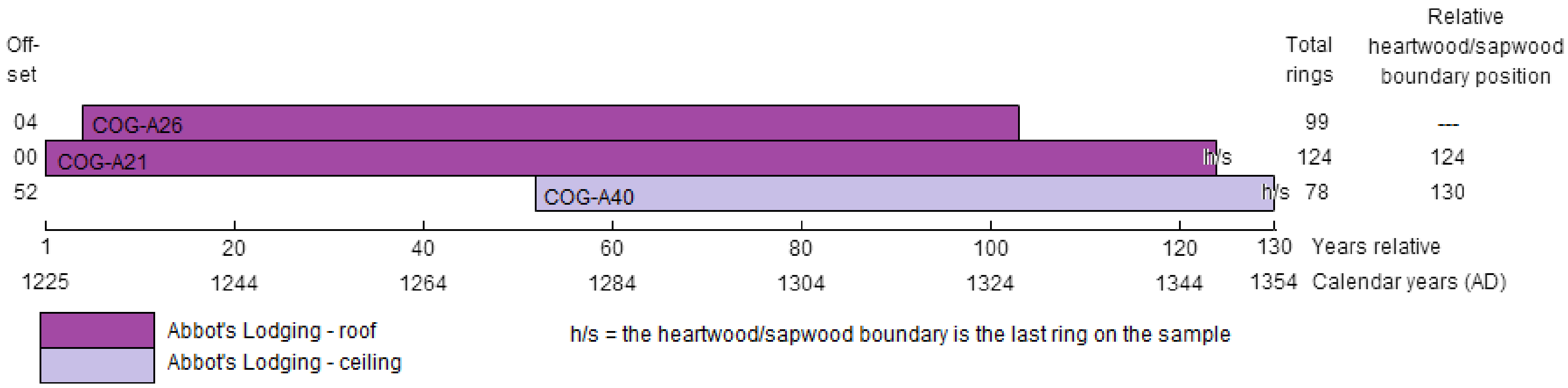

Figure 11: Bar diagram of samples in site sequence COGASQ01

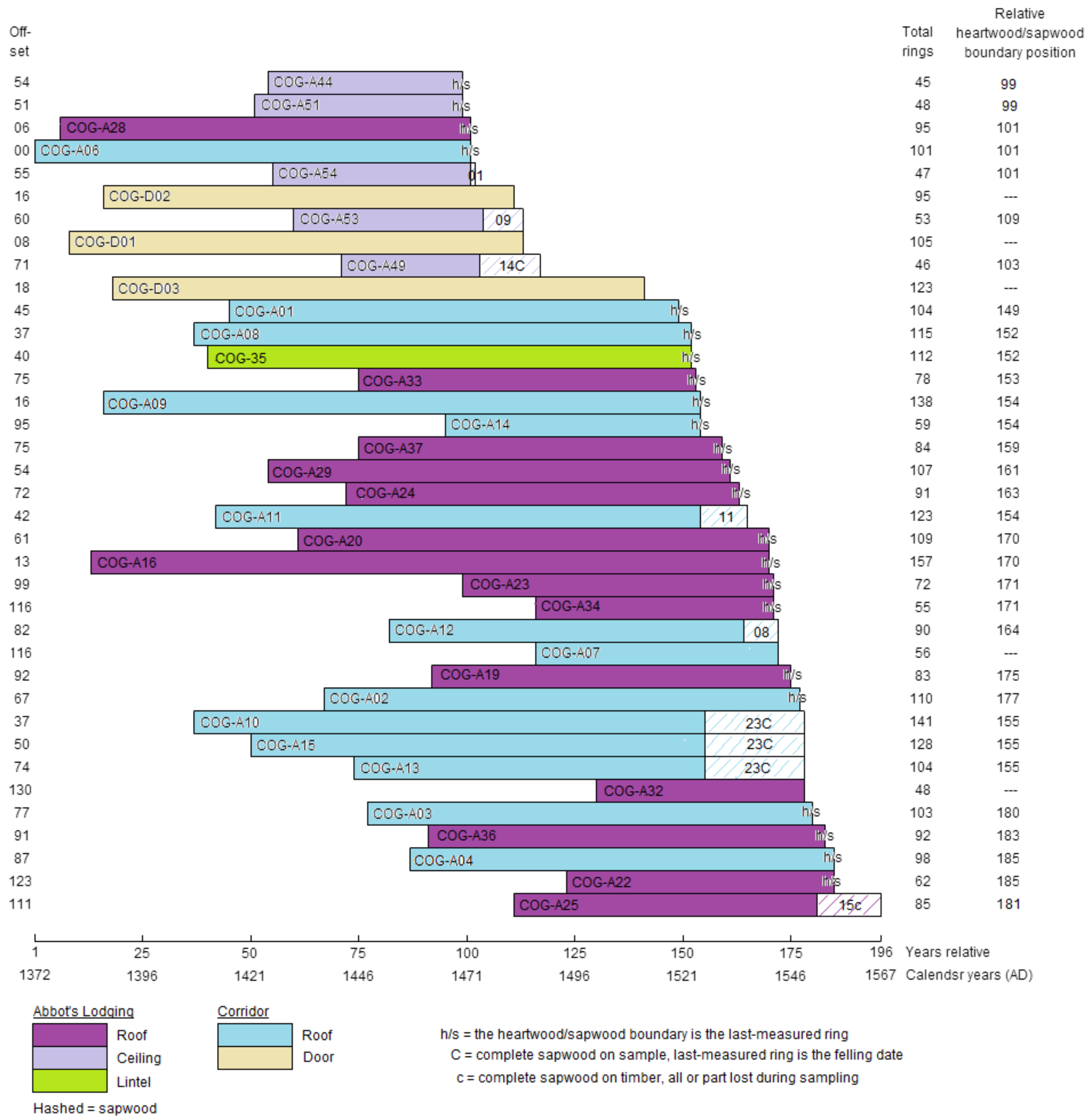

Figure 12: Bar diagram of samples in site sequence COGASQ02

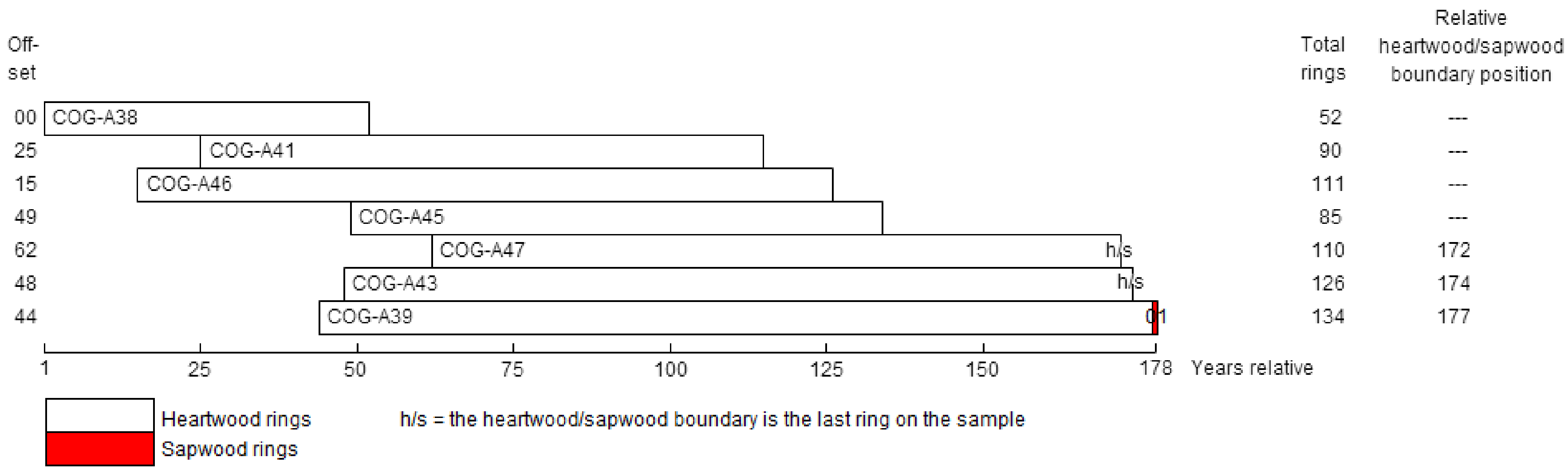

Figure 13: Bar diagram of samples, all from the Abbot's Lodging ground-floor ceiling, in undated site sequence COGASQ03

Figure 14: Bar diagram of all dated samples, sorted by area

DATA OF MEASURED SAMPLES

Measurements in 0.01mm units with the exception of samples COG-D01–03 which are in 0.1mm

COG-A01A 104
204 221 224 340 255 275 345 322 373 197 194 287 375 255 331 338 266 186 167 192
268 275 231 232 198 215 135 122 144 203 207 108 132 150 123 116 142 154 151 136
101 131 136 179 148 154 151 125 155 141 109 123 141 173 128 133 126 135 163 146
106 111 135 148 155 94 93 83 71 98 139 79 89 134 95 94 89 101 101 109
85 66 63 80 57 57 38 55 76 87 62 64 73 76 94 122 93 105 123 125
72 108 139 93
COG-A01B 104
203 216 226 339 263 259 352 318 370 190 188 282 380 266 326 332 262 187 172 183
288 267 247 234 193 203 125 131 147 202 205 112 128 150 129 114 140 166 157 133
107 128 128 181 151 151 157 121 165 132 112 132 144 170 130 128 125 131 166 146
112 102 129 146 156 87 105 82 69 99 135 69 98 137 83 90 88 102 97 122
88 56 65 86 55 53 50 57 80 95 61 64 73 83 104 120 95 109 117 112
68 115 137 93
COG-A02A 110
124 175 258 287 283 187 140 140 117 96 98 55 54 43 43 25 21 37 25 21
40 94 29 71 115 73 68 41 44 43 49 78 60 47 67 50 62 48 49 33
43 50 43 29 50 52 34 25 35 36 34 43 29 37 59 92 117 136 134 98
79 123 128 88 131 181 246 206 121 138 149 122 176 219 175 155 197 181 116 146
175 118 68 170 102 177 114 135 110 123 120 110 123 104 85 69 154 123 89 80
95 67 49 50 80 62 113 126 143 115
COG-A02B 110
126 173 254 291 286 195 134 141 126 89 92 59 59 38 37 27 22 41 24 24
30 102 29 64 114 73 61 48 42 37 61 72 63 41 57 60 81 46 40 33
41 43 29 34 36 49 32 40 41 37 36 35 39 33 49 102 125 148 140 100
89 122 124 94 142 195 250 215 137 130 164 108 161 198 174 151 175 175 119 143
173 116 85 169 117 189 122 136 122 119 117 109 126 98 82 66 153 109 88 84
97 81 47 57 70 61 128 133 130 146
COG-A03A 103
196 185 156 184 175 226 158 189 170 126 116 143 156 140 100 72 99 279 151 99
140 109 75 71 73 74 86 76 69 56 84 90 78 62 57 42 48 77 95 100
117 138 99 91 85 126 225 411 377 163 208 180 74 109 113 109 106 145 102 114
115 72 150 151 161 136 179 158 101 162 145 127 104 76 132 147 71 145 155 175
144 128 196 154 120 138 232 127 98 98 173 121 123 87 99 76 134 110 88 139
150 95 115
COG-A03B 103
237 192 164 185 156 216 164 185 172 135 113 140 152 145 102 69 101 276 155 98
137 112 77 77 68 78 79 79 64 62 81 81 86 54 63 48 42 83 93 102
114 138 106 82 91 118 236 399 383 166 199 186 77 116 109 116 106 144 105 112
111 74 154 144 167 136 177 160 98 162 146 127 100 81 119 140 69 141 158 170
143 128 195 155 129 148 232 131 95 104 167 125 121 84 101 79 126 109 94 123
154 95 93

COG-A04A 98
120 120 104 124 111 131 166 118 116 150 144 110 130 102 118 171 176 140 108 107
128 134 175 132 109 146 125 115 159 143 141 142 107 117 115 124 137 248 173 125
111 109 87 74 82 103 114 121 110 118 119 137 124 120 116 123 155 161 116 136
198 168 176 203 142 143 150 123 103 132 128 119 154 116 129 134 158 137 171 172
175 172 176 97 128 118 150 146 111 141 178 149 160 127 180 199 166 166
COG-A04B 98
112 125 98 123 110 127 175 122 108 143 142 124 115 112 121 171 170 137 96 117
119 135 174 131 116 140 121 118 147 144 132 146 108 109 115 132 132 230 166 122
107 111 84 83 71 109 109 122 114 118 114 142 124 111 118 126 149 163 121 130
187 171 176 205 145 139 144 116 112 131 121 124 165 107 126 130 159 138 176 171
173 175 173 95 127 125 146 138 112 136 178 145 162 124 179 194 170 182
COG-A05A 74
134 183 188 134 179 164 172 183 183 231 220 231 205 154 102 79 123 137 182 194
135 157 111 114 73 82 106 130 57 65 57 53 47 61 54 52 56 64 40 43
73 56 73 53 41 46 44 38 32 27 26 31 34 30 18 32 33 39 35 37
38 34 55 49 71 93 69 76 83 87 107 99 150 114
COG-A05B 74
128 187 189 138 171 158 164 181 190 228 217 213 211 150 112 93 117 138 182 183
139 152 105 107 72 81 111 123 71 63 53 53 48 62 51 54 54 53 50 44
59 59 71 57 45 51 47 41 33 27 26 21 29 31 24 34 31 36 34 37
43 30 52 55 65 82 68 81 80 93 109 115 129 111
COG-A06A 101
324 211 213 91 128 125 207 280 289 258 256 171 139 211 179 217 264 242 155 113
117 176 165 233 202 141 172 191 172 99 143 129 169 171 170 104 114 99 153 187
162 137 94 112 109 86 75 77 147 121 100 154 149 105 80 71 109 124 106 164
151 139 138 85 100 96 115 95 70 73 91 74 70 67 76 66 69 70 101 102
90 67 85 86 107 104 86 84 79 64 63 72 52 54 42 33 37 35 37 40
26
COG-A06B 101
332 216 202 98 139 119 216 254 287 253 264 167 139 221 173 219 261 240 157 111
119 175 164 233 206 145 170 188 177 101 140 114 170 178 170 104 113 97 152 188
165 129 104 114 113 85 85 74 141 122 101 152 149 116 79 70 106 124 107 163
154 144 136 86 100 95 119 95 73 65 94 73 62 75 90 67 78 73 104 100
93 66 84 95 111 106 86 93 83 73 71 65 52 63 40 34 42 38 35 42
33
COG-A07A 56
119 36 102 100 128 108 231 194 230 161 98 100 164 198 132 104 225 272 220 173
154 188 285 291 235 190 185 188 173 68 282 201 108 117 155 128 195 115 267 293
333 338 288 352 294 258 363 627 334 428 345 556 349 345 341 314
COG-A07B 56
107 43 104 105 122 104 223 192 216 168 87 113 177 192 131 98 235 257 215 176
180 214 274 292 244 192 161 160 164 71 286 199 109 124 152 125 197 116 275 284
330 351 293 337 289 260 367 630 331 416 352 551 340 342 343 390
COG-A08A 115
389 308 371 331 327 170 211 172 144 112 83 63 63 45 64 84 59 50 46 39
46 45 43 75 55 72 61 41 64 59 86 63 70 56 51 39 57 81 139 102
177 179 151 121 106 120 128 140 132 105 67 99 106 75 87 73 106 98 79 145
123 125 76 118 151 208 280 177 118 108 165 115 153 150 146 108 133 115 202 195
158 181 79 100 86 113 68 159 128 62 68 78 69 84 77 88 94 92 78 81
63 102 94 119 94 90 120 111 80 121 147 148 164 215 166

COG-A08B 115
407 321 345 362 328 187 193 180 144 119 72 69 62 45 67 86 58 52 45 38
51 36 39 77 63 72 57 47 50 61 88 58 70 68 50 41 54 84 132 102
184 174 144 112 98 109 116 119 126 115 67 105 102 79 81 81 99 105 75 138
131 118 76 122 154 208 277 177 122 122 171 106 169 148 151 108 123 121 212 200
168 171 95 92 94 118 68 175 127 57 72 67 63 86 75 87 97 94 85 74
66 100 115 106 105 88 131 113 75 139 145 120 129 214 172
COG-A09A 138
191 146 209 210 231 315 325 342 401 333 258 186 126 142 137 209 221 181 226 191
171 138 178 152 116 85 122 142 120 98 87 95 103 139 126 143 131 118 97 91
138 121 112 112 126 91 71 69 90 118 128 87 87 72 78 101 87 69 73 72
60 64 60 65 64 66 65 75 61 74 72 76 92 84 80 83 77 104 64 46
52 76 81 93 64 78 67 83 55 42 48 45 59 79 43 48 47 35 68 103
75 95 88 80 73 61 55 65 96 67 50 58 53 45 36 42 57 72 90 72
71 68 52 95 104 81 67 69 111 94 87 100 79 58 101 81 110 96
COG-A09B 138
205 150 207 209 235 317 325 341 404 343 250 181 136 138 137 215 218 180 229 190
172 140 177 147 117 91 125 142 117 100 83 98 102 136 127 143 135 116 99 92
136 125 111 109 125 100 64 66 90 119 128 86 85 73 77 106 79 72 78 73
52 67 64 65 62 65 67 74 62 72 75 75 95 90 82 84 73 99 59 51
48 74 81 87 66 80 72 75 59 43 45 50 47 78 42 46 57 44 69 113
76 101 82 84 67 64 56 61 101 62 46 57 54 42 37 40 52 72 90 71
67 65 61 96 99 82 73 64 110 90 96 93 80 67 98 85 105 75
COG-A10A 141
126 86 134 134 170 150 164 134 108 120 87 108 91 82 112 123 84 58 55 82
93 80 91 167 129 121 105 104 109 108 110 83 87 97 68 42 72 71 69 46
77 45 52 75 85 76 69 61 85 88 74 89 99 76 83 75 102 97 79 115
95 103 96 112 120 110 139 111 67 84 102 136 147 116 95 89 72 87 89 78
102 110 71 80 69 76 63 98 70 71 73 71 71 69 64 86 78 87 58 47
59 41 77 95 88 88 76 101 78 98 98 70 51 78 59 74 54 64 68 71
56 64 83 79 54 65 76 89 97 96 85 64 77 49 80 72 75 70 73 81
96
COG-A10B 141
129 84 136 135 169 153 155 136 115 112 90 111 89 85 114 125 81 60 56 87
90 80 98 175 131 117 105 107 107 117 108 85 86 97 78 42 58 82 68 54
71 45 58 70 81 84 67 70 79 92 74 95 94 82 84 75 93 98 79 110
102 104 93 115 117 112 137 110 69 86 90 128 132 112 94 86 76 87 88 78
100 107 78 93 63 94 72 109 78 74 73 72 74 67 75 80 74 87 55 50
63 44 71 101 86 84 79 105 77 104 87 73 45 80 50 72 53 52 59 61
54 66 86 76 58 70 78 86 113 85 84 68 74 60 83 62 82 60 76 85
100
COG-A11A 123
192 173 145 101 122 99 123 108 80 98 115 69 55 57 88 109 80 95 158 115
104 115 95 115 148 163 109 111 143 76 64 70 74 91 52 88 58 51 85 76
91 78 65 67 81 87 77 103 98 130 111 131 140 90 134 146 135 137 169 219
149 183 111 104 112 150 196 210 189 174 157 123 140 143 132 122 154 115 113 106
180 110 171 102 103 106 115 94 101 105 121 100 100 73 63 72 58 82 98 89
109 88 132 98 117 83 64 53 69 51 81 53 60 55 62 60 62 82 76 75
57 81 85

COG-A11B 123
201 171 151 105 117 105 123 101 85 91 117 77 60 48 100 105 92 92 160 122
103 108 102 108 149 163 117 112 139 82 62 67 74 80 56 81 62 55 75 86
78 81 65 69 78 91 79 104 94 134 119 136 138 103 141 124 142 133 166 220
152 187 112 101 113 155 198 209 196 170 149 127 140 138 141 113 153 94 119 102
175 113 166 100 98 113 109 99 99 103 125 95 99 81 61 71 58 83 96 92
107 85 140 96 116 85 64 48 68 55 76 57 52 54 63 55 60 80 83 64
57 81 84
COG-A12A 90
129 148 142 79 89 106 94 102 82 87 71 81 77 65 90 107 138 123 86 107
133 160 129 71 103 117 101 106 85 92 90 79 112 157 136 144 187 126 131 136
153 155 210 198 120 106 117 117 111 131 152 181 194 179 153 168 167 143 151 155
122 186 198 100 130 156 121 109 157 160 178 119 148 159 199 154 135 161 143 121
101 201 135 144 124 147 137 121 97 148
COG-A12B 90
151 147 137 78 95 103 94 97 85 86 66 84 75 66 99 95 141 118 93 104
137 162 125 73 107 117 103 108 87 90 97 73 113 154 135 143 185 126 128 140
151 159 210 209 108 102 119 117 112 127 153 181 191 181 156 163 167 145 153 150
126 180 198 99 128 159 118 106 191 125 177 117 147 156 199 157 140 164 136 121
106 194 150 130 119 155 130 119 101 146
COG-A13A 104
92 88 54 69 56 50 76 84 71 54 47 73 89 77 106 130 114 110 93 142
133 113 146 142 164 148 131 162 170 222 129 104 114 147 153 191 169 136 111 90
102 122 117 112 133 86 103 91 123 100 174 101 100 105 107 81 82 82 103 96
104 72 53 58 57 57 64 60 67 67 110 82 97 97 68 43 86 51 78 57
66 52 56 51 47 63 57 49 45 49 50 60 42 60 57 74 44 84 81 110
95 93 129 133
COG-A13B 104
92 95 49 68 60 45 75 96 63 55 58 62 88 83 105 119 115 102 97 142
135 114 146 132 162 144 131 158 169 225 129 108 112 152 146 192 170 134 113 88
105 123 114 113 135 90 94 94 123 102 171 102 99 108 105 77 79 67 104 93
100 76 57 69 47 62 62 55 68 62 111 78 86 97 75 44 77 59 80 48
64 52 56 49 50 62 56 52 40 49 56 56 44 59 58 68 40 86 86 92
113 93 127 153
COG-A14A 59
86 113 145 167 162 131 163 143 128 106 78 81 71 115 125 94 96 79 68 80
85 89 82 123 136 119 158 164 140 172 156 102 94 121 115 82 102 91 137 158
142 142 157 163 143 167 150 111 169 192 127 178 211 147 147 201 147 190 132
COG-A14B 59
91 110 146 167 162 129 166 145 130 102 83 73 77 111 127 88 97 81 76 69
87 81 95 117 144 120 161 162 149 162 164 97 102 115 112 80 100 103 129 157
137 139 164 164 147 174 144 110 166 198 126 174 207 152 149 196 144 196 136
COG-A15A 128
58 99 104 84 55 51 71 83 54 83 169 172 122 103 108 94 136 107 107 88
104 91 46 65 70 98 51 68 55 41 77 80 65 69 52 57 89 63 80 91
97 78 77 95 92 81 109 89 124 97 95 149 95 132 82 57 81 94 100 117
108 85 73 58 80 74 71 94 91 69 73 70 100 74 112 65 57 69 79 52
77 73 60 68 62 65 58 47 43 60 65 64 67 52 98 64 87 76 63 39
88 45 91 64 54 50 61 56 68 65 80 65 41 84 67 96 69 102 80 67
55 86 74 91 95 85 101 91

COG-A15B 128
55 101 102 87 53 48 75 77 62 78 169 170 118 104 106 100 133 106 104 95
101 90 56 65 68 100 46 72 55 37 88 73 68 71 58 63 84 70 75 88
93 79 77 92 97 79 108 92 119 107 97 148 94 130 84 67 78 91 96 117
109 94 69 64 75 81 74 84 102 74 80 65 98 72 116 67 60 70 73 71
65 74 66 54 68 60 50 46 36 60 60 70 61 56 96 61 82 67 56 42
88 41 83 47 55 47 75 47 71 57 70 64 51 87 73 83 80 95 75 70
50 84 73 97 104 76 73 101
COG-A16A 157
250 250 314 308 236 211 174 127 154 218 238 264 183 172 146 142 108 64 126 156
159 163 127 106 139 135 164 167 166 129 150 122 99 58 64 57 110 68 88
109 113 108 102 111 106 110 128 209 117 109 96 62 68 71 63 78 85 89 173
118 108 63 128 94 115 104 135 88 105 128 95 86 55 62 60 93 91 79 60
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41 31 28 29 40 35 25 30 33 47 31 78 46 61 35 72 60 63
COG-A16B 157
243 255 334 299 225 215 171 125 155 226 229 269 190 163 169 140 93 75 156 172
155 148 140 110 151 124 166 163 150 105 133 98 77 56 63 62 106 64 86
134 118 121 97 115 108 105 103 185 115 106 104 55 71 70 61 78 82 94 179
118 107 62 127 112 106 107 132 88 110 121 101 90 52 60 61 94 90 76 54
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27 25 27 30 26 45 33 47 41 49 31 73 45 60 40 70 67 63
COG-A17A 149
180 209 153 201 83 112 151 279 278 168 152 136 115 140 142 173 214 178 126 135
108 64 107 99 109 113 70 69 76 99 81 124 97 96 91 114 66 60 67 71
66 76 66 57 44 45 43 50 50 35 35 32 35 50 51 35 54 42 48 38
31 93 58 54 55 51 45 42 41 39 47 56 41 35 42 42 34 35 34 36
36 39 34 30 36 34 43 63 61 75 73 70 58 58 73 63 28 69 52 54
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51 67 66 85 98 94 59 55 63 62 66 68 60 70 52 78 48 35 48 30
42 37 41 54 67 33 48 40 57
COG-A17B 149
178 204 158 189 90 96 153 267 255 175 169 139 121 140 136 176 214 179 120 141
111 59 104 100 110 114 71 64 82 92 87 121 99 100 92 111 66 52 75 67
68 75 67 52 51 42 48 50 44 36 36 30 35 51 55 43 43 43 51 37
37 85 59 53 56 52 43 41 43 43 48 45 40 40 43 37 36 42 36 28
36 38 30 37 36 36 40 65 63 71 78 64 63 53 77 50 43 61 56 55
42 43 32 33 28 30 31 27 46 25 33 30 33 26 19 27 31 29 33 47
48 61 72 77 109 87 59 56 61 63 64 69 64 64 58 71 47 35 51 37
35 38 44 58 60 36 52 42 50
COG-A18A 83
333 254 168 225 160 241 179 131 190 299 185 152 135 192 234 324 332 301 233 106
166 255 358 385 303 228 127 157 95 117 196 190 284 270 205 243 222 202 250 283
293 242 236 155 98 99 140 125 149 114 120 107 111 82 76 93 105 113 108 112
109 113 110 90 65 56 59 65 90 77 90 90 116 120 139 145 161 124 117 114
124 148 130

COG-A18B 83
318 228 188 181 165 278 219 148 201 260 190 149 118 204 239 342 333 316 232 106
165 274 365 365 292 209 131 155 117 135 177 197 279 260 214 236 216 197 230 269
283 245 203 149 106 95 144 120 161 103 127 107 111 86 74 95 100 118 110 105
113 109 107 93 61 56 66 56 93 83 86 81 124 119 142 149 155 131 117 109
126 143 125
COG-A19A 83
276 357 303 373 314 270 270 229 260 206 275 299 242 174 166 216 247 307 240 296
286 154 181 232 224 270 231 127 143 138 180 194 361 213 125 94 58 56 73 70
86 110 171 143 133 119 93 169 164 152 125 127 157 100 150 165 109 87 70 144
165 116 193 173 153 135 118 218 138 115 148 261 170 211 178 240 153 157 139 162
121 206 137
COG-A19B 83
276 347 270 351 308 261 244 205 268 204 266 299 258 168 152 240 257 328 267 250
307 146 177 226 233 266 218 126 152 139 175 198 360 212 127 89 63 54 69 65
93 109 170 139 129 122 94 172 158 153 127 133 159 93 151 168 115 84 69 139
160 123 196 167 160 134 121 207 140 112 133 264 171 224 171 231 162 167 136 150
131 197 119
COG-A20A 109
68 86 116 217 101 192 140 118 97 104 132 131 134 161 158 138 161 126 178 119
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99 105 115 82 88 128 125 100 133 106 129 112 66 101 128 125 114 118 126 101
107 143 120 274 336 212 258 214 192 172 138 179 336 223 242 158 183 168 182 183
163 116 158 146 119 181 182 132 136 175 132 145 111 156 115 163 133 119 143 103
121 126 192 138 222 218 285 261 180
COG-A20B 109
70 76 118 219 104 190 144 111 94 90 128 136 127 156 156 128 156 127 180 116
129 112 79 121 105 71 61 107 102 87 68 65 111 91 109 127 167 137 97 90
107 101 117 89 87 114 127 100 144 103 127 115 59 103 125 127 115 112 127 104
100 150 127 269 334 219 259 212 190 176 136 178 335 225 254 151 189 176 180 181
167 119 161 143 115 181 180 133 129 160 134 136 115 149 119 165 138 116 140 113
120 117 204 124 233 225 305 280 191
COG-A21A 124
194 382 281 218 299 170 106 107 164 199 159 151 260 193 263 159 112 82 117 63
144 150 188 73 105 94 113 71 149 129 172 136 104 93 115 122 132 136 74 83
105 116 87 71 95 81 139 108 112 106 70 57 88 98 107 156 158 188 175 138
127 95 66 78 148 189 169 178 204 211 164 231 225 186 127 164 157 154 101 111
127 128 158 90 167 100 101 106 104 154 258 214 198 115 77 86 114 130 178 117
137 91 301 275 229 170 94 119 149 191 196 164 121 108 221 251 207 184 167 183
280 258 254 231
COG-A21B 124
206 399 285 232 297 173 113 112 167 199 163 149 259 203 272 157 115 82 115 77
137 155 195 66 94 95 104 73 139 143 160 122 103 89 114 124 143 121 87 86
115 115 88 73 90 84 145 92 115 103 66 57 96 91 112 156 141 171 186 130
132 94 74 80 167 189 167 177 206 210 165 208 228 190 129 165 138 142 100 116
127 125 159 92 175 96 101 113 104 158 277 204 207 118 69 91 111 138 171 138
137 95 299 278 247 165 93 119 149 189 195 162 125 111 236 244 212 190 177 217
253 251 260 228
COG-A22A 62
218 333 239 195 214 157 96 108 111 109 77 143 111 167 128 84 127 124 154 121
154 133 99 98 113 122 108 102 136 121 91 138 160 152 120 112 145 115 82 96
171 161 148 112 139 115 128 94 158 124 232 122 122 186 219 125 129 124 338 251
252 181

COG-A22B 62
222 333 241 185 205 153 93 102 125 96 90 131 113 166 122 90 120 132 152 132
165 144 95 94 117 126 109 108 134 106 105 131 167 150 124 107 141 106 85 89
171 162 157 117 139 116 133 93 166 121 224 124 135 184 222 136 131 121 329 260
235 185
COG-A23A 72
139 418 263 323 215 165 231 256 322 310 346 361 278 234 133 231 273 213 251 219
155 151 162 145 161 261 253 173 172 150 91 117 109 264 214 267 420 280 155 103
85 80 94 75 77 76 52 83 67 79 67 56 92 76 77 99 94 136 99 102
169 103 93 58 114 116 121 75 110 102 96 98
COG-A23B 72
160 425 270 326 160 148 191 242 324 307 345 356 285 257 144 171 257 231 226 225
164 153 161 122 181 274 268 184 177 158 81 114 115 255 208 250 421 281 146 107
86 83 94 82 84 84 54 88 79 86 61 75 89 72 81 97 107 128 104 104
175 109 95 69 118 119 116 75 111 106 85 93
COG-A24A 91
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201 141 179 235 210 216 206 154 171 139 147 166 262 227 189 210 151 79 75 73
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141 143 169 192 179 125 118 179 137 122 119
COG-A24B 91
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201 142 178 225 208 216 210 148 158 147 146 155 266 222 178 213 151 78 75 72
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140 140 166 199 185 126 120 173 141 120 117
COG-A25A 85
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82 104 73 70 61
COG-A25B 85
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122 109 188 106 99 171 181 131 129 88 153 128 126 123 90 73 98 65 95 88
90 106 65 66 67
COG-A26A 99
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100 71 92 82 146 141 214 138 130 86 94 121 133 155 106 105 127 119 87 66
116 105 127 91 124 93 69 54 67 67 76 120 162 152 133 113 84 59 52 44
82 112 90 122 156 135 143 157 180 129 124 163 128 127 90 85 95 90 91 81
103 101 86 99 85 104 181 156 213 125 125 107 177 202 238 152 125 114 179
COG-A26B 99
304 180 133 126 170 143 100 73 128 95 149 137 89 74 76 52 76 114 177 65
92 76 94 81 143 135 210 148 127 77 92 117 138 161 108 104 129 124 84 68
113 102 138 86 114 98 69 52 66 75 73 119 158 162 131 111 88 50 54 48
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97 95 92 106 87 109 186 160 222 129 123 118 173 189 234 143 130 115 183

COG-A28A 95
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100 81 89 69 88 84 64 87 84 65 57 73 73 71 90 74 108 111 112 127
121 87 94 95 108 80 77 65 65 46 74 102 126 109 102
COG-A28B 95
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183 185 139 109 57 150 167 131 116 88 104 133 165 105 146 120 96 114 87 78
81 87 130 98 75 146 117 87 64 61 94 111 98 100 131 96 62 80 62 108
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189 239 179 191 194 153 125 134 165 162 182 176 134 124 123 148 119 143 163 167
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113 103 99 101 116 146 124
COG-A29B 107
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COG-A31B 89
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COG-A32B 48
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COG-A33A 78
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COG-A33B 78
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132 132 129 149 120 142 171 127 104 109 87 89 107 76 67 102 111 132
COG-A34A 55
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COG-A34B 55
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134 85 97 117 104 75 96 103 73 85 95 98
COG-A35B 112
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207 207 238 189 229 195 221 162 147 121 158 148 105 92 115 135 137 130 134 108
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47 45 53 46 36 63 75 53 62 36 114 123
COG-A36B 92
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232 207 159 174 222 170 148 182 121 120 111 149 139 197 155 128 105 99 51 37
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52 103 70 114 80 89 77 79 84 55 59 51 72 62 71 57 64 61 54 43
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113 116 169 180 184 146 133 153 126 113 105 72 54 83 123 254 346 264 323 269
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65 71 70 71 83 124 87 80 84 98 46 68 57 48 32 90 90 125 77 116
92 109 114 102
COG-A37B 84
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97 113 113 98
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121 101 101 66 57 81 84 76 83 91 129 117 106 96 120 126 120 103 152 138
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49 47 52 66 69 101 123 200 157 154 161 180 191 161
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124 113 164 174 144 107 76 120 132 142 163 142 136 84 120 107 133 116
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315 274 300 326 306 286 231 210 197 162 97 117 197 185 184 297 229 230 166 162
185 161 200 192 208 200 154 182 182 200 185 254 183 180 142 98 114 146 202 162
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COG-A41B 90
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127 147 161 167 125 122 152 127 137 110 108 139 44 82 128 141 142 136 155 149
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COG-A43B 126
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397 361 214 361 273 169 195 208 208 238 221 202 209 178 353 377 305 264 169 192
188 152 153 192 202
COG-A44B 45
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95 76 95 78 78

COG-A46A 111
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127 175 191 201 63 42 50 93 101 140 164 141 191 229 168 183 273 218 226 172
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COG-A46B 111
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COG-A49B 46
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COG-A51B 48
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COG-A54B 47
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COG-A55A 56
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18 22 23 20 20
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COG-D03A 123
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14 10 15

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 Nottingham Tree-ring Dating Laboratory's Monograph, *An East Midlands Master Tree-Ring Chronology and its uses for dating Vernacular Buildings* (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.

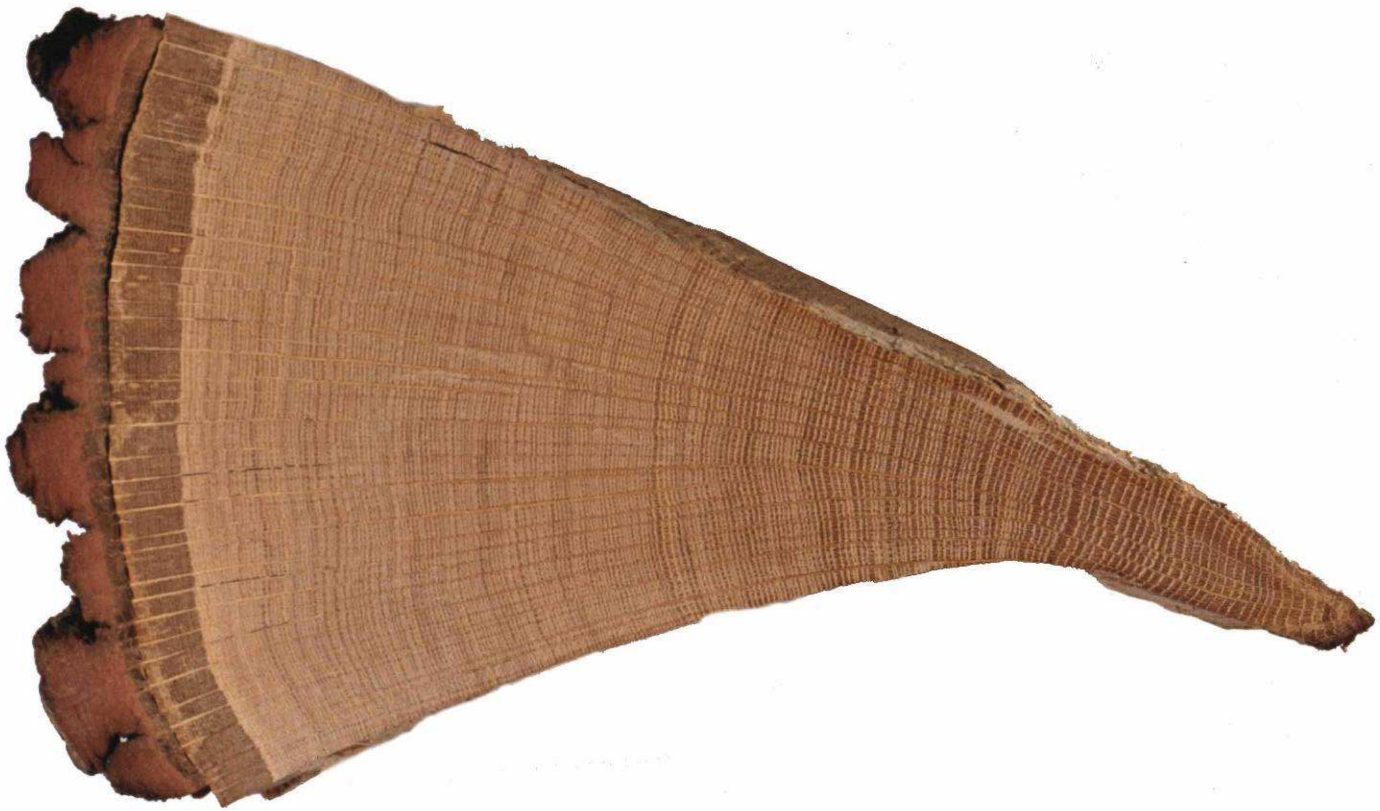


Figure A1: A wedge of oak from a tree felled in 1976. It shows the annual growth rings, one for each year from the innermost ring to the last ring on the outside just inside the bark. The year of each ring can be determined by counting back from the outside ring, which grew in 1976

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

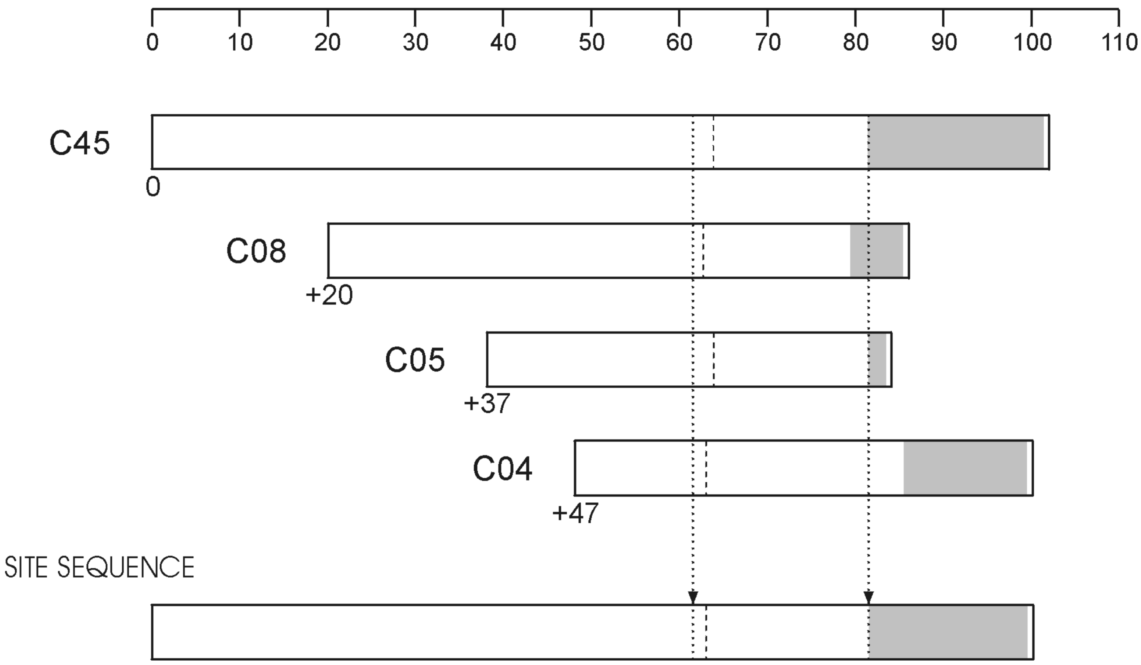


Figure A5: Cross-matching of four sequences from a Lincoln Cathedral roof and the formation of a site sequence from them

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.

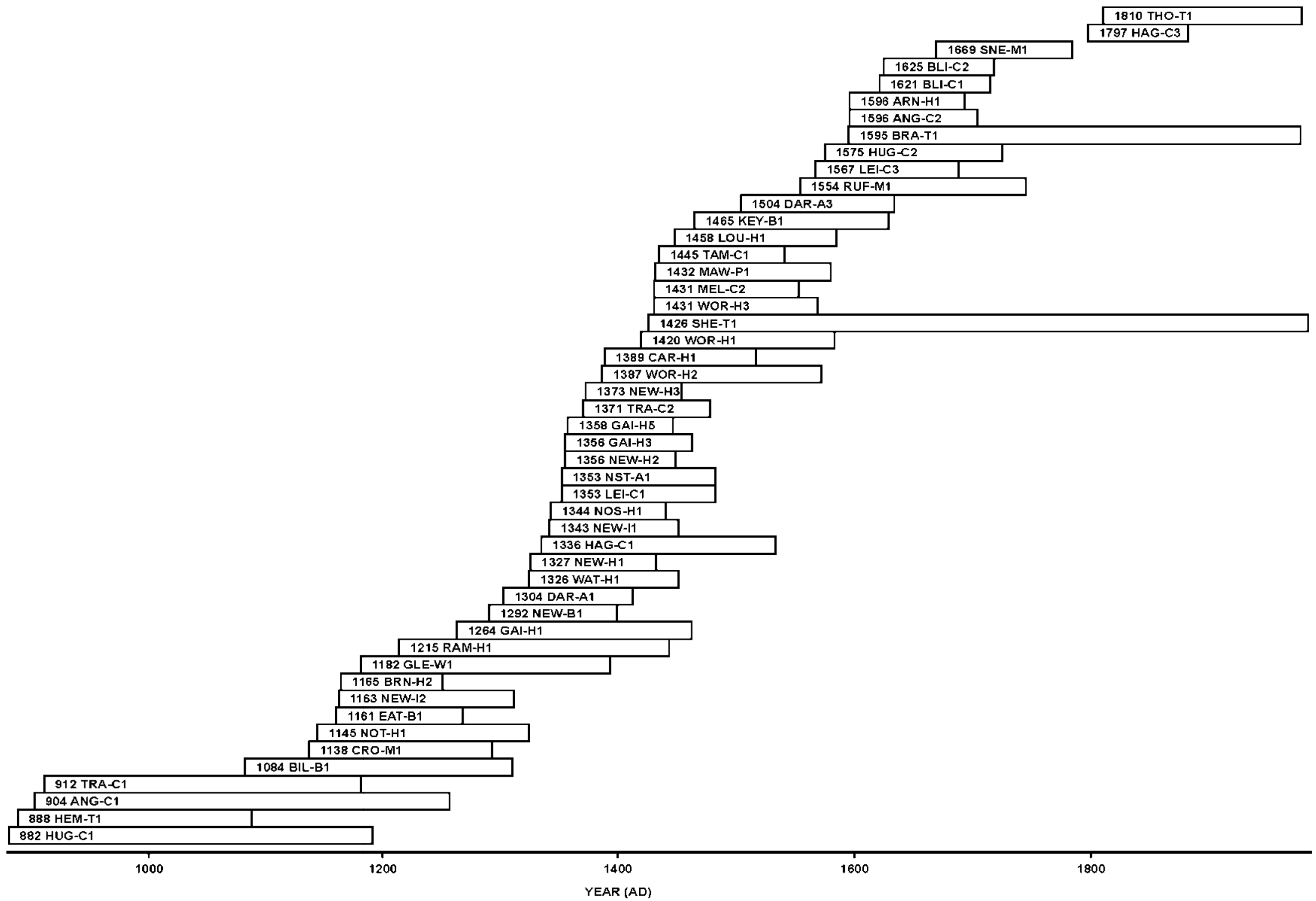
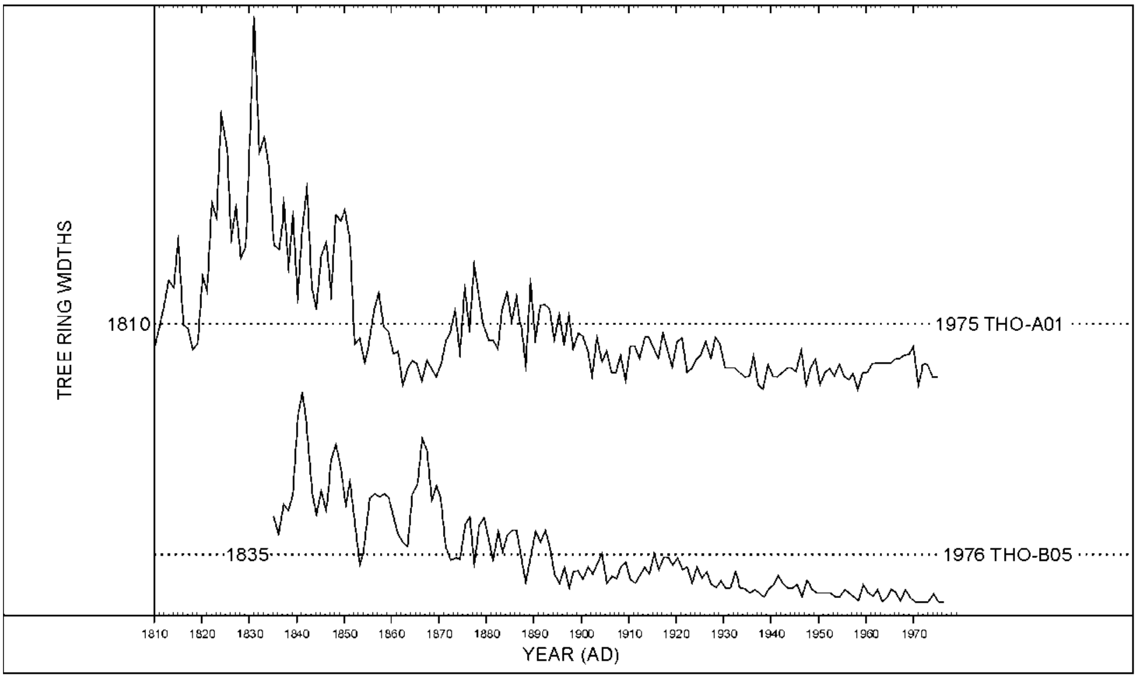


Figure A6: Bar diagram showing the relative positions and dates of the first rings of the component site sequences in the East Midlands Master Dendrochronological Sequence, EM08/87

(a)



(b)

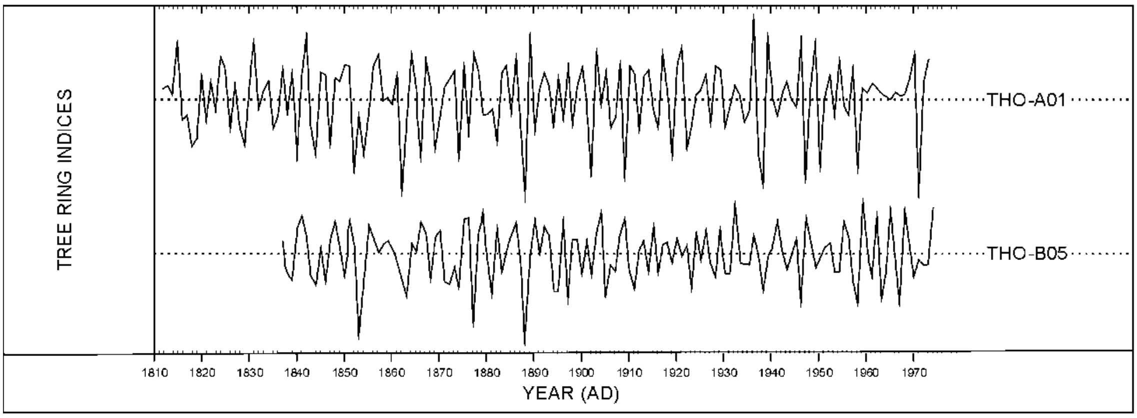


Figure A7 (a): The raw ring-widths of two samples, THO-A01 and THO-B05, whose felling dates are known

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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