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Dendrochronological Investigation and Radiocarbon Wiggle-matching of Oak Timbers from the Nave and Chancel Roofs

Martin Bridge, Cathy Tyers, Alex Bayliss, Michael Dee, and Sanne Palstra

Discovery, Innovation and Science in the Historic Environment

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SUMMARY

Repair work was too far advanced to give access to the chancel roof timbers, although what could be seen looked similar in character to the nave roof timbers, to which access was also restricted. Sapwood disintegrated on most cores, with the result that most cores retained limited numbers of sapwood rings, and all samples therefore had less than 65 rings. Only two timbers cross-matched, but none could be dated by ring-width dendrochronology.

Radiocarbon wiggle-matching of one of the two cross-matching cores suggests that these were felled in *1464–1485 cal AD (95% probability; borl63m felling)*, which is in accordance with fifteenth-century date of these roofs expected on typological grounds. Although only two timbers have been dated by the analysis, these appear to be representative of the surviving fabric and suggest that this is largely medieval in date.

CONTRIBUTORS

Martin Bridge, Cathy Tyers, Alex Bayliss, Michael Dee, and Sanne Palstra

ACKNOWLEDGEMENTS

We would like to thank Mike Heyhow of Lodge & Sons (Builders) Limited, for arranging access at short notice for the sampling to be carried out We are also grateful to Patricia Ferero, architect at Purcell for advice through the project. We would also like to thank Alison Arnold and Robert Howard of the Nottingham Tree-ring Dating Laboratory for the dissection of the core sample for radiocarbon dating. At Historic England we would like to thank Trudi Hughes, Heritage at Risk surveyor for requesting this work and Malcolm Star for his input on the historical overview, also to Beki Burns and Shahina Farid of the Scientific Dating Team, for commissioning and facilitating this study.

ARCHIVE LOCATION

The Historic England Archive
The Engine House
Fire Fly Avenue
Swindon SN2 2EH

HISTORIC ENVIRONMENT RECORD

Essex Historic Environment Record
Place services
County Hall
Chelmsford CM1 1QH

DATE OF INVESTIGATION

2016 and 2020–1

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CONTENTS

INTRODUCTION

This Grade I listed church (LEN 1169675 here) is in the village of Borley, about 5km north-west of the Suffolk town of Sudbury (Fig 1). It has origins in the eleventh century, but was extensively remodelled in the fifteenth and sixteenth centuries. The nave roof is believed to be fifteenth century, with king posts mounted on collars for two central trusses and tiebeams at the ends. The chancel roof is also fifteenth century and has seven cants. A dendrochronological survey of both roofs was requested by Trudi Hughes, Heritage at Risk Surveyor for Historic England, at short notice during ongoing repairs and renovation to the roofs, in order to provide independent dating evidence to ascertain a construction date for the roof structures over the nave and chancel, and hence to inform advice and understanding of the historical development of the church and its chronological relationship with the Manor house and tithe barn.

METHODOLOGY FOR DENDROCHRONOLOGY

Fieldwork for the present study was carried out in August 2016 immediately following an initial assessment of the potential for dating. In the initial assessment, accessible oak timbers with more than 50 rings and where possible traces of sapwood were sought, although slightly shorter sequences are sometimes sampled if little other material is available. Those timbers judged to be potentially useful were cored using a 16mm auger attached to an electric drill. The cores were glued to wooden laths, labelled, and stored for subsequent analysis.

The cores were polished on a belt sander using 80 to 400 grit abrasive paper to allow the ring boundaries to be clearly distinguished. The samples had their tree-ring sequences measured to an accuracy of 0.01mm, using a specially constructed system utilising a binocular microscope with the sample mounted on a travelling stage with a linear transducer linked to a PC, which recorded the ring widths into a dataset. The software used in measuring and subsequent analysis was written by Ian Tyers (2004). Cross-matching was attempted by a combination of visual matching and a process of qualified statistical comparison by computer. The ring-width series were compared for statistical cross-matching, using a variant of the Belfast CROS program (Baillie and Pilcher 1973). Ring sequences were plotted on the computer monitor to allow visual comparisons to be made between sequences. This method provides a measure of quality control in identifying any potential errors in the measurements when the samples cross-match.

In comparing one sample or site master against other samples or chronologies, *t*-values over 3.5 are considered significant, although in reality it is common to find demonstrably spurious *t*-values of 4 and 5 because more than one matching position is indicated. For this reason, dendrochronologists prefer to see some *t*-value ranges of 5, 6, and higher, and for these to be well replicated from different, independent chronologies with both local and regional chronologies well represented, except where imported timbers are identified. Where two individual samples match together with a *t*-value of 10 or above, and visually exhibit exceptionally similar ring patterns, they may have originated from the same parent tree. Same-tree matches can also be identified through the external characteristics of the timber itself, such as knots and shake patterns. Lower *t*-values however do not preclude same tree derivation.

Ascribing felling dates and date ranges

Once a tree-ring sequence has been firmly dated in time, a felling date, or date range, is ascribed where possible. With samples which have sapwood complete to the underside of, or including bark, this process is relatively straightforward. Depending on the completeness of the final ring, ie if it has only the spring vessels or early wood formed, or the latewood or summer growth, a precise felling date and season can be given. If the sapwood is partially missing, or if only a heartwood/sapwood transition boundary survives, then an estimated felling date range can be given for each sample. The number of sapwood rings can be estimated by using an empirically derived sapwood estimate with a given confidence limit. If no sapwood or heartwood/sapwood boundary survives then the minimum number of sapwood rings from the appropriate sapwood estimate is added to the last measured ring to give a *terminus post quem* (*tpq*) or felled-after date.

A review of the geographical distribution of dated sapwood data from historic timbers has shown that a sapwood estimate relevant to the region of origin should be used in interpretation, which in this area is the probability distribution illustrated by Miles (1997, fig 5c). It must be emphasised that dendrochronology can only date when a tree has been felled, not when the timber was used to construct the structure or object under study.

SAMPLING AND TREE-RING ANALYSIS

Many of the timbers were difficult to get access to as the repair and renovation work was well advanced at the time of sampling (Fig 2). None of the chancel timbers could be accessed. Access to the nave roof timbers was also very restricted (Fig 3), with parts of the inner wallplates, outer wallplates, several wallplate ties, and ashlar pieces not being available for sampling as a result of boarding already fixed to the rafters. Fourteen of the nave timbers were considered marginal, but were sampled as this was a rare opportunity to access them. Unfortunately the sapwood, as is often the case, proved to be very fragile, and many sapwood rings were lost during the coring process.

Table 1 gives details of the samples taken. Their locations are illustrated in Figure 4. No sample had more than 64 rings, and many had fewer than 45 rings, with those with fewer than 40 rings being considered not useful for ring-width dendrochronology and not being measured in the first instance. They were however measured at a later stage when radiocarbon wiggle-matching was considered. Two samples were found to cross-match with each other (06 *v* 03, $t = 5.9$ with 41 years overlap) and these were combined into a single 61-year long mean series (borl63m) for subsequent analysis. Plots of these two samples are shown (Fig 5) supporting the overlap proposed. Neither this series, nor any of the individual series gave consistent acceptable matches with the dated reference material available, and therefore no timbers were dated by ring-width dendrochronology.

RADIOCARBON DATING

Following the failure of the dendrochronology to provide calendar dating for the felling of the timbers in Borley Church and, given the potential significant survival of original medieval fabric, the longest tree-ring sequence (borl03) from the pair of samples cross-matched by the ring-width dendrochronology was selected for radiocarbon dating and wiggle-matching.

Radiocarbon dating is based on the radioactive decay of ^{14}C, which trees absorb from the atmosphere during photosynthesis and store in their growth-rings. The radiocarbon from each year is stored in a separate annual ring. Once a ring has formed, no more ^{14}C is added to it, and so the proportion of ^{14}C versus other carbon isotopes reduces in the ring through time as the radiocarbon decays. Radiocarbon ages, like those in Table 2, measure the proportion of ^{14}C in a sample and are expressed in radiocarbon years BP (before present, 'present' being a constant, conventional date of AD 1950).

Five radiocarbon measurements have been obtained from single annual tree-rings from timber borl03 (Table 2). Dissection was undertaken by Alison Arnold and Robert Howard at the Nottingham Tree-Ring Dating Laboratory. Prior to sub-sampling, the core was checked against the tree-ring width data. Then each annual growth ring was split from the rest of the tree-ring sample using a chisel or scalpel blade. Each radiocarbon sample consisted of a complete annual growth ring, including both earlywood and latewood. Each annual ring was then weighed and placed in a labelled bag. Rings not selected for radiocarbon dating as part of this study have been archived by Historic England.

Radiocarbon dating was undertaken by the Centre for Isotope Research, University of Groningen, the Netherlands in 2020–1. Each ring was converted to α-cellulose using an intensified aqueous pretreatment (Dee *et al* 2020) and combusted in an elemental analyser (IsotopeCube NCS), coupled to an Isotope Ratio Mass Spectrometer (Isoprime 100). The resultant CO_2 was graphitised by hydrogen reduction in the presence of an iron catalyst (Aerts-Bijma *et al* 1997; De Rooij *et al* 2010; Dee *et al* 2020). The graphite was then pressed into aluminium cathodes and dated by AMS (Synal *et al* 2007; Salehpour *et al* 2016). Data reduction was undertaken as described by Wacker *et al* (2010). The facility maintains a continual programme of quality assurance procedures (Aerts-Bijma *et al* 2021), in addition to participation in international inter-comparison exercises (Scott *et al* 2017; Wacker *et al* 2020). These tests demonstrate the reproducibility and accuracy of these measurements.

The results are conventional radiocarbon ages, corrected for fractionation using $\delta^{13}C$ values measured by Accelerator Mass Spectrometry (Stuiver and Polach 1977; Table 2). The quoted $\delta^{13}C$ values were measured by Isotope Ratio Mass

Spectrometry, and more accurately reflect the natural isotopic composition of the sampled wood.

WIGGLE-MATCHING

Radiocarbon ages are not the same as calendar dates because the concentration of ^{14}C in the atmosphere has fluctuated over time. A radiocarbon measurement has thus to be calibrated against an independent scale to arrive at the corresponding calendar date. That independent scale is the IntCal20 calibration curve (Reimer *et al* 2020). For the period covered by this study, this is constructed from radiocarbon measurements on tree-ring samples dated absolutely by dendrochronology. The probability distributions of the calibrated radiocarbon dates from Borley Church, derived from the probability method (Stuiver and Reimer 1993) are shown in outline in Figure 6 (lower).

Wiggle-matching is the process of matching a series of calibrated radiocarbon dates which are separated by a known number of years to the shape of the radiocarbon calibration curve. At its simplest, this can be done visually, although statistical methods are usually employed. Floating tree-ring sequences are particularly suited to this approach as the calendar age separation of tree-rings submitted for dating is known precisely by counting the rings in the timber. A review of the method is presented by Galimberti *et al* (2004).

The approach to wiggle-matching adopted here employs Bayesian chronological modelling to combine the relative dating information provided by the tree-ring analysis with the calibrated radiocarbon dates (Christen and Litton 1995). It has been implemented using the program OxCal v4.3 (http://c14.arch.ox.ac.uk/oxcal.html; Bronk Ramsey *et al* 2001; Bronk Ramsey 2009). The modelled dates are shown in black in Figure 6 and quoted in italics in the text. The Acomb statistic shows how closely the assemblage of calibrated radiocarbon dates as a whole agree with the relative dating provided by the tree-ring analysis that has been incorporated in the model; an acceptable threshold is reached when it is equal to or greater than An (a value based on the number of dates in the model). The A statistic shows how closely an individual calibrated radiocarbon date agrees its position in the sequence (most values in a model should be equal to or greater than 60).

Figure 6 (lower) illustrates the chronological model for borl03. This model incorporates the gaps between each dated annual ring known from tree-ring counting (eg that the carbon in ring 4 of the measured tree-ring series (GrM-24045) was laid down 15 years before the carbon in ring 19 of the series (GrM-24047)), with the radiocarbon measurements (Table 2) calibrated using the internationally agreed radiocarbon calibration data for the northern hemisphere, IntCal20 (Reimer *et al* 2020).

The model has good overall agreement (Acomb: 119.7, An: 31.6, n: 5), with only *GrM-24047* having poor individual agreement (A: 57). This is within statistical expectation. It suggests that the final surviving ring of borl03 formed in *cal AD*

1452–1463 (95% probability; borl03 h/s; Fig 6 (lower)), probably in *cal AD 1453–1460 (68% probability)*. Since we know from the ring-width dendrochronology that the last ring of borl06 is six years earlier than the last ring of borl03 (Fig 4), the model also suggests that the final surviving ring of borl06 formed in *cal AD 1446–1457 (95% probability; borl06 h/s*; Fig 6 (lower)), probably in *cal AD 1447–1454 (68% probability).*

Discussion of wiggle-matching results

Neither of the samples included in site master sequence borl36m has complete sapwood (Fig 5; Table 1), but both retain the heartwood/sapwood transition. We can estimate the felling dates of these timbers by adding the probability distribution of the expected number of sapwood rings in ancient oak timbers from southern England (Miles *et al* 1997, fig 5c) to the estimated dates of the last rings of the respective timbers. These distributions are shown in outline in Figure 6 (upper).

The tree-ring analysis has revealed the strong similarity between the two samples in site sequence borl63m (t = 5.9) which, together with the similarity of the relative heartwood/sapwood boundary position on the two timbers, indicates that the two ashlar pieces represented were likely to have been felled at the same time. The date of this felling episode can be estimated by combining the probability distributions for the felling of each timber. This model also has good overall agreement (Acomb: 113.0, An: 50.0, n: 2; Fig 6 (upper)), with both prior distributions having good individual agreement (A > 60). This analysis suggests these timbers were felled in *1464–1485 cal AD (95% probability; borl63m felling*; Fig 6 (upper)), probably in *cal AD 1467–1478 (68% probability).*

CONCLUSIONS

The scope of this scientific dating programme has been restricted by the limited accessibility of timbers for sampling. No samples could be obtained from the chancel roof, and the selection of timbers sampled from the nave roof was severely restricted. Sapwood disintegrated on most cores, with the result that most samples retained limited numbers of sapwood rings, and all therefore had less than 65 rings. Only two timbers cross-matched, but none could be dated by ring-width dendrochronology.

The results of the radiocarbon wiggle-matching of one of the pair of cross-matching timbers, however, demonstrates that at least two of the timbers from the nave roof were felled in *1464–1485 cal AD (95% probability; borl0306 felling*; Fig 6 (upper)*)*, which is in accordance with fifteenth-century date of both the nave and chancel roofs expected on typological grounds. Although only two timbers have been dated by the analysis, these appear to be representative of the nave roof and suggest that the surviving fabric is largely medieval in date.

Should further access to these roofs become available in the future, additional sampling for dendrochronology from a wider range of timbers in these roofs would be merited.

REFERENCES

Aerts-Bijma, A T, Meijer, H, and van der Plicht, J, 1997 AMS sample handling in Groningen, *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, **123**, 221–5 (https://doi.org/10.1016/S0168-583X(96)00672-6)

Aerts-Bijma, ATh, Paul, D, Dee, MW, Palstra, SWL, and Meijer, HAJ, 2021 An independent assessment of uncertainty for radiocarbon analysis with the new generation high-yield Accelerator Mass Spectrometers, *Radiocarbon*, **63**, 1–22 (https://doi.org/10.1017/RDC.2020.101)

Baillie, M G L, and Pilcher, J R, 1973 A simple cross-dating program for tree-ring research, *Tree Ring Bulletin*, **33**, 7–14

Bronk Ramsey, C, 2009 Bayesian analysis of radiocarbon dates, *Radiocarbon*, **51**, 37–60 (https://doi.org/10.1017/S0033822200033865)

Bronk Ramsey, C, van der Plicht, J, and Weninger, B 2001 'Wiggle matching' radiocarbon dates, *Radiocarbon*, **43**, 381–9 (https://doi.org/10.1017/S0033822200038248)

Christen, J A, and Litton, C D, 1995 A Bayesian approach to wiggle-matching, *J Archaeol Sci*, **22**, 719–25 (https://doi.org/10.1016/0305-4403(95)90002-0)

De Rooij, M, van der Plicht, J, and Meijer, H A J, 2010 Porous iron pellets for AMS ^{14}C analysis of small samples down to ultra-microscale size (10–25µgC), *Nuclear Instruments and Methods in Physics Research B*, **268**, 947–51 (https://doi.org/10.1016/j.nimb.2009.10.071)

Dee, M W, Palstra, S W L, Aerts-Bijma, A T, Bleeker, M O, de Bruin, S, Ghebru, F, Jansen, H G, Kuitems, M, Paul, D, Richie, R R, Spriensma, J J, Scifo, A, von Zonneveld, D, Verstappen-Dumoulin, B M A A, Wietzes-Land, P, and Meijer, H A J, 2020 Radiocarbon dating at Groningen: new and updated chemical pretreatment procedures, *Radiocarbon*, **62**, 63–74 (https://doi.org/10.1017/RDC.2019.101)

Galimberti, M, Bronk Ramsey, C, and Manning, S, 2004 Wiggle-match dating of tree-ring sequences, *Radiocarbon*, **46**, 917–24 (https://doi.org/10.1017/S0033822200035967)

Miles, D H, 1997 The interpretation, presentation, and use of tree-ring dates, *Vernacular Architect*, **28**, 40–56

Reimer, P J, Austin, W E N, Bard, E, Bayliss, A, Blackwell, P, Bronk Ramsey, C, Butzin, M, Cheng, H, Edwards, R L, Friedrich, M, Grootes, P M, Guilderson, T P, Hajdas, I, Heaton, T J, Hogg, A G, Hughen, K A, Kromer, B, Manning, S W, Muscheler, R, Palmer, J G, Pearson, C, van der Plicht, J, Reimer, R W, Richards, D A, Scott, E M, Southon, J R, Turney, C S M, Wacker, L, Adolphi, F, Büntgen, U, Capano, M, Fahrni, S, Fogtmann-Schultz, A, Friedrich, R, Kudsk, S, Miyake, F, Olsen, J, Reinig, F, Sakamoto, M, Sookdeo, A, and Talamo, S, 2020 The IntCal20 Northern Hemispheric radiocarbon calibration curve (0–55 kcal BP), *Radiocarbon*, **62**, 725–57 (https://doi.org/10.1017/RDC.2020.41)

Salehpour, M, Håkansson, K, Possnert, G, Wacker, L, and Synal, H-A, 2016 Performance report for the low energy compact accelerator mass spectrometer at Uppsala University, *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, **371**, 360–4 (https://doi.org/10.1016/j.nimb.2015.10.034)

Scott, E M, Naysmith, P, and Cook, G T, 2017 Should archaeologists care about ^{14}C intercomparisons? Why? A summary report on SIRI, *Radiocarbon*, **59**, 1589–96 (https://doi.org/10.1017/RDC.2017.12)

Stuiver, M, and Polach, H A, 1977 Reporting of ^{14}C data, *Radiocarbon*, **19**, 355–63 (https://doi.org/10.1017/S0033822200003672)

Stuiver, M, and Reimer, P J, 1993 Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program, *Radiocarbon*, **35**, 215–30 (https://doi.org/10.1017/S0033822200013904)

Synal, H A, Stocker, M, and Suter, M, 2007 MICADAS: a new compact radiocarbon AMS system, *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, **259**, 7–13 (https://doi.org/10.1016/j.nimb.2007.01.138)

Tyers, I, 2004 Dendro for Windows Program Guide 3rd edn, *ARCUS Report*, **500b**

Wacker, L, Christl, M, and Synal, H A, 2010 Bats: A new tool for AMS data reduction, *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, **268**, 976–9 (https://doi.org/10.1016/j.nimb.2009.10.078)

Wacker, L, Scott, E M, Bayliss, A, Brown, D, Bard, E, Bollhalder, S, Friedrich, M, Capano, M, Cherkinsky, A, Chivall, D, Culleton, B J, Dee, M W, Friedrich, R, Hodgins, G W L, Hogg, A, Kennett, D J, Knowles, T D J, Kuitems, M, Lange, T E, Miyake, F, Nadeau, M-J, Nakamura, T, Naysmith, J P, Olsen, J, Omori, T, Petchey, F, Philippsen, B, Ramsey, C B, Prasad, G V R, Seiler, M, Southon, J, Staff, R, Tuna, T, 2020 Findings from an in-depth annual tree-ring radiocarbon intercomparison, *Radiocarbon*, **62**, 873–82 (https://doi.org/10.1017/RDC.2020.49)

TABLES

Table 1: Details of samples taken from the nave roof, Borley Church, Borley, Essex

Sample number	Timber and position	No of rings	Mean ring width (mm)	Sapwood rings	Mean sensitivity
borl01	South common rafter, 1st from west	52	1.75	h/s	0.25
borl02	South common rafter, 4th from west	64	1.50	10 +5NM	0.16
borl03	South ashlar piece, 3rd from west	61	1.55	h/s	0.19
borl04a	South inner wallplate, west end	49	2.49	-	0.16
borl04b	*ditto*	14	1.70	h/s	0.15
borl04	Mean of 04a and 04b	57	2.36	h/s	0.16
borl05	South common rafter, 11th from west	59	1.95	5	0.19
borl06	South ashlar piece, 9th from west	41	2.03	h/s	0.25
borl07	South common rafter 14th from west	41	2.48	14	0.13
borl08a	South ashlar piece, 14th from west	43	1.16	1	0.16
borl08bi	*ditto*	29	2.14	-	0.27
borl08bii	*ditto*	40	1.14	2	0.15
borl08	Mean of 08a and 08bii	44	1.20	2	0.15
borl09a	South common rafter, 16th from west	22	1.81	8	0.20
borl09b	*ditto*	27	1.14	14	0.22
borl10	South common rafter, 18th from west	22	2.01	h/s	0.25
borl11	North common rafter, 2nd from west	26	2.99	7	0.14
borl12	North common rafter, 6th from west	42	2.40	1	0.12
borl13	North common rafter, 8th from west	21	4.40	-	0.18
borl14	North common rafter, 11th from west	59	1.79	h/s +11NM	0.16

Key: NM = not measured; h/s = heartwood/sapwood boundary

Table 2: Radiocarbon measurements and stable isotope measurements from Borley Church

Laboratory Number	Sample	Radiocarbon Age (BP)	$\delta^{13}C_{IRMS}$ (‰)
GrM-24045	borl03, ring 4 (Quercus sp. heartwood)	559±11	−25.81±0.15
GrM-24047	borl03, ring 19 (Quercus sp. heartwood)	556±16	−24.23±0.15
GrM-24048	borl03, ring 31 (Quercus sp. heartwood)	503±16	−25.02±0.15
GrM-24049	borl03, ring 43 (Quercus sp. heartwood)	469±16	−23.75±0.15
GrM-24050	borl03, ring 53 (Quercus sp. heartwood)	443±16	−24.98±0.15

FIGURES

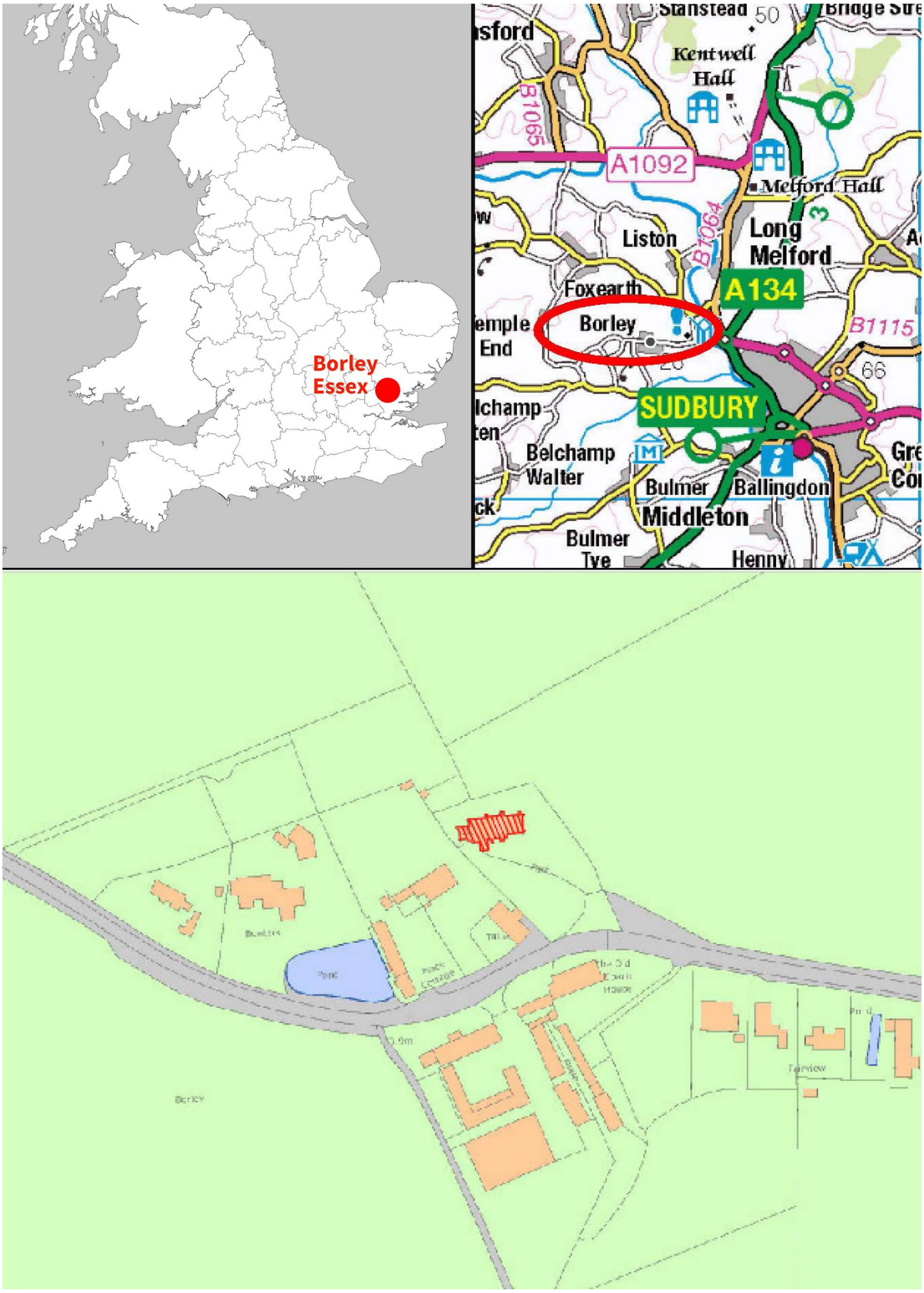


Figure 1: Maps to show the location of the church in Borley in Essex, marked in red. Scale: top right 1:105,000, bottom 1:1700 © Crown Copyright and database right 2022. All rights reserved. Ordnance Survey Licence number 100024900

Figure 2: East end of the chancel (north slope) showing the extent of renovation and repairs preventing access to old timbers (photograph Martin Bridge)

Figure 3: View of the south nave roof, looking west, showing restricted access to rafter feet and wallplates (photograph Martin Bridge)

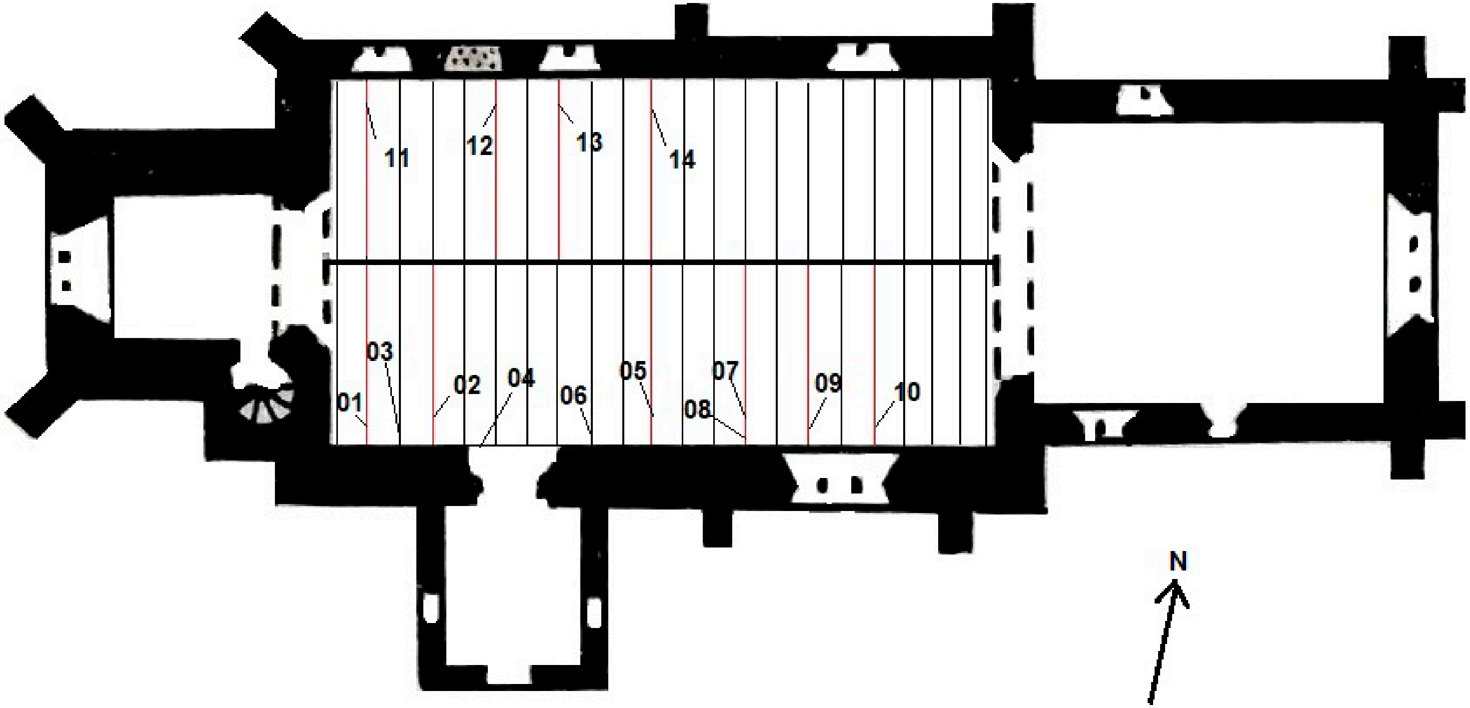


Figure 4: Plan of Borley church showing the approximate position of timbers sampled for dendrochronology. Source: Historic England Archive. Ref:MD92/00191

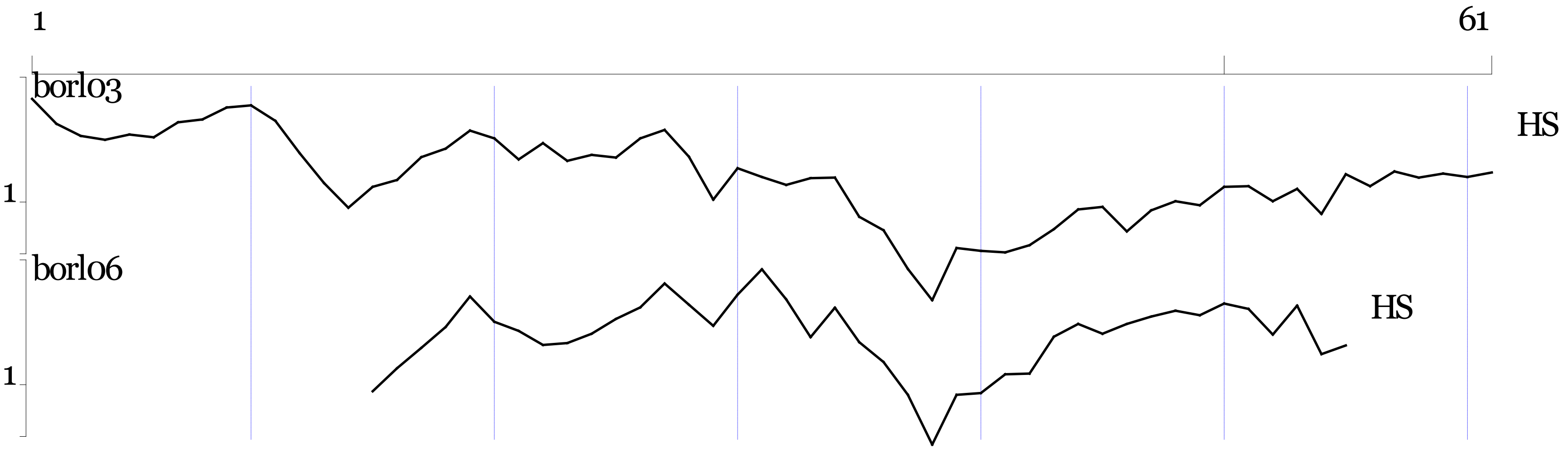


Figure 5: Plots of the two matching timbers. HS marks the presence of the heartwood/sapwood boundary. The y-axis is ring width (mm) on a logarithmic scale

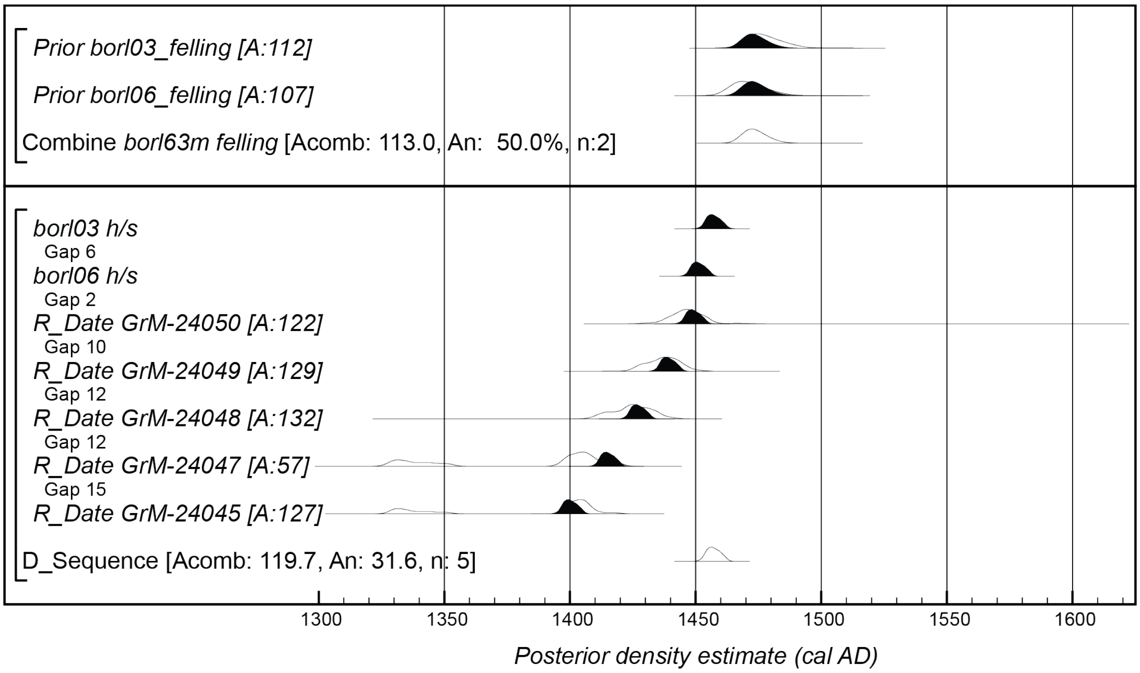


Figure 6: Probability distributions of dates from timber borl03. Each distribution represents the relative probability that an event occurs at a particular time. For each of the dates two distributions have been plotted: one in outline, which is the simple radiocarbon calibration, and a solid one, based on the wiggle-match sequence. Distributions other than those relating to particular samples correspond to aspects of the model. For example, the distribution 'borl63m felling' is the estimated date when the timbers in site master sequence borl63m were felled. The model is defined by the CQL2 OxCal keywords and brackets on the left-hand side of the diagram, and by the description of sapwood offsets in the text

APPENDIX

Ring width values (0.01mm) for the sequences measured

borl01

326	217	100	185	239	319	252	137	125	92
126	203	184	185	150	123	182	245	194	210
192	184	184	193	75	111	99	134	173	234
231	168	166	124	173	146	122	178	154	156
110	159	156	129	108	159	196	156	136	169
304	309								

borl02

86	121	121	138	95	83	85	90	111	103
86	111	122	111	129	143	161	160	152	113
164	119	137	178	176	201	206	186	195	158
181	162	250	265	253	230	208	330	348	390
245	162	104	89	103	100	80	74	75	77
118	121	88	112	115	107	116	163	198	151
153	124	125	116						

borl03

367	268	230	219	234	226	273	283	329	338
278	185	127	93	121	132	176	196	246	223
171	210	168	181	175	223	248	177	103	153
137	124	135	136	83	70	43	29	56	54
53	58	71	91	94	69	90	101	96	121
122	101	118	86	142	122	147	136	143	137
145									

borl04a

367	453	397	403	311	268	203	209	184	218
294	309	203	265	270	257	230	283	200	246
251	336	392	303	306	333	236	160	197	228
270	210	201	193	206	226	183	235	221	216
230	186	196	198	218	148	185	205	147	

borl04b

191	213	189	217	211	168	119	130	127	165
136	127	188	204						

borl05

262	240	167	125	125	158	208	268	244	285
211	196	247	283	206	216	248	293	287	248
287	233	221	244	255	221	205	224	168	217
154	228	169	208	181	237	250	180	237	162
128	171	181	247	187	194	184	105	107	80
87	129	140	134	166	157	135	72	99	

borl06

92	123	159	207	304	221	197	165	169	190

229 265 358 274 210 311 428 293 182 264
171 133 88 47 88 90 114 115 183 215
190 215 236 254 240 278 260 188 271 147
164

borl07
458 450 371 246 268 212 256 260 249 262
298 290 285 223 264 212 259 253 204 196
180 187 174 181 131 218 214 201 204 266
209 270 258 315 235 217 230 243 246 226
238

borl08a
251 250 206 152 95 99 108 117 129 148
125 83 76 69 67 55 80 44 60 59
83 83 110 129 111 122 121 109 104 130
126 134 127 123 145 115 139 119 133 97
88 136 141

borl08bi
301 311 350 268 294 237 154 197 163 90
86 158 84 152 148 195 160 183 136 232
239 284 211 282 189 244 249 376 237

borl08bii
115 122 139 142 154 203 141 97 97 89
85 72 88 51 56 66 77 72 87 122
127 137 104 97 97 116 138 138 133 123
150 128 156 132 110 92 90 131 139 157

borl09a
273 343 439 334 156 131 126 101 98 151
160 193 123 122 102 107 118 155 180 207
227 145

borl09b
310 124 135 158 86 58 51 59 44 55
70 95 103 85 79 73 88 119 162 147
151 168 110 148 166 114 116

borl10
131 151 95 150 162 214 177 134 164 131
193 301 319 424 286 311 263 202 160 119
140 202

borl11
378 420 294 426 393 289 326 339 343 288
321 282 269 345 261 329 312 230 240 230
264 265 300 206 204 207

borl12
315 290 288 285 268 300 341 294 364 406

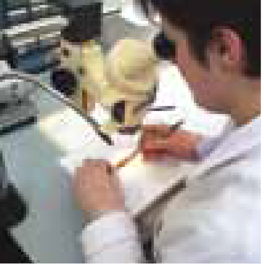
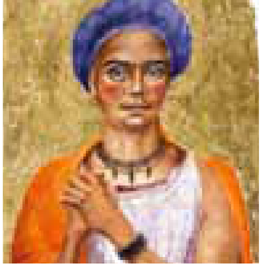
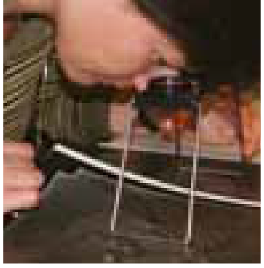
343	288	253	248	256	229	195	202	174	164
125	151	153	152	185	190	224	219	290	259
242	254	237	329	218	229	194	177	168	170
221	172								

borl13

347	542	349	476	475	432	396	414	326	383
466	385	473	457	403	453	556	514	387	553
444									

borl14

275	277	255	262	241	231	235	278	307	249
249	241	226	186	153	208	231	262	210	183
198	189	216	143	155	189	165	163	155	142
150	97	127	105	100	148	158	175	128	195
117	135	165	212	230	156	163	164	113	152
177	199	141	135	116	82	66	66	99	



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