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Monks Walk, 19 Highgate, Beverley, East Riding of Yorkshire

Radiocarbon wiggle-matching of oak timbers

Alison Arnold, Robert Howard, Cathy Tyers, Silvia Bollhalder, Lukas Wacker, and Peter Marshall

Scientific Dating

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Summary

Independent validation of tentative tree-ring dating for a previously undated site chronology, BEVFSQ02, from Monks Walk, Beverley, East Riding of Yorkshire, has been obtained by radiocarbon wiggle-matching and it can now be considered as a radiocarbon-supported dendrochronological date, that spans AD 1142–1300$_{DR}$. The three-bay front range to Monks Walk was therefore constructed in the early fourteenth century with significant rebuilding or repair work being undertaken to the building in the late sixteenth century.

Illustration credits

Front cover image: Monks Walk, Highgate, Beverley, East Riding of Yorkshire, East Yorkshire, HU17 0DN on the 8 Apr 2001. © Terry Dawson [IOE01/03041/09]

Contributors

Alison Arnold, Robert Howard, Cathy Tyers, Silvia Bollhalder, Lukas Wacker, and Peter Marshall

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Archive location

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

Date of research

2021–2023

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Contents

Illustrations

Tables

Introduction

The Early Fabric in Historic Towns: Voluntary Group Projects, funded by Historic England, have been developed in the recognition and acknowledgement of the excellent work being undertaken by local vernacular groups in the study of local architectural trends and fabrics. The project's intention is to encourage this type of study through the provision of support and to facilitate training of more people in building analysis and recording. The local projects were coordinated by Rebecca Lane (Historic England).

Early Fabric in Beverley Project

Whilst there is a corpus of research on form and age of the town of Beverley, it does not cover detailed examination of early fabric or aspects of typology, with analysis and interpretation of existing buildings until now not having benefited from dendrochronology, with the exception of some limited work on the Minster.

Initially, 13 properties were identified that were thought to be key to understanding the town's architectural development for a programme of comprehensive investigation. These properties were assessed for their suitability for tree-ring dating and those found to contain timbers potentially suitable for analysis were sampled. As the project progressed and some of the original buildings identified were rejected as unsuitable for tree-ring dating, further candidates for tree-ring analysis were assessed and sampled if appropriate.

It was hoped that successful dating of these buildings would extend the knowledge of early fabric and selected buildings in the historic town of Beverley in support of Historic England's responsibility to identify and understand the urban vernacular and historic environment of a market town. The reports produced on the buildings recorded as part of this project by the Yorkshire Vernacular Buildings Study Group, led by David Cook, will be held in the YVBSG archive and will be available through their website (www.yvbsg.org.uk), whilst a summary of the project is presented in Vernacular Architecture (Cook and Neave 2018).

Monks Walk

The Grade II* Monks Walk (List Entry Number 1161054), now a public house, is located on the east side of Highgate, one of the oldest streets in Beverley (Fig 1). It comprises a front range with two wings (north and south) located behind. Behind these, a long curving Garth extends through to Eastgate. Around the sides of this Garth were a number of buildings, since demolished, and a pair of rebuilt cottages.

The front range is the earliest part of the building and is thought to date to the early-fourteenth century. Although seemingly five bays now, this is likely to have originally been three bays, with the central bay taken up by a through passage on the ground floor. The upper floor was open to the roof and probably jettied to the front (west) elevation.

The present roof is of softwood common rafter type with intermittent plank-like collars and a pair of purlins; this would have replaced an earlier roof at a lower level. An open loft runs the length of the range, and is supported on joists, tenoned into five tiebeams three of which, the ones at each gable and the middle one are thought to be survivals from the earlier roof, with the other two being later insertions. The north tiebeam sits on a large post at its eastern end, over which sits a wallplate which runs southwards to another post in the south-east corner of the front range; there is not an uninterrupted view of this wallplate. A metre above this wallplate there is another wallplate sitting on brick walling and thought to be a later insertion associated with the raising of the walls although the timber itself is made up of reused timbers.

The passageway continues behind the front range separating the single-storey north and two-storey south wings. The upper floor of the south wing is thought to have been the solar with an open hall to the east and probably a screens passage and kitchen/service block beyond. The north wing may have always been for storage or commercial use. These two wings are believed to have been added in *c* AD 1500 and rebuilt in brick in the late-seventeenth century (north wing; as evidenced by a datestone of AD 1671) and the mid-eighteenth century (south wing).

Tree-ring analysis

Sampling and original tree-ring analysis

A total of ten samples were taken from various oak (*Quercus* sp.) timbers of the front range in November 2015 (Arnold *et al* 2020a, figs 6–9; Table 1). Sample BEV-B06, taken from a section of wallplate, had too few rings for secure dating and so was rejected prior to measurement. The remaining nine samples were prepared by sanding and polishing, and their growth-ring widths measured; the data of these measurements are given at the end of the report. These samples were then compared with each other by the Litton/Zainodin grouping programme (Arnold *et al* 2020a, appendix), resulting in six samples matching to form two groups.

Firstly, four samples matched each other (minimum *t*-value of 5.2) and were combined at the relevant offset positions to form BEVBSQ01, a site sequence of 129 rings (Arnold *et al* 2020a, fig 10). This site sequence was compared against a series of relevant reference chronologies for oak where it was found to match securely and consistently as a first-ring date of AD 1463 and a last-measured ring date of AD 1591 (Arnold *et al* 2020a, table 2).

One of these four samples, BEV-B03, has complete sapwood and a last-measured ring date of AD 1591, the felling date of the timber represented. Two of the other samples, BEV-B07 and BEV-B08 retain the heartwood/sapwood boundary. The estimated felling dates of these timbers can be determined by the addition of the probability distribution for the expected number of sapwood rings in ancient oak timbers from England (Arnold *et al* 2019, fig 9) to the dates of the last rings of the respective timbers. These distributions are shown in outline in Figure 2.

The relative positions of the heartwood/sapwood boundaries on the samples in BEVBSQ01 where it survives lie within narrow limits, having a 5-year difference (Arnold *et al* 2020a, fig 10; table 1). It is thus possible that these timbers have the same, or at least a very similar felling date. The date of this felling episode can be estimated by combining the probability distributions for the felling of each timber that has a heartwood/sapwood boundary. The model shown in Figure 2 that combines the felling dates for the three timbers in BEVBSQ01 that have heartwood/sapwood boundaries has good overall agreement (Acomb:89.9, An: 40.8, n: 3; Fig 2), with each prior distribution having good individual agreement (A:>60). This analysis suggests the timbers in BEVBSQ01 were felled in AD 1591 (*95% probability*; BEVBSQ01; Fig 2).

The fourth dated sample, BEV-B04, does not have the heartwood/sapwood boundary but with a last-measured heartwood ring date of AD 1549 this timber would be estimated to have a *terminus post quem* for felling date of AD 1564, also potentially consistent with the felling date of AD 1591 identified.

Two other samples also matched each other at t=10.2 and were again combined at the relevant offset positions to form BEVBSQ02, a site sequence of 159 rings (Arnold *et al* 2020a, fig 11). Attempts to date this site sequence and the remaining ungrouped samples were unsuccessful and all remain undated.

Revised tree-ring analysis

Following completion of the tree-ring analysis of all the building's sampled as part of the Early Fabric in Beverley Project further attempts to date the undated site sequence BEVBSQ02 were undertaken. Comparison of the undated site sequence with the extensive corpus of reference chronologies for oak once again failed to identify a conclusive cross-dating position, however, a low but consistent correlation was noted against a number of reference chronologies for BEVBSQ02 when it spans AD 1142–1300 (Table 2).

Radiocarbon dating

In order to provide independent validation of the calendar dating for BEVBSQ02 suggested by the revised tree-ring analysis, the longest tree-ring sequence, BEV-B01, from site sequence BEVBSQ02 (Fig 3) was selected for radiocarbon dating and wiggle-matching. BEV-B01 has 128 rings and comprises relative years 32–159 of BEVBSQ02 that potentially spans AD 1173–1300. Although normally the longest tree-ring sequence in an undated site sequence would be selected for radiocarbon dating and wiggle-matching in this case given the potential span of BEV-B01 includes the AD 1279 candidate solar energetic particle (SEP) event (Fig 4; Brehm *et al* 2021) we have attempted to wiggle-match against this sharp increase in atmospheric ^{14}C.

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 3, 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).

Radiocarbon measurements have been obtained from eight single annual tree-rings from timber BEV-B01 (Table 3). 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 Laboratory of Ion Beam Physics, ETH Zürich, Switzerland in 2021. Cellulose was extracted from each ring using the base-acid-base-acid-bleaching (BABAB) method described by Němec *et al* (2010), combusted and graphitised as outlined in Wacker *et al* (2010a), and dated by Accelerator Mass Spectrometry (Synal *et al* 2007; Wacker *et al* 2010b). Data reduction was undertaken as described by Wacker *et al* (2010c). The facility maintains a continual programme of quality assurance procedures (Sookdeo *et al* 2020), 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 3).

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 BEVBSQ02, derived from the probability method (Stuiver and Reimer 1993), are shown in outline in Figure 5.

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 v4.4 (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 5 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 5 illustrates the chronological model for BEVBSQ02. This model incorporates the gaps between each dated annual ring known from tree-ring counting (eg that the carbon in ring 53 of the measured tree-ring series (ETH-112807) was laid down 52 years before the carbon in ring 105 of the series (ETH-112808), with the radiocarbon measurements (Table 3) calibrated using the internationally agreed radiocarbon calibration data for the northern hemisphere, IntCal20 (Reimer *et al* 2020).

The model has good overall agreement (Acomb: 81.0, An: 25.0, n: 8; Fig 5), with only one radiocarbon date having poor individual agreement (A > 60): ETH-112806 (A:14). It suggests that the final ring of BEVBSQ02 formed in *cal AD 1296–1301* (*95% probability*; *Ring 159 (AD 1300)*; Fig 5), probably in *cal AD 1297–1300* (*68% probability*), compatible with the last measured ring being formed in AD 1300 (Table 2). When the last ring of the wiggle-match is constrained to be AD 1300, the model also has good overall agreement (Acomb: 46.7, An: 23.6, n: 9; Fig 6), although three radiocarbon dates have poor individual agreement (A < 60): ETH-112806 (A:11), ETH-112809 (A:57), and ETH-112810(A:44). This allows confirmation of the ring-width dendrochronology and the dating of BEVBSQ02 to be considered as a radiocarbon-supported dendrochronological date, that spans AD 1142–1300, with the final ring having been formed in AD1300$_{DR}$ (Table 2) The superscript $_{DR}$ indicates that this is not a date determined independently by ring-width dendrochronology, and that the master sequence, BEVBSQ02, should not be utilised as a ring-width master sequence for dating other sites.

Discussion of wiggle-matching results

Neither of the two samples in sequence BEVBSQ02 have complete sapwood (Fig 3; Arnold *et al*. 2020, table 1), and only BEV-B01 retains the heartwood/sapwood transition. Using the same methodology outlined above the distribution for the estimated felling date of this timber is shown in Figure 7 and estimated to within the range AD 1309–1342$_{DR}$ (*95% probability*; *BEV-B01 Felling*; Fig 7).

Discussion

Radiocarbon wiggle-matching has demonstrated that two of the three tiebeams that are thought to be the only extant remains of the original roof date to the early fourteenth century. Another tiebeam and three other dated timbers from the front range have previously been dated to the late-sixteenth century (Arnold *et al* 2020a) and thus identify significant rebuilding or repair work being undertaken to the building at this time.

Exploiting the rapid changes in atmospheric ^{14}C concentration associated with the AD 1279 candidate SEP event together with the annually resolved ^{14}C calibration data in IntCal20 (Reimer *et al* 2020) precise dating for the undated site sequence BEVBSQ02 was achieved; *cal AD 1296–1301* (*95% probability*; *Ring 159 (AD 1300)*; Fig 4), probably *cal AD 1297–1300* (*68% probability*). Although such SEP events are rare (Brehm *et al* 2021; Miyake *et al* 2012; 2013) where present they offer the potential for radiocarbon dating wiggle-matching to potentially achieve the yearly precision of dendrochronology (Wacker *et al* 2014).

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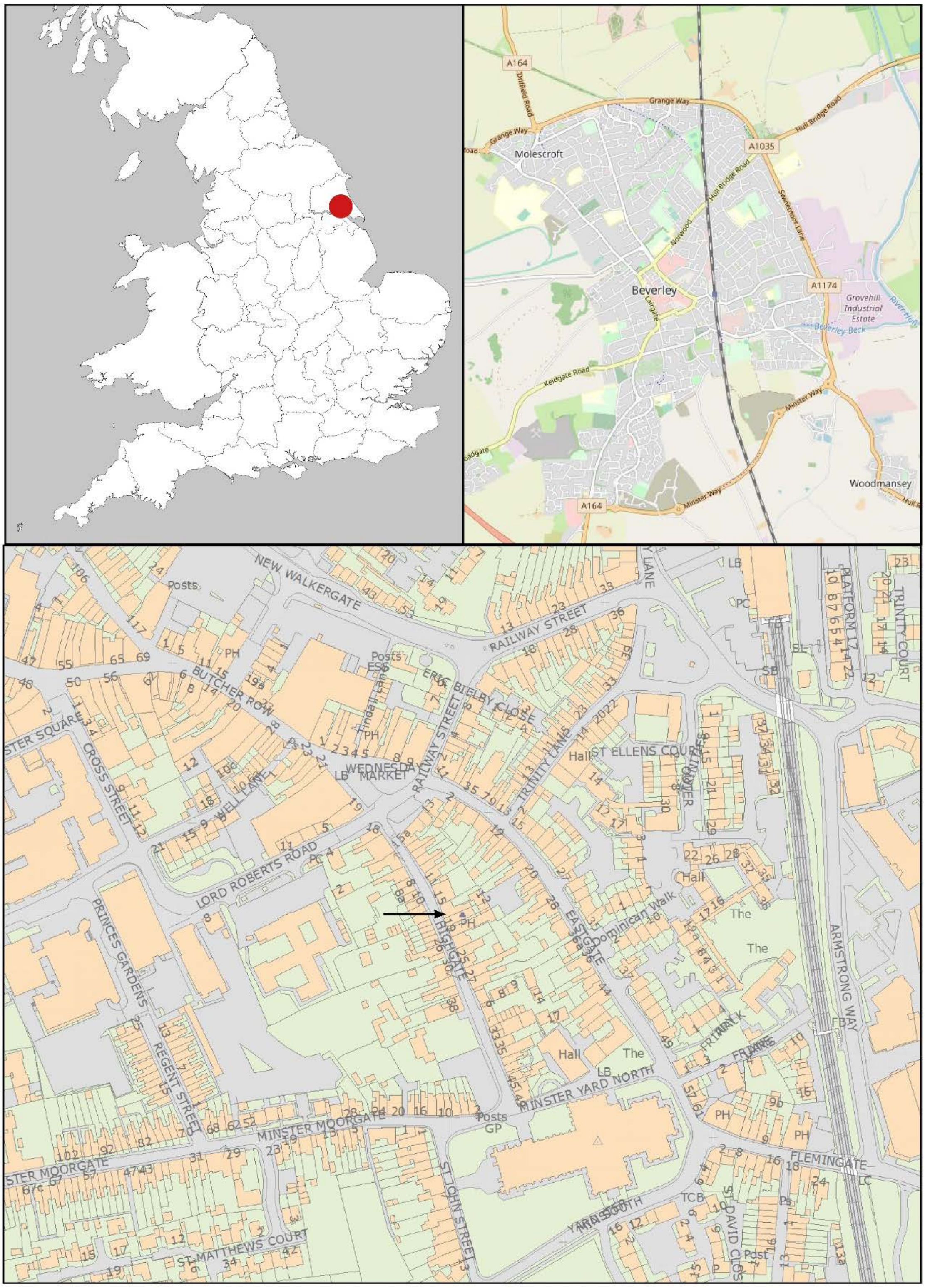

Figure 1: Maps to show the general location of Beverley (red dot), Beverley and Monk’s Walk (arrow). Scale: top right 1:50000; bottom 1:2500. © Crown Copyright and database right 2023. All rights reserved. Ordnance Survey Licence number 100024900. © OpenStreetMap contributors.

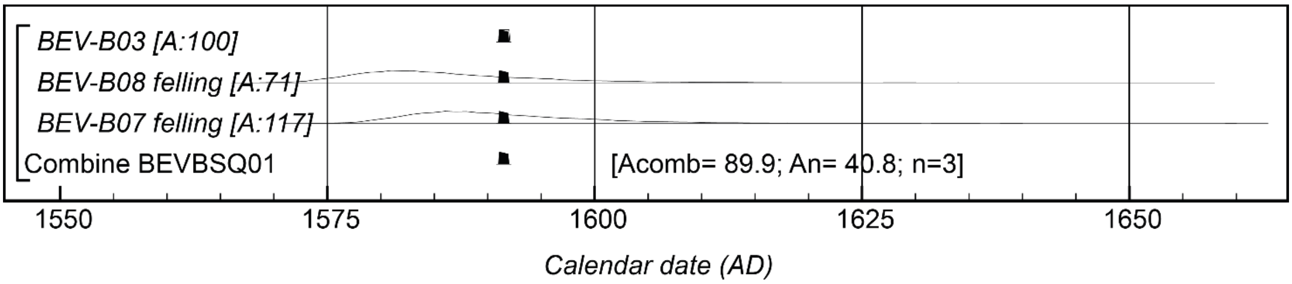

Figure 2: Combined probability distribution estimating the felling date of timbers in site sequence BEVBSQ01, if it is interpreted as representing a single felling event.

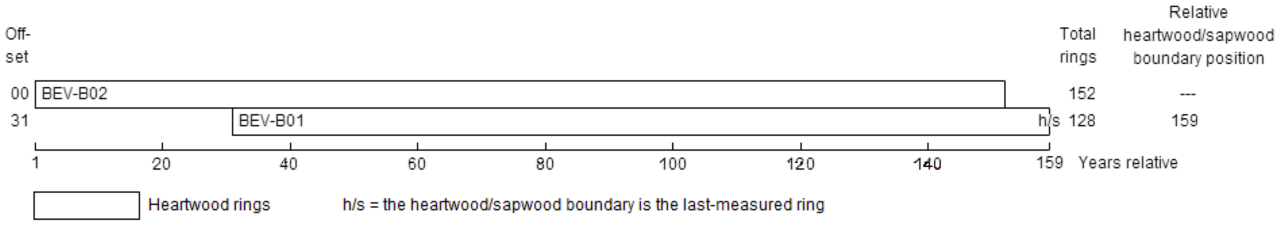

Figure 3: Bar diagram to show the position of samples in undated site sequence BEVBSQ02

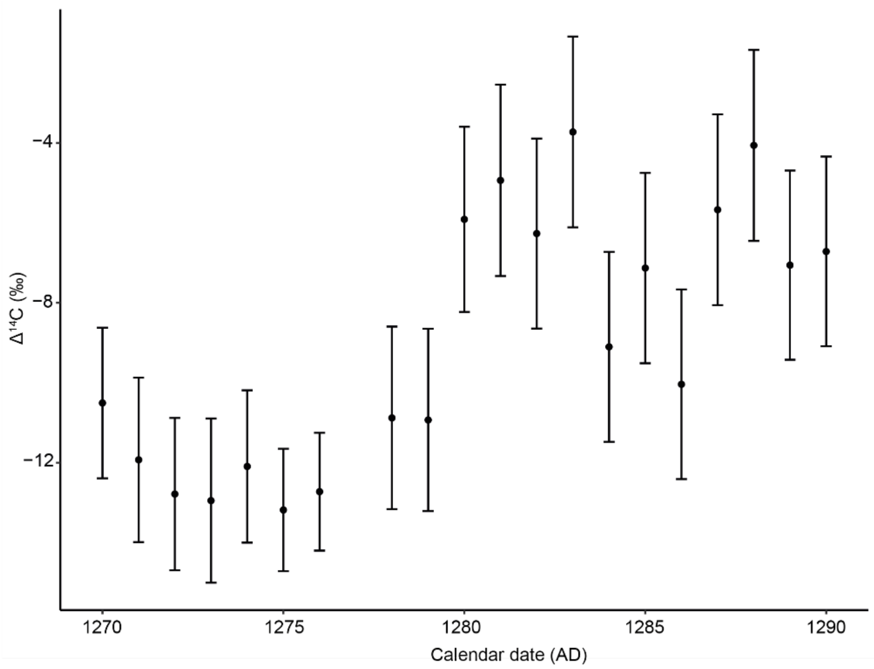

Figure 4: The AD 1279 SEP candidate event recorded in ETH data (Brehm *et al* 2021); error bars indicate the 2σ measurement uncertainty

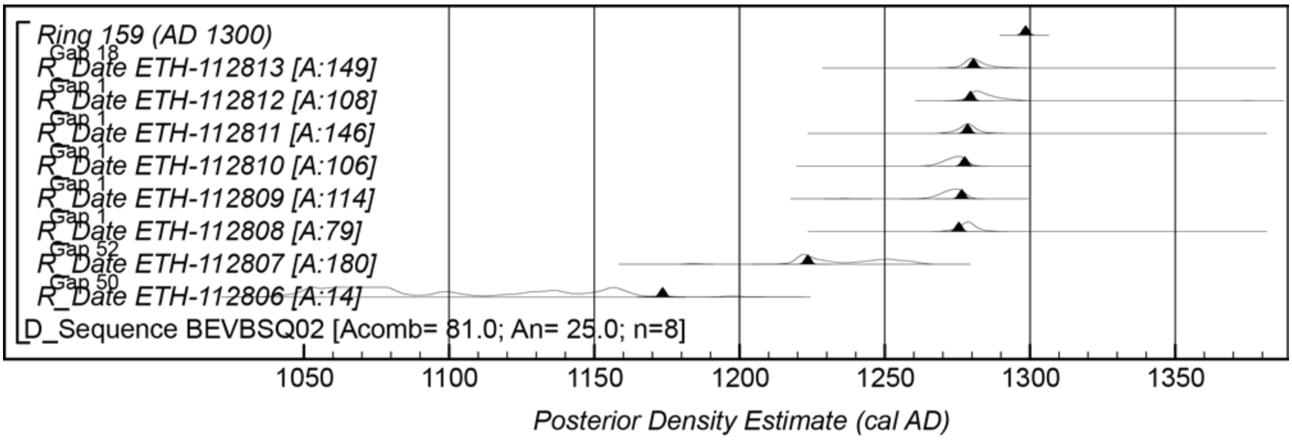

Figure 5: Probability distributions of dates from the undated site sequence BEVBSQ02. Each distribution represents the relative probability that an event occurs at a particular time. For each of the dates two distributions have been plotted: one in outline, which is the simple radiocarbon calibration, and a solid one, based on the wiggle-match sequence. The large square brackets down the left-hand side along with the OxCal keywords define the overall model exactly

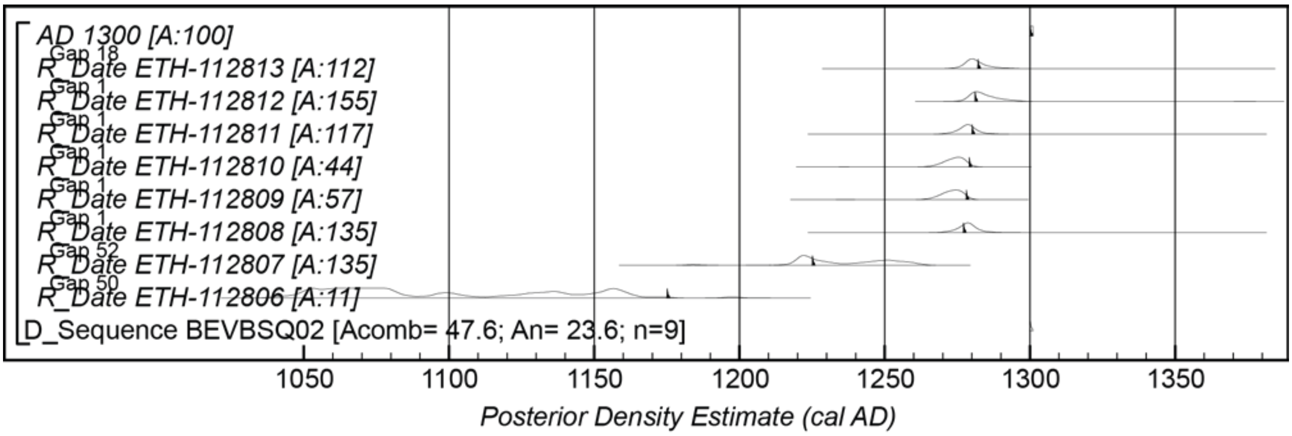

Figure 6: Probability distributions of dates from the undated site sequence BEVBSQ02, including the tree-ring date of AD 1300 for ring 159. The format is identical to Figure 5

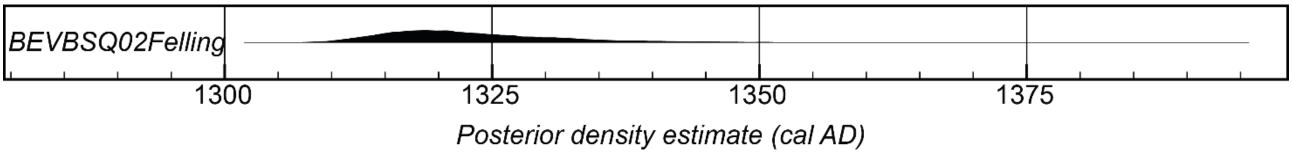

Figure 7: Probability distribution estimating the felling date of timbers in site sequence BEVBSQ02

Table 1: Details of tree-ring samples from Monks Walk, 19 Highgate, Beverley, Yorkshire

Sample number	Sample location	Total rings	Sapwood rings	First measured ring date (AD)	Last heartwood ring date (AD)	Last measured ring date (AD)
BEV-B01	Tiebeam (north gable)	128	h/s	1173_{DR}	1300_{DR}	1300_{DR}
BEV-B02	Tiebeam (mid truss)	152	--	1142_{DR}	1293_{DR}	1293_{DR}
BEV-B03	Tiebeam (south gable)	122	24C	1470	1567	1591
BEV-B04	South east corner post	87	--	1463	----	1549
BEV-B05	Plate in south gable wall – reused	84	h/s	----	----	----
BEV-B06	East wall plate (north end)	NM	--	----	----	----
BEV-B07	East wall plate (south end)	99	h/s	1470	1568	1568
BEV-B08	Pad block	89	h/s	1475	1563	1563
BEV-B09	North-east corner post	47	h/s	----	----	----
BEV-B10	Wall plate (later modification)	141	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

$_{DR}$ = radiocarbon supported dendrochronological date

Table 2: Results of the cross-matching of site sequence BEVBSQ02 and the reference chronologies when the first-ring date is AD 1142 and the last-measured ring date is AD 1300

Reference chronology	*t*-value	Span of chronology (AD)	Reference
Home Farm, Doveridge, Derbyshire	6.1	1050–1319	Howard *et al* 1996
Tithe barn, Englishcombe, Somerset	5.2	1157–1304	Groves and Hillam 1994
Queen's Hotel, York, Yorkshire	5.2	1061–1271	Groves 1990
Chapel Lane, Hull, Yorkshire	5.2	1126–1297	Hillam 1979
York Minster (Chapter House roof), York, Yorkshire	5.1	1135–1288	Howard *et al* 1998
Kenilworth Castle (gatehouse), Kenilworth, Warwickshire	4.7	1092–1332	Arnold and Howard 2007
St Mary's Court, Beverley, Yorkshire	4.6	1173–1336	Arnold *et al* 2020b
Salisbury Cathedral, Wiltshire	4.8	1057–1250	Miles *et al* 2005
Salisbury Cathedral, Wiltshire	4.7	1106–1213	Miles 2002
Witches Tower, Lancaster Castle, Lancashire	4.6	1154–1368	Groves 1994

Table 3: Radiocarbon measurements and associated $\delta^{13}C$ values from oak sample BEV-B01

Laboratory Number	**Sample**	**Radiocarbon Age (BP)**	**δ13CAMS (‰)**
ETH-112806	BEV-B01, ring 3 (*Quercus* sp., heartwood), relative year 34 of BEVBSQ02	923±15	−23.7±1.0
ETH-112807	BEV-B01, ring 53 (*Quercus* sp., heartwood), relative year 84 of BEVBSQ02	826±11	−26.0±1.0
ETH-112808	BEV-B01, ring 105 (*Quercus* sp., heartwood), relative year 136 of BEVBSQ02	731±11	−25.3±1.0
ETH-112809	BEV-B01, ring 106 (*Quercus* sp., heartwood), relative year 137 of BEVBSQ02	754±11	−25.0±1.0
ETH-112810	BEV-B01, ring 107 (*Quercus* sp., heartwood), relative year 138 of BEVBSQ02	750±11	−25.1±1.0
ETH-112811	BEV-B01, ring 108 (*Quercus* sp., heartwood), relative year 139 of BEVBSQ02	731±11	−24.9±1.0
ETH-112812	BEV-B01, ring 109 (*Quercus* sp., heartwood), relative year 140 of BEVBSQ02	712±11	−25.9±1.0
ETH-112813	BEV-B01, ring 110 (*Quercus* sp., heartwood), relative year 141 of BEVBSQ02	721±11	−25.3±1.0

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