Scientific Dating

91 HIGH STREET, ST MARY CRAY, ORPINGTON, GREATER LONDON RADIOCARBON WIGGLE MATCHING OF TIMBERS

Alistair Barclay, Alex Bayliss, Christopher Bronk Ramsey, Gordon Cook, Peter Marshall, Cathy Tyers, and Paula Reimer

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SUMMARY
Radiocarbon dating and wiggle match analysis was undertaken on a series of five single-year samples from each of three cores taken from oak and elm timbers thought to be associated with the primary construction phase of 91 High Street, St Mary Cray. The analysis suggests that the timbers were all felled in *cal AD 1370–1395* (*95% probability*), thus indicating a late-fourteenth century date for the construction of this building.

CONTRIBUTORS
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CONTENTS

INTRODUCTION

The grade II listed building, 91 High Street, St Mary Cray, Orpington, Greater London (Figs 1 and 2), is listed as possibly dating from the sixteenth century, albeit much altered. Recent discussions have, however, raised the possibility of an earlier origin of around AD 1400. The building is thought to be the south cross-range of a two-storey timber-framed building, the middle range of which may survive as 89 High Street, whilst the north cross-range (87 High Street) appears to be a nineteenth century brick construction with little or no original structure surviving (Meekums pers comm).

The south cross-range comprises two bays with what is described by Michael Meekums (pers comm) as a plain crown post roof with only two 'crowns' (Fig 3) that is hipped at the east end with the outer rafter couples thought to be a later addition (Fig 4). The extant floor at first-floor level in the west, or front, bay facing the road appears likely to be part of the original build but whether or not the east, or rear bay, which incorporates some new joists is original or a later insertion is less clear (Meekums pers comm).

Following a change in ownership the Orpington and District Archaeological Society were requested to record the building (Meekums and Clayton forthcoming) in order to elucidate understanding of the building and hence inform the planning of a potential extension. Scientific dating was requested by the Historic England London Region in order to inform a forthcoming listed building consent application through the provision of independent dating evidence for the primary construction of 91 High Street.

TREE-RING ASSESSMENT

An assessment of the dendrochronological potential was commissioned by the Historic England Scientific Dating team. This concluded that the timbers associated with the roof and floor were unsuitable for dendrochronological analysis as they were a mixture of very young fast-grown oak (*Quercus* spp) and elm (*Ulmus* spp) timbers all containing less than 40 annual growth rings (Moir pers comm 2012; Bridge pers comm 2012). This outcome was perhaps not surprising as assessments of dendrochronological potential, commissioned by Historic England and undertaken by Martin Bridge in 1998, on The Blue Anchor Public House (1 High Street, St Mary Cray) and Survey House (5–9 High Street, St Mary Cray) highlighted the use of elm timbers throughout both buildings with only some oak timbers present and all of which were unsuitable for analysis with the timbers containing very few growth rings. Both of these listed buildings were also thought at the time to date on stylistic grounds to the late-fifteenth or early-sixteenth centuries.

RADIOCARBON DATING - SAMPLING AND ANALYSIS

Following the negative dendrochronological assessment, but bearing in mind the potential significance of this building, a programme of radiocarbon dating and wiggle matching was agreed. Martin Bridge was commissioned to take core samples predominantly from a series of timbers associated with the primary construction, targeting those timbers with the most rings but which also had sapwood or the heartwood/sapwood boundary present. Details of the ten samples taken are given in Table 1 and the locations of these samples are illustrated in Figures 5–8. It was subsequently noted that the timber from which ulm05 was taken had a redundant peg hole and was thus potentially reused in its current location.

The cores (ulm07 and ulm10) from joists from the west bay of the floor frame were considered unsuitable for wiggle-matching as they contained so few annual growth rings and the fact that the other sampled joist in the east bay of the floor frame appeared to be reused meant that no radiocarbon dating was undertaken on the floor frames. However, three cores (ulm01, ulm03, and ulm04), all thought to be associated with the primary construction, were selected for sub-sampling for radiocarbon dating and subsequent wiggle-matching. These were selected on the basis of the length of the ring sequence and the presence of sapwood and deliberately included both oak and elm in order to attempt to ascertain that these species are coeval within the primary construction. A series of five individual annual growth rings were sub-sampled from each core (Table 2).

The 15 individual ring samples were analysed at Oxford University Radiocarbon Accelerator Unit (OxA), Queens University Belfast ^{14}CHRONO Centre (UBA), and the Scottish Universities Environmental Research Centre (SUERC) (Tables 2a, 3a, and 4a).

The five samples submitted to the Oxford University Radiocarbon Accelerator Unit were pretreated using the acid-base-acid protocol followed by bleaching with sodium chlorite (Brock *et al* 2010, Table 1 (UW)). They were combusted and graphitised as described by Brock *et al* (2010, 110) and Dee and Bronk Ramsey (2000) and dated by Accelerator Mass Spectrometry (AMS) (Bronk Ramsey *et al* 2004).

The five samples submitted to the Queens University Belfast ^{14}CHRONO Centre were pretreated using the acid-alkali-acid protocol followed by bleaching and dated by AMS as described in Reimer *et al* (2015).

The five samples submitted to the Scottish Universities Environmental Research Centre α-cellulose, combusted, graphitised, and dated by AMS as described by Dunbar *et al.* (2016)

All three laboratories maintain a continual programme of quality assurance procedures, in addition to participation in international inter-comparisons (Scott 2003; Scott *et al* 2010). These tests indicate no laboratory offsets and demonstrate the reproducibility and accuracy of these measurements.

The results are conventional radiocarbon ages (Stuiver and Polach 1977; Table 2), and are quoted in accordance with the international standard known as the Trondheim convention (Stuiver and Kra 1986).

RADIOCARBON DATING

Radiocarbon dating is based on the radioactive decay of carbon-14 and can be used to date organic materials, including wood. A small proportion of the carbon atoms in the atmosphere are of a radioactive form, carbon-14. Living plants and animals take up carbon from the environment, and therefore contain a constant proportion of carbon-14. Once a plant or animal dies, however, its carbon-14 decays at a known rate. This makes it possible to calculate the date of formerly living material from the concentration of carbon-14 atoms remaining. Radiocarbon measurements are expressed in radiocarbon years BP, like those in Table 2.

CALIBRATION

Radiocarbon ages are not the same as calendar ages because the concentration of carbon-14 in the atmosphere has fluctuated over time and therefore have to be calibrated against an independent scale to arrive at the corresponding calendar date. The independent scale is the IntCal13 calibration curve (Reimer *et al* 2013) which is constructed from radiocarbon measurements on tree rings, plant macrofossils, speleothems, corals, and foraminifera. The calibrations which relate the radiocarbon measurements directly to the calendrical time scale (Fig 12) have been calculated using IntCal13 and the computer program OxCal4.2.3 (https://c14.arch.ox.ac.uk/oxcal/; Bronk Ramsey 1995; 2001; 2009a). The calibrated date ranges quoted for each sample in Table 2, expressed as 'cal AD', were calculated by the maximum intercept method (Stuiver and Reimer 1986) and are rounded outwards to the 10 years or 5 years if the error was <25 as recommended by Mook (1986). The graphical distributions of the calibrated dates, shown in black in Figures 13, 17, and 20 are derived from the probability method (Stuiver and Reimer 1993).

BAYESIAN WIGGLE-MATCHING

Wiggle-matching uses information derived from tree-ring analysis, in combination with radiocarbon measurements to provide a revised understanding of the age of a timber; a review is presented by Galimberti *et al* (2004). In this technique, the shapes of multiple radiocarbon distributions can be "matched" to the shape of the radiocarbon calibration curve. The exact interval between radiocarbon results can be derived from tree-ring analysis.

Although the technique can be done visually, Bayesian statistical analyses (including functions in the OxCal computer program) are now routinely employed. A general introduction to the Bayesian approach to interpreting archaeological data is provided by Buck *et al* (1996). The approach to wiggle-matching adopted here is described by Christen and Litton (1995).

Details of the algorithms employed in this analysis — a form of numerical integration undertaken using OxCal — are available from the on-line manual or in Bronk Ramsey (1995; 1998; 2001; 2009a). Because it is possible to constrain a sequence of radiocarbon dates using this highly informative prior information (Bayliss *et al* 2007), model output will provide more precise posterior density estimates. These *posterior density estimates* are shown in black in the relevant figures and quoted in italic in the text.

The A_{comb} statistic shows how closely the dates as a whole agree with other information in the model; an acceptable threshold is reached when it is equal or greater than A_n, a value based on the number of dates in the model. The A statistic shows how closely an individual date agrees with the other information in the model; an acceptable threshold is reached when it is equal to or greater than 60.

Noisy data

The two main approaches for dealing with noisy date or 'outliers' in radiocarbon dating are either to eliminate them manually from the analysis or to use a more objective statistical approach (Bronk Ramsey 2009b; Christen 1994). The model averaging approach (Bronk Ramsey *et al* 2010) offers a more systematic approach than testing many different models individually by adding variable parameters to a model.

Given there is no prior information to suggest any of the measurements might be contaminated or effected by a short-lived offset in the calibration curve it is more realistic that any outliers are solely due to the measurement process. Therefore any outliers can be reasonably expected to be related to the quoted uncertainty in the measurement. The *s-type* outlier model (Bronk Ramsey 2009b; Bronk Ramsey *et al* 2010), based on the approach first outlined in Christen (1994) can be used that tests the effect for each sample of increasing the uncertainty in the measurement (typically by just over 2). A sample is thus likely to be an outlier if the agreement with the other data is much better when such a change has been implemented.

As the number of samples for all the St Mary Cray wiggle-matches are small we have chosen to use the *s-type* model (Christen 1994) solely for outlier detection rather than 'model averaging' that is most useful for large datasets (Bronk Ramsey *et al* 2010).

RESULTS AND INTEPRETATION

ulm01

A chronological model (Fig 13) that includes all the radiocarbon dates on the five single-year tree-ring samples has poor overall agreement (Acomb=7.4, An=31.6; n=5), and it is noticeable that *UBA-23588* has a very low agreement index (A=0). The model shown in Figure 14, that excludes UBA-23588 has good overall agreement (Acomb=98.6, An=35.4; n=4) indicating that these four radiocarbon dates are compatible with the evidence from the tree-ring analysis.

The decision to manually remove UBA-23588 was confirmed by formal outlier analysis, with *UBA-23588* having an outlier probability of 79% (Fig 15).

Calculating a felling date for ulm01

The final ring of core ulm01 (*UBA-23589_last_ring)*, marks the transition between heartwood and sapwood and thus it is necessary to allow for the expected number of missing sapwood rings from the core in order to provide an estimate of the date of felling. The methodology for this approach is described by Bayliss and Tyers (2004). It should be noted that a probability distribution for the expected number of sapwood rings, derived from dendrochronological studies, is not available for elm due to the extreme paucity of material previously examined. Thus the probability distribution for oak sapwood (Bayliss and Tyers 2004) is applied, even though it is considered as likely to be too broad for elm. The estimated felling date for ulm01 is *cal AD 1355–1410 (95 probability; ulm01_felling*, Fig 16; Table 3), probably *cal AD 1365–1395 (68% probability).*

ulm03

The model shown in Figure 17 has poor agreement between the radiocarbon dates and prior information derived from the tree-ring analysis (Acomb=0.1, An=31.6 n=5), with three samples have very low agreement index values (OxA-28714, *O=0*; SUERC-48929, *O=27,* and SUERC-48930, *O=0*].

A model excluding SUERC-48929 and SUERC-48930 (Fig 18), the two oldest dates has good overall agreement (Acomb=90.3, An=40.8; n=4)
Outlier analysis (Fig 19) confirms SUERC-48930 (*O:=92/5*) and SUERC-48929 (*O:=61/5*) as both being outliers.

Calculating a felling date for ulm03

Core ulm03 has 12 sapwood rings and thus, as above, it is necessary to allow for the expected number of missing sapwood rings from this oak core in order to provide an estimate of the date of felling. The estimated felling date for ULM03 is *cal AD 1315–1325 (1% probability)* or *cal AD 1365–1420 (94% probability; ulm03_felling*, Fig 20), probably *cal AD 1375–1400 (68% probability).*

ulm04

The chronological model shown in Figure 21 for core ulm04 has good overall agreement (Acomb=70.9 An=31.6; n=5). Core ulm04 has 5 sapwood rings and thus, as above, it is necessary to allow for the expected number of missing sapwood rings order to provide an estimate of the date of felling. The estimated felling dates for ulm04 is *cal AD 1345–1400 (95% probability; ulm04_felling*, Fig 22), probably *cal AD 1355–1385* (*68% probability*).

Combined felling ulm01, ulm03, and ulm04

The three cores from which samples for wiggle matching were submitted were, based on constructional evidence, thought to be associated with the initial construction of the south cross-range and hence felled at the same time. The probability distributions of the estimated felling dates for each of the cores (Figs 16, 20, and 22) were combined to produce a single felling date estimate (Fig 23; Acomb=108.1; An=40.8, n=3). Thus the estimated date for construction of the south cross-range is *cal AD 1365-1395* (*95% probability*; *build_south_cross_range;* Fig 23), probably *cal AD 1375–1390* (*68% probability*).

INTERPRETATION

Radiocarbon wiggle matching of three undated tree-ring sequences suggests the construction of the south cross-range took place in *cal AD 1365-1395* (*95% probability*; *build_south_cross_range;* Fig 23), probably *cal AD 1375–1390* (*68% probability*). This supports the earlier *c* AD 1400 origin of the building that has been suggested recently, as opposed to the sixteenth century date given in the listing description.

Examining the reliability of the south cross-range chronology

An alternative model for construction of the south cross-range incorporating the estimated felling date ranges derived from the outlier models for cores ulm01 and ulm03 (distributions not shown), combine to produce a single felling date estimate (Fig 24; Acomb=92.8; An=40.8, n=3). This result is remarkably similar to that presented in the preferred model (Fig 25).

DISCUSSION AND CONCLUSION

This analysis has clearly placed this extant range at 91 High Street somewhat earlier than previously thought and raises the question as to whether other buildings on the High Street (eg The Blue Anchor Public House and Survey House) with elm present throughout, also thought on stylistic grounds to be of late-fifteenth or early-sixteenth century date, could perhaps have earlier origins. In addition the use of elm in extant buildings has generally been considered to be a later medieval phenomenon when local oak resources are under pressure, although elm from earlier medieval contexts has been excavated on archaeological sites, so the widespread use of elm within 91 High Street in the latter fourteenth century is notable and has implications concerning the timber resources in the area at that time.

Given the reliance of wiggle-matching on a detailed understanding of the structure of the ^{14}C calibration curve it is not surprising that two of the three dated sequences initially produced models that had poor agreement between the radiocarbon dates and the tree-ring evidence. This is a result of calibration data before AD 1510 being based on decadal wood samples (from AD 1510–1950 single year data is available) and the short sequences available from the south cross-range (Bayliss *et al* 2016).

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TABLES

Table 1: Details of core samples taken from 91 High Street, St Mary Cray; h/s indicates the heartwood/sapwood boundary

Core	Timber and position	Species	Total number of rings	Sapwood	Mean ring width (mm)
ulm01	Tiebeam, central truss	elm	31	h/s	1.92
ulm02	South wall plate, near west end	oak	13	h/s	5.69
ulm03	North common rafter, 5th from west end	oak	25	12	2.61
ulm04	North wall plate, near east end	oak	28	5	2.27
ulm05	Joist, 2nd from south, east bay (?reused)	oak	22	h/s	2.69
ulm06	South post to central truss	oak	27	h/s	4.74
ulm07	Joist, southernmost, west bay	elm	7	h/s	5.19
ulm08	North post to central truss	elm	10	h/s	5.29
ulm09	Girding beam, central truss	elm	unknown, fragmented	h/s	-
ulm10	Joist, 2nd from north, west bay	oak	15	h/s	3.23

Table 2: Radiocarbon results for cores ulm01, ulm03, and ulm04

Laboratory Number	Sample ID	Material	$\delta^{13}C$ (‰)	Radiocarbon Age (BP)	Calibrated Date (2σ) cal AD	*Posterior Density Estimate (95% probability) cal AD*
Core ulm01						
SUERC-48927	ulm01 ring 1	elm, heartwood	−22.5%±0.2	567±28	1300–1430	*1310–1355*
OxA-28713	ulm01 ring 8	elm, heartwood	−20.7%±0.2	601±22	1295–1410	*1315–1360*
UBA-23588	ulm01 ring 17	elm, heartwood	−22.8%±0.22	488±24	1410–1450	–
SUERC-48928	ulm01 ring 24	elm, heartwood	−19.9%±0.2	581±28	1300–1420	*1330–1375*
UBA-23589	ulm01 ring 31	elm, heartwood	−21.2%±0.22	633±24	1285–1400	*1340–1385*
Core ulm03						
OxA-28714	ulm03 ring 1	oak, heartwood	−25.6±0.2	627±23	1285–1400	*1340–1370*
SUERC-48929	ulm03 ring 7	oak, heartwood	−23.8±0.2	790±29	1200–1280	–
UBA-23590	ulm03 ring 13	oak, heartwood	−25.5±0.22	663±24	1275–1390	*1350–1385*
SUERC-48930	ulm03 ring 18	oak, sapwood	−23.9±0.2	810±28	1160–1280	–
OxA-28715	ulm03 ring 24	oak, sapwood	−25.0±0.2	673±23	1275–1390	*1365–1395*
Core ulm04						
UBA-23591	ulm04 ring 1	oak, heartwood	−25.3±0.22	602±25	1290–1410	*1310–1350*
OxA-28716	ulm04 ring 8	oak, heartwood	−25.1±0.2	585±23	1300–1415	*1315–1355*
SUERC-48931	ulm04 ring 15	oak, heartwood	−23.5±0.2	592±29	1290–1420	*1320–1360*
UBA-23592	ulm04 ring 22	oak, heartwood	−24.8±0.22	554±26	1310–1430	*1330–1370*
OxA-28717	ulm04 ring 28	oak, sapwood	−25.3±0.2	647±23	1280–1395	*1335–1375*

FIGURES

Figure 1: Location of 91 High Street, St Mary Cray (circled). © Crown Copyright and database right 2014. All rights reserved. Ordnance Survey Licence number 100024900

Figure 2: The west gable end of 91 High Street, St Mary Cray (photograph: Martin Bridge)

Figure 3: The plain crown post, with only two ‘crowns’ of 91 High Street, St Mary Cray (photograph: Michael Meekums)

Figure 4: The hipped east end of crown post roof of 91 High Street, St Mary Cray (photograph: Martin Bridge)

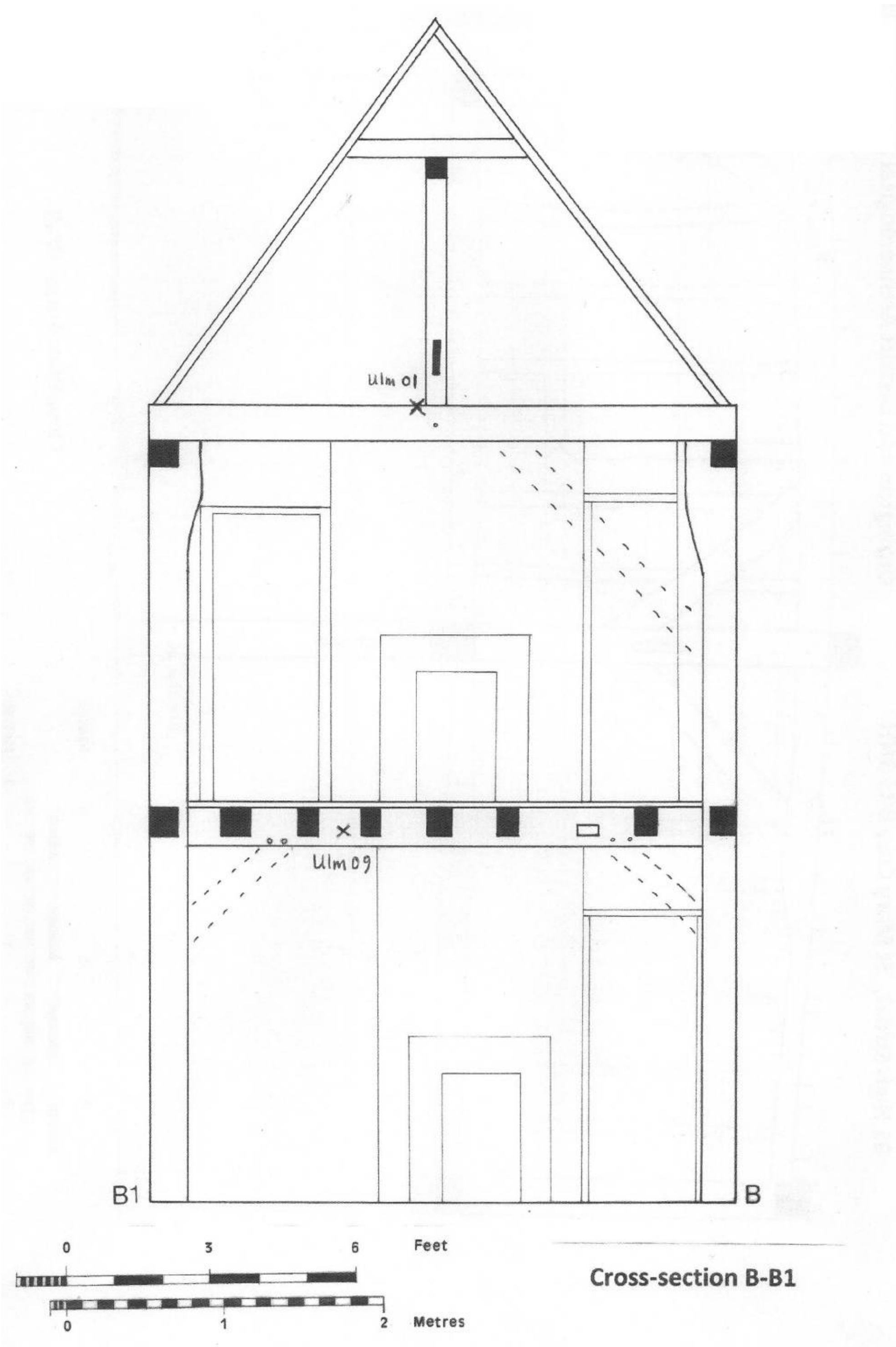


Figure 5: The central frame of 91 High Street, St Mary Cray showing the location of the sampled timbers (Orpington and District Archaeological Society)

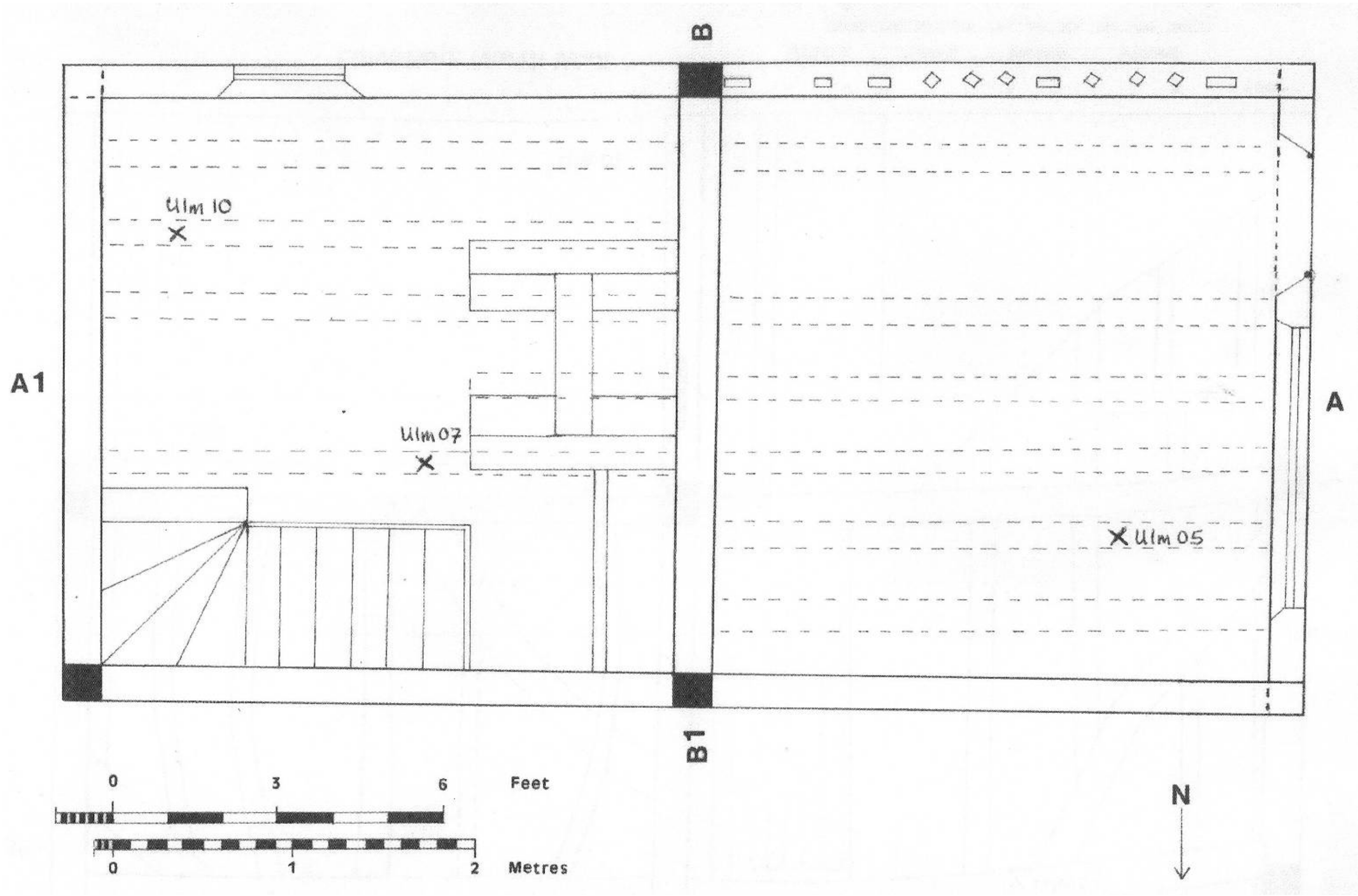


Figure 6: Plan of the ground floor of 91 High Street, St Mary Cray showing the location of the sampled timbers (Orpington and District Archaeological Society)

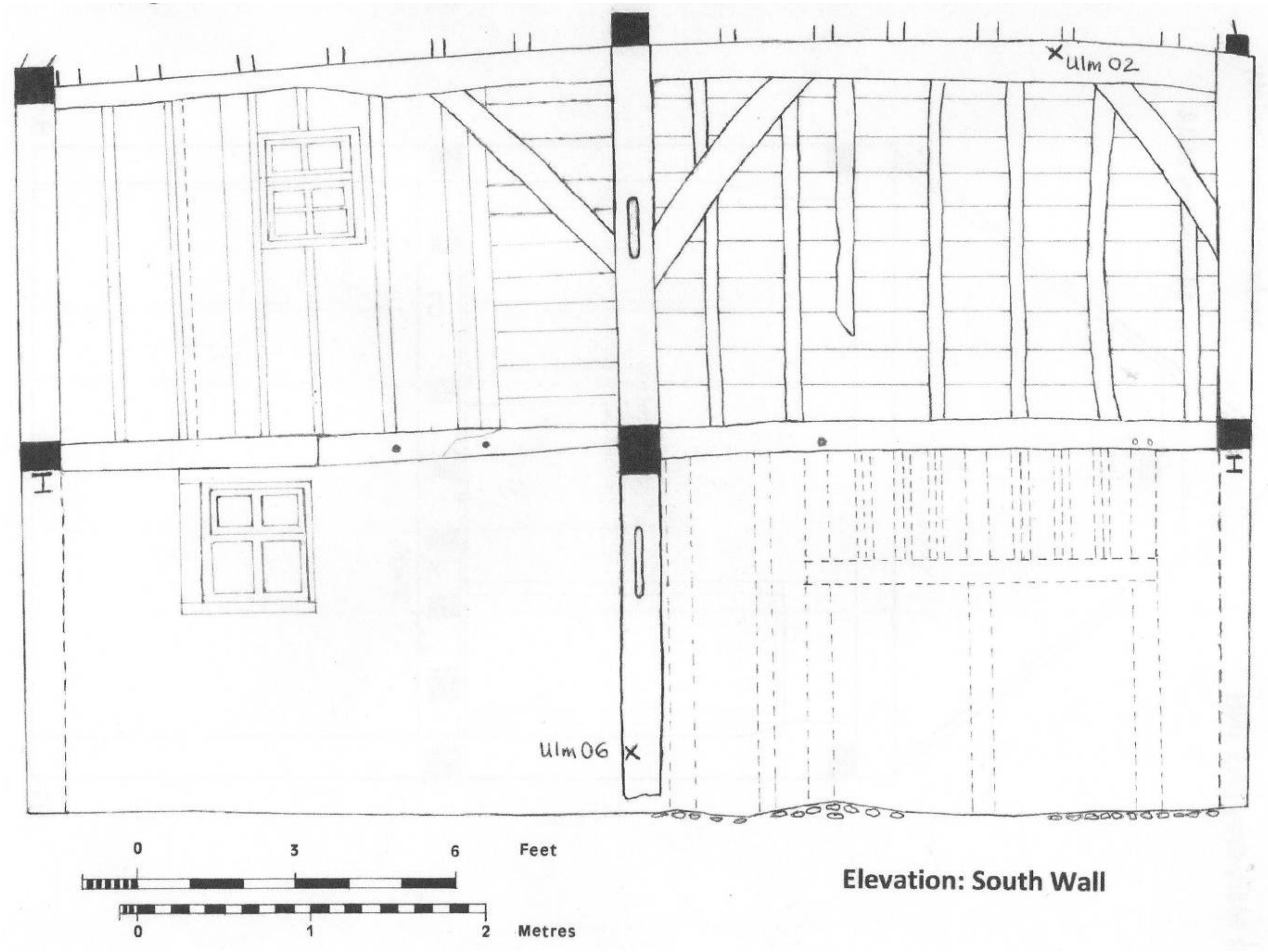


Figure 7: Elevation of the south wall of 91 High Street, St Mary Cray showing the location of the sampled timbers (Orpington and District Archaeological Society)

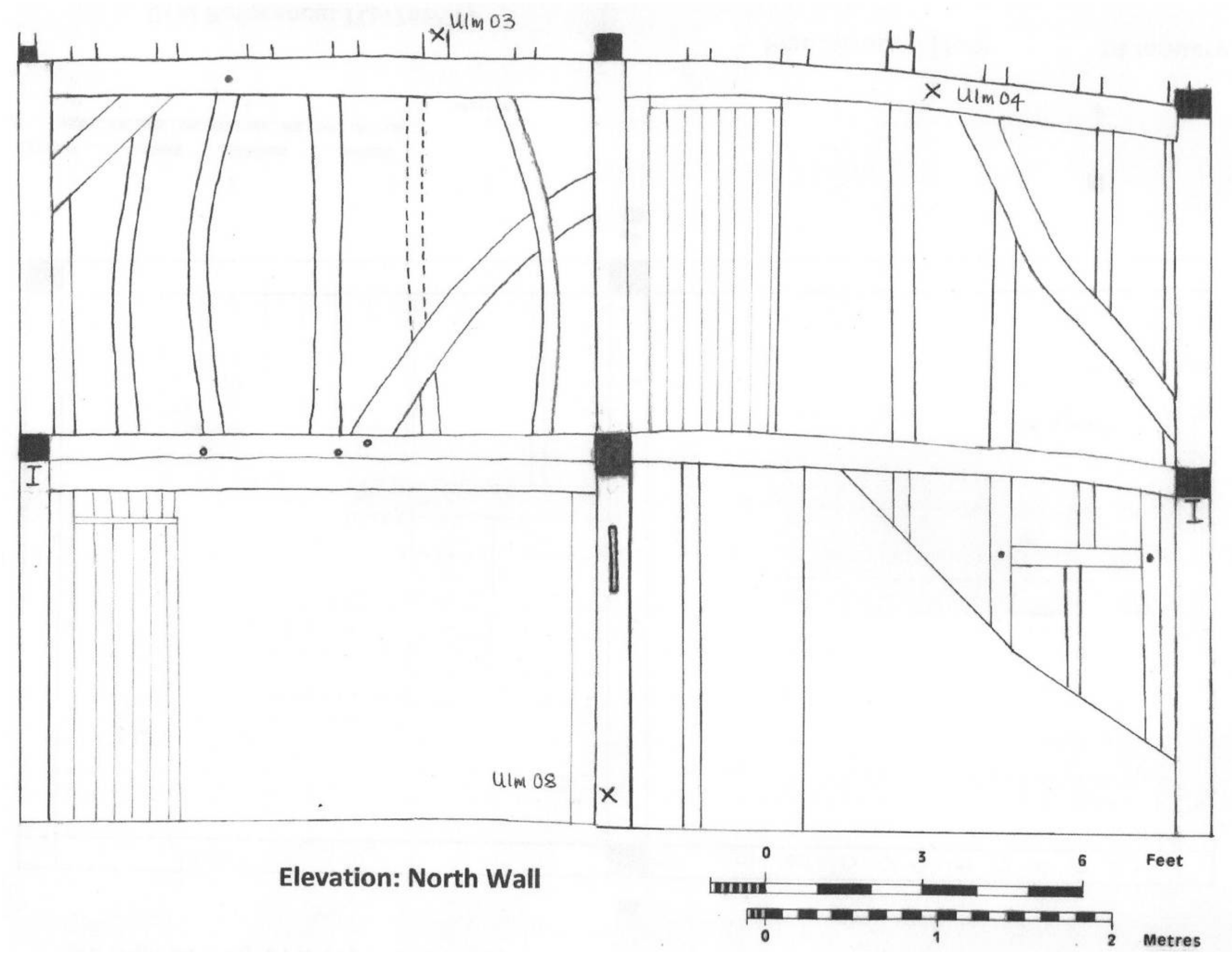


Figure 8: Elevation of the north wall of 91 High Street, St Mary Cray showing the location of the sampled timbers (Orpington and District Archaeological Society)

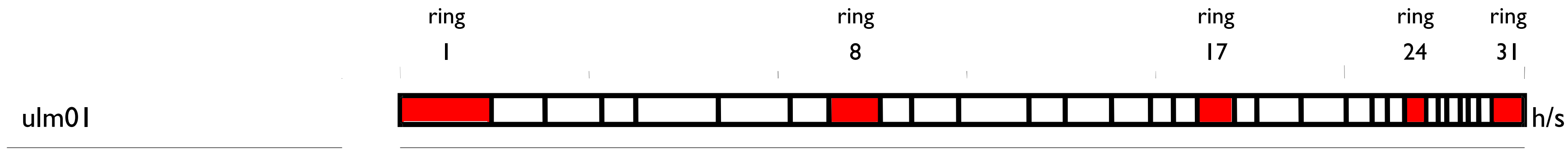


Figure 9: Schematic representation of elm core ulm01 showing the rings sampled for radiocarbon dating. h/s indicates heartwood/sapwood boundary

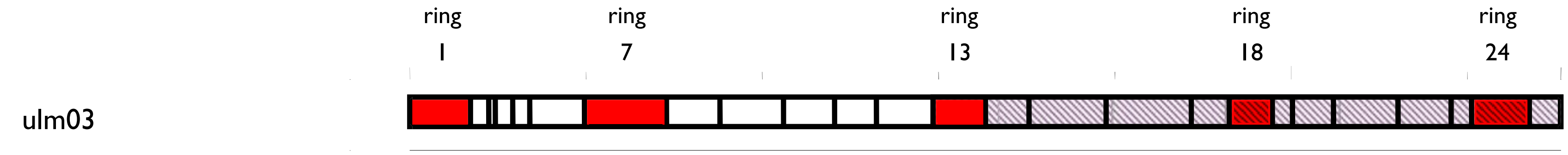


Figure 10: Schematic representation of oak core ulm03 showing the rings sampled for radiocarbon dating. Hatching indicates sapwood

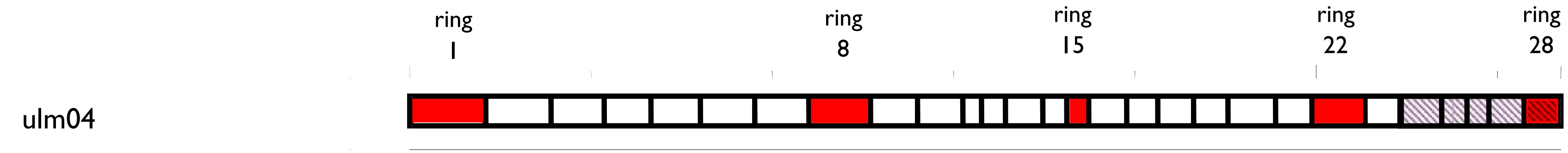


Figure 11: Schematic representation of oak core ulm04 showing the rings sampled for radiocarbon dating. Hatching indicates sapwood

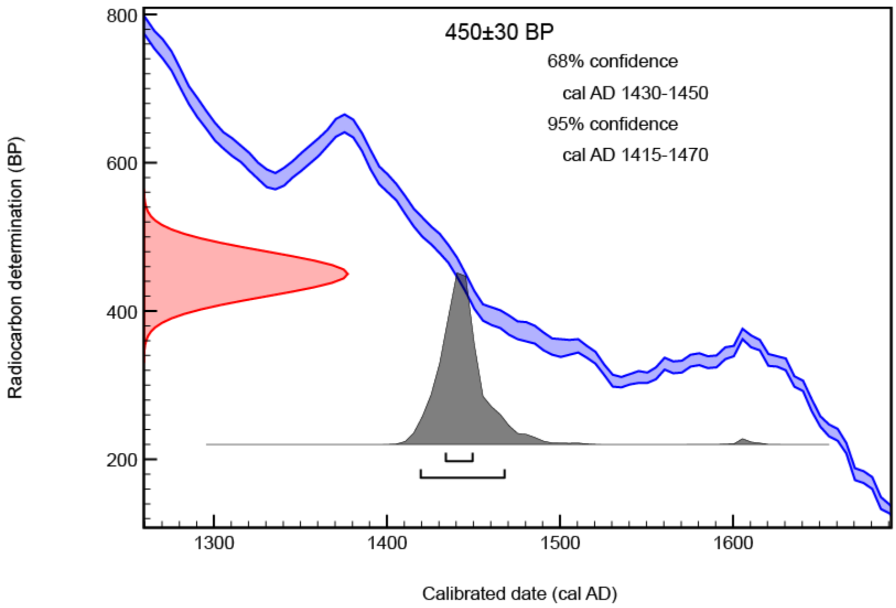


Figure 12: An example radiocarbon measurement of 450±30 BP (in pink on the vertical axis) calibrated to AD 1430–1450 (1σ) and AD 1415–1470 (2σ) (in black on the horizontal axis). The blue band is the relevant part of the calibration curve

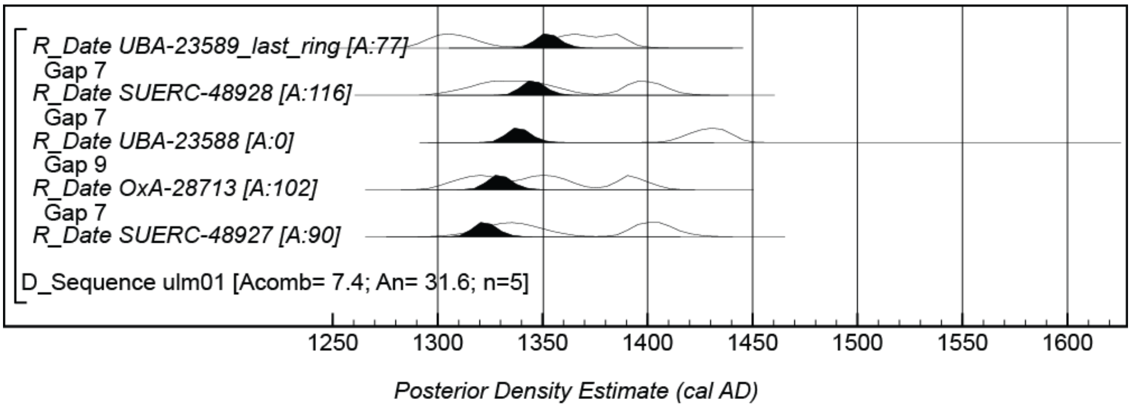


Figure 13: Probability distributions of dates from core ulm01. Each distribution represents the relative probability that an event occurs at a particular time. For each of the dates two distributions have been plotted: one in outline, which is the simple radiocarbon calibration, and a solid one, based on the wiggle-match sequence. Distributions other than those relating to particular samples correspond to aspects of the model. The large square brackets down the left-hand side along with the OxCal keywords define the overall model exactly

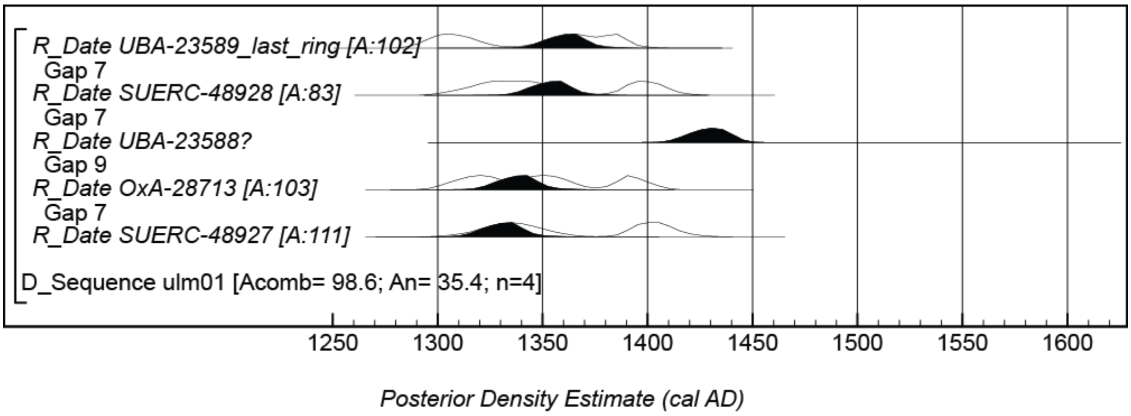


Figure 14: Probability distributions of dates from core ulm01. Each distribution represents the relative probability that an event occurs at a particular time. UBA-23588 *has been excluded from the overall model and the solid distribution plotted is the simple radiocarbon calibration. The overall format is identical to Figure 14*

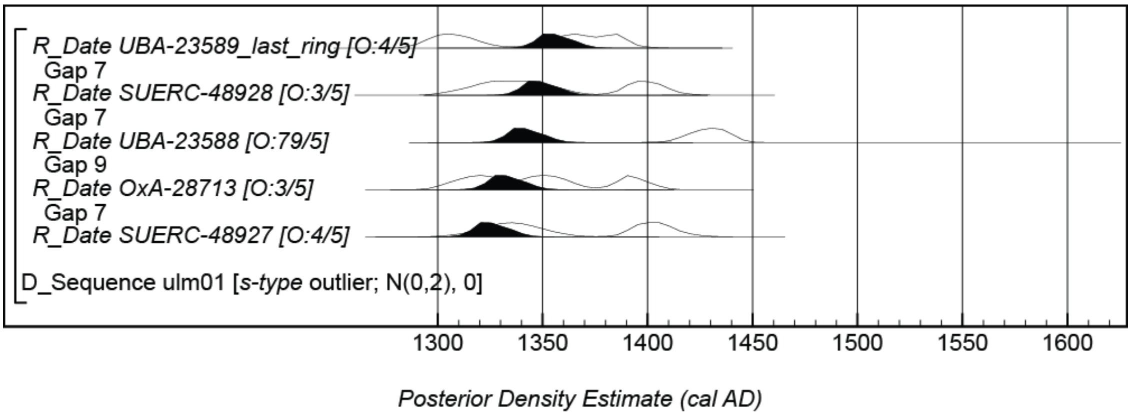


Figure 15: Probability distributions of dates from the core ulm01 (s-type Outlier_Model). Each distribution represents the relative probability that an event occurs at a particular time. For each of the dates two distributions have been plotted: one in outline, which is the simple radiocarbon calibration, and a solid one, based on the wiggle-match sequence with the applied

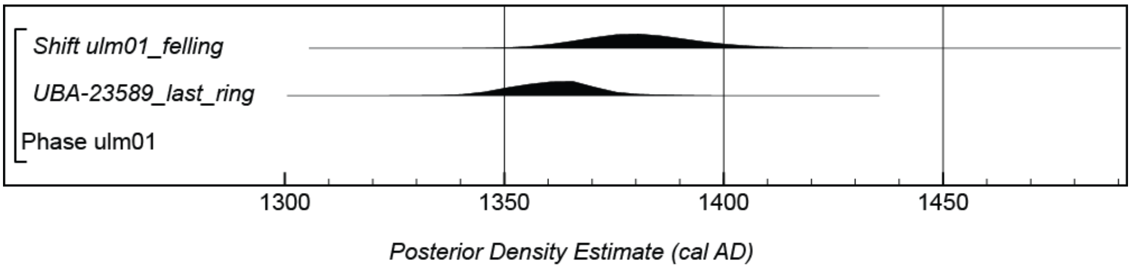


Figure 16: Probability distribution of the last ring of ulm01 (the heartwood/sapwood boundary) and the estimated felling date for timber ulm01

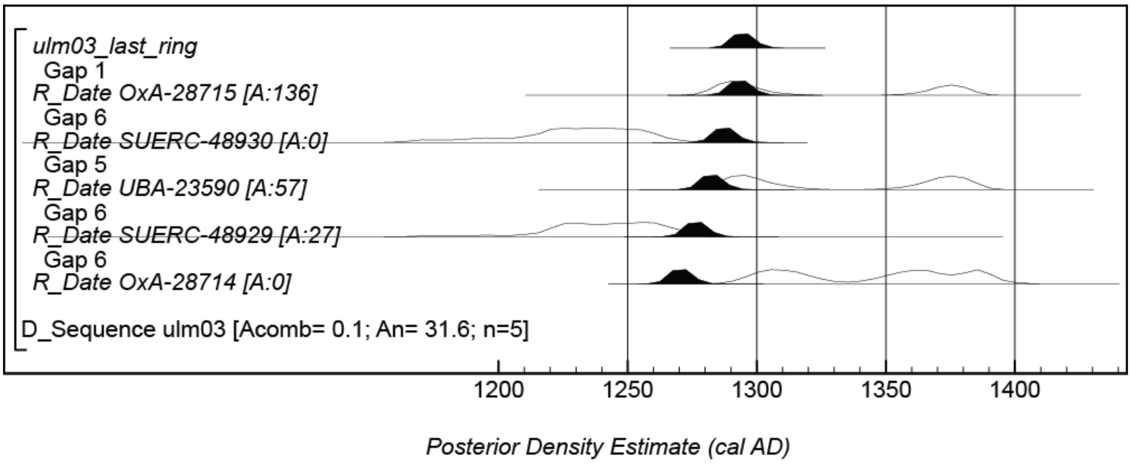


Figure 17: Probability distributions of dates from core ulm03. The overall format is identical to Figure 13

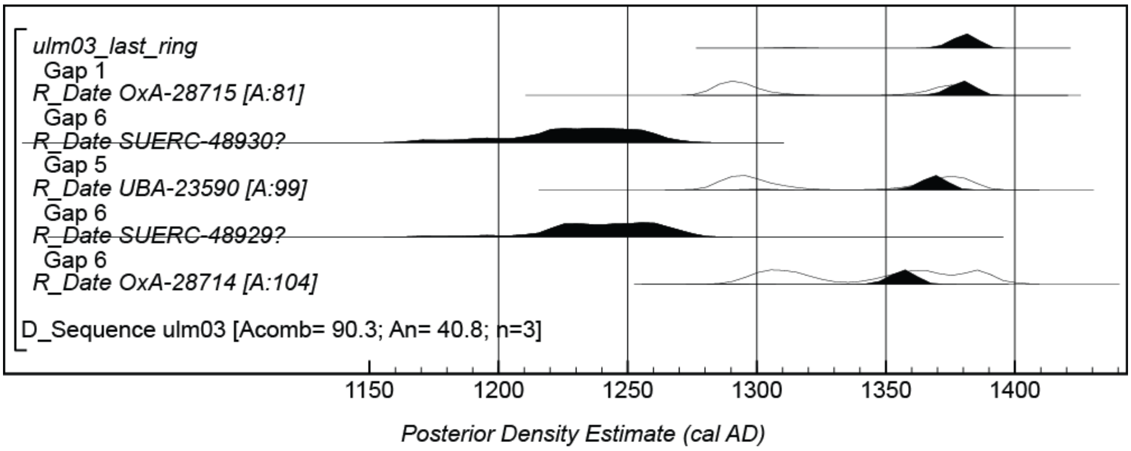


Figure 18: Probability distributions of dates from core ulm03. The overall format is identical to Figure 14

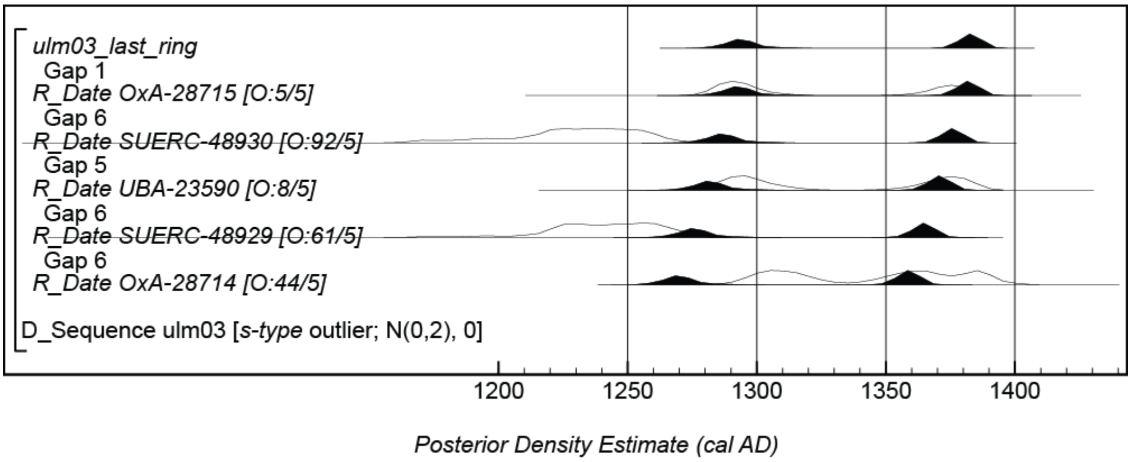


Figure 19: Probability distributions of dates from the core ulm03. The overall format is identical to Figure 15

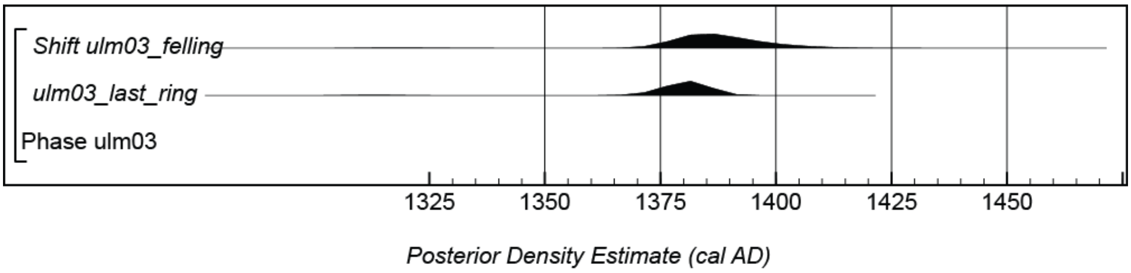


Figure 20: Probability distributions of the last ring of ulm03 and the estimated felling date for timber ulm03

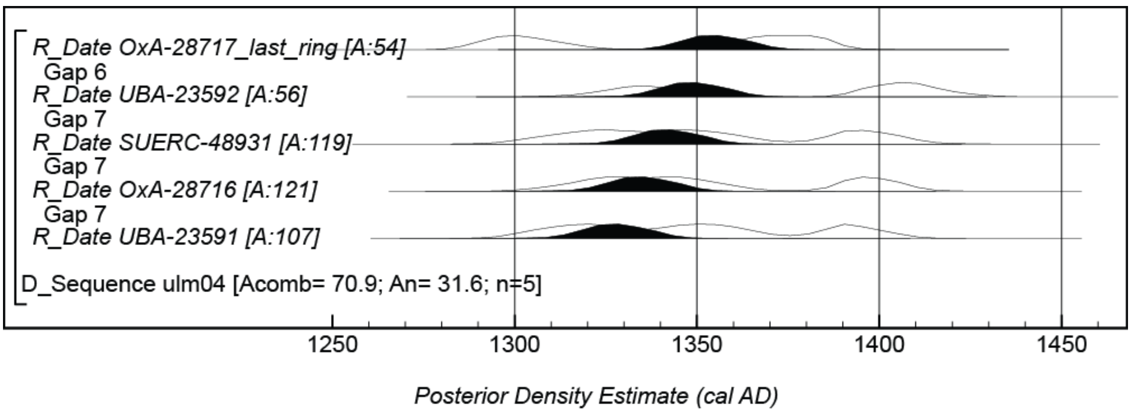


Figure 21: Probability distributions of dates from core ulm04. The overall format is identical to Figure 13

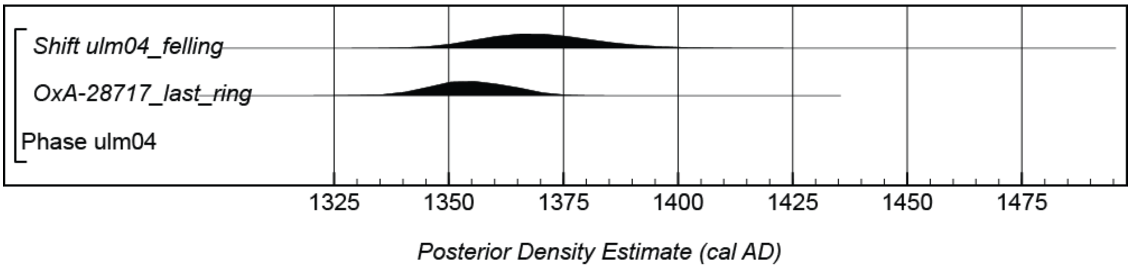


Figure 22: Probability distributions of the last ring of ulm04 and the estimated felling date for timber ulm04

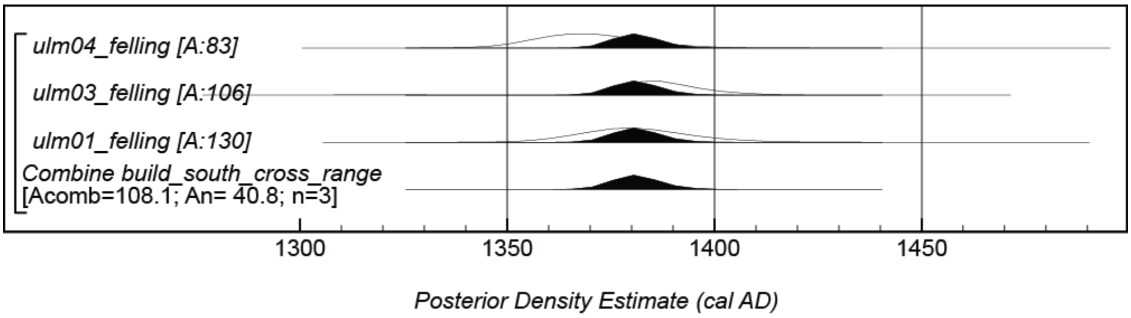


Figure 23: Combined probability distribution estimating the construction date of the south cross-range, if ulm01, ulm 03*, and* ulm 04 *are assumed to have a common felling date*

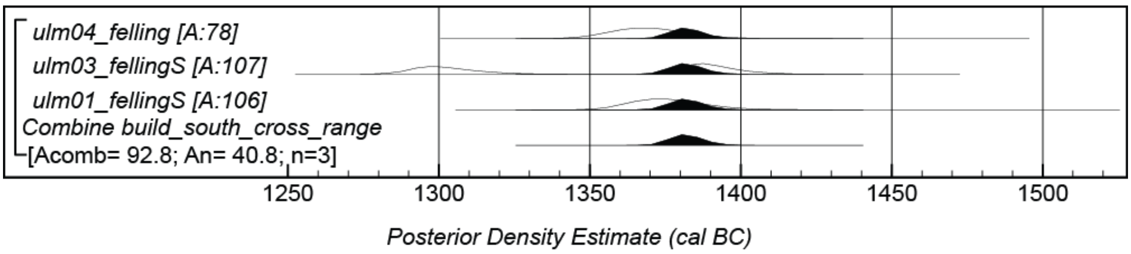


Figure 24: Combined probability distribution estimating the construction date of the south cross-range, if ulm01, ulm 03S, *and* ulm 04S *are assumed to have a common felling date*

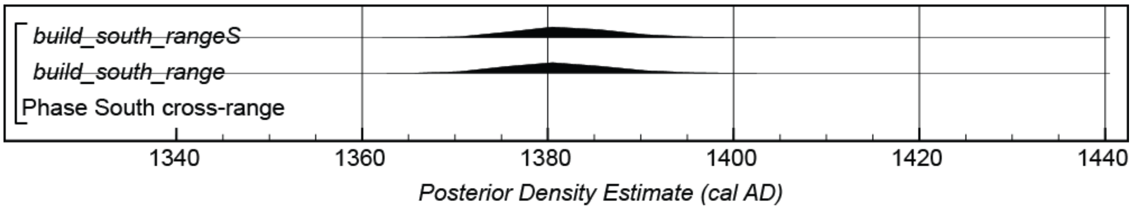
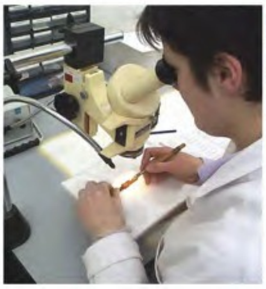


Figure 25: Probability distributions for the construction date of the south cross-range from the preferred (Fig 23) and alternative (Fig 24) models



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