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Scientific Dating

Church of St Peter, West Liss, Hampshire Tree-ring analysis and radiocarbon wiggle-matching of the nave, south aisle and porch roofs

Alison Arnold, Seren Griffiths, Christopher Bronk Ramsey, Gordon Cook, Paula Reimer and Peter Marshall

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TREE-RING ANALYSIS AND RADIOCARBON WIGGLE-MATCHING OF THE NAVE, SOUTH AISLE AND PORCH ROOFS

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SUMMARY
Forty samples from the nave, south aisle, and porch of this church were subject to tree-ring dating; three of these also underwent radiocarbon and wiggle-match analysis.

Three nave timbers were dendrochronologically dated to AD 1581–1606 and two to *c* AD 1616. A further nine timbers from this roof have now been dated by radiocarbon wiggle-matching to the early fourteenth century and five backing rafters have also been dated by radiocarbon wiggle-matching to the eighteenth or nineteenth century

These results suggest construction of the present roof at the beginning of the fourteenth century with repairs and modifications undertaken in *c* AD 1616 and the eighteenth or nineteenth century.

Eight timbers of the south aisle roof were tree-ring dated by dendrochronology to *c* AD 1616 and two reused timbers dated by radiocarbon wiggle-matching to the early fourteenth century, suggesting the primary construction utilised some reused material.

Two timbers from the porch have been dated by radiocarbon wiggle-matching to the late fourteenth or early fifteenth century, a date at odds with the inscribed date of AD 1639

CONTRIBUTORS
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CONTENTS

INTRODUCTION

The Church of St Peter, situated some 5km north-east of Petersfield and about 29km east of Winchester, in the village of West Liss (Figures 1 and 2), is a grade II* listed building. It is believed that there has been a church on this site since sometime after AD 900. The foundations of the tower are Saxon, though it is mainly of early-thirteenth century date, as are the nave and chancel. The south arcade, aisle and south door date from the late-thirteenth century, whilst the south porch was built in AD 1639. There is a seventeenth-century window at the west end of the south aisle. The chancel was restored in AD 1864 at the same time as the north organ chamber/vestry was added.

Nave

The roof consists of 19 frames of common rafters with collars and arch braces. At some point 'backing rafters' have been attached to the rear of the common rafters on the south side, presumably for strengthening purposes (Fig 3). Some of the timbers are thought to be reused. This roof is believed to date from the early-thirteenth century.

South Aisle

The construction of this roof is similar to that of the nave, with each of the 26 frames again consisting of common rafters, collars, and arch braces (Fig 4). Some of these rafters also have the strengthening 'backing rafters and higher 'modern' collars. Some of the rafters show signs of reuse in the form of empty mortices. This roof is believed to be late-thirteenth century in date.

Porch

This very simple roof has six frames of common rafters and collars. The seventh (most northernmost frame) also has a tiebeam with empty mortices from which arch braces may have once run to now removed posts (Fig 5). The south porch has an inscribed date of AD 1639 commemorating its gift by Henry James.

TREE-RING SAMPLING

Sampling and analysis by tree-ring dating were commissioned by English Heritage to inform grant-aided work under the Places of Worship Scheme. The results of this exercise, which are reported elsewhere (Arnold and Howard 2012), are summarised here. Forty-nine core samples and one sliced sample were obtained from timbers of the roofs of the nave (23 samples), south aisle (18 samples), and porch (eight samples). Details of these samples are given by Arnold and Howard (2012, table 1).

TREE-RING ANALYSIS

Fourteen samples grouped (five from the nave, eight from the south aisle, and the sample taken from the timber beneath the valley gutter between the two) and were combined to form LSSASQ01, a site sequence of 151 rings. When compared against a series of relevant reference chronologies this site sequence was found to span the period AD 1464–1614 (Arnold and Howard 2012, table 2).

Four other site sequences of 11 (LSSASQ02), five (LSSASQ03), two (LSSASQ04), and two (LSSASQ05) samples were also constructed by combining the samples at the relevant offset positions (Arnold and Howard 2012, figs 45–8). These site sequences were each compared against the reference chronologies but no secure match could be found and these were undated.

Tree-ring analysis of samples taken from the roofs of the nave, south aisle, and porch at St Peter's Church resulted in two collars from the nave, both thought to be reused at the time of sampling, being dated to an estimated felling date of AD 1581–1606 whilst three nave rafters, believed to be primary, are slightly later, dating to *c* AD 1616. Primary rafters from the south aisle were dated to AD 1615–40. The sample taken from the timber which once supported the valley gutter has a heartwood/sapwood boundary ring date of AD 1566, giving the timber represented the felling date range of AD 1581–1606. No timbers from the porch roof were successfully tree-ring dated.

RADIOCARBON DATING SAMPLING AND ANALYSIS

Prior to tree-ring analysis being undertaken the nave roof was thought to date to the early thirteenth century with the south aisle roof dating to the late-thirteenth century. Unfortunately dendrochronology was unable to positively identify any thirteenth-century timbers from either of these two roofs, though clearly many sampled timbers remain undated.

Furthermore it has not been possible to provide any dating evidence for the insertion of the backing rafters in the nave roof, nor has it been possible to either confirm or refute the AD 1639 date ascribed to the porch roof. By association with the south aisle roof, the unusual stone valley-gutter probably predates *c* AD 1616. It was not possible to conjecture how much earlier this could have been due to the lack of significantly earlier timbers being identified in either the nave or south-aisle roofs.

Given the existence of two well replicated undated site sequences, LSSASQ02 and LSSASQ03, of reasonable length that contained timbers from the nave (primary, reused and backing; Arnold and Howard 2012, table 1; figs 45–6) and south aisle (Arnold and Howard 2012, table 1; fig 46), and the importance of dating them to inform future conservation and management of the building, a programme of further dating was required. In addition, although site sequence LSSASQ04 (Arnold and Howard 2012, table 1; fig 4) only contained two timbers, both were from the undated porch roof, and further dating should therefore provide a date for its construction.

To this end, three series of six single-year tree-rings were sub-sampled from timbers that formed part of the undated site sequences LSSASQ02, LSSASQ03, and LSSASQ04.

Sample LSS-A21, a component of undated site sequence LSSASQ03, is from a backing rafter in the nave roof and has complete sapwood. Several tentative tree-ring matches were noted for this site sequence, including end dates of AD 1570, AD 1559, and AD 1744. Radiocarbon wiggle-matching was undertaken to determine whether support could be gained for any of these tentative dates.

Sample LSS-A37, a component of undated site sequence LSSASQ02, is from a rafter in the south aisle roof and has the heartwood/sapwood boundary as its last ring. This site sequence had two tentative tree-ring end dates, AD 1287 and AD 1515 and it was hoped that the radiocarbon wiggle-matching could provide support for one of these.

Finally, LSS-A50, a component of undated site sequence LSSASQ04, taken from a collar of the porch roof has five surviving sapwood rings. The porch has an inscribed date of AD 1639 and it was hoped that the radiocarbon wiggle-matching would provide support for this.

The samples were dated at Oxford Radiocarbon Accelerator Unit (samples with laboratory codes "OxA-"), Scottish Environments Research Centre ("SUERC-") and Queen's University, Belfast ("QUB-").

Samples measured at Oxford are pretreated (Brock *et al* 2010), combusted and graphitised (Brock *et al* 2010; Dee and Bronk Ramsey 2000), and dated by Accelerator Mass Spectrometry (AMS) (Bronk Ramsey *et al* 2004). Samples measured at SUERC were pretreated using an acid-base-acid protocol (Stenhouse and Baxter 1983), then combusted (Vandeputte *et al* 1996; Freeman *et al* 2010), graphitised (Slota *et al* 1987), and dated by AMS (Xu *et al* 2004; Freeman *et al* 2010). The samples dated by AMS at Belfast were processed and measured as described in Reimer *et al* (2015).

These 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 1), 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, like those in Table 1 are expressed in radiocarbon years BP.

CALIBRATION

Calibration is an essential step in using radiocarbon measurements to estimate the calendar date of samples. It is necessary because the production rate of radiocarbon in the atmosphere is not constant, but varies through time. This means that we need to convert the radiocarbon measurement of a sample to the calendar scale using a calibration curve made up of radiocarbon ages on samples of known calendar date.

That independent scale is the IntCal13 calibration curve (Reimer *et al* 2013) 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 have been calculated using IntCal13 and the computer program OxCal4.2 (https://c14.arch.ox. ac.uk/oxcal/; Bronk Ramsey 1995; 2001; 2009). The calibrated date ranges quoted for each sample in Table 1, expressed 'cal AD' or 'cal BC', were calculated by the maximum intercept method (Stuiver and Reimer 1986) and are rounded outwards to the nearest five years as recommended by Mook (1986). The graphical distributions of the calibrated dates, shown in outline in Figures 6–10 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; 2009). 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 as black distributions in the Figures 6–10 and quoted in italic in the text.

Sample LSS-A21

The chronological model shown in Figure 6 includes the radiocarbon dates on the six single-year tree-ring samples and the relative dating information about the relationship between the samples provided by dendrochronology (Table 1). The model has good overall agreement (A_{comb} = 45.9; A_n = 26.7; n = 7) and provides an estimate for the felling of the timber of *cal AD 1715–1745 (32%)* or *cal AD*

1795–1810 (18%) or *cal AD 1830–1860 (45% probability*; *LSS-A21_felling*; Fig 6) probably *cal AD 1720–1735 (17%)* or *cal AD 1800–1810 (14%)* or *cal AD 1835–1855 (37% probability*).

Two of the three tentative tree-ring dates for the felling of LSS-A21, AD 1570 and AD 1559, are clearly much earlier than the estimate derived from the radiocarbon wiggle-match, but a model (Fig 7) including AD 1744 shows poor overall agreement (Acomb = 12.4; An = 26.7; n = 7).

Sample LSS-A37

The chronological model shown in Figure 8 includes the radiocarbon dates on the six single-year tree-ring samples and the relative dating information about the relationship between the samples provided by dendrochronology (Table 1). The model for LSS-A37 has good overall agreement (Acomb = 89.6; An = 28.9; n = 6) and provides an estimate for the heartwood/sapwood boundary of *cal AD 1280–1305 (95% probability*; *LSS-A37_h/s*; Fig 8) probably *cal AD 1285–1300 (68% probability*).

The tentative tree-ring date of AD 1515 for the heartwood/sapwood boundary of LSS-A37, is much later than the estimate derived from the radiocarbon wiggle-match, but a model (Fig 9) including the other tentative date, AD 1287, shows good overall agreement (Acomb = 62.1; An = 26.7; n = 7).

Sample LSS-A50

The chronological model shown in Figure 10 includes the radiocarbon dates on the six single-year tree-ring samples and the relative dating information about the relationship between the samples provided by dendrochronology (Table 1).   The model for LSS-A50 has good overall agreement (Acomb = 125.7; An =28.9; n = 6) and provides an estimate for the last measured ring of *cal AD 1370–1400 (95% probability; LSS-A50_ring_60*; Fig 10) probably *cal AD 1375–1395 (68% probability*).

INTERPRETATION

LSSASQ03

Sample LSS-A21 is a component of site sequence LSSASQ03 with all five samples taken from backing rafters in the nave roof (Arnold and Howard 2102, fig 46). Four of the samples (including LSS-A21) have complete sapwood and the same last-ring position, thus demonstrating contemporary felling. The heartwood/sapwood boundary ring position on the fifth sample is also consistent with the timber represented having been felled at the same time as the others. Hence all samples are likely to have been felled at the same time the in eighteenth or nineteenth century.

LSSASQ02

Sample LSS-A37 is a component of site sequence LSSASQ02 which contains nine samples from timbers of the nave (eight primary rafters and one potentially reused collar) and two (including LSS-A37) potentially reused rafters from the south aisle.

The last ring of LSS-A37 forms the last-measured ring of LSSASQ02 and the relative heartwood/sapwood boundary ring position of those samples where this is retained suggests that these timbers are likely to be broadly coeval (Arnold and Howard 2102, fig 45). Using the 95% confidence limit of 15–40 sapwood rings standardly applied by the Nottingham Tree-ring Dating Laboratory to native oak to the estimate for the date of the heartwood/sapwood boundary for LSS-A37 provides an estimated felling date for this timber of *cal AD 1305–1345* (*95% probability*; *LSS-A37_felling*; Fig 11), probably *cal AD 1310–1335* (*68% probability*).

LSSASQ04

Sample LSS-A50 from a collar in the porch roof, is a component of site sequence LSSASQ04. This site sequence also contains a sample from a rafter in this roof. The relative heartwood/sapwood boundary ring positions of these two samples are broadly contemporary (Arnold and Howard 2102, fig 47), suggestive of contemporary felling.

Using the 95% confidence limit of 15–40 sapwood rings standardly applied by the Nottingham Tree-ring Dating Laboratory to native oak to the estimate for the date of the heartwood/sapwood boundary for LSS-A50 provides an estimated felling date for this timber of *cal AD 1385–1430* (*95% probability*; *LSS-A50_felling*; Fig 12) probably *cal AD 1395–1425* (*68% probability*).

DISCUSSION

Tree ring analysis and Bayesian wiggle-matching has resulted in precise felling dates for 27 timbers from all areas under investigation (Fig 13).

The tree-ring analysis previously undertaken on the nave roof had resulted in the successful dating of two potentially reused collars to AD 1581–1606 and three apparently primary rafters to *c* AD 1616. All of these dated timbers were located at the east end of the roof raising the possibility that they might signify a small scale repair of this part of the roof rather than represent a replacement roof or a larger phase of building works. At this point no thirteenth century timbers had been identified and none of the backing rafters had been dated.

The successful radiocarbon wiggle-match dating of one of the component samples of site sequence LSSASQ02 and, therefore, the rest of the samples contained within this chronology has dated a further eight primary rafters and one collar (thought at the time of sampling to be reused) from the nave roof to the early fourteenth century.

These newly dated samples, in contrast to those dated by dendrochronology, were taken from timbers along the length of the nave roof and, therefore, suggests that the extant structure dates to the early-fourteenth century with a small scale repair at the east end being undertaken in the early-seventeenth century. With timbers identified as primary and reused being found to being broadly contemporary raises the possibility that these were incorrectly identified at the time of sampling.

One of the backing rafters in the nave roof, and by association the other four backing rafters in site sequence LSSASQ03, has now been dated to the eighteenth or nineteenth century. This demonstrates additional strengthening works being undertaken on this roof in the eighteenth or nineteenth century.

The dendrochronology had dated timbers of the south aisle to *c* AD 1616 with construction of the roof thought to have occurred shortly after. A further two south aisle timbers (components of LSSASQ02), both reused rafters, have now been dated by radiocarbon wiggle-matching to the early fourteenth century. These samples are thought to represent inclusion of some reused material in this structure. The good level of cross-matching seen between these two samples (especially LSS-A37) and the rest of the components of LSSASQ02 suggests they are reused either from the nave itself or from a contemporary structure since demolished.

None of the porch samples were dated during the programme of tree-ring analysis. However, one of these (and by its inclusion in site sequence LSSASQ4 a second) has now been dated by radiocarbon wiggle-matching to the late fourteenth or early fifteenth century. This porch has the inscribed date AD 1639; these results suggest a much earlier construction date for this element of the church or the inclusion of reused timber.

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TABLES

Table 1: Church of St Peter, West Liss radiocarbon and stable isotope results

Laboratory Number	Sample and material	$\delta^{13}C_{IRMS}$ (‰)	Radiocarbon Age (BP)	Calibrated Date; cal AD (2σ)	*Posterior Density Estimate; cal AD (95% probability)*
LSS-A21; nave backing rafter, frame 7					
OxA-28718	Ring 1, oak, heartwood	−24.1±0.2	208±23	1650–1950*	*1645–1690 (37%),* or *1730–1750 (14%), or 1765–1800 (45%)*
SUERC-49065	Ring 13, oak, heartwood	−23.2±0.2	184±34	1655–1950*	*1650–1700 (37%),* or *1740–1760 (14%),* or *1780–1820(45%)*
UBA-23582	Ring 25, oak, heartwood	−26.2±0.22	170±26	1665–1950*	*1670–1710(37%),* or *1750–1780(14%),* or *1790–1830 (45%)*
OxA-28719	Ring 37, oak, heartwood	−25.6±0.2	119±24	1685–1930*	*1680–1725 (37%),* or *1765–1785 (14%),* or *1800–1840 (45%)*
SUERC-49066	Ring 50, oak, sapwood	−24.4±0.2	174±37	1660–1950*	*1690–1740 (37%),* or *1770–1800 (14%),* or *1810–1850 (45%)*
UBA-23583	Ring 63, oak, sapwood	−26.4±0.22	164±27	1665–1950*	*1700–1750 (37%),* or *1790–1810 (14%),* or *1830–1870 (45%)*
LSS-A37; south aisle north rafter, frame 4					
SUERC-49070	Ring 2, oak, heartwood	−21.3±0.2	896±34	1030-1220	*1180–1210*
UBA-23584	Ring 22, oak, heartwood	−25.4±0.22	833±26	1160-1270	*1200–1230*
OxA-28720	Ring 41, oak, heartwood	−25.1±0.2	798±23	1210-1275	*1220–1245*
SUERC-49071	Ring 63, oak, heartwood	−23.8±0.2	838±34	1150-1270	*1240–1270*
UBA-23585	Ring 84, oak, heartwood	−28.0±0.22	684±26	1270-1390	*1270–1290*
OxA-28721	Ring 98, oak, heartwood	−23.8±0.2	682±23	1275-1385	*1280–1305*
LSS-A50; porch, collar, frame 6					
UBA-23586	Ring 2, oak, heartwood	−26.1±0.22	607±24	1290–1410	*1310–1340*

Laboratory Number	Sample and material	$\delta^{13}C_{IRMS}$ (‰)	Radiocarbon Age (BP)	Calibrated Date; cal AD (2σ)	*Posterior Density Estimate; cal AD (95% probability)*
OxA-28722	Ring 14, oak, heartwood	−23.4±0.2	569±23	1310–1420	*1320–1355*
SUERC-49591	Ring 26, oak, heartwood	−23.0±0.2	619±26	1290–1405	*1330–1365*
UBA-23587	Ring 38, oak, heartwood	−25.7±0.22	624±24	1285–1400	*1340–1380*
OxA-28723	Ring 50, oak, heartwood	−23.9±0.2	651±23	1280–1395	*1355–1390*
SUERC-49073	Ring 58, oak, sapwood	−23.3±0.2	615±34	1285–1410	*1365–1400*

*NB these calibrated ranges have been produced on results that have been specified to be younger than 1950 (otherwise the ranges extend beyond the present).

FIGURES

Figure 1: Map to show the general location of West Liss, Hampshire, circled.

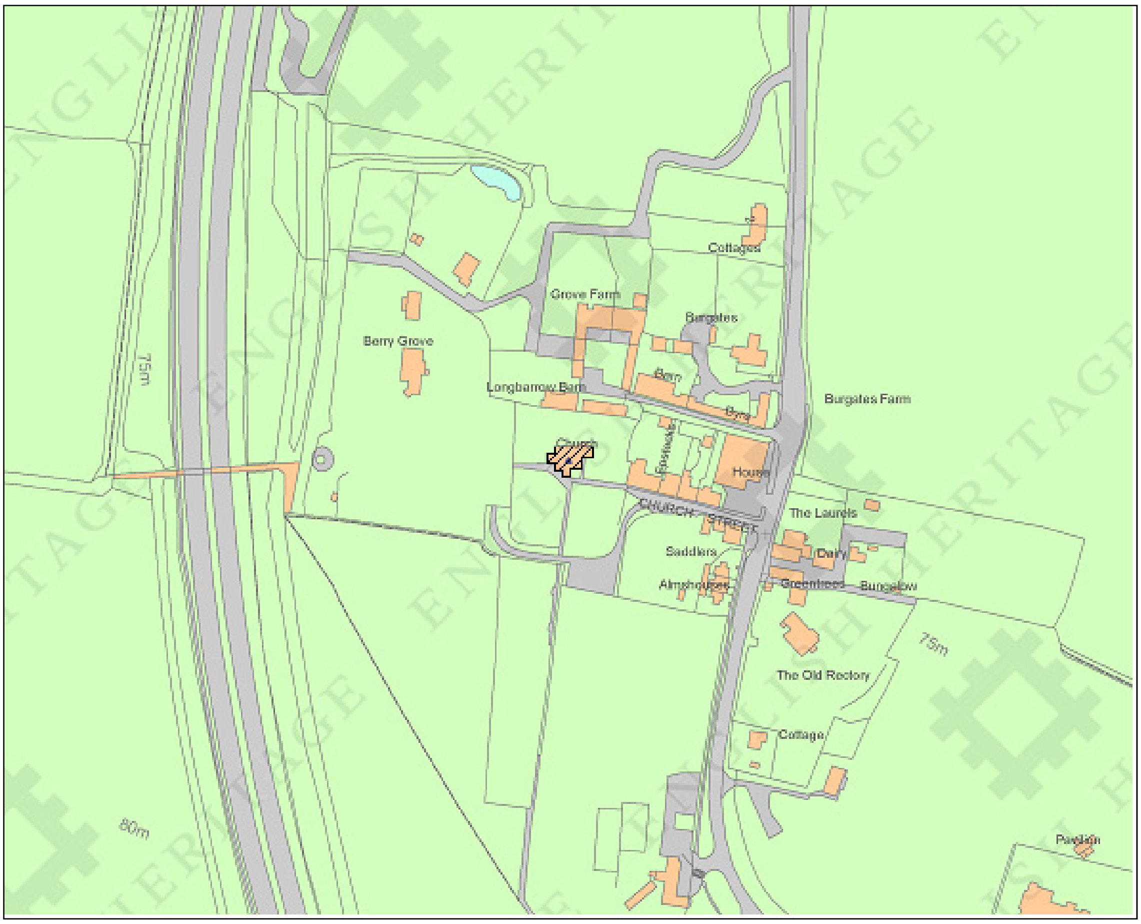

Figure 2: Location of St Peter's Church, West Liss (hashed).

Figure 3: Nave roof showing the backing rafters (photograph taken from the south-east)

Figure 4: South aisle roof (photograph taken from the west)

Figure 5: Porch roof (photograph taken from the south)

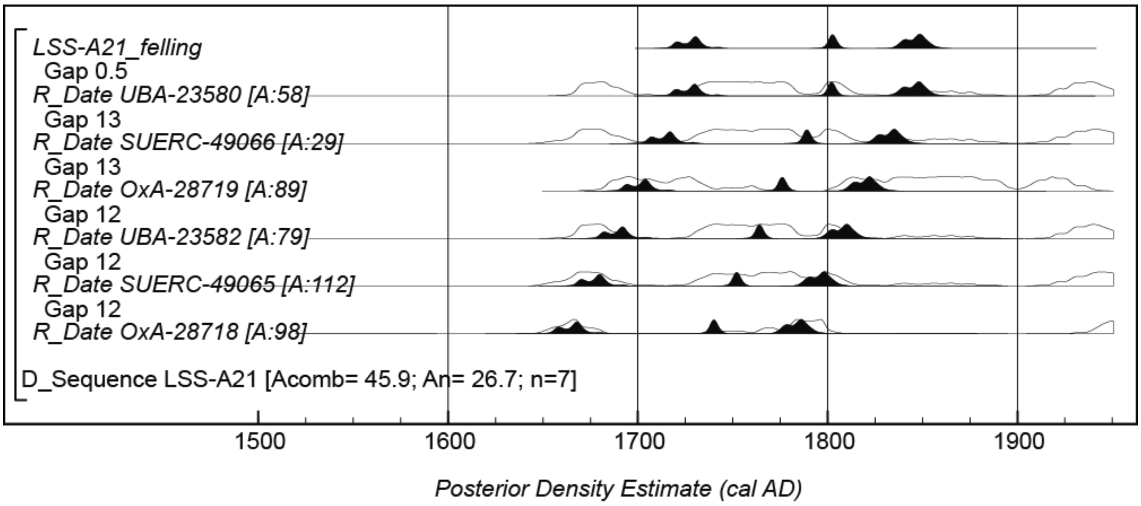

*Figure 6: Probability distributions of dates from the timber LSS-A21. Each distribution represents the relative probability that an event occurs at a particular time. For each of the dates two distributions have been plotted: one in outline, which is the simple radiocarbon calibration, and a solid one, based on the wiggle-match sequence. Distributions other than those relating to particular samples correspond to aspects of the model. For example, the distribution '*LSS_A21_felling*' is the estimated date when the timber was felled. The large square brackets down the left-hand side along with the OxCal keywords define the overall model exactly.*

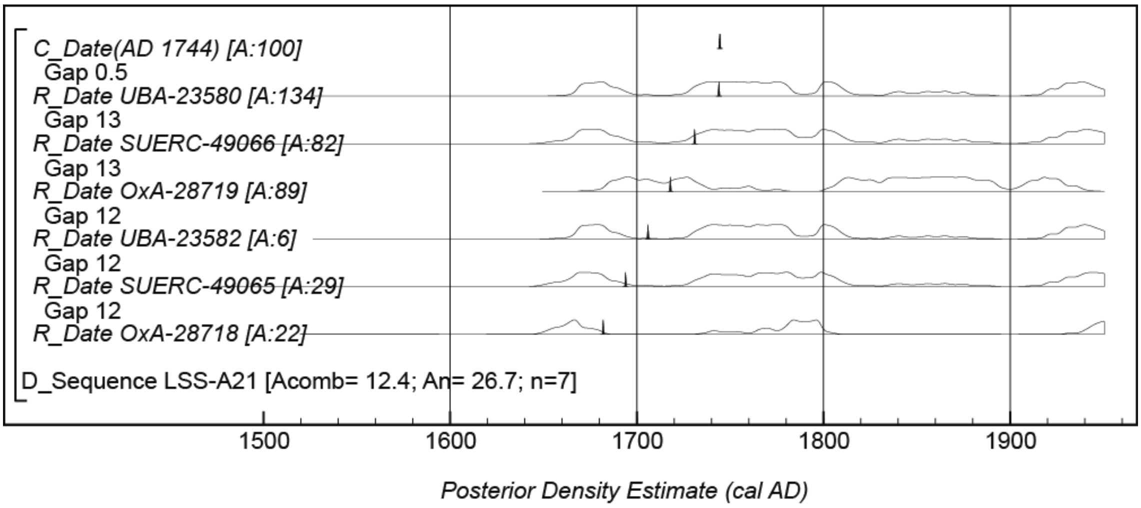

Figure 7: Probability distributions of dates from the timber LSS-A21 including the tentative date obtained from dendrochronology for the end of the sequence (AD 1744). The overall format is identical to that shown in Figure 6

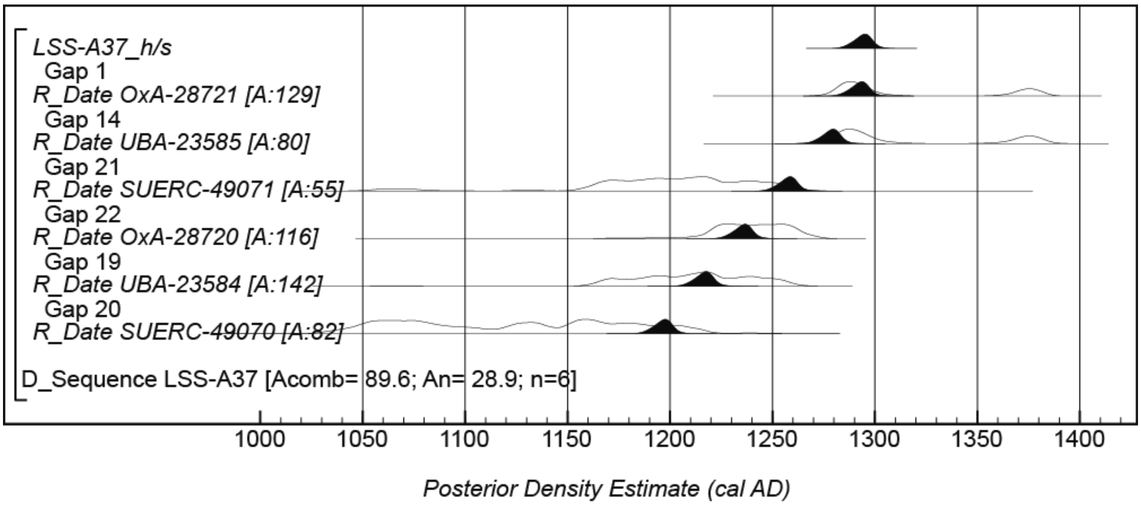

Figure 8: Probability distributions of dates from the timber LSS-A37. The overall format is identical to that shown in Figure 6

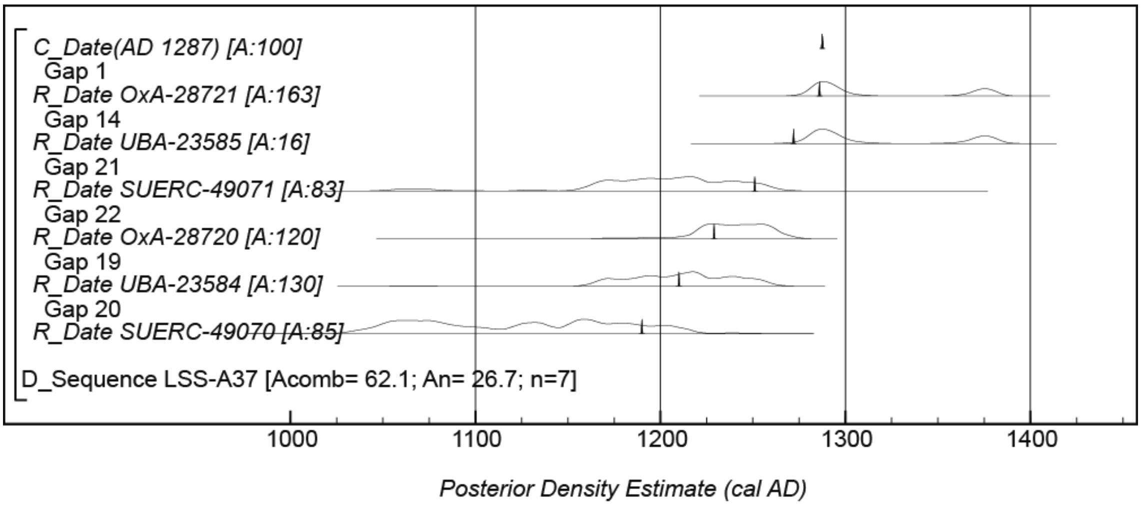

Figure 9: Probability distributions of dates from the timber LSS-A37 including the tentative date obtained from dendrochronology for the end of the sequence (AD 1287). The overall format is identical to that shown in Figure 6

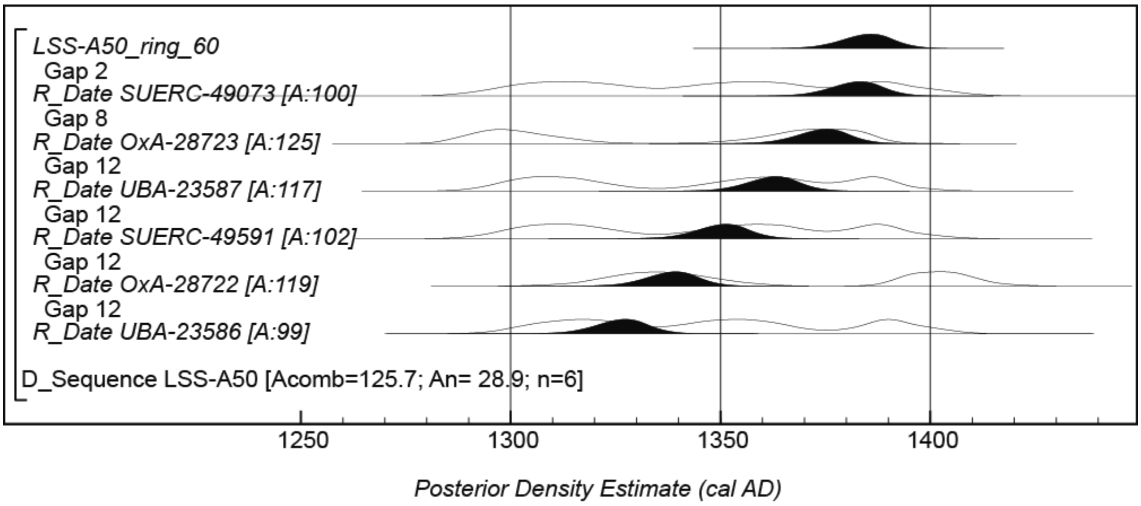

Figure 10: Probability distributions of dates from the timber LSS-A50. The overall format is identical to that shown in Figure 7

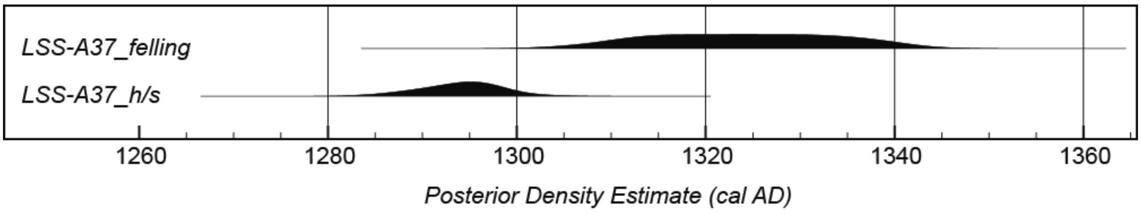

Figure 11: Probability distributions of the estimate for the last dated ring from the timber LSS-A37 (calculated in Figure 6), and an estimate for the felling date, using the NTRDL sapwood estimate

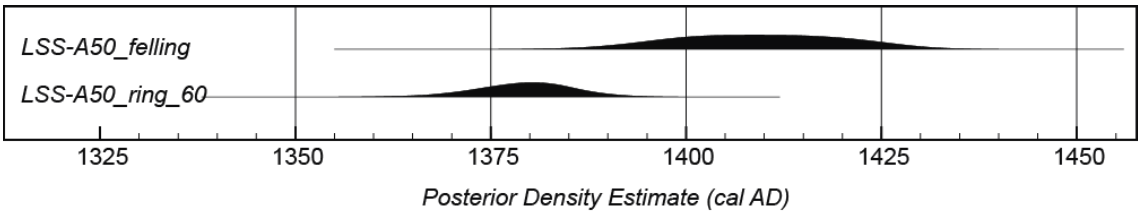

Figure 12: Probability distributions of the estimate for the last dated ring from the timber LSS-A50 (calculated in Figure 17), and an estimate for the felling date, using the NTRDL sapwood estimate

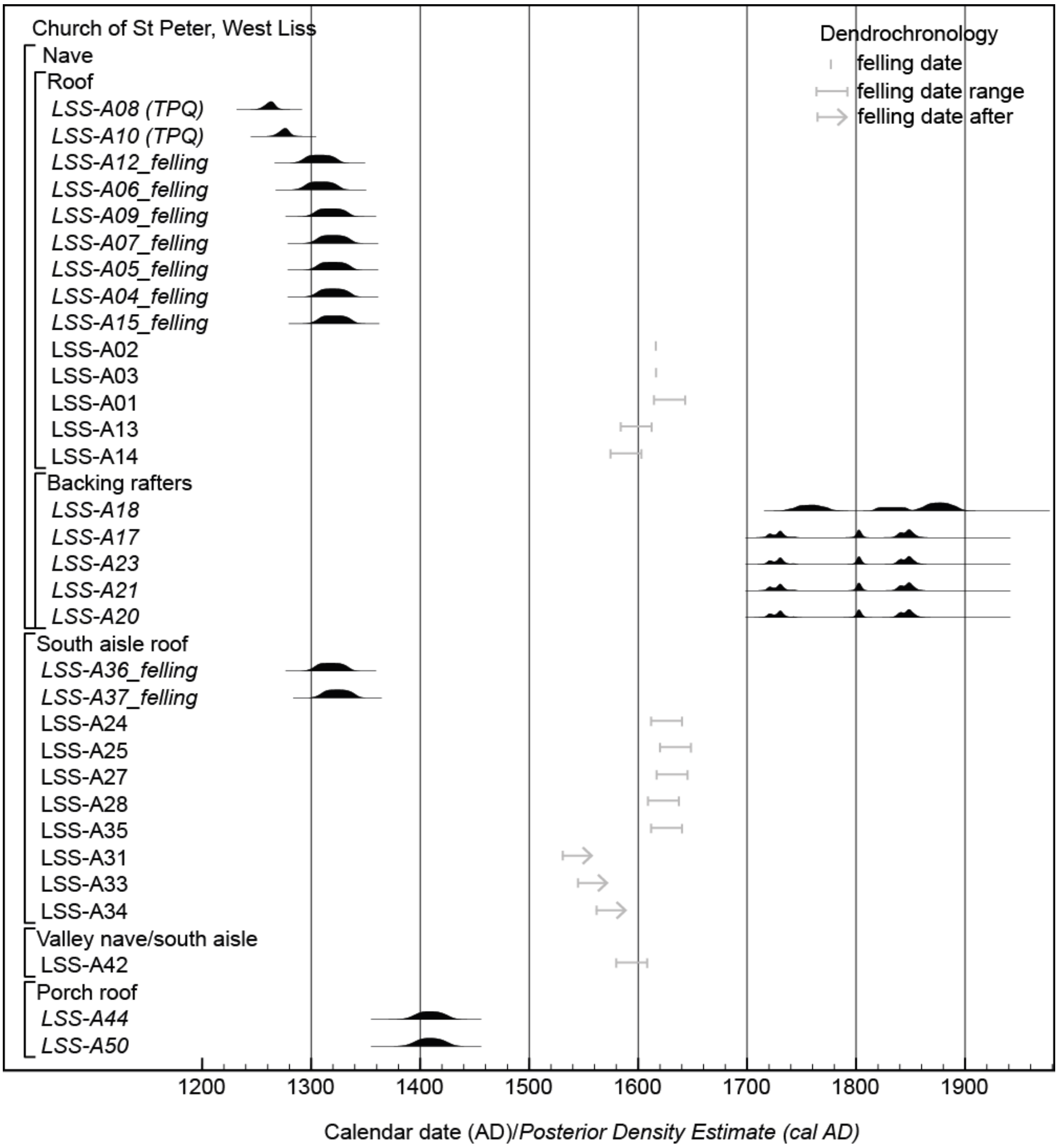

Figure 13: Summary diagram of samples dated by dendrochronology and radiocarbon wiggle-matching grouped by area






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