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CHURCH OF ST ANDREW, WISSETT, SUFFOLK RADIOCARBON WIGGLE-MATCHING OF THE SECOND FLOOR OF THE BELL TOWER

SCIENTIFIC DATING REPORT

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Radiocarbon Wiggle-Matching of the Second Floor of the Bell Tower at the Church of St Andrew, Wissett, Suffolk

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Summary

Analysis by dendrochronology had been undertaken previously on samples from four timbers from the second floor of the bell tower of this church. Two of the samples cross-matched, but neither the mean sequence nor the individual timbers could be dated.

A series of six radiocarbon measurements was undertaken on samples from the mean chronology once tree-ring analysis had failed to produce absolute dating. Wiggle-matching of these results against the currently internationally-agreed calibration data set, suggests that these timbers were felled in *cal AD 1095 – 1135 (13% probability)* or *cal AD 1145 – 1205 (82% probability)*. Consequently it appears that the second floor of the bell tower at St Andrew's, Wissett is a survival of the original twelfth-century construction.

Introduction

The parish church of St Andrew, Wissett (NGR TM3661 7929; Fig 1) is of twelfth-century origin with a round tower to the west (Fig 2). The church is constructed of flint rubble and has a plain-tile roof.

Tree-ring dating was commissioned by English Heritage and undertaken by Dr Martin Bridge of University College London in March AD 2004 on the bell-tower floor. In connection with current proposals for a new bell frame, which may impact on this floor, it had been suggested that it may be an original twelfth-century survival. It was hoped that the programme of dendrochronology would be useful in determining the scope of the proposed works to the tower.

The results of the tree-ring dating programme, however, were inconclusive (Bridge 2004), and so a new programme of radiocarbon wiggle-matching was initiated to determine if the floor was, in fact, a twelfth-century survival, or if it was of a later date.

Radiocarbon Sampling and Analysis

Two of the cores taken for dendrochronology, samples saw01 and saw03, cross-matched with each other at a *t*-value of 9.5, with 58 years of overlap (Bridge 2004, 3). The final ring present on both of these timbers was the heartwood/sapwood boundary. These cores were cut up to provide six contiguous blocks, each containing wood of ten-year's growth. The earliest decadal block came from core saw01, with the five later samples taken from core saw03 (Fig 3). Four further heartwood rings were present on saw03, but were not included in the samples dated by radiocarbon assay. The heartwood/sapwood boundary on timber saw01 was six years later than this. The location of these cores in the floor is shown in Figure 4.

All six wood samples were dated by the Oxford Radiocarbon Accelerator Unit. The pre-treatment method was acid/base/acid (Hedges *et al* 1989), followed by the use of a hypochlorite bleach to minimize the amount of lignin (Hoper *et al* 1998). All samples were graphitised as outlined in Dee and Bronk Ramsey (2000) and measured by Accelerator Mass Spectrometry as described by Bronk Ramsey *et al* (2004).

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).

As part of the tree-ring analysis, the cores had been glued to wooden laths using Evostick™. In order to ensure that the radiocarbon results from the wood samples were not contaminated with modern carbon from this source, a sample of the glue was also dated. This was not pre-treated, but was graphitised and measured as outlined above. The Evostick™ produced a result of >58000 BP (OxA-X-2128-16), demonstrating that this product is petroleum based and cannot have introduced modern contamination into the samples.

The Oxford laboratory maintains a continual programme of quality assurance procedures, in addition to participation in international inter-comparisons (Scott 2003). These tests indicate no laboratory offsets and demonstrate the reproducibility and accuracy of these measurements.

Calibration

The calibrations of these results, relating the radiocarbon measurements directly to calendar dates, have been calculated using the calibration curve of Reimer *et al* (2004) and the computer program OxCal (v3.10) (Bronk Ramsey 1995; 1998; 2001). The calibrated date ranges for each sample given in Table 1 have been calculated using the maximum intercept method (Stuiver and Reimer 1986). They are quoted in the form recommended by Mook (1986), with the end points rounded outwards to 5 years. The graphical distributions of the calibrated dates, given in outline in Figures 6 and 8, are derived from the probability method (Stuiver and Reimer 1993).

Wiggle-matching

Wiggle-matching is the process of matching a series of radiocarbon determinations 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 different blocks of wood submitted for dating is known precisely by counting the rings in the timber.

Radiocarbon wiggle-matching of tree-ring sequences that cannot be absolutely dated through dendrochronology is not new (eg, Clarke and Renfrew 1972; Clarke and Morgan 1983; Baillie 1995, 69-70), although until now it has been largely confined to assemblages of waterlogged wood (eg van der Plicht *et al* 1995; Bayliss and Pryor 2001; Kromer *et al* 2001; Bayliss *et al* 2003). This is because large samples of wood were required for high-precision radiocarbon dating by Liquid Scintillation Spectrometry or Gas Proportional Counting. Recent advances in the accuracy and precision of radiocarbon measurements produced by Accelerator Mass Spectrometry (eg Bronk Ramsey *et al* 2004; Dellinger *et al* 2004), however, now make this approach feasible for small wood samples, such as those available from cores taken for tree-ring dating. An excellent summary of the history and variety of approaches employed for wiggle-matching is provided by Galimberti *et al* (2004).

A variety of the wiggle-matching approach has also been applied to validate, or choose between, different matching positions of a floating tree-ring sequence against the absolutely dated master chronologies (Bayliss *et al* 1999). This is useful in situations where possible cross-matching positions have been identified by the tree-ring analysis, but where these are not strong enough statistically to be accepted without independent, confirmatory, evidence.

The 'least-squares' Method

The first approach used to fit the radiocarbon measurements from St Andrew's, Wissett to the radiocarbon calibration curve places the results from the bell-tower floor in a position which minimises the differences between the radiocarbon results from the timber samples and those forming the calibration curve. This method is described by Pearson (1986).

At Wissett, we know that the mid-point of each wood sample submitted for radiocarbon dating is 10 years earlier or later than the next sample in the sequence. The mid-point of the final dated block is five years earlier than the last dated ring of the sequence. The heartwood/sapwood boundary on saw03 is, however, four years later than this, and the heartwood/sapwood on saw01 ten years later. The average of the two heartwood/sapwood boundaries therefore falls seven years after the last dated ring of the sequence. Consequently, the heartwood/sapwood boundary falls 12 years after the date provided by the wiggle-matching, and an allowance for the missing sapwood rings has to be added to this to provide an estimated date for the felling of the actual timbers (see Fig 3).

This approach has been applied using a non-distributed version of the computer program CAL25 (van der Plicht 1993). The specific algorithm implemented is described in Bronk Ramsey *et al* (2001).

The least-squares 'best fit' for this sequence against the calibration curve indicates a mean date for sample saw03(5) of AD 1147 (Fig 5). The result is in accordance with the simple calibrated date range of cal AD 1010 – 1160 (95% confidence) for the same sample.

This method, however, only provides a single date and with no estimate of error, unlike the Bayesian approach described below.

A Bayesian Approach

A second method of wiggle-matching has been applied to these data, applying a Bayesian approach to combine the radiocarbon dates with the relative dating provided by the tree-ring analysis. This is a probabilistic approach, which determines which parts of the calibrated radiocarbon date are most likely given the tree-ring evidence. This results in a reduced date range, known as a *posterior density estimate*, which is shown in black in Figures 6 and 8, and given in italics in the text. 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).

The technique used is a form of Markov Chain Monte Carlo sampling, and has been applied using the program OxCal v3.10 (http://www.rlaha.ox.ac.uk/orau/), which uses a mixture of the Metropolis-Hastings algorithm and the more specific Gibbs sampler (Gilks *et al* 1996; Gelfand and Smith 1990). Details of the algorithms employed by this program are available from the on-line manual or in Bronk Ramsey (1995; 1998; 2001). The algorithms used in the models described below can be derived from the structure shown in Figures 6 and 8.

The chronological model for the dating the timbers from St Andrew's, Wissett is shown in Figure 6. This includes the radiocarbon measurements on each of the decadal blocks of wood, the information that the centre ring of each block is 10 years earlier or later than the next in the sequence, and the information that after the centre point of the outermost block there were 12 years to the average heartwood/sapwood boundary of the sampled timbers. In addition, the probability distribution of the number of sapwood rings expected to be missing from the sample has been applied to the result of the wiggle-match to provide an estimate of the date of felling of the timber. The methodology for this approach is described by Bayliss and Tyers (2004; and see a graphical summary of this information in Fig 3).

This analysis suggests that timbers of the second floor of the bell-tower at Wissett were felled in *cal AD 1095 - 1135 (13% probability)* or *cal AD 1145 – 1205 (82% probability; barkEdge*; Fig 6). This model has good overall agreement ($A_{overall}$ =

88.9%; Bronk Ramsey 1995). This means that the radiocarbon measurements are in accord with the tree-ring sequence of the timber samples.

The least-squares method gave a wiggle-match result for sample saw03(5) of AD 1147 (χ^2 fit value=0.956). This date corresponds extremely well with the *82% probability* derived for the same sample using the Bayesian methodology (*cal AD 1120 – 1165*), lying very near the mid-point of this range.

To test the sensitivity of this analysis in relation to the calibration data, the model shown in Figure 6 was re-calculated using the older calibration dataset of Stuiver *et al* (1998). This model also has good overall agreement ($A_{overall}$ = 72.7%), and suggests that the timbers were felled in *cal AD 1090 – 1140 (19% probability)* or *cal AD 1150 – 1205 (76% probability)*. Inspection of the calibration data covering the period of the Wissett timbers shows that nearly all of the data points show considerable spread (Fig 7). For this reason the currently internationally-agreed calibration curve (Reimer *et al* 2004), which adopts a more sophisticated approach to the estimation of the errors on the curve (Buck and Blackwell 2004) is to be preferred. This exercise, however, does suggest that our estimate of the felling date of these timbers may vary by up to a decade as radiocarbon calibration data are refined.

Two potential tree-ring matches were indicated by the initial tree-ring analysis – one where the final ring of the saw0103m mean falls in AD 1114, and one where the final ring of this chronology falls in AD 1196. A selection of the highest *t*-values for saw0103m against a selection of independent reference chronologies is given in Table 2, although in neither case are the matches sufficiently strong for acceptance in absence of confirmatory evidence, and in both cases they are barely replicated elsewhere.

The wiggle-match of the radiocarbon dates from the sequence was repeated, this time including the information that timber saw01 was felled in AD 1114, and so the wood sample centres on AD 1099 (15 years before the last ring in saw0103m)(Fig 8). This model has poor overall agreement ($A_{overall}$ = 17.0%), suggesting that this potential match is incorrect. The overall agreement of a similar model, constraining the felling date of saw01 to be AD 1196 (Fig 9), is also unsatisfactory ($A_{overall}$ = 2.4%). Consequently neither potential tree-ring date can be accepted, and the absolute dating of this floor must rest on the radiocarbon wiggle-matching alone.

Conclusion

Analysis by dendrochronology was undertaken of samples from four timbers from the second floor of the bell tower of the church of St Andrew, Wissett (Bridge 2004). Two of the samples cross-matched, but neither the mean sequence nor the individual timbers could be dated. The dating of so few samples is often difficult.

A series of six radiocarbon measurements from cores saw01 and saw03 were undertaken once tree-ring analysis had failed to produce absolute dating. Wiggle-matching of these results against the currently internationally-agreed calibration data set (Reimer *et al* 2004), suggests that these timbers were felled in *cal AD 1095 - 1135 (13% probability)* or *cal AD 1145 – 1205 (82% probability; barkEdge*; Fig 6). Consequently it appears that the second floor of the bell tower at St Andrew's, Wissett is a survival of the original twelfth-century construction.

Acknowledgements

We would like to thank Dr Martin Bridge, University College London, for sub-sampling the tree-ring cores for radiocarbon dating and providing additional archive material from his dendrochronological study. Cathy Groves, Sheffield University, also provided additional information on potential tree-ring cross-matches for this material. Dr Mike Cook, chief chemist at Evostick, provided useful discussion on the possibility of modern carbon contamination from this adhesive. Finally, thanks to Roy and Maureen Stoddard for their patience while we developed this new approach.

Table 1: Radiocarbon results from SAW03, St Andrew's Church, Wissett

Laboratory Number	**Sample ID**	**Material**	**δ ^{13}C (‰)**	**Radiocarbon Age (BP)**	**Calibrated Date (95% confidence)**	***Posterior Density Estimate (95% probability)***
OxA-14544	SAW03 (5)	wood, *Quercus* sp.	-24.9	968±28	cal AD 1010-1160	*cal AD 1070-1095 (at 13%) or cal AD 1120-1165 (at 82%)*
OxA-14543	SAW03 (4)	wood, *Quercus* sp.	-23.6	918±28	cal AD 1020-1210	*cal AD 1060-1085 (at 13%) or cal AD 1110-1155 (at 82%)*
OxA-14542	SAW03 (3)	wood, *Quercus* sp.	-24.0	966±28	cal AD 1010-1160	*cal AD 1050-1075 (at 13%) or cal AD 1100-1145 (at 82%)*
OxA-14541	SAW03 (2)	wood, *Quercus* sp.	-24.0	951±28	cal AD 1020-1160	*cal AD 1040-1065 (at 13%) or cal AD 1090-1135 (at 82%)*
OxA-14663	SAW03 (1)	wood, *Quercus* sp.	-24.7	978±26	cal AD 1010-1160	*cal AD 1030-1055 (at 13%) or cal AD 1080-1125 (at 82%)*
OxA-15035	SAW01 (1)	wood, *Quercus* sp.	-24.3	941±24		
OxA-15036	SAW01 (1)	wood, *Quercus* sp.	-24.5	972±26		
mean	SAW01 (1)	T'=0.8; T(5%)=3.8; v=1; Ward and Wilson 1978)		955±18	cal AD 1020-1160	*cal AD 1020-1045 (at 13%) or cal AD 1070-1115 (at 82%)*

Table 2: Potential tree-ring cross-matches for saw0103m against independent reference chronologies (***please note:*** this sequence remains undated by dendrochronology)

Reference chronology	**Start date**	**End date**	***t*-value**
saw0103m (AD 1120 – 1196)			
East Anglia (Tyers pers comm)	AD 406	AD 1899	4.12
London: Bull Wharf (Hillam 1981)	AD 1090	AD 1202	3.76
Medbourne Manor, Leicestershire (Howard *et al* 1999)	AD 1068	AD 1287	3.75
Herefordshire (Tyers pers comm)	AD 901	AD 1729	4.19
Oxford: Christ Church chapter house (Worthington and Miles 2003)	AD 1142	AD 1260	4.15
Salisbury Cathedral, sarum4 (Miles *et al* 2004)	AD 1053	AD 1241	3.97
saw0103m (AD 1038 – 1114)			
London (Tyers pers comm)	AD 413	AD 1782	5.92
Norwich Quayside (Groves 1993)	AD 972	AD 1145	4.86
Shackerley, Shropshire (Hillam 1984)	AD 1008	AD 1266	4.02
Herefordshire (Tyers pers comm)	AD 901	AD 1729	4.44
Bordesley Abbey, Worcestershire (Brown 1993)	AD 860	AD 1264	5.01
Southampton Friary, Hampshire (Hillam 1986)	AD 935	AD 1137	5.57

Figure 1: Location of the Church of St Andrew, Wissett

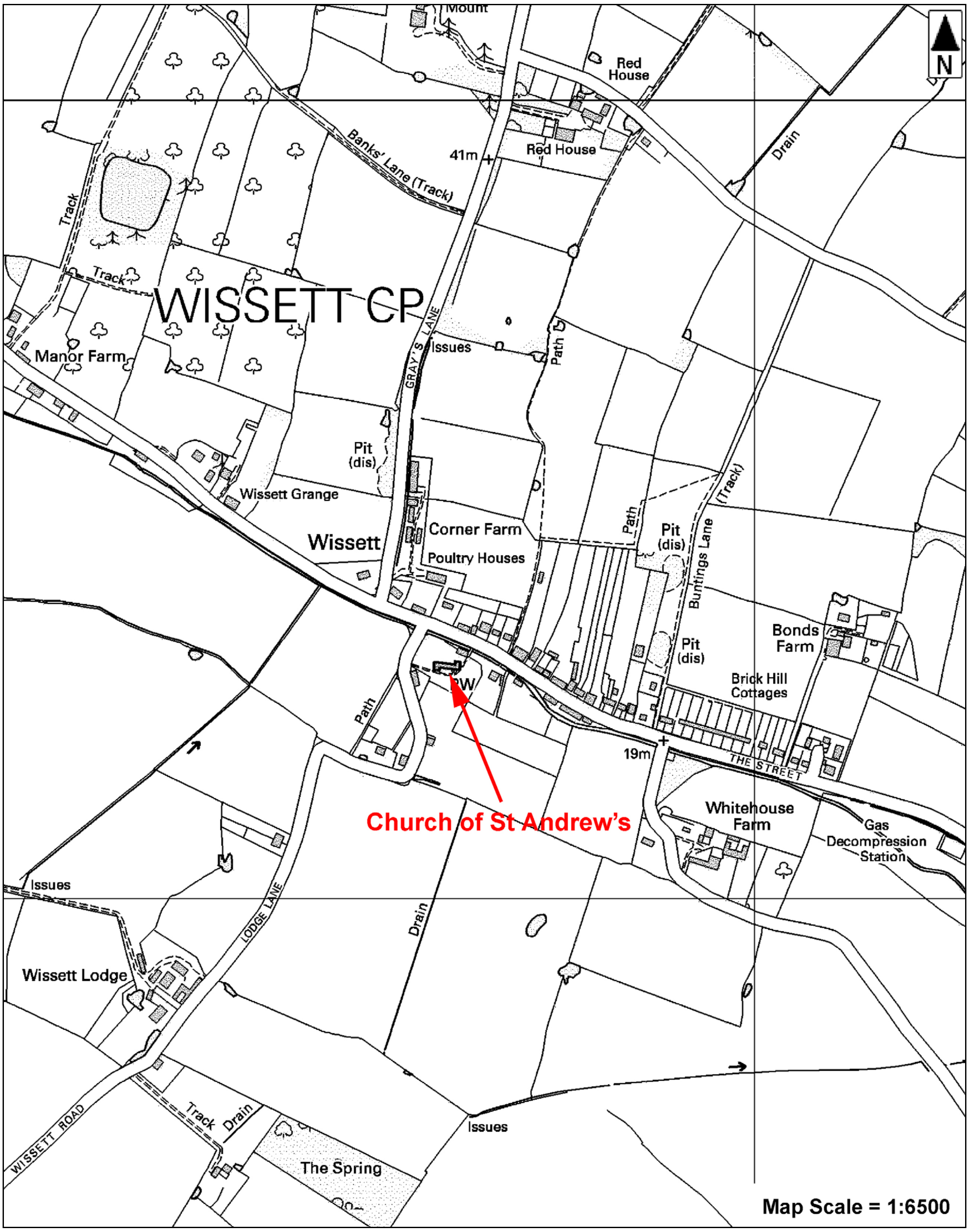


Figure 2: View of the Tower of the Church of St Andrew, Wissett, Suffolk (Dr Martin Bridge)

Figure 3: Schematic showing the cross-match between saw01 and saw03, and the location from where the six samples were taken. The 'Average Heartwood/Sapwood Boundary' has been shown in relation to the heartwood/sapwood boundaries of the two cores, and the probability distribution for the sapwood estimate follows beyond it

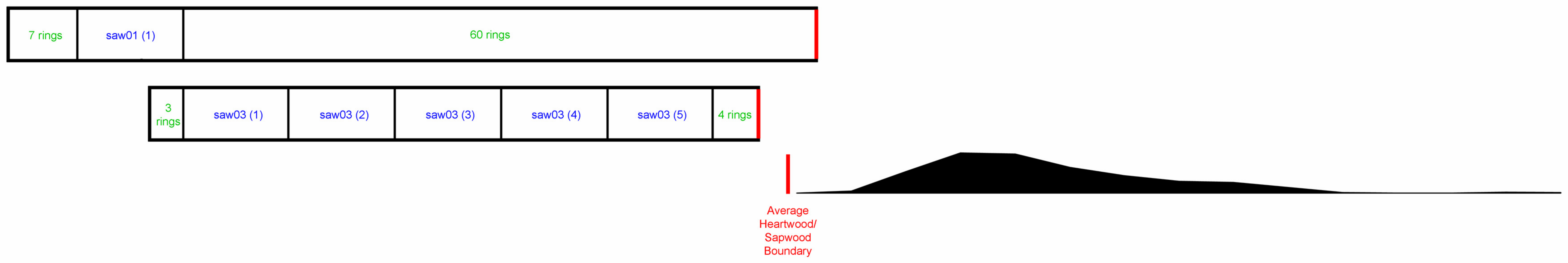


Figure 4: Plan of the bell tower second floor at the Church of St Andrew, Wissett (adapted from an original by R Stoddard)

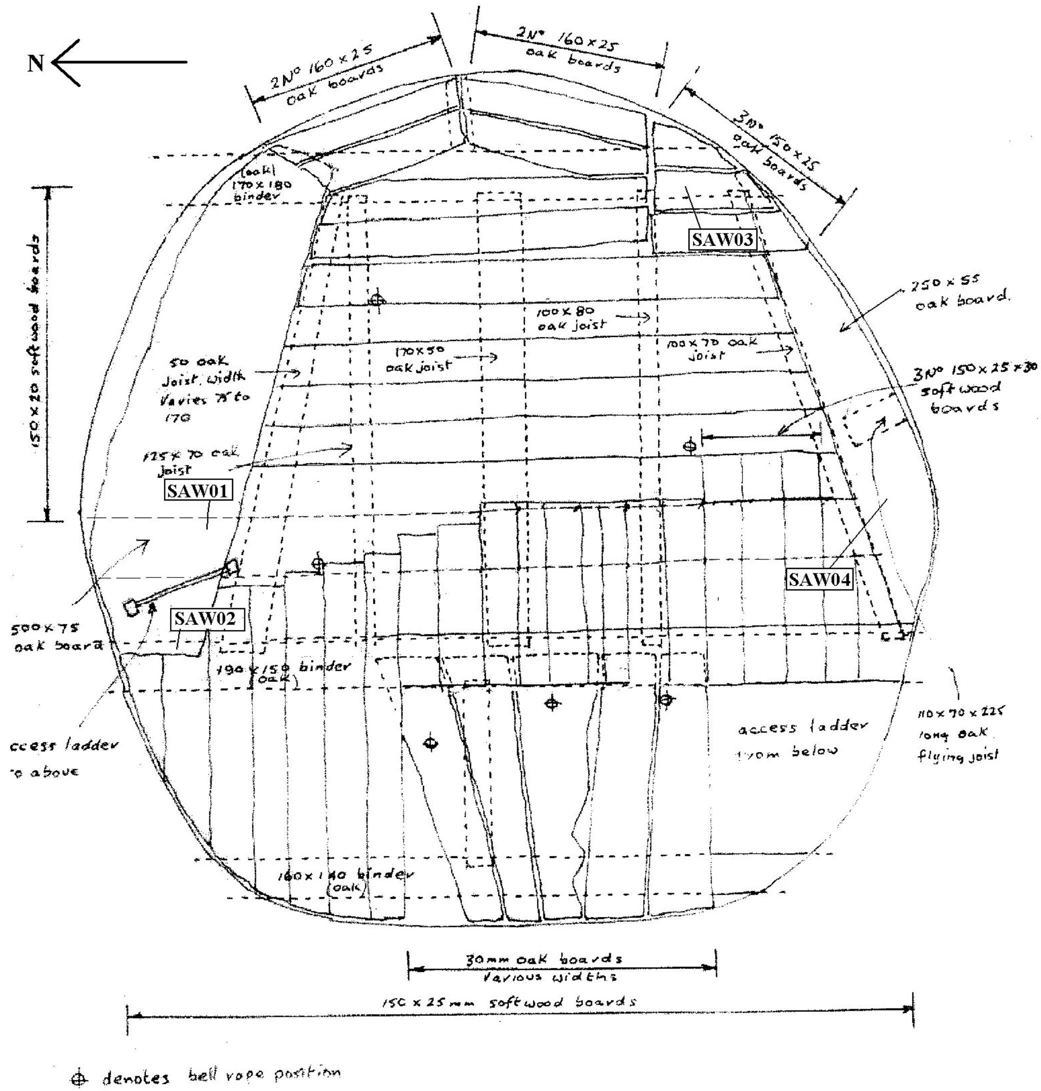


Figure 5: Least-squares wiggle-match, which provides a date for the mean of saw03(5) of AD 1147

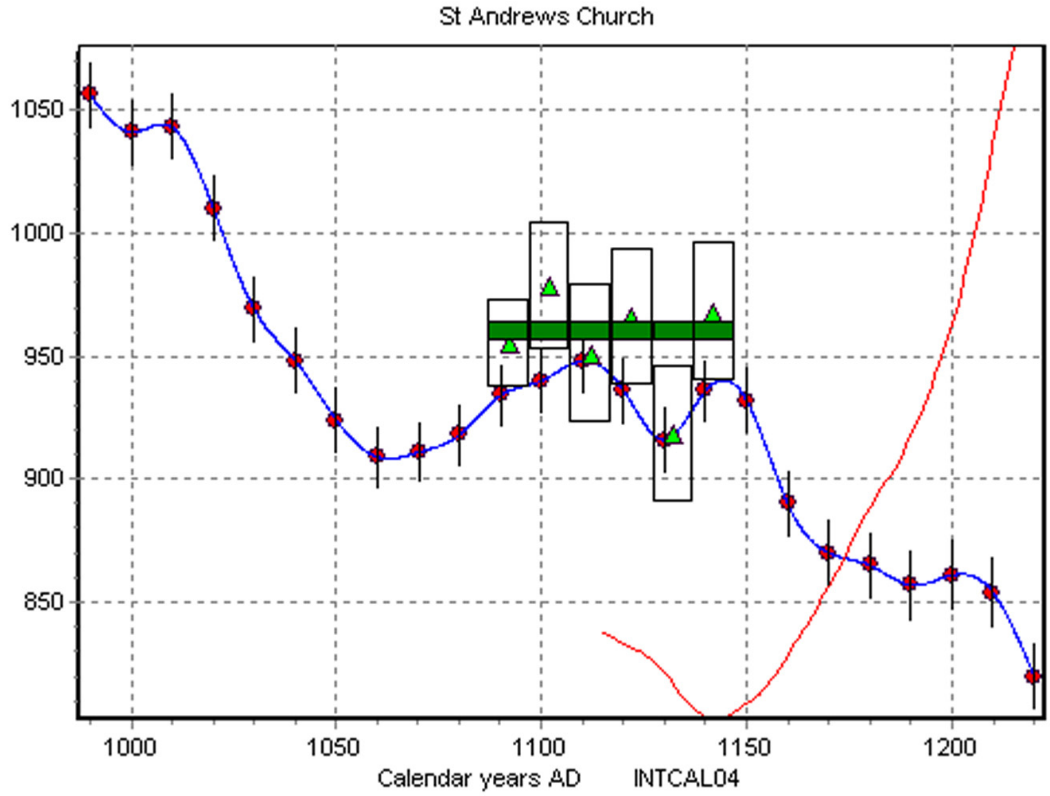


Figure 6: Probability distributions of dates from the cores saw01 and saw03. Each distribution represents the relative probability that an event occurs at a particular time. For each of the dates two distributions have been plotted: one in outline, which is the simple radiocarbon calibration, and a solid 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 '*barkEdge*' 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

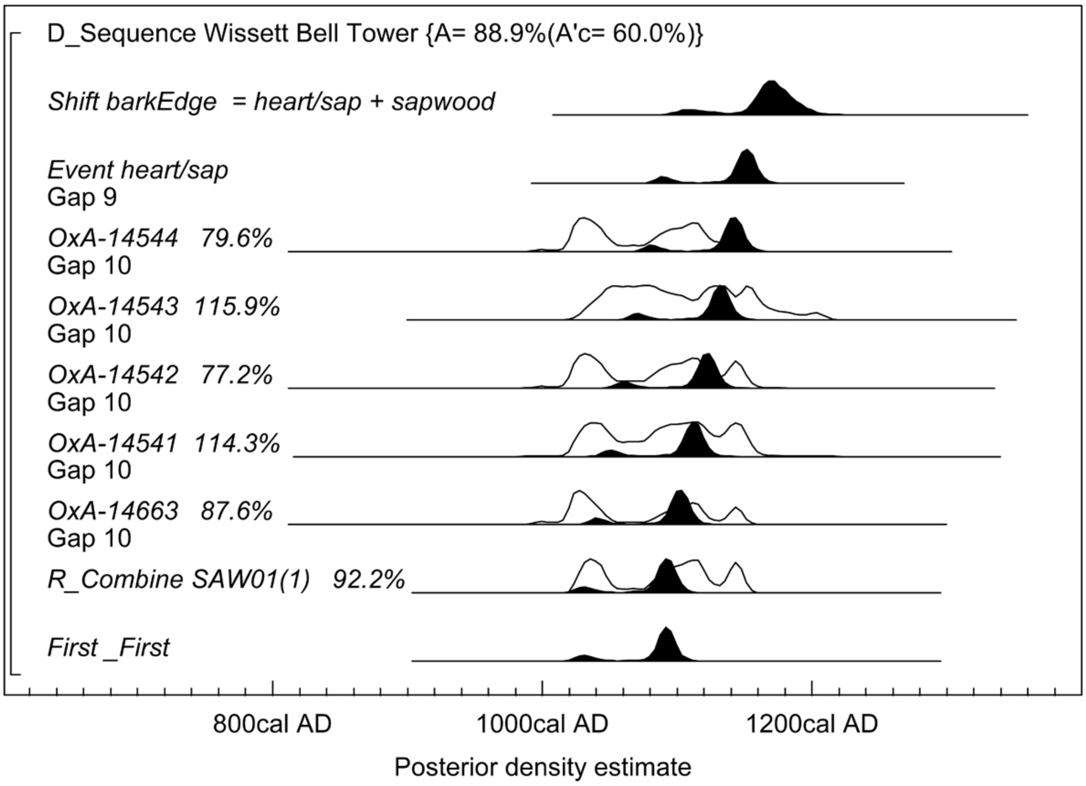


Figure 7: Graphical representation showing the data-points and their 1σ errors in the INTCAL04 radiocarbon calibration curve dataset

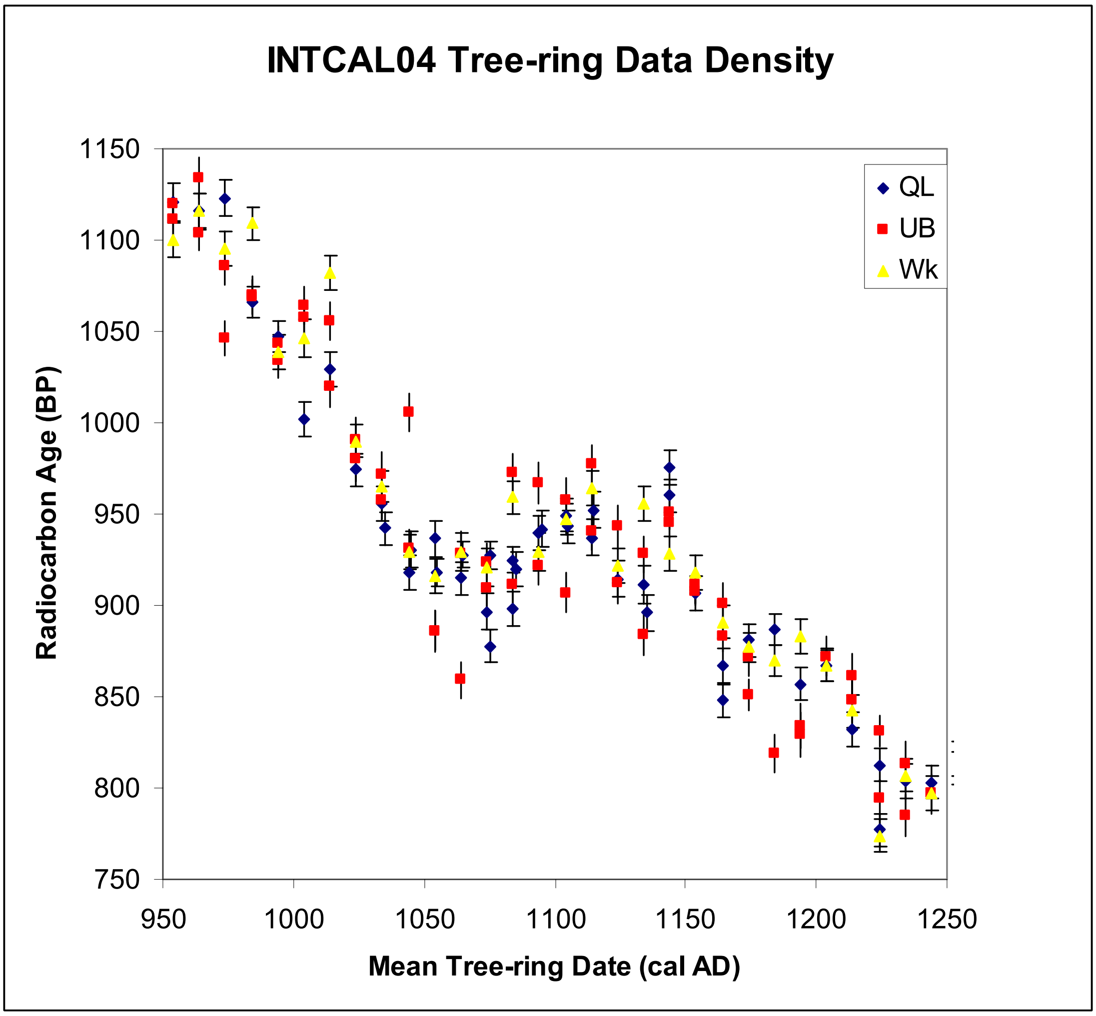


Figure 8: Probability distributions of dates from the cores saw01 and saw03, with the format being identical to Figure 6. *C_Date AD 1114* has been included to test whether the heartwood/sapwood boundary for this sequence agrees with the weak match provided by tree-ring analysis at this date. The large square brackets down the left-hand side along with the OxCal keywords define the overall model exactly

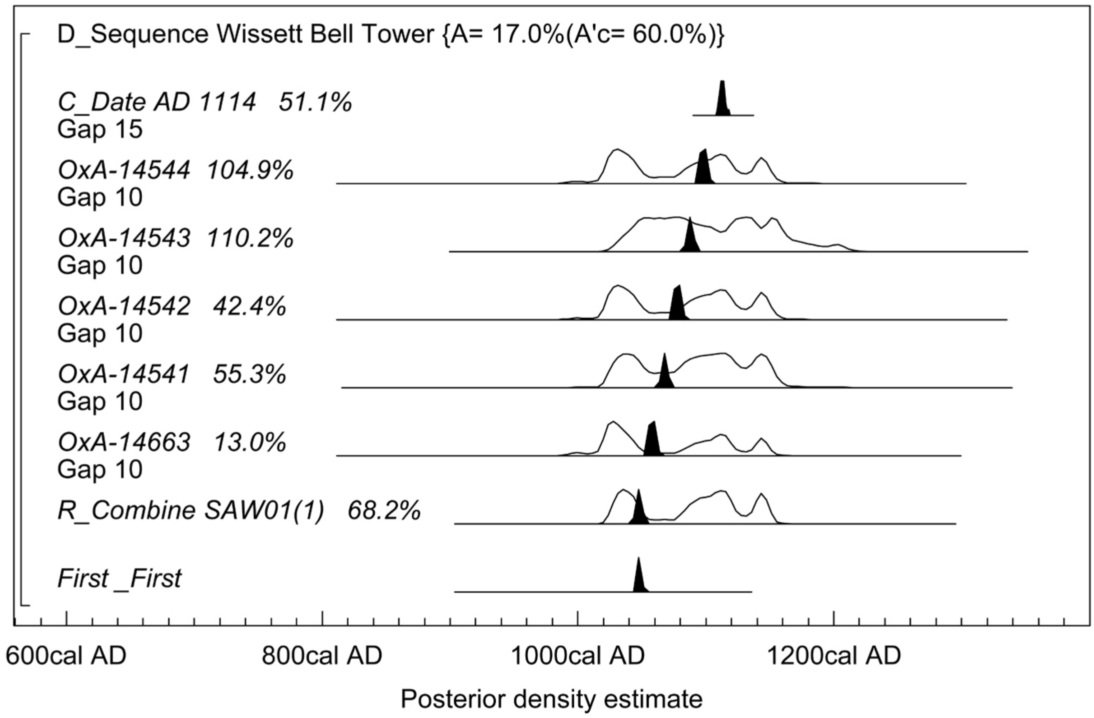
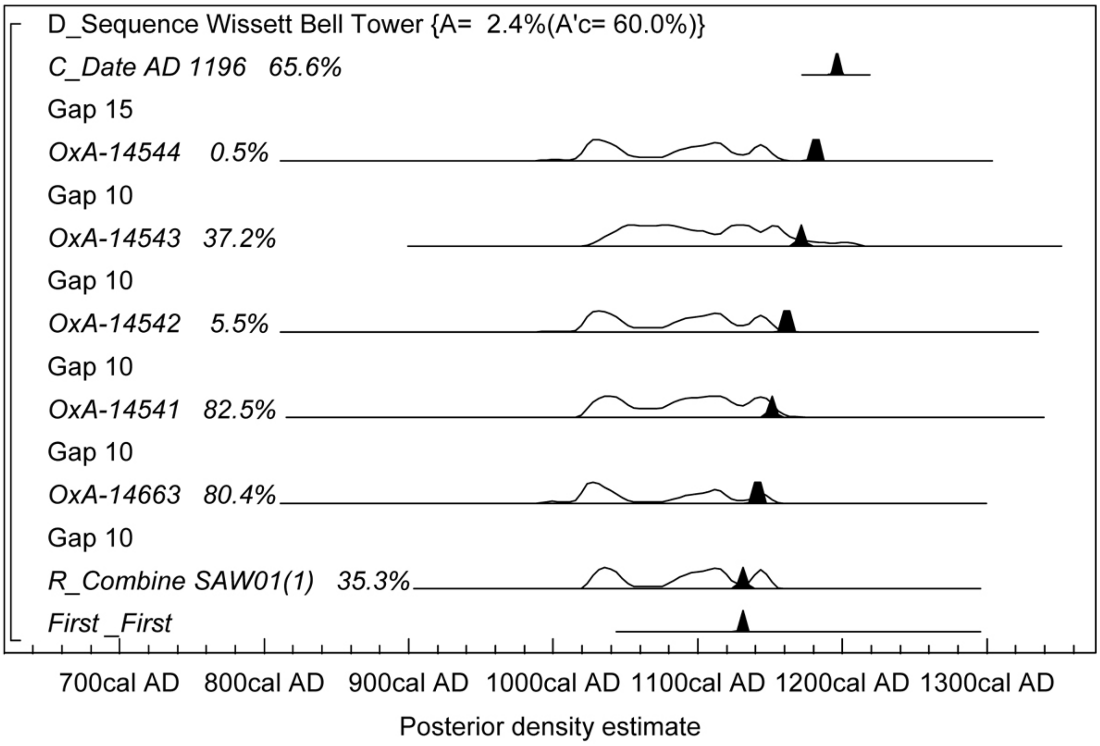


Figure 9: Probability distributions of dates from the cores saw01 and saw03, with the format being identical to Figure 6. *C_Date AD 1196* has been included to test whether the heartwood/sapwood boundary for this sequence agrees with the weak match provided by tree-ring analysis at this date. The large square brackets down the left-hand side along with the OxCal keywords define the overall model exactly



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