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Scientific Dating

Glastonbury Lake Village, Glastonbury, Somerset Dendrochronological analysis and radiocarbon wiggle-matching of oak timbers

Nigel Nayling, Roderick Bale, Christopher Bronk Ramsey, Elaine Dunbar, Paula Reimer, and Peter Marshall

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GLASTONBURY LAKE VILLAGE
GLASTONBURY
SOMERSET

DENDROCHRONOLOGICAL ANALYSIS AND RADIOCARBON WIGGLE MATCHING OF OAK TIMBERS

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SUMMARY
Sixteen timbers from worked wood and a tree stump excavated from Glastonbury Lake Village were submitted for tree-ring dating, Five oak samples, that had originally be excavated by Bulleid and Grey in 1896–7 but been reburied, were deemed suitable for analysis. Two sets of two samples (GLV 206 and 214, and GLV 207 and 213) crossmatched against each other. None of the timbers, or means of the two series of relatively dated samples, crossdate against reference chronologies. Three of the unmeasured timbers were sub-sampled for radiocarbon wiggle-matching, the results of which are presented in this report.

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INTRODUCTION

Glastonbury Lake Village is located in a pasture field on Common Moor, 1km north of Glastonbury, and is made up of 90 mounds, representing 40 roundhouses and associated unenclosed working areas covering a *c* 1ha triangular area of land (Coles and Minnitt 1995; Fig 1). The site was discovered by Arthur Bullied in 1892, and he and Harold St George Gray excavated most of the settlement and traced the palisade that enclosed the structures from 1892–1907 (Bulleid and Grey 1911; 1917). Further small-scale excavations were subsequently undertaken in 1968–1969 by Michael Avery, in 1984 under the auspices of the Somerset Levels Project (Coles *et al* 1988), and as part of Monuments at Risk in Somerset Peatlands (MARISP) project in 2003 (Brunning 2013).

The date of the settlement

Dr Robert Munro after reviewing the artefactual evidence in his introduction to the first monograph (Bulleid and Grey 1911), concluded that the date of the settlement 'should be, at least provisionally, restricted to a period of 150 years, extending from 100 B.C. to 50 A.D' (Munro 1911, 35). Further attempts to provide timings for the settlement variously suggested a beginning in *c* 250–200 BC and abandonment in *c* AD 50 (Tratman 1970, 164–6) and a duration of about 100 years from *c* 150±50 to 50±50 BC (Clarke 1972, 829). Although two radial oak planks from the 1984 SLP excavations produced tree ring series of 99 and 117 rings (Coles *et al.* 1988, table 17), they failed to date, as have subsequent attempts using the original ring-width measurements (C Tyers pers comm). The first two radiocarbon dates from the site (Q-2618–9) were obtained on samples from two monoliths taken in 1984 from a fairly woody *Carex* and *Cladium* fen sedge peat upon which the Causeway was constructed. These confirmed a late Iron Age date for the occupation (Housley 1988, 81, fig 83).

The first attempt to provide a comprehensive independent scientific chronology for the date of the site was undertaken in 1993–5 (Coles and Minnitt 1995). Nine radiocarbon determinations (Bronk Ramsey *et al.* 2002) were obtained from the 15 samples submitted to the Oxford Radiocarbon Accelerator Unit, with the calibrated dates providing 'a potential maximum time span of 792 BC to AD 145 or a minimum span of 472–8 BC' (Coles and Minnitt 1995, 176; fig 6.16). The authors concluding that the 'structural and artefactual evidence do not support either possibility' (Coles and Minnitt 1995, 176).

On the basis of the extremely rich assemblage of artefacts from the site, Coles and Minnitt (1995, 176–8) concluded the site was established in about 250 BC and abandoned in *c* 50 BC. Subsequently a further review of the currency of the brooches (Haslegrove 1997) argued for a slightly later date for the middle and late settlement phases. Coles and Minnitt (2000, 178) used this to derive an estimate for its occupation of 170 years.

South West Heritage Trust excavations

In 2014 a project to generate comprehensive baseline data for the survival and condition of the waterlogged archaeological remains on the site, and to install infrastructure to enhance the burial regime and lessen the risk of desiccation, was funded by Historic England (then English Heritage) as part of a HLF Landscape Partnership Scheme for the Avalon Marshes. Although primarily a project to ensure the long-time preservation of the site, then classified as at high risk on the Heritage at Risk Register (English Heritage 2014), keyhole excavations of *in situ* deposits provided the opportunity to obtain samples for tree-ring dating.

DENDROCHRONOLOGY

Dendrochronology sampling

Sixteen samples (Table 1) from worked timbers and a tree stump excavated in 2014 were submitted for tree-ring dating. Five oak samples that had originally been excavated by Bulleid and Grey in 1896–7 but been reburied (Fig 1) (GLV 206–7, GLV 211 and GLV 213–4) contained sufficient rings (>50) to warrant analysis (Table 2).

Dendrochronology methods

Methods employed at the Lampeter Dendrochronology Laboratory in general follow those described in Historic England guidance (English Heritage 1998). All samples were waterlogged and a clean surface was achieved by hand using razor blades. The complete sequence of growth rings in each sample was measured to an accuracy of 0.01mm using a micro-computer based travelling stage (Tyers 2004). Cross-correlation algorithms (Baillie and Pilcher 1973; Munro 1984) are employed to search for positions where the ring sequences are highly correlated against each other.

Dating is dependent on trees over large geographical areas showing a similar relative pattern of wide and narrow annual rings as a result of climate during the growing season. Of course, tree growth is not only affected by climate, and individual tree growth or growth of trees in one cohort or area can be affected by a whole host of other environmental variables. For example, a tree growing on a flat area close to a stream with abundant water is less likely to exhibit a narrow ring in a dry year than a tree on a steep slope with thin soils, and in such a case the ring width series would be termed complacent. Competition, age trends, injury, and human/animal interference (such as pollarding or foliage defoliation by insects) can result in a ring width pattern unrelated to climate. Even in regions with harsh climate up to a quarter of the trees within a woodland will contain ring-width patterns that do not correspond to the wider climate and therefore do not date. In order to eliminate some of the background, non-climate driven 'noise' in individual tree/timber data, multiple radii are measured from a single tree or timber, followed by the creation of a multiple sample mean ring-width series that contains less of the 'noise' associated with individual samples, and which is more likely to cross-date against external reference chronologies. The likelihood of a sample dating is further increased by the availability of well-replicated tree-ring series from the time period and geographical source that a given timber sample comes from, with some time periods and geographical areas less well represented in terms of tree-ring data.

The ring sequences in this instance were tested against a range of oak reference chronologies from Britain and Europe. The *t*-values reported are derived from the original CROS algorithm (Baillie and Pilcher 1973). A *t*-value of 3.5 or over is usually indicative of a good match, although this is with the proviso that high *t*-values at the same relative or absolute position must be obtained from a range of independent sequences, and that satisfactory visual matching supports these positions and that the overlap is at least 50 years. A *t*-value of over 10 between samples is indicative of originating from the same parent tree, though *t*-values of far less than 10 are often observed from measuring different radii across a single oak tree cross section. Correlated positions are checked visually using computerised ring-width plots.

Interpretation of any tree ring date is limited by whether sapwood or bark edge is present in a sample. Sapwood is distinguishable as lighter coloured band around the outer annual rings of a tree and represents the part of the tree that is alive. For British oaks the number of sapwood rings is estimated to be between 10 and 46 (English Heritage 1998), an estimate based on observations of many thousands of samples from living trees and archaeological wood. At a microscopic level, sapwood in *Quercus* spp. is recognisable by the open earlywood vessels used for water and mineral transport. Heartwood earlywood vessels appear filled when viewed microscopically as the cell walls have collapsed (tyloses) and no longer form the living part of the tree. Should a sample contain sapwood and bark edge, the year and even season of felling can be inferred from a dated sample. Should partial sapwood be present the estimate of between 10 and 46 rings is used to infer a date range the sample. In samples where there is no sapwood or microscopic sign of the heartwood/sapwood boundary a date will represent a *terminus post quem* (date after which) the parent timber must have been felled. The date in this case will refer to the date of the last complete annual ring and the felling of the timber will be at least ten years after the date of that final ring.

Dendrochronology results

None of the five measured samples cross-dated with the two previously measured samples from the site (Coles *et al* 1988, table 17) or with external reference chronologies, so it is not possible to provide calendar dates for any of the timbers. However, two sets of two samples (GLV 206 and 214 and GLV 207 and 213) crossmatch against each other (Tables 3 and 4; Figs 2 and 3). The raw ring-widths for the measured samples are provided in the Appendix. Unfortunately none of these samples contained sapwood or definite heartwood/sapwood boundary. The relatively high *t*-values between the two timbers from each of the two sets of .relatively-dated timbers suggest that the parent trees in each of the two groups were growing in relatively close proximity and, based on visual observation of the samples and the ring series, a possible same-tree derivation cannot be discounted. The failure of GLV 211 to cross date against the other timbers may be a result of it being attributed by Coles and Minnitt (1995) to the 'early phase' of occupation rather than the 'late phase' from which the two other groups of samples were derived.

RADIOCARBON DATING

Radiocarbon sampling

Following the tree-ring analysis described above, two samples (each of five annual rings) were taken from oak timber GLV 206, for radiocarbon wiggle-matching (Galimberti *et al* 2004). These were taken from the beginning (rings 1–5) and end (rings 153–157) of the 157 year sequence of GLV 206 with a possible heartwood/sapwood boundary. These range finder dates would enable us to better understand where the actual date of the timber fell on the radiocarbon calibration curve and whether submission of further samples might be merited to help in dating the occupation of the site.

In addition samples of five-year blocks of annual growth rings for radiocarbon wiggle-matching were submitted from timbers GLV 47 and GLV 48(1), two oak posts that had been driven through the mortice holes of a substantial oak beam excavated in Trench 2 (Fig 1). As these lie underneath the floors of Mound 75 and under the later floor of Mound 74, dating them will provide a constraint for the construction of the floors on these mounds. GLV 47 contained 13 rings including two sapwood rings and ?bark edge. Two samples (rings 1–5 and 9–13) were dated. GLV 48(1) contained 33 rings including six sapwood rings. Two samples (rings 1–5 and 29–33) were dated from timber GLV 48(1).

Radiocarbon methods

Samples for radiocarbon dating were submitted to the Oxford Radiocarbon Accelerator Unit (ORAU), Scottish Universities Environmental Research Centre (SUERC), and the ^{14}CHRONO Centre, The Queen's University Belfast.

The samples dated at ORAU were pretreated using the acid-base-acid protocol followed by bleaching (Brock *et al* 2010, table 1 (UW)), combusted and graphitized (Dee and Bronk Ramsey 2000), and dated by AMS (Bronk Ramsey *et al* 2004).

Samples dated at SUERC were pretreated and dated by AMS as outlined in Dunbar *et al* (2016) and those at the ^{14}CHRONO Centre, according to the methods described in Reimer *et al* (2015). All samples were graphitised using zinc reduction (Slota *et al.* 1987).

The $\delta^{13}C$ values were all measured by Isotope Ratio Mass Spectrometry (IRMS) as described by Brock *et al* (2010), Dunbar *et al* (2016), and Reimer *et al* (2015).

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

Radiocarbon wiggle-matching

Wiggle-matching uses information derived from tree-ring analysis, in combination with radiocarbon dates, to provide a revised understanding of the age of a timber (see 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). The chronological modelling described belown has been undertaken using OxCal v4.3 (Bronk Ramsey 1995;

2009), and the internationally agreed calibration curve for terrestrial samples from the northern hemisphere (IntCal13; Reimer *et al.* 2013). The models are defined by the OxCal CQL2 keywords and by the brackets on the left-hand side of Figs 4–6. In the diagrams, calibrated radiocarbon dates are shown in outline and the posterior density estimates produced by the radiocarbon wiggle-match are shown in solid black. The Highest Posterior Density intervals which describe the posterior distributions are given in italics.

Radiocarbon results

The results are conventional radiocarbon ages (Stuiver and Polach 1977; Table 5), and are quoted in accordance with the international standard known as the Trondheim convention (Stuiver and Kra 1986).

Two pairs of replicate measurements are available on samples that were divided and submitted for dating to different laboratories. Both these pairs of measurements are statistically consistent at 95% confidence (Table 5; Ward and Wilson, 1978) and have been combined by taking a weighted mean before calibration (Ward and Wilson 1978) and inclusion in the wiggle-matches.

GLV 206 wiggle-match

The chronological model for the dating of timber GLV 206 is shown in Figure 4. This incorporates the information that the centre of the block dated by SUERC-59112 (ring 3) is 152 years earlier than the centre of the block dated by UBA-28812 (ring 155) and that there is then two years to the ?H/S boundary. The radiocarbon dates and prior information derived from the tree-ring analysis (the relative number of years between the samples) have good agreement (Acomb=106.7%, An=50.0%, n=2). The model provides an estimate for the formation of the last ring of the tree-ring sequence (?H/S boundary) of the timber of *355–285 cal BC* (*95% probability*; *GLV 206_HS*; Fig 4), probably *350–315 cal BC* (*68% probability*).

GLV 47 wiggle-match

The chronological model for the dating of timber GLV 47 is shown in Figure 5. This incorporates the information that the centre of block dated by UBA-28809 (ring 3) is eight years earlier than the centre of the block dated by Combine rings 9–13 (ring 11) and that there is then two years to the ?bark edge. The radiocarbon dates and prior information derived from the tree-ring analysis (the relative number of years between the samples) have good agreement (Acomb = 105.6%, An=50.0%, n=2). As the timber had ?bark edge the model provides an estimate for the felling of the timber of *355–195 cal BC* (*95%*

probability; *GLV 47_felling*; Fig 5) and probably *340–275 cal BC* (*46% probability*) or *245–200 cal BC* (*21% probability*).

GLV 48(1) wiggle-match

The chronological model for the dating of timber GLV 48(1) is shown in Figure 6. This incorporates the information that the centre of block dated by SUERC-59108 (ring 3) is 28 years earlier than the block dated by Combine rings 29-33 and there are then two years until the last ring of the sequence (ring 33). The radiocarbon dates and prior information derived from the tree-ring analysis (the relative number of years between the samples) have good agreement (Acomb = 112.5%, An=50.0%, n=2). The model provides an estimate for the formation of the last ring of the tree-ring sequence of the timber of *350–310 cal BC* (*26% probability*; *GLV 48(1)_outer_ring*; Fig 6), or *230–165 cal BC* (*69% probability*), probably *335–320 cal BC* (*9% probability*) or *205–175 cal BC* (*59% probability*).

Estimating felling dates

In order to derive an estimate for the felling date of timbers GLV 206 and GLV 48 the probability distribution for the number of sapwood rings, for native English oak (Bayliss and Tyers 2004, table 1), truncated to allow for the extant sapwood rings in the case of timber GLV 48), has been applied to the estimated date for the final measured ring of both tree-ring sequences in order to produce an estimate for the felling date of the timbers.

The final ring of timber GLV 206, ring 157, is the ?H/S boundary (*GLV 206_HS),* and the addition of a sapwood estimate (Bayliss and Tyers 2004, table 1) provides an estimate for its felling of *345–265 cal BC* (*95% probability*; *GLV 206_felling*; Fig 7) probably *335–290 cal BC* (*68% probability*).

For timber GLV 48(1) a sapwood distribution, that allows for the six surviving sapwood rings was calculated (Bayliss and Tyers 2004) and then added to the last dated ring (*GLV 48(1)_ring_33*; Fig 6). This suggests that timber 48 was felled in *340–280 cal BC* (*27% probability*; *GLV 48(1)_felling*; Fig 7) or *205–135 cal BC* (*68% probability*) probably *320–305 cal BC* (*10% probability*) or *195–150 cal BC* (*58% probability*).

INTERPRETATION

The lack of similarity of the tree-ring data from Glastonbury with chronologies from other parts of Britain suggests that either local conditions are masking the climatic signal on which the success of dendrochronological dating relies or that different climatic signals are being observed which would necessitate the construction of local chronologies.

A PRECISE CHRONOLOGY?

The radiocarbon wiggle-match results obtained on the three timbers dated have been included in chronological models for Glastonbury Lake Village that include radiocarbon dates obtained from small short-lived timbers used in the construction of buildings and palisades. A full discussion of these results and the implications for the chronology of the settlement can be found in Marshall *et al* (submitted).

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TABLES

Table 1. Details of samples assessed for tree-ring dating from Glastonbury Lake Village. Bold indicates samples used for radiocarbon dating (see Table 5). H/S = heartwood/sapwood boundary

Sample	Structural Group	Species	Dimensions (mm)	Rings	Average Ring Width (mm)	Sapwood	Conversion	Notes
Trench 1								
GLV 32	4	Non oak	120x90	23	2.61	Bark?	Roundwood	Horizontal timber
GLV 46	2	Oak	90x80	20	4.5	2 sapwood rings	Radial	Post west of palisade SG2
GLV 83	6	Non oak	90x80	15	3.33	Bark?	Roundwood	Pile
GLV 86	6	Non oak	100x80	22	2.72	Bark?	Roundwood	Large post at edge of palisade
Trench 2								
GLV 47	9	Oak	95x80	13	3.85	Bark?	Roundwood	One of three oak posts that had been driven through the mortice holes of a substantial oak beam. These lie underneath the floors of Mound 75 and under the later floor of Mound 74
GLV48(1)	10	Oak	95x85	33	2.96	6 sapwood rings	Radial	One of three oak posts that had been driven through the mortice holes of a substantial oak beam. These lie underneath the floors of Mound 75 and under the later floor of Mound 74
GLV 48(2)	10	Oak	85x80	27	3.15	1 sapwood ring	Radial	Large posts south of mound 74
GLV 49	10	Oak	95x90	17	5.29	H/S?	Radial	One of three oak posts that had been driven through the mortice holes of a substantial oak beam. These lie underneath the floors of Mound 75 and under the later floor of Mound 74
GLV 50	-	Non oak	80x80	25	3.2	Bark?	Radial	Tree stump
Trench 3								

Sample	Structural Group	Species	Dimensions (mm)	Rings	Average Ring Width (mm)	Sapwood	Conversion	Notes
GLV 206	-	Oak	140x30	153	0.99	H/S?	Radial	Timber reburied by Bulleid and Grey. Originally ?timber from the east side of Mound VI.
GLV 207	-	Oak	120x30	138	1.07	None	Radial	Timber reburied by Bulleid and Gray
GLV 211(1)	-	Oak	280x50	100	1.48	H/S?	Tangential	Timber reburied by Bulleid and Gray
GLV 211(2)	-	Oak	115x20	28	3.57	H/S?	Tangential	Timber reburied by Bulleid and Gray
GLV 213	-	Oak	200x40	135	1.14	None	Radial	Timber reburied by Bulleid and Gray. May be from mound LVII (1896) plate XXIX
GLV 214	-	Oak	170x20	95	0.92	H/S?	Radial	Timber reburied by Bulleid and Gray
GLV 219	-	Oak	55x15	31	1.77	16 sapwood rings	Radial	Timber reburied by Bulleid and Gray

Table 2. Details of samples analysed for tree-ring dating from Glastonbury Lake Village. Bold indicates samples used for radiocarbon dating (see Table 5)

Sample	Conversion	Cross section (mm)	Number of rings	Sapwood	ARW (mm)	Date range	Interpretation
GLV 206	Radial	150 x 30	157	+?HS	0.99	1–157	167–203?
GLV 207	Radial	160 x 20	150+11h unmeasured	-	1.07	1–150	after 171
GLV 211	Tangential	280 x 50	113	+?HS	1.48	1–113	123–59?
GLV 213	Radial	200 x 35	159	-	1.14	13–171	after 181
GLV 214	Radial	110 x 20	122	-	0.92	35–156	after 166

Table 3. t-*value and position of match between GLV 206 and GLV 214*

Filenames	-	-	GLV 206	GLV 214
-	start	dates	1	35
-	dates	end	157	156
GLV 206	1	157	*	7.18
GLV 214	35	156	7.18	*

Table 4. t-*value and position of match between GLV 207 and GLV 213*

Filenames	-	-	GLV 213	GLV 207
-	start	dates	13	1
-	dates	end	171	150
GLV 213	13	171	*	8.99
GLV 207	1	150	8.99	*

Table 5: Glastonbury Lake Village radiocarbon and δ¹³C measurements. Replicate measurements have been tested for statistical consistency and combined by taking a weighted mean before calibration as described by Ward and Wilson (1978; T'(5%)=3.8, ν=1).

Laboratory number	Sample reference	Material & context	δ¹³C (‰)	Radiocarbon Age (BP)
GLV 47				
UBA-28809	GLV 47, rings 1–5	Waterlogged wood, *Quercus* sp. heartwood rings 1–5 (R Bale) from timber GLV 47 one of three oak posts that had been driven through the mortice holes of a substantial oak beam. These lie underneath the floors of Mound 75 and under the later floor of Mound 74	−27.1±0.22	2177±39
UBA-28810	GLV 47, rings 9–13 – sample A	Waterlogged wood, *Quercus* sp. heartwood (3) and sapwood (2) rings 9–13 (R Bale) from timber GLV 47 one of three oak posts that had been driven through the mortice holes of a substantial oak beam. These lie underneath the floors of Mound 75 and under the later floor of Mound 74	−27.0±0.22	2172±31
OxA-31792	GLV 47, rings 9–13 – sample B	Replicate of UBA-28810	−25.1±0.2	2245±30
^{14}C: 2149±19 BP, T'=0.3; δ^{13}C: −26.0±0.15‰, T'=40.8				
GLV 48(1)				
SUERC-59108	GLV 48(1), rings 1–5	Waterlogged wood, *Quercus* sp. heartwood rings 1–5 (R Bale) from timber GLV 48(1) one of three oak posts that had been driven through the mortice holes of a substantial oak beam. These lie underneath the floors of Mound 75 and under the later floor of Mound 74	−24.6±0.2	2223±29
UBA-28811	GLV 48(1), rings 29–33 - sample A	Waterlogged wood, *Quercus* sp. sapwood rings 29–33 (R Bale) from timber GLV 48(1) one of three oak posts that had been driven through the mortice holes of a substantial oak beam. These lie underneath the floors of Mound 75 and under the later floor of Mound 74	−27.4±0.22	2140±25
OxA-31793	GLV 48(1), rings 29–33 - sample B	Replicate of UBA-28811	−25.2±0.2	2158±26
^{14}C: 2210±22 BP, T'=2.9; δ^{13}C: −26.2±0.15‰, T'=54.8				
GLV_206				
SUERC-59112	GLV 206, rings 1–5	Waterlogged wood, *Quercus* sp. heartwood rings 1–5 (R Bale) of a 157 rings sequence, from timber GLV 2016, from a collection of worked timbers that	−24.9±0.2	2425±29

Laboratory number	Sample reference	Material & context	$\delta^{13}C$ (‰)	Radiocarbon Age (BP)
		were excavated by Bulleid and Grey and reburied on-site. Originally ?timber from the east side of Mound VI.		
UBA-28812	GLV 206, rings 153–157	Waterlogged wood, *Quercus* sp. heartwood rings 153–157 (R Bale) of a 157 rings sequence, from timber GLV 2016, from a collection of worked timbers that were excavated by Bulleid and Grey and reburied on-site. Originally ?timber from the east side of Mound VI.	−26.8±0.22	2154±24

FIGURES

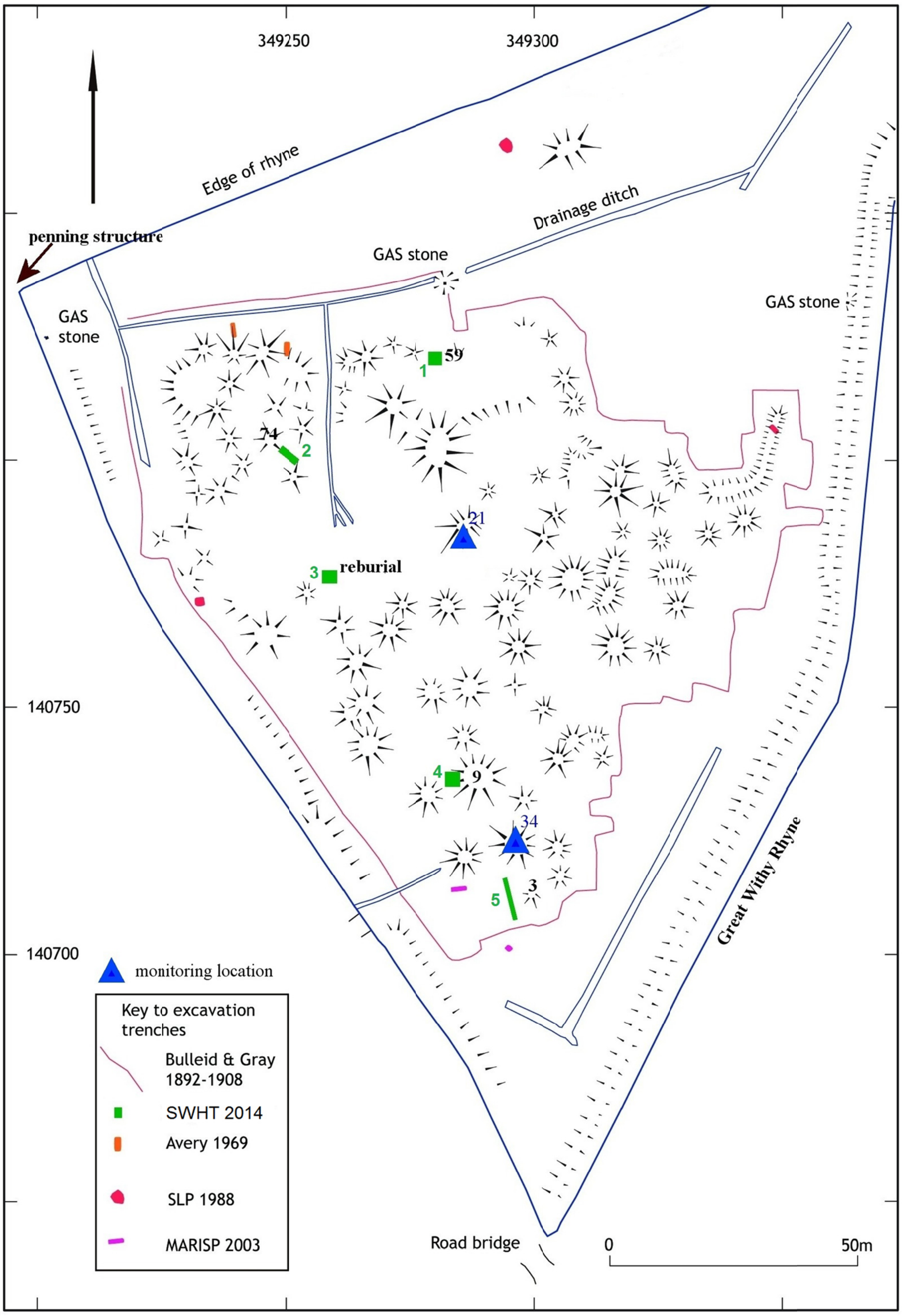

Figure 1: Plan of Glastonbury Lake Village showing the location of excavation trenches: Bulleid and Grey 1892–1908, Michael Avery 1969, Somerset Levels Project 1988, MARISP 2003, and South West Heritage Trust 2014

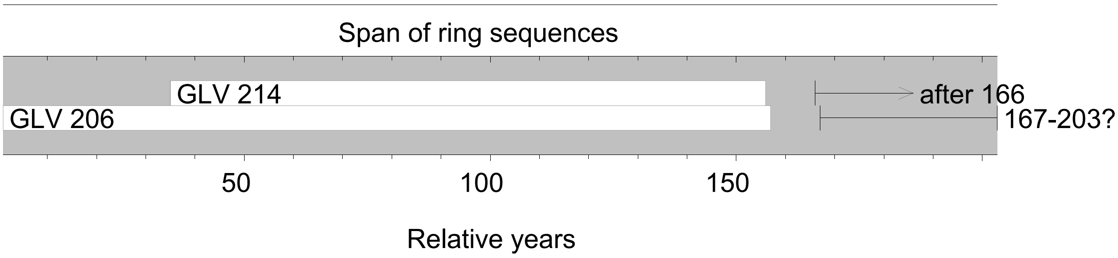

Figure 2: Bar diagram showing position of matching between GLV 206 and GLV 214 and the individual relative felling dates

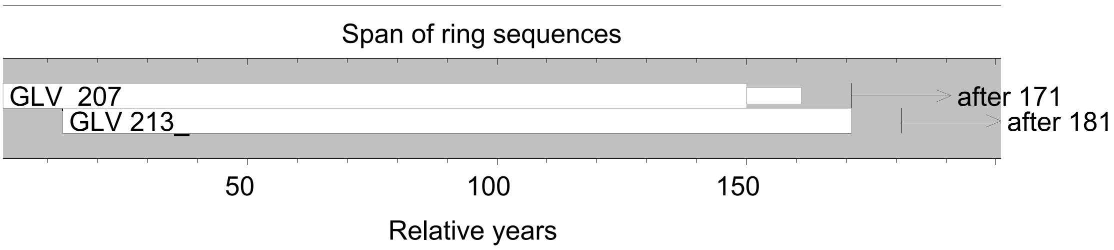

Figure 3: Bar diagram showing position of matching between GLV 207 and GLV 213 and the individual relative felling dates

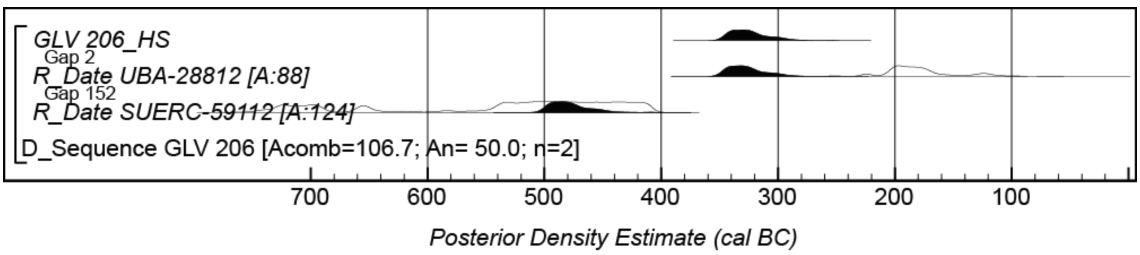

Figure 4. Probability distributions of dates from timber GLV 206. Each distribution represents the relative probability that an event occurs at a particular time. For each of the dates two distributions have been plotted: one in outline, which is the simple radiocarbon calibration, and a solid one, based on the wiggle-match sequence. The large square brackets down the left-hand side along with the OxCal keywords define the overall model exactly.

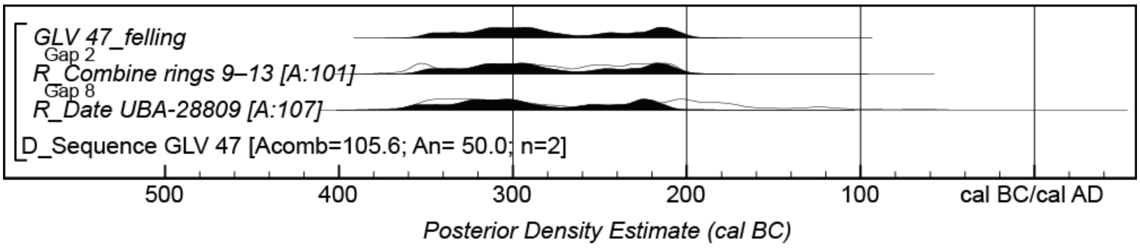

Figure 5. Probability distributions of dates from timber GLV 47. The format is identical to Figure 4.

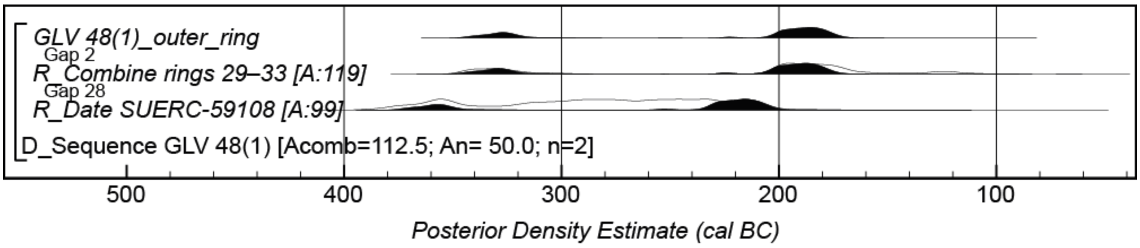

Figure 6. Probability distributions of dates from timber GLV 48(1). The format is identical to Figure 4.

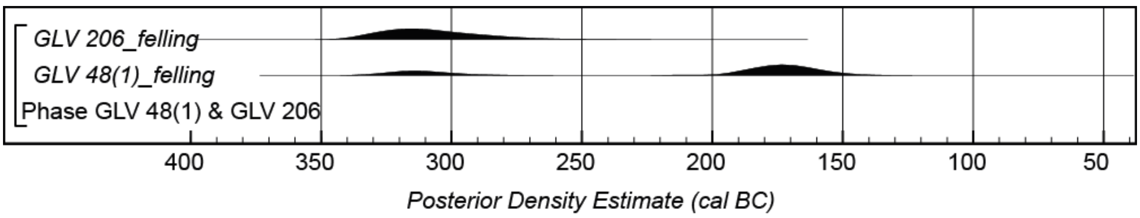

Figure 7. Probability distribution for the felling dates of the timbers GLV 48(1) and GLV 206. The distributions from Figs 4 (GLV 206_HS) and 6 (GLV 48(1)_outer_ring) have been shifted by the expected number of sapwood rings for ancient oak trees in England (Bayliss and Tyers 2004)

APPENDIX

Annual ring widths for GLV 206

Relative Year	Annual ring width (units of 0.01mm)									
1	190	120	129	130	75	114	146	93	118	164
-	154	128	238	150	203	184	129	93	107	110
-	86	119	163	99	140	223	177	94	85	116
-	132	97	79	101	128	111	120	96	71	146
-	138	107	72	110	141	110	124	116	131	104
51	88	101	78	73	96	107	99	103	115	92
-	121	97	83	89	99	96	60	92	63	78
-	77	85	80	97	95	105	82	92	68	62
-	74	89	76	90	76	70	67	64	72	85
-	66	83	95	92	91	68	65	69	59	88
101	83	96	56	85	76	99	105	86	91	53
-	99	88	105	66	71	64	64	73	114	91
-	67	75	79	56	75	58	56	86	92	66
-	60	70	73	121	83	75	102	77	61	92
-	95	119	135	94	124	130	155	103	68	95
151	72	82	112	116	130	114	107	151	72	82

Annual ring widths for GLV 207

Relative Year	Annual ring width (units of 0.01mm)									
1	127	109	65	81	122	134	71	135	130	118
-	154	89	107	117	139	80	101	98	84	113
-	195	201	120	115	116	78	74	86	97	82
-	126	76	81	79	111	85	99	90	98	89
-	101	49	69	82	74	58	63	72	85	108
51	121	101	84	83	84	89	95	101	54	84
-	62	43	73	70	72	103	73	131	116	65
-	52	109	107	79	71	79	99	95	63	72
-	45	31	168	117	116	74	87	70	92	116
-	216	114	104	93	86	118	106	121	184	179
101	152	133	111	133	157	150	130	109	122	192
-	157	172	93	98	66	110	126	77	53	92
-	119	103	146	94	99	63	46	101	88	117
-	111	103	161	179	171	164	115	111	100	196
-	139	95	109	117	99	151	181	141	209	155

Annual ring widths for GLV 211

Relative Year	Annual ring width (units of 0.01mm)								
1	136	125	132	239	176	95	158	177	207	180
-	171	146	135	168	164	195	145	208	166	135
-	169	221	236	194	196	154	168	144	189	149
-	237	170	106	170	159	103	148	86	153	164
-	139	114	171	105	165	121	161	129	136	107
51	166	126	154	187	147	165	118	168	126	144
-	114	174	154	186	148	116	173	140	173	135
-	150	91	72	157	119	139	141	151	170	127
-	102	89	114	167	120	132	122	160	143	196
-	138	183	178	140	105	104	131	132	79	168
101	142	90	111	124	122	143	130	111	173	150
-	163	129	138							

Annual ring widths for GLV 213

Relative Year	Annual ring width (units of 0.01mm)								
13			116	97	72	60	69	72	81	146
-	153	108	87	93	77	97	102	103	149	91
-	100	104	129	101	83	58	87	73	75	85
-	125	84	84	91	78	55	83	54	76	84
51	80	76	71	87	82	79	85	86	56	69
-	54	42	58	49	59	52	47	102	63	54
-	69	72	71	66	70	85	143	98	53	64
-	83	34	193	141	126	111	87	85	85	83
-	133	115	101	103	80	93	82	90	118	138
101	121	126	109	153	112	114	94	101	135	145
-	110	236	166	151	151	162	180	129	113	133
-	161	161	231	220	212	169	129	154	116	134
-	135	157	222	278	200	207	174	146	176	194
-	126	114	143	136	101	171	156	156	180	203
151	189	182	140	135	139	155	142	87	114	91
-	94	122	122	115	103	98	90	64	76	150
-	172									

Annual ring widths for GLV 214

Relative Year	Annual ring width (units of 0.01mm)									
35					261	179	141	105	88	175
-	140	99	105	124	142	79	155	147	158	103
51	78	64	87	73	107	106	126	119	92	97
-	102	115	112	116	135	78	83	107	69	56
-	66	67	80	103	71	116	80	83	80	72
-	128	88	61	92	47	47	41	55	69	62
-	69	75	94	82	69	64	56	40	63	85
101	109	53	63	61	88	132	75	84	76	57
-	82	97	144	94	92	67	78	94	88	68
-	65	84	78	62	110	73	50	71	68	80
-	56	59	72	95	91	79	114	90	53	93
-	105	124	131	92	113	68	152	97	50	91
151	68	105	92	114	102	116				






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