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WEST DEEPING, LINCOLNSHIRE
DENDROCHRONOLOGICAL AND RADIOCARBON ANALYSIS OF A BOG OAK

SCIENTIFIC DATING REPORT

Ian Tyers, John Meadows and Derek Hamilton

ARCHAEOLOGICAL SCIENCE

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SUMMARY

A tree-ring dating investigation of a single bog oak recovered from a field drain at West Deeping, Lincolnshire, produced a measured ring sequence of 364 years. To test a possible cross-match for this sequence, and thus potentially enhance tree-ring data coverage for the prehistoric period, eight radiocarbon samples were dated. A wiggle-match of the radiocarbon results shows that the tree died towards the end of the second century cal BC. The tree-ring match indicates the sequence runs from 489 BC–126 BC

CONTRIBUTORS

Ian Tyers, John Meadows, and Derek Hamilton

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Maisie Taylor provided the timber and background information; Peter Marshall of Scientific Dating team (EH) provided helpful discussion of the radiocarbon data. Dave Brown and Anne Crone kindly provided unpublished tree-ring data sets of the Iron Age period.

ARCHIVE LOCATION

Lincolnshire Historic Environment Record
Planning Services
Environment and Economy Directorate
Lincolnshire County Council
Witham Park House
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DATE OF INVESTIGATION

2009–10

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CONTENTS

INTRODUCTION

This document is a technical archive report on the tree-ring and radiocarbon analysis of a single oak timber, originally recovered during drainage works between West Deeping, Lincolnshire and Maxey, Cambridgeshire (the modern administrative boundary is within a few metres of the find spot) (Fig 1). This bog oak timber was subsequently stored by the Fenland Archaeological Trust at Flag Fen, Peterborough. It was sampled during the clearance of the wet wood storage facilities there in 2009. The timber contained an unusually large number of tree-rings, comprising 364 years, and there was an indication that its tree-ring date fell in an area of relatively sparse reference chronology coverage. The potential of this timber to provide more than a third of a millennia of reference data by itself meant that a radiocarbon wiggle-matching programme was employed to attempt to confirm the potential dendrochronological date for the sequence. Subsequently obtained tree-ring data has provided further confirmatory evidence for its date.

METHODOLOGY

Dendrochronology

Tree-ring dating employs the patterns of tree-growth to determine the calendar dates for the period during which the sampled trees were alive. The amount of wood laid down in any one year by most trees is determined by the climate and other environmental factors. Trees over relatively wide geographical areas can exhibit similar patterns of growth, and this enables dendrochronologists to assign dates to some samples by matching the growth pattern with other ring-sequences that have already been linked together to form reference chronologies.

A segment of the timber was removed and, to facilitate analysis and maximise the length of the derived ring sequence, two radii were prepared with a variety of bladed tools. This preparation revealed the width of each successive annual tree ring. Each prepared sample could then be accurately assessed for the number of rings it contained, and at this stage it was also possible to determine whether the sequence of ring widths within it could be reliably resolved. Dendrochronological samples need to be free of aberrant anatomical features, such as those caused by physical damage to the tree, which may prevent or significantly reduce the chances of successful dating.

Standard dendrochronological analysis methods (see eg English Heritage 1998) were applied to each suitable sample. The complete sequences of the annual growth rings in the suitable samples were measured to an accuracy of 0.01mm using a micro-computer based travelling stage. The sequences of ring widths were then plotted onto semi-log graph paper to enable visual comparisons to be made between the sequences. In addition, cross-correlation algorithms (eg Baillie and Pilcher 1973) were employed to search for positions where the ring sequences were highly correlated. Highly correlated positions were checked using the graphs and, if any of these were satisfactory, new composite sequences were constructed from the synchronised sequences. Any *t*-values reported below were 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 need to have been obtained from a range of independent sequences, and that these positions were supported by satisfactory visual matching.

Not every tree can be correlated by the statistical tools or the visual examination of the graphs. There are thought to be a number of reasons for this: genetic variations; site-specific issues (for example, a tree growing in a stream bed will be less responsive to rainfall); or some traumatic experience in the tree's lifetime, such as injury by pollarding, defoliation events by caterpillars, or similar. These could each produce a sequence dominated by a non-climatic signal. Experimental work with modern trees shows that 5–20% of all oak trees cannot be reliably cross-matched, even when enough rings are obtained.

Converting the date obtained for a tree-ring sequence into a useful date requires a record of the nature of the outermost rings of the sample. If bark or bark-edge survives, a felling date precise to the year or season can be obtained. If no sapwood survives, the date obtained from the sample gives a *terminus post quem* for its use. If some sapwood survives, as here, an estimate for the number of missing rings can be applied to the end-date of the heartwood. This estimate is quite broad and varies by region. This report uses a minimum of 10 rings and a maximum of 46 rings as a sapwood estimate (see eg English Heritage 1998, 10–11).

Radiocarbon Wiggle-matching

Wiggle-matching is the process whereby a series of radiocarbon determinations which are separated by a known number of years are fitted, or 'matched', 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). 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 where there are different potential 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, although it must be stressed that whilst this approach may provide support for a potential matching position identified by dendrochronology, it does not prove that the potential match is correct.

RESULTS

Dendrochronology

The two prepared radii on the segment were measured. Both series run from the centre of the tree, with one including 44 more outermost rings including some surviving sapwood (Table 1). Not surprisingly these radii cross-match strongly (*t*-value 22.51, Fig 2). They provide a composite sequence of 364 rings, and a replicated sequence for the first 320 years. The measurement data are listed in Appendix 1. The heartwood/sapwood boundary is at years 339/340 and the sample has 25 sapwood rings, but it is not complete to the bark-edge. This sequence was compared with prehistoric and historic data from throughout England and from western and northern Europe.

It was noted that two strongly statistically significant matches occurred with regional master series from London and Ireland/Northern Ireland that gave the sequence the same date, and that there was a supporting cast of less significant matches to material from Lancashire, Cumbria, Northumberland, Yorkshire, and Wales at the same dating position (Table 2a). Whilst this position seemed to offer significant possibilities, it should be borne in mind that this timber was effectively unstratified and could theoretically have been derived from any period in the Holocene. As a single, albeit unusually long sequence, good matches with long overlaps to a number of separate datasets would be required to consider it reliably dated by purely dendrochronological methods. The proposed dating position, however, also provided a number of additional problems; it implied that the timber fitted into a partial gap in the national sequence, straddling the chronological position where the Roman chronologies from long living trees started, and the handful of later Iron Age chronologies ended. The sequences in Table 2a only overlap portions of the West Deeping sequence; they are relatively poorly replicated at the points where they do overlap, and they are geographically well spread across the British Isles. The closest geographic sequence that partially overlaps West Deeping is the material from Fiskerton, near Lincoln, but this data exhibits one of the less significant correlations at the proposed position. None of this is unusual with the prehistoric tree-ring sequence, making advances in either the overall data extent or the strengthening of regional coverage reliant upon locating material that is only preserved by complex taphonomic processes and often only recovered by chance findings.

As a result of this uncertainty it was suggested that a radiocarbon wiggle-match could identify if this dating position was likely to be correct. The results and interpretation of this are discussed in the subsequent sections. This radiocarbon wiggle-match result provides an independent constraint on the calendrical location of the tree-ring data, and whilst not proving that the tree-ring date is correct, it provides significant support for the date initially noted.

As luck would have it, during the period the wiggle matching samples from West Deeping were at the radiocarbon laboratory, an assemblage of later Iron Age material from Scotland was analysed by Anne Crone in Edinburgh, and sent to various dendrochronologists for comparison with their datasets. This site, Dorman's Island crannog, Whitefield Loch, south-west Scotland, also exhibited matches to the inner end of the Roman sequences from London, Carlisle, and Ribchester, as well as the regional series from Ireland/Northern Ireland (Anne Crone pers comm; Cavers *et al* 2011). These observations suggested that broad regional matching might be expected at this period for long datasets. In addition, one of the Dorman's Island individual component timbers matched to West Deeping at its possible dating position (*t*-value 3.21, Dorman's timber 12). This finding prompted a re-examination of the West Deeping sequence with the site chronologies from Ireland and Northern Ireland, which would normally be considered too far away from West Deeping to be of interpretative use. This group of data includes some of the components of the original regional sequence (Pilcher *et al* 1984), but includes more recently analysed material (Dave Brown pers comm). This identified a new independent set of significant matches, at the same dating position, with these independent series providing more complete overlaps with the West Deeping sequence. These additional results are given in Table 2b.

Radiocarbon

Eight decadal blocks of wood were sampled for radiocarbon dating, as shown in Table 3. The samples were submitted to the Scottish Universities Environmental Research Centre, East Kilbride (SUERC) for dating by Accelerator Mass Spectometry (AMS). The samples were pretreated following Hoper *et al* (1998). They were then combusted to carbon dioxide (Vandeputte *et al* 1996), graphitised (Slota *et al* 1987), and measured by AMS (Xu *et al* 2004). SUERC maintains a continual programme of quality assurance procedures and participates in international inter-comparisons (Scott 2003), the results of which confirm the absence of laboratory offsets and to demonstrate the validity of the precision quoted.

Table 3 includes the radiocarbon results, quoted in accordance with the international standard known as the Trondheim Convention (Stuiver and Kra 1986). These are conventional radiocarbon ages (Stuiver and Polach 1977). The calibrated date ranges in

Table 3 have been calculated using the maximum intercept method (Stuiver and Reimer 1986), the calibration curve of Reimer *et al* (2013) and the computer program OxCal v4.2 (Bronk Ramsey 1995; 1998; 2001; 2009). They are quoted with endpoints rounded outwards to 10 years, following Mook (1986).

DISCUSSION

Radiocarbon

The graphical distributions of the calibrated results are derived from the probability method (Stuiver and Reimer 1993). A Bayesian wiggle-match model (Fig 3) that combines the radiocarbon results with their age differences, was constructed using OxCal v4.2 (Bronk Ramsey 2009; Christen and Litton 1995; Bronk Ramsey *et al* 2001; Galimberti *et al* 2004). The samples were of decadal blocks, and it is assumed that the radiocarbon measurements date the midpoint of each decade sampled. Furthermore, there is a 40-year gap between each sample. The final radiocarbon sample, years 311–320, provides a result that corresponds to year 315/6 in the dendrochronological sequence. Given the heartwood/sapwood transition was at year 339/40 in the dendrochronological sequence, and 25 rings of sapwood survived; the date of the outermost sapwood ring (year 364 in the dendrochronological sequence) should therefore fall 49 years after the final submitted sample.

The model, shown in Figure 3, shows a good fit between the calibrated radiocarbon results and the relative dating required by the dendrochronological sequence (A_{comb}=116.6%, A_n= 25.0%, n=8; Bronk Ramsey *et al* 2001).

Each radiocarbon sample from West Deeping consisted of a decadal block from the dendrochronological sequence, and the calibration data spanning this period are composed of radiocarbon measurements attributed to the midpoints of blocks of dendro-dated wood from each calendar decade. The ranges for *posterior density estimates* given in Table 3 have been rounded outwards to the nearest five calendar years. There is thus at least a 95% probability that the midpoint of the decadal block sampled dates to within the corresponding range. The model estimates that the *last ring date* (Fig 3; equivalent to year 364 in the dendrochronological sequence) falls between *150–115 cal BC* (*95% probability*) or *140–115 cal BC* (*68% probability*). This radiocarbon date range is the one of interest in supporting the dendrochronological dating position of the tree-ring sequence.

Dendrochronology

The wiggle-match calibration given above constrains the end date of the measured tree-ring sequence to the narrow window of *150–115 cal BC* (*95% probability;* Fig 3), for normal archaeological purposes this is of course more than an adequate precision.

However, in this case it is supporting a series of significant dendrochronological correlations identified for the tree-ring data that place its proposed end date at 126 BC, see Figure 4. A radiocarbon wiggle-match that includes the date of 126 BC for the last ring of the sequence (Fig 5) has good agreement (A_{comb}=126.5%, A_n= 25.0%, n=8; Bronk Ramsey *et al* 2001). For a piece of unstratified timber that could have been derived from any stage in the Holocene, this constraint is remarkably useful. For the long term aims of the refinement and strengthening of the British Isles prehistoric tree-ring data sets the West Deeping timber provides a 364-year measure of data from central England that can now be used with confidence to compare with data from previously analysed but undated groups of later Iron Age timbers, as well as assist with material excavated in the future.

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TABLES

Table 1: Details of the West Deeping sample

Sequence	Radius	Species	Rings	Sapwood Rings	Growth Rate (mm/year)	Relative Dating	Proposed Absolute Dating
wdbo1	radius 1	Oak	320	-	1.14	1–320	489 BC–170 BC
wdbo2	radius 2	Oak	364	25	1.06	1–364	489 BC–126 BC

Table 2a: Initial t-values, against regional data sets and other material that mostly provide partial overlaps with the West Deeping bog-oak sequence

	West Deeping 489 BC–126 BC
Cumbria, Carlisle The Lanes north area, 434 BC–AD 118 (Groves 1996)	3.93
Ireland/Northern Ireland, Long Chronology, 5289 BC–AD 1983 (Pilcher *et al* 1984)	5.42
Lancashire, Ribchester, 295 BC–AD 91 (Hillam 2000)	4.81
Lincolnshire, Fiskerton 498 BC–339 BC (Hillam 2003)	3.21
London, regional master, 368 BC–AD 294 (Tyers unpubl)	5.60
Northumberland, Vindolanda, 367 BC–AD 103 (Hillam 1993)	4.32
Wales, Goldcliff, 593 BC–272 BC (Hillam & Groves 2003)	3.47
Yorkshire, Hasholme logboat, 588 BC–323 BC (Hillam 1987)	3.36

Table 2b: Subsequent t-values identified by additional data provided by Dave Brown, these series' provide much longer overlaps with the West Deeping sequence than the series' used in Table 1

	West Deeping 489 BC–126 BC
Ireland, Corlea 1 trackway, 446 BC–148 BC (Dave Brown pers comm.)	7.26
Ireland, Derraghan More trackway, 415 BC–167 BC (Dave Brown pers comm.)	4.10
Ireland, Killoran, 870 BC–193 BC (Dave Brown pers comm.)	4.07
Northern Ireland, Navan, 275 BC–126 BC (Dave Brown pers comm.)	4.23
Northern Ireland, The Dorsey, 575 BC–116 BC (Dave Brown pers comm.)	5.09

Table 3: Radiocarbon and stable isotope results

Sample	Laboratory Code	Radiocarbon age (BP)	δ^{13}C (‰)	Calibrated date (95% confidence)	*Posterior density estimate (95% probability)*
years 31–40	SUERC-28945	2420±30	–22.8±0.2	750–400 cal BC	*480–445 cal BC*
years 71–80	SUERC-28949	2400±30	–22.9±0.2	740–390 cal BC	*440–405 cal BC*
years 111–20	SUERC-28950	2250±30	–23.2±0.2	400–200 cal BC	*400–365 cal BC*
years 151–60	SUERC-28951	2220±30	–23.8±0.2	390–190 cal BC	*360–325cal BC*
years 191–200	SUERC-28952	2225±30	–23.4±0.2	390–190 cal BC	*320–285 cal BC*
years 231–40	SUERC-28953	2225±30	–23.4±0.2	390–190 cal BC	*280–245 cal BC*
years 271–80	SUERC-28954	2240±30	–22.7±0.2	400–200 cal BC	*240–205 cal BC*
years 311–20	SUERC-28955	2155±30	–22.9±0.2	360–100 cal BC	*200–165 cal BC*

Each sample represents one decade of growth from a single oak (*Quercus* spp) tree with 364 measured annual rings (see Appendix 1). Posterior density estimates are derived from the model shown in Figure 3.

FIGURES

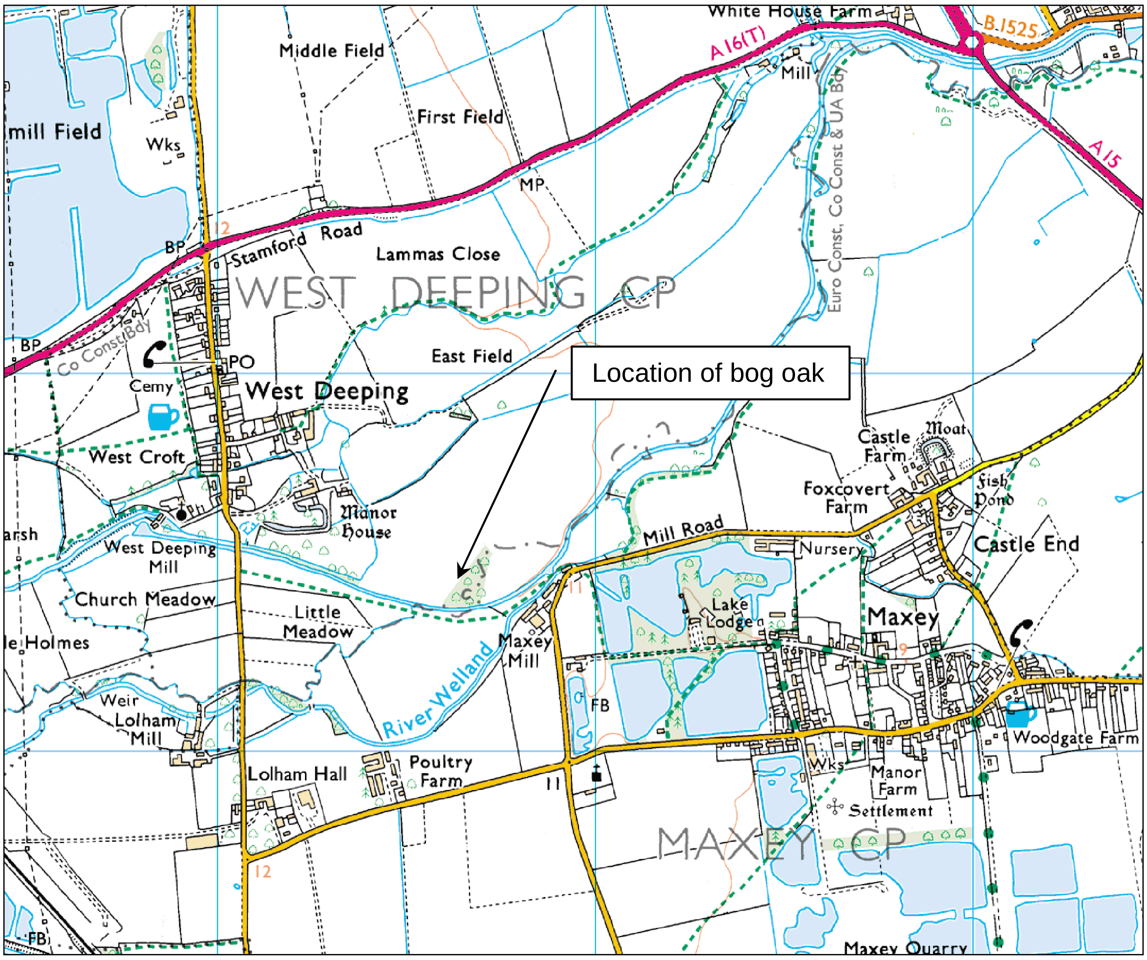

Figure 1: Map showing the approximate location of the field drain at West Deeping, Lincolnshire. This map is based upon Ordnance Survey material with the permission of Ordnance Survey on behalf of the Controller of Her Majesty's Stationery Office. © Crown Copyright. Unauthorised reproduction infringes Crown Copyright and may lead to prosecution or civil proceedings. English Heritage. 100019088. © English Heritage 2010

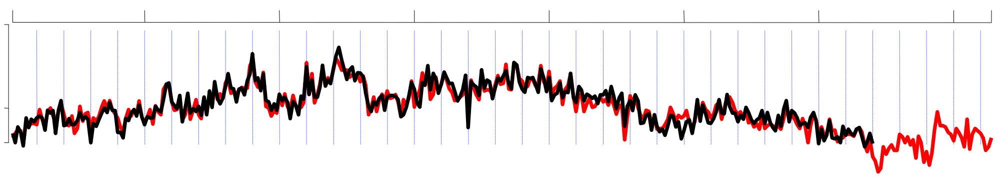

Figure 2: The 2 measured radii of the tree-ring sequence from the West Deeping bog oak (radius 1 black, radius 2 red)

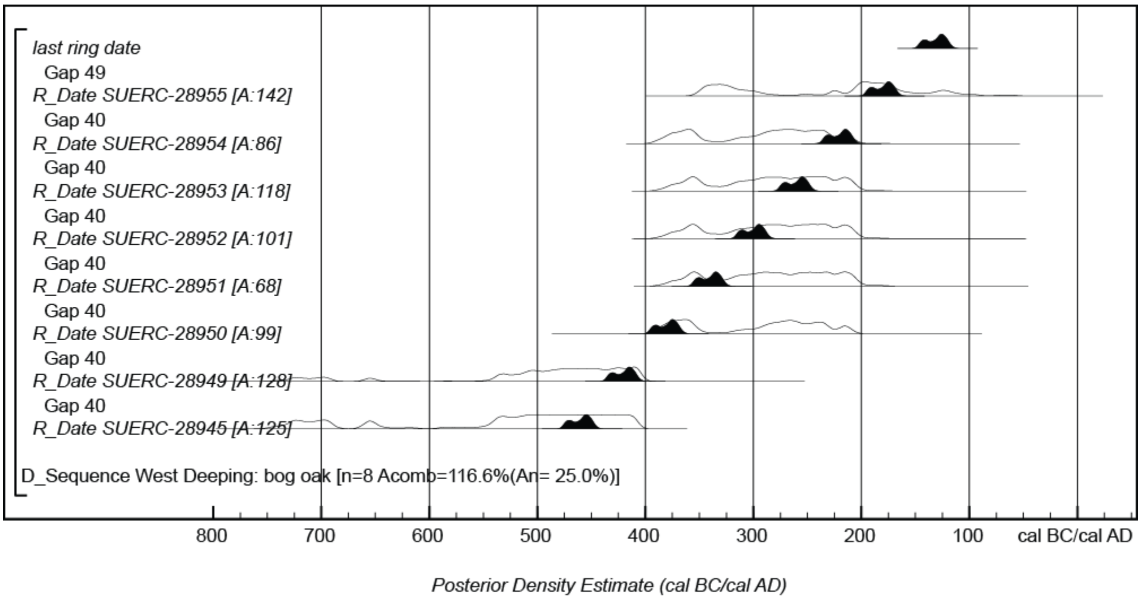

Figure 3: Probability distributions of dates obtained on the West Deeping bog oak. Distributions in outline are the results of radiocarbon calibration (Stuiver and Reimer 1993). The solid distributions are based on the wiggle-match sequence (Bronk Ramsey et al *2001). The distribution 'last ring date' is the estimated age of the outermost surviving sapwood ring. The OxCal keywords define the model exactly*

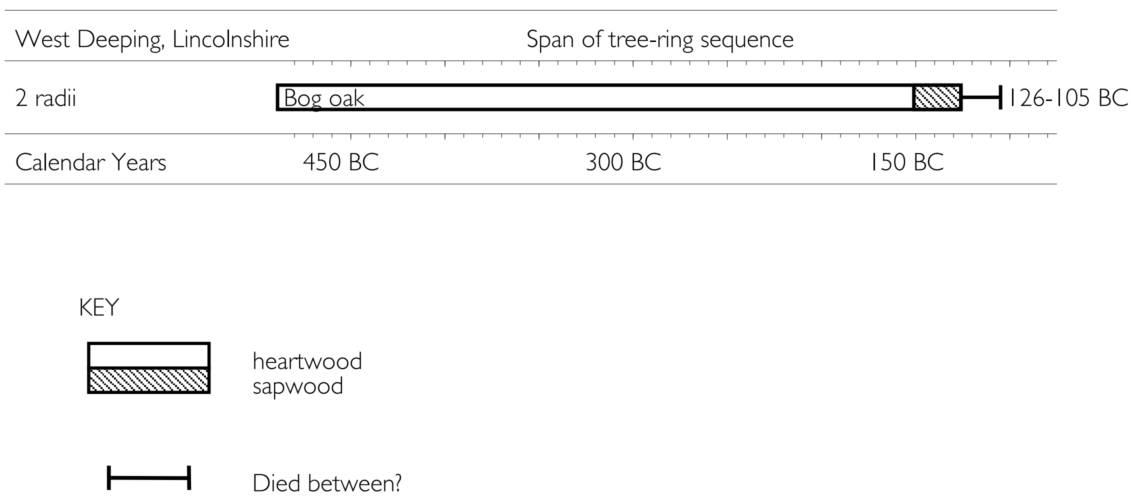

Figure 4: Bar diagram showing the proposed absolute dating position of the West Deeping boat oak sequences. The interpreted date of likely death of this tree is also shown, see text for discussion.

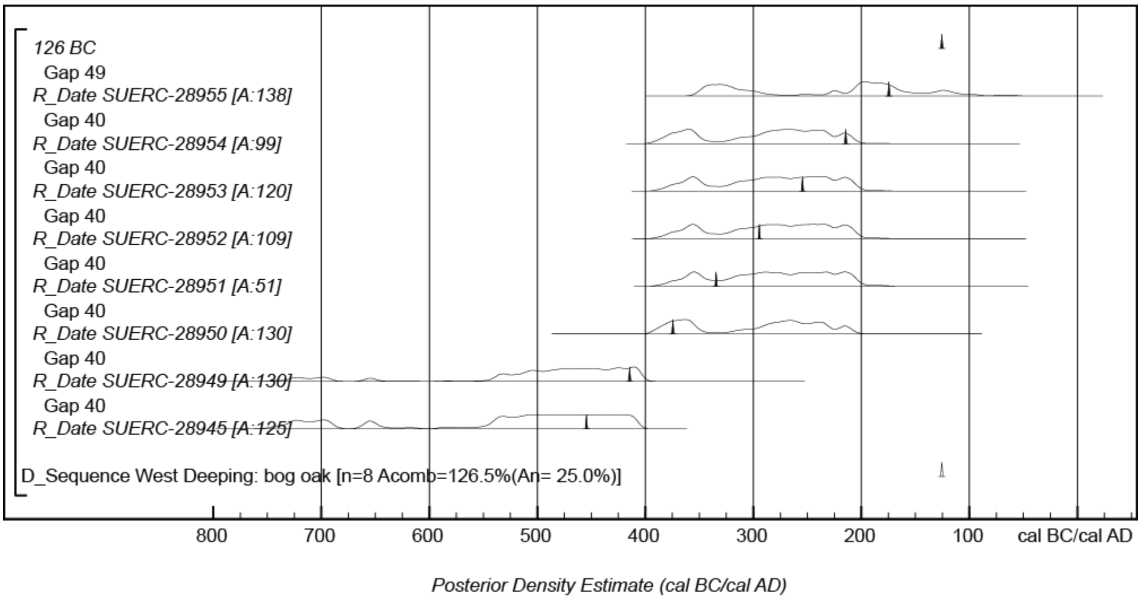

Figure 5: Probability distributions of dates obtained on the West Deeping bog oak. The format is identical to Figure 4 apart from the inclusion of the date of 126 BC for the last ring of the sequence

APPENDIX 1

wdbo1

62	52	70	63	49	83	69	81	77	83
86	83	66	96	91	95	62	96	115	72
73	82	73	73	79	92	80	85	81	52
75	71	80	91	100	92	111	96	95	63
63	57	82	79	91	97	86	106	84	73
85	83	83	103	96	93	117	156	160	112
105	99	127	77	100	132	91	99	94	103
87	123	88	138	101	164	120	108	121	150
191	145	144	112	143	146	128	167	189	279
168	177	139	190	116	112	96	108	96	130
115	123	111	82	113	106	88	125	118	218
129	169	123	123	148	224	152	169	158	210
266	314	247	206	171	205	217	167	195	193
180	132	103	94	112	106	120	127	96	122
127	127	124	118	85	88	102	127	161	142
110	102	161	154	223	140	192	173	132	157
197	177	158	159	137	114	124	141	185	69
164	155	149	127	205	146	169	164	119	148
176	166	183	202	158	144	236	225	163	142
135	178	174	178	155	135	209	177	136	178
115	128	132	160	121	136	134	192	121	111
150	140	114	130	126	120	125	109	128	128
139	113	150	124	99	121	132	71	103	115
95	128	114	75	76	87	90	66	88	71
64	67	60	72	87	86	70	77	56	65
77	80	62	80	117	78	106	90	76	75
82	93	117	91	90	129	103	91	91	77
87	81	101	92	80	75	80	83	95	75
92	76	69	65	87	71	98	115	77	95
91	83	72	75	76	69	84	92	79	51
67	54	60	79	57	56	58	52	71	60
67	62	60	67	69	59	48	53	62	51

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57	62	67	65	51	76	71	75	75	73
97	81	72	93	100	86	77	94	109	89
73	72	86	62	68	103	78	90	92	65
83	78	85	102	114	100	115	97	90	83
69	64	82	97	86	97	89	114	83	77
85	97	74	104	93	88	142	157	154	112
96	97	122	80	88	125	81	97	117	88
82	121	90	129	105	155	117	131	120	161
174	132	136	132	139	147	146	145	221	246
163	148	149	196	103	100	86	95	91	125
105	131	102	97	127	106	99	101	110	234
132	191	110	129	158	208	151	177	161	206
256	233	204	206	204	179	188	179	185	164
183	154	88	100	123	94	114	130	112	138
120	122	129	112	85	117	104	122	166	102
122	141	193	154	202	118	129	179	138	156
191	168	144	134	115	119	123	128	155	92
169	147	129	117	181	138	141	140	129	157
184	157	159	227	143	141	229	222	174	166
146	151	175	172	151	160	222	164	151	200
126	145	151	166	107	142	153	191	124	94
129	129	94	109	119	101	103	113	122	112
118	106	121	106	89	105	106	55	83	126
110	127	100	87	82	96	94	73	85	67
68	68	73	81	101	91	78	87	83	86
95	76	71	77	106	87	111	97	93	83
89	106	111	81	98	124	123	111	95	88
93	83	97	76	78	70	74	67	87	68
72	74	72	69	71	67	82	100	86	87
81	73	68	82	71	52	72	88	80	62
70	61	60	81	65	66	53	57	57	62
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37	30	32	48	42	47	50	45	45	61
58	52	58	50	55	39	59	52	36	44
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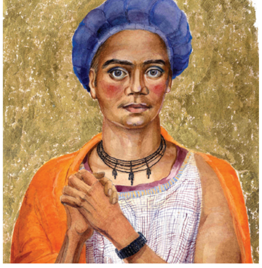
68	63	57	48	81	46	61	68	65	62
57	45	48	57						

ENGLISH HERITAGE RESEARCH DEPARTMENT

English Heritage undertakes and commissions research into the historic environment, and the issues that affect its condition and survival, in order to provide the understanding necessary for informed policy and decision making, for sustainable management, and to promote the widest access, appreciation and enjoyment of our heritage.

The Research Department provides English Heritage with this capacity in the fields of buildings history, archaeology, and landscape history. It brings together seven teams with complementary investigative and analytical skills to provide integrated research expertise across the range of the historic environment. These are:

- *Aerial Survey and Investigation*
- *Archaeological Projects (excavation)*
- *Archaeological Science*
- *Archaeological Survey and Investigation (landscape analysis)*
- *Architectural Investigation*
- *Imaging, Graphics and Survey (including measured and metric survey, and photography)*
- *Survey of London*

The Research Department undertakes a wide range of investigative and analytical projects, and provides quality assurance and management support for externally-commissioned research. We aim for innovative work of the highest quality which will set agendas and standards for the historic environment sector. In support of this, and to build capacity and promote best practice in the sector, we also publish guidance and provide advice and training. We support outreach and education activities and build these in to our projects and programmes wherever possible.

We make the results of our work available through the Research Department Report Series, and through journal publications and monographs. Our publication Research News, which appears three times a year, aims to keep our partners within and outside English Heritage up-to-date with our projects and activities. A full list of Research Department Reports, with abstracts and information on how to obtain copies, may be found on www.english-heritage.org.uk/researchreports

For further information visit www.english-heritage.org.uk

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