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TOWN QUARRY FARM, BURLESCOMBE, DEVON DENDROCHRONOLOGICAL ANALYSIS OF OAK TIMBERS

SCIENTIFIC DATING REPORT

Ian Tyers

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DENDROCHRONOLOGICAL ANALYSIS OF OAK TIMBERS

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SUMMARY

A tree-ring dating programme was commissioned on timbers excavated at Town Quarry Farm, Burlescombe, Devon. Dates were obtained for Bronze Age and early medieval structures, and were used to inform the publication of the archaeological excavations. This report archives the dendrochronological results.

CONTRIBUTORS

Ian Tyers

ACKNOWLEDGEMENTS

The spot-dating of this material, and the production of publication texts and archive reports was funded by Exeter Archaeology. The radiocarbon dating of timber 475 was funded by the Aggregates Levy Sustainability Fund, administered by English Heritage (project 4534). Steve Allen, Richard Brunning, Rowena Gale, Tim Gent, Jim Spriggs, and Vanessa Straker all kindly provided discussion, data, drawings, photos, or text about the timbers. Derek Hamilton and Peter Marshall discussed the radiocarbon selection criteria and results for the structure 658 sample, Peter kindly provided the text and tables for the radiocarbon calibration and Bayesian modelling sections of this report and corrected earlier drafts of my interpretation of the data.

ARCHIVE LOCATION

Devon Historic Environment Record

DATE OF ANALYSIS

2006

CONTACT DETAILS

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INTRODUCTION

This document is a technical archive report on the tree-ring analysis of oak timbers from excavations at Town Quarry Farm, Burlescombe, Devon (sitecode BLC04, NGR *c* ST 0810 1658, Figs 1 and 2) during 2004. This report describes the analytical results of the dendrochronological analysis of 40 samples of timbers from this site. This information has been synthesised with stratigraphic interpretation and other scientific dating information to provide part of the dating framework for the publication of the excavation (Best and Gent forthcoming).

METHODOLOGY

A large number of timbers from the Burlescombe site were examined at the York Archaeological Trust Archaeological Wood Centre in March 2006. This examination was undertaken in conjunction with wood identification lists, record drawings, and site context and grouping information. Only oak timbers were selected for sampling. A number of oak timbers were rejected prior to sampling, because visual inspection indicated they contained too few rings for analysis. Each sample from the selected timbers was obtained by sawing a cross-section from the timber at the optimum location for sapwood and bark survival, whilst also attempting to maximise the ring sequence length. Three ready-cut samples were also collected. The sampled assemblage thus comprised only oaks with possible dendrochronological potential. They were prepared for analysis in order to identify their detailed potential, and the tree-ring analysis of the suitable samples was then undertaken.

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.

Each sample was placed in a deep-freeze for 48 hours in order to consolidate the timber. A surface equivalent to the original horizontal plane of the parent tree was then 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 (eg English Heritage 1998) were applied to each suitable sample. The complete sequence of the annual growth rings in the suitable samples was 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 sequences. In addition, cross-correlation algorithms (eg Baillie and Pilcher 1973) were employed to search for positions where the ring sequences were highly correlated (Tyers 2004a). 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, even when enough rings are obtained, cannot be reliably cross-matched. With the additional problems of archaeological material, it is typically found that less than 80% of apparently suitable archaeological oak samples are datable.

Converting the date obtained for a tree-ring sequence into a useful archaeological 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, 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 period and region. For this report, a minimum of 10 rings and a maximum of 46 rings is used as a sapwood estimate for the early medieval material, whilst a minimum of 10 rings and a maximum of 55 rings is used as a sapwood estimate for the Bronze-Age material.

Timber technology studies demonstrate that many of the tool marks recorded on archaeological timbers can only have been done on green timber. There is little evidence for long-term storage of timber or of widespread use of seasoned, rather than green, timber in either the Roman or the early medieval periods.

Reused timbers can only provide tree-ring dates for the original usage date, not for their reuse. Identifying reused timbers requires careful timber recording during or after archaeological fieldwork, which notes the presence of features which are not functional in the structure. It is always possible that some timbers exhibit no evidence of their earlier usage and are thus 'hidden reused' timbers. The dendrochronological impact of this problem is particularly acute where only single timbers have been dated from a structure.

The analysis may highlight potential same-tree identifications if two or more tree-ring sequences are obtained that are exceptionally highly correlated. Such pairs, or more, are then used as a same-tree group and each can be given the interpreted date of the most complete of the samples. They are most useful where several slices each have lots of rings but only one has any sapwood or where same-tree identifications yield linkages between different structures.

The BC scale used in this report has no year zero, and the year 1 BC immediately precedes the year AD 1. The term 'bog-oak' is used in this report to cover all naturally deposited oaks in bogs, peats, or gravels.

RESULTS

The selected material comprised 40 oak samples each obtained by sawing a cross section from the timber at the optimum location selected in order to maximise the dendrochronological potential.

Structure 678

Structure 678 is the eastern of two wells on the site. The almost-complete absence of finds from this structure meant that it was of unknown date, although it was thought it might be Iron Age on the basis of a single fragment of pottery, and the types of tool marks on the timbers. A total of 22 of the 40 dendrochronological samples obtained from this site were derived from this structure (Table 1a). The material included a mixture of tangential and radial boards, several of which contained large numbers of annual rings.

After preparing the material for measurement, four of the samples were found to contain too few rings for analysis, but the remaining 18 were measured. Fifteen of the measured sequences were found to cross-match (Table 2) to yield a single 208-year composite sequence. Three pairs of samples are sufficiently alike to indicate each pair was derived from the same parent log. The composite sequence mathematically constructed from the matched series at their synchronised positions was compared with reference data of prehistoric and historic date from throughout England and northern Europe. A number of statistically significant matches were obtained between the sequence and reference series indicating the sequence dates from AD 421–628 inclusive (Table 3).

The structure 678 *t*-table (Table 3) lists examples of matches for this tree-ring data against independent reference series. This table is intended to show that there is adequate independent corroboration for the absolute dating given here for this structure. The chronologies which match the structure 678 tree-ring data do not provide any useful indication of the provenance of this material, since many of the data sets available for this period are relatively poorly replicated and somewhat unevenly distributed geographically (eg Tyers *et al* 1994).

Sample 538 is complete to bark-edge, and this sample was felled in the spring of AD 629. Felling date ranges were calculated for seven of the other samples complete to either heartwood/sapwood boundaries or with some surviving sapwood, using a 10–46 year range for the number of missing sapwood rings. The remaining seven samples consisted entirely of heartwood, and for these *terminus post quem* dates were calculated using a 10-year minimum for missing sapwood. Table 1a lists the dates of the individual series, and their calculated interpreted date, and Figure 3 shows the date spans of the individual sequences, and their calculated interpreted dates. The clustering of the end-dates of the entire dated group suggests they are the product of a single event. If this assumption is correct, then sample 538 indicates a construction date of spring AD 629 for this feature.

Structure 658

Structure 658 is a waterlogged pit. A total of 12 of the 40 dendrochronological samples obtained from this site were derived from this structure (Table 1b). The material included some large radial boards, which contained large numbers of annual rings, and a variety of smaller timbers. After preparing the material for measurement, seven of the samples were found to contain too few rings for analysis, or to contain bands of slow growth which included ring sequences that could not be resolved reliably. The remaining five samples were suitable for measurement. Two of the measured sequences were found to cross-match (Table 4), yielding a single 245-year composite sequence. These samples are sufficiently alike to indicate they were derived from the same parent log (Table 4 and Fig 4; blue and red sequences). A composite sequence, mathematically constructed from the matched series at their synchronised positions, was compared with other data from Burlescombe and with reference data of prehistoric and historic date from throughout England and northern Europe.

Initially, no statistically significant matches were obtained between the sequence and reference series. However, it was noted that these two samples exhibit a particularly awkward band of narrow rings that onsets after ring 122 of the composite sequence. This is visible on Figure 4 as a dramatic dip in growth rate. It was also apparent that whilst the two sequences remain synchronised, their overall degree of similarity drops after ring 122. This can be seen by inspection of Figure 4 and also from Tables 5a–c, which show the inter-correlation 'r' values for sub-segments of the two series. Utilising the tree-ring data from this pair of series only up to the onset of this narrow band allows the use of a 122-year ring sequence that is internally consistent.

This 'short' composite sequence was separately compared with other data from Burlescombe and with reference data of prehistoric and historic date from throughout England and northern Europe. The 'short' series was found to strongly correlate with mid second-millennium BC data derived from a site at Testwood in Hampshire and from two sites on the Somerset Levels. Table 6 illustrates this for both the separate samples, and the composite, all in their 'short' form. Table 7 gives the correlations for the full data at the same calendar position.

Table 8 gives the matches between the full and short versions of these series against sample 474 from the same structure. Sample 474 does not have any aberrant growth characteristics, suggesting that the problem growth period in 475 and 483 is caused by an intrinsic factor specific to this tree, rather than indicative of a wider environmental issue. The full composite series from 475 and 483 was combined with 474 to provide a final structure 654 composite sequence.

Table 9 gives the correlations for this sequence against the same chronologies originally identified as matching the 'short' version of 475 and 483. The full composite tree-ring sequence appears to date from 1677–1433 BC. The chronologies which match the structure 658 composite (Table 9) represent most of the extant English oak tree-ring data for this period. This group of correlations were not felt to be sufficiently strong or adequately replicated to use for dating this important feature without additional support. The Testwood3 master sequence and the Testwood3 evaluation sample were themselves used to provide the dating evidence for Meare Heath and Tinneys, so although these are all independent series they are quite closely related, and it is hard to know for certain how the Burlescombe data can be expected to behave in these circumstances.

There are a number of other tree-ring series of this period with which the Burlescombe data set does not provide correlations of any statistical significance. Several of these only overlap with the latter half of the structure 654 sequence, which is demonstrated to be of poorer statistical quality (Fig 4, Tables 5a–c). These includes data from Newington Quarry, Nottinghamshire (Tyers 2003), and Croston Moss, and Leyland, both in Lancashire (Brown and Baillie 1990). It is reasonable to assume that middle Bronze Age tree-ring data cross-matches over similar distances as oak series from earlier and later periods. Hence it is likely these series are too far away geographically to be of any value for analysing Burlescombe. In addition, there are overlapping contemporaneous data sets from a number of locations in Ireland and on the Continent, but these are also mostly likely to be too far away to be of any significant use for the Burlescombe analysis. A further Testwood sequence, Testwood1 (Boswijk and Groves 1997), does overlap the Burlescombe series but does not correlate well (t = 1.70). This observation was not felt to be especially disturbing, as the Testwood1 sequence is itself of relatively poor statistical quality, on the basis of its comparison with the contemporary Testwood3 sequence.

Following extensive discussion with English Heritage Scientific Dating Section, it was agreed to undertake a radiocarbon wiggle-matching programme. Sample 475 was the obvious choice for this, since it provided the longest series of rings, and it was a larger timber, which allowed for better sub-sampling. A series of models was employed to identify the most appropriate sampling strategy, and the most appropriate radiocarbon dating technique to employ (Hamilton and Marshall pers comm).

Sample 475 was sectioned into a series of 50mm-thick slices; from each, a series of blocks was cut, containing ten identical discrete 10-year sets of rings. The blocks represent years 18–27, 38–47, … , 178–187, and 198–207 inclusive of sample 475, when labelled year 1 as the innermost and 245 as the outermost ring (Table 10). If the dendrochronological match identified for this material was correct these should produce radiocarbon dates for the blocks centred on 1660–1651 BC, 1640–1631 BC, … , 1500–1491 BC, and 1480–1471 BC, ie the block edges were deliberately chosen to lie on decade boundaries.

The outermost rings present on sample 475 were avoided because the presence of fragmented sapwood reduced the overall amount of timber available for sampling at this end of the timber. Similarly, the relatively small amount of timber available on its inner edge reduced the potential of this area. Blocks were cut until each decadal group contained sufficient dry weight for radiometric dating (300–500g). Some of the thicker parts of the plank, with sections of faster-than-average growth, only required a few blocks to be cut, whereas the slowest-growing section required seven separate blocks. This material was submitted to the University of Groningen for gas-proportional radiocarbon dating as samples GrN-30162 to GrN-30171 inclusive. The calibration of these results is described in detail by Marshall *et al* (forthcoming).

In summary, a Bayesian chronological model was constructed that incorporated the relative dating of the blocks, and the number of additional rings after the last block. The Bayesian model was run utilising a number of different calibration datasets, and where possible the agreement between the dendrochronological analysis and the modelled radiocarbon results was tested statistically (Table 11). The different calibration datasets lead to slightly different posterior density estimates of the last ring date, all of which suggest that the last ring should be later than 1455 cal BC and earlier than 1390 cal BC. The agreement between the radiocarbon and the dendrochronological dating was testable and acceptable for three of the four calibration datasets.

A least-squares 'best fit' for the sequence of radiocarbon results from sample 475 against the calibration curve of Reimer *et al* (2004), utilising the algorithm described in Bronk Ramsey *et al* (2001), indicates a date of *1460 BC* for the last ring submitted as part of the wiggle match (actual date 1471 BC). The result is in accordance with the posterior density estimate of *1480–1440 cal BC (at 95% probability)* provided by the Bayesian analysis using the same calibration data (Reimer *et al* 2004).

The consistency of the results produced by these two methodologies is not surprising, since it has been shown that the least-squares fit gives the highest point in the probability density function derived by the Bayesian method (Bronk Ramsey *et al* 2001). The least-squares method only provides a single date, with no estimate of error.

Given the variety of radiocarbon support, it was felt that the dendrochronological dating derived from cross-correlation with material from Hampshire and Somerset (given in Table 9) could be regarded as reliable. The dendrochronological date of 1433 BC is for the date for the last surviving ring from sample 475. The date of the construction of feature 654 cannot be identified precisely, due to the lack of surviving bark edge on any of the datable samples. Two separate approaches are possible here, both with potential problems in this particular case.

A standard dendrochronological approach would be by applying maximum and minimum sapwood estimates, based on contemporaneous and/or geographically similar figures for oak sapwood. The normal dataset employed (Bayliss and Tyers 2004) is based on medieval and modern oak data. This is probably unsuitable in this case, because samples 475 and 483 are unusually long-lived and slow-grown, both factors which appears to raise the number of sapwood rings present in English oak (Hillam *et al* 1987; Miles 1997). In addition, sample 475 already includes 36 sapwood rings, which raises the strong possibility that this tree had an unusually large number of sapwood rings by recent standards. There is no appropriate prehistoric sapwood dataset to employ, since few prehistoric samples are recovered with complete sapwood and bark. The estimates here have instead utilised an earlier 'generic' English oak estimate of 10–55 sapwood rings, employed as 95% probability range (Hillam *et al* 1987). These calculations indicate that 475 was probably felled between 1433 BC and 1414 BC, whilst 483 (from the same tree) is likely to have been felled before 1422 BC. In combination, this suggests that this pair of timbers was from a tree felled between 1433 BC and 1422 BC. Since they are from a single, somewhat aberrant tree, this interpretation may be inaccurate. A date post-1433 BC and pre-1400 BC is perhaps a more appropriate, if cautious, interpretation, as it is extremely unusual to see English oak timbers from any period or deposit type with more than 70 sapwood rings.

An estimate of the felling date of the timber, utilising the radiocarbon dating and then the probability distribution of the number of sapwood rings expected to be missing from the sample, has also been used to provide an estimate of the date of the felling of the timber. The methodology for this approach is described by Bayliss and Tyers (2004). This method is best employed in situations where multiple trees, each with some evidence of sapwood, are derived from single structural contexts. The calendar ranges calculated are independent of the dendrochronological date, but this approach also utilises sapwood data from medieval and modern oaks, and (as before) may not be appropriate to two samples from a single, possibly aberrant prehistoric tree. Using data from Reimer *et al* (2004), this method suggests that the feature was probably constructed in *1440–1405 cal BC (95% probability)* (Marshall *et al* forthcoming).

Table 1b lists the dendrochronological dates of the individual series from this structure, and their calculated interpreted date. Figure 5 shows the spans of the individual sequences, and their calculated interpreted dates.

Structure 673

Structure 673 is a group of timbers forming a possible revetment near structure 678. A total of three of the 40 samples obtained from this site were derived from this structure (Table 1c). The material included both radial and tangential fragments, each of which contained sufficient, although low, numbers of annual rings for measurement. None of the measured sequences were found to cross-match with each other. The individual series were compared with other data from Burlescombe and with reference data of prehistoric and historic date from throughout England and northern Europe. No statistically significant matches were obtained between the structure 673 series and any of the reference series.

Other material

A total of three other samples were obtained from this site (Table 1d). The material included one tangential fragment. This sample contained sufficient, although low, numbers of annual rings for measurement, whilst the other two samples were unsuitable for measurement. The measured sequence was not found to cross-match with other data from Burlescombe and with reference data of prehistoric and historic date from throughout England and northern Europe. No statistically significant matches were obtained between this series and any of the reference series.

OVERALL DISCUSSION

Burlescombe provides two highly significant groups of tree-ring data, though no tree-ring dating can been obtained for the well containing the shoe, because of the absence of suitable timbers. The dated material from structure 678 is the first 'post-Roman dark-age' material analysed from Devon. The production of a precise felling date for the timbers, and hence for the construction of the well, allow for use of written and other historical sources to place this material in a local and national economic, environmental, and historical context.

Structure 658 is more difficult to place in any wider context. Baillie and Brown (2002) produced a figure demonstrating the clustering of the tree-ring dated archaeological features in Ireland, typically trackways. Their figure shows the highly non-random nature of their results (Baillie and Brown 2002, Figure 1), with two very strong clusters, and two or three lesser ones, of dates from archaeological contexts between 2000 BC and 1 BC. One of these major clusters is at around 1500 BC, containing around 20 structures. This clustering led them to propose that archaeological assemblages of prehistoric timber are derived from a complex interaction of anthropological and environmental circumstances, such that 'there were only narrow time windows when people were felling mature oak trees in order to build structures in wet contexts, wherein those timbers might survive to the present' (Baillie and Brown 2002, 499). Whilst Meare Heath, Tinneys, and Testwood fit into this proposition as being trackways, brushwood platforms, or bridges, and are clustered around 1500 BC, the Burlescombe structure 658 material is slightly later in date, and being a pit or well represents a different type of structure, with different taphonomic processes at work.

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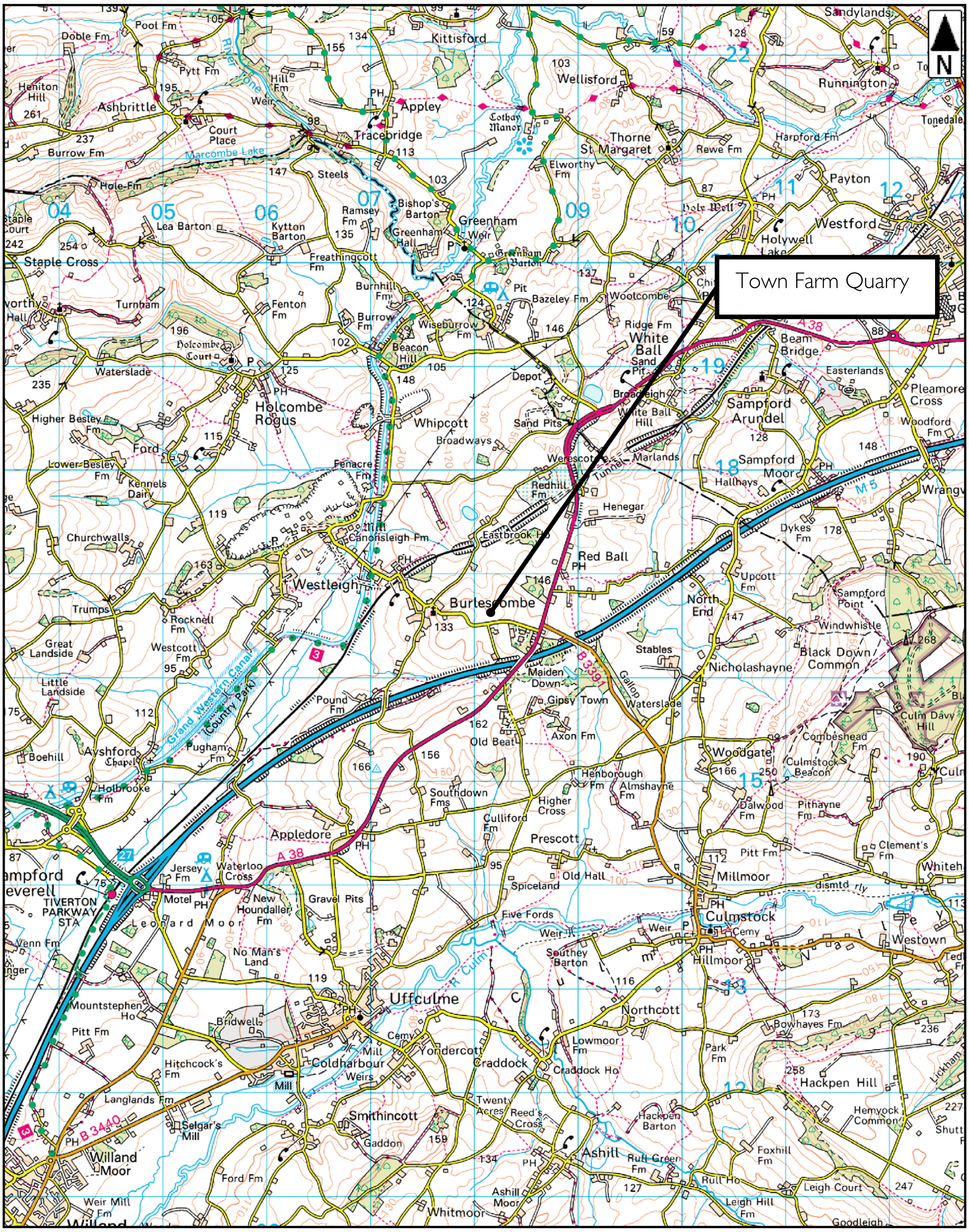

Figure 1. Town Quarry Farm, Burlescombe, site location.

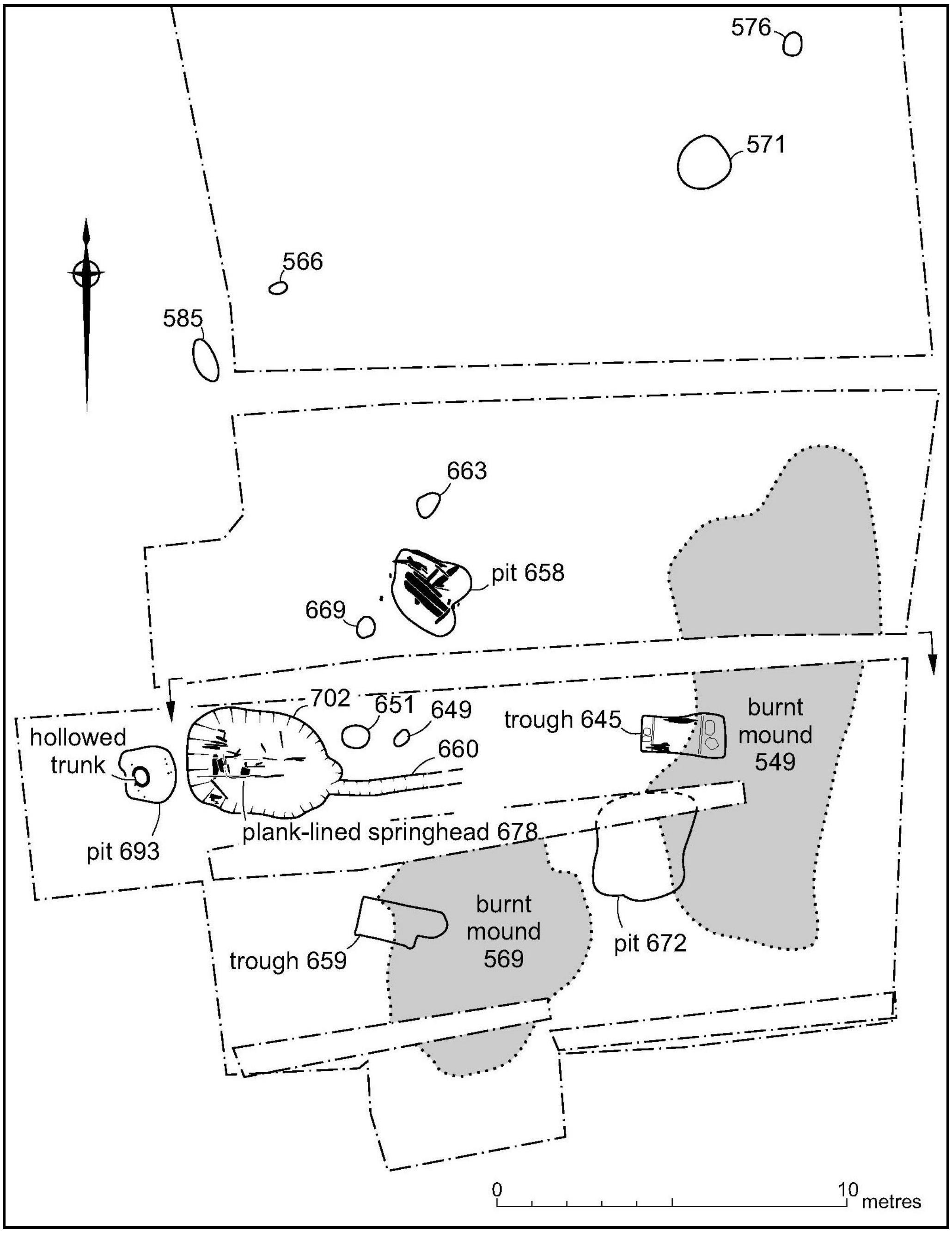

Figure 2. The Burlescombe site, showing the relative location of the principal wood bearing structures 658 and 678. Figure supplied by Tim Gent, Exeter Archaeology

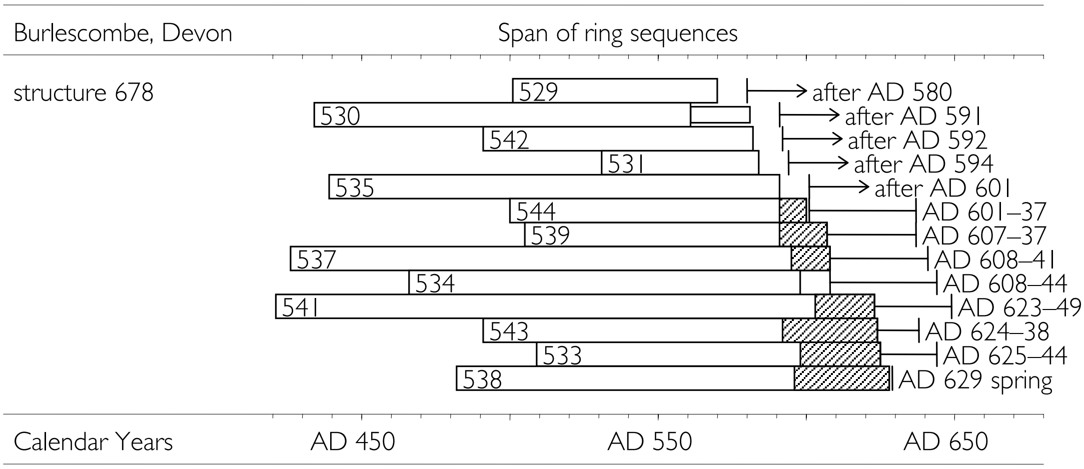

Figure 3 Bar diagram showing the calendar positions of the measured and dated tree-ring sequences for samples from Burlescombe site BLC04 structure 678. The felling date interpretations utilising a 10–46 sapwood estimate are given for each timber. White segments of bars are heartwood. Hatched segments are sapwood

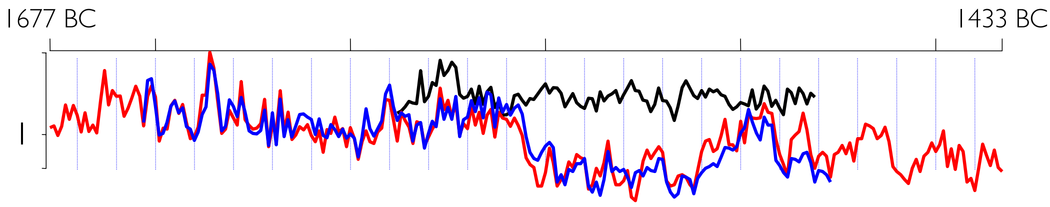

Figure 4. The tree-ring series from 475 (red), 483 (blue) and 474 (black). Note the major dip in growth between c 1555 BC and c 1510 BC in samples 475 and 483, and again after c 1490 BC. Neither of these events occur in sample 474. These two samples are less similar after 1555 BC than they are before it, see Table 5. The 'short' series used in Tables 6 and 8 utilise the 475 and 483 series from their earliest rings through to 1556 BC inclusive

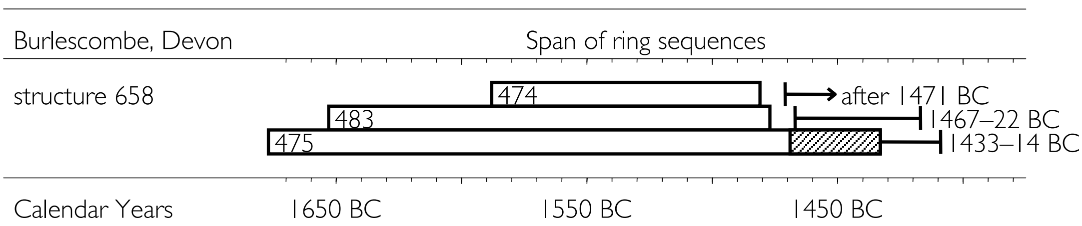

Figure 5 Bar diagram showing the calendar positions of the measured and matched tree-ring sequences for samples from Burlescombe site BLC04 structure 658. The felling date interpretations utilising a 10–55 sapwood estimate are also given for each timber

Table 1 Details of the dendrochronological samples from Burlescombe site BLC04

a) Structure 678

Sample	Size (mm)	Type	Rings	Sap and Bark	Date of measured sequence	Interpreted result
488	120 x 75	Oak	*c* 36	-	unmeasured	-
500	55 x 25	Oak	50	-	undated	-
520	270 x 35	Oak	161	h/s	AD 438–598	AD 608–44 [a]
522	70 x 40	Oak	*c* 39	-	unmeasured	-
526	285 x 40	Oak	169	20	AD 455–623	AD 623–49 [a]
529	115 x 30	Oak	70	-	AD 501–70	after AD 580
530	200 x 40	Oak	128+*20*	-	AD 434–561	after AD 591
530b	60 x 30	Oak	*c* 15	-	unmeasured	-
531	80 x 50	Oak	54	-	AD 531–84	after AD 594
533	180 x 25	Oak	117	27	AD 509–625	AD 625–44
534	260 x 45	Oak	133	h/s	AD 466–598	AD 608–44
535	235 x 50	Oak	153	-	AD 439–591	after AD 601 [b]
536	170 x 35	Oak	93	-	undated	-
537	220 x 40	Oak	183	13	AD 426–608	AD 608–41 [b]
538	155 x 30	Oak	147	32+Bs	AD 482–628	Spring AD 629
539	290 x 45	Oak	103	16	AD 505–607	AD 607–37 [c]
540	110 x 95	Oak	62	-	undated	-
541	220 x 40	Oak	203	20	AD 421–623	AD 623–49
542	230 x 25	Oak	92	-	AD 491–582	after AD 592
543	175 x 25	Oak	134	32	AD 491–624	AD 624–38
544	180 x 35	Oak	101	9	AD 500–600	AD 601–37 [c]
545	85 x 80	Oak	*c* 39	-	unmeasured	-

KEY [a] [b] [c] indicates same tree pairs, a small sample labelled 530, arbitrarily assigned 530b here, may or may not be a separate timber from 530, h/s indicates heartwood/sapwood boundary, Bs indicates bark-edge with the start of the following years spring growth, the value in italics indicates the estimated number of unmeasured rings at the end of the measured sequence from 530, *c* indicates estimated numbers of rings in unmeasured samples.

b) Structure 658

Sample	Size (mm)	Type	Rings	Sap and Bark	Date of measured sequence	Interpreted result
465	95 x 85	Oak	*c* 60	-	unmeasured	-
468	170 x 160	Oak	*c* 55	h/s	unmeasured	-
470	90 x 60	Oak	*c* 20	h/s	unmeasured	-
471	65 x 65	Oak	*c* 37	?h/s	unmeasured	-
473	120 x 30	Oak	*c* 31	-	unmeasured	-
474	230 x 30	Oak	108	-	1588–1481 BC	after 1471 BC
474A	155 x 20	Oak	73	-	undated	-
475	250 x 85	Oak	245	36	1677–1433 BC	1433–14 BC [d]
476	55 x 25	Oak	65	-	undated	-
483	195 x 30	Oak	177	h/s	1653–1477 BC	1467–22 BC [d]
485	80 x 65	Oak	*c* 100	-	unmeasured	-
487	130 x 85	Oak	*c* 70	-	unmeasured	-

KEY [d] indicates a same tree pair, timber 474A is a separate timber from 474, h/s indicates heartwood/sapwood boundary, ?h/s indicates possible heartwood/sapwood boundary, *c* indicates estimated numbers of rings in unmeasured samples, note many of the unmeasured samples contain one or more bands of narrow rings that cannot be resolved. Interpretations for the dated material utilises a 10–55 year sapwood range.

Table 1 continued

c) Structure 673

Sample	Size (mm)	Type	Rings	Sap and Bark	Date of measured sequence	Interpreted result
506	70 x 30	Oak	42	-	undated	-
507	160 x 35	Oak	58	31+?B	undated	-
508	100 x 35	Oak	37	-	undated	-

KEY ?B indicates possible bark-edge.

d) miscellaneous structures

Sample	Size (mm)	Type	Rings	Sap and Bark	Date of measured sequence	Interpreted result
450	155 x 105	Oak	*c* 40	?h/s	unmeasured	-
511	125 x 60	Oak	*c* 30	?h/s	unmeasured	-
616	400 x 90	Oak	*10*+77	-	undated	-

KEY ?h/s indicates possible heartwood/sapwood boundary, value in italics indicates the estimated number of unmeasured rings at start of the measured sequence from 616, *c* indicates the estimated numbers of rings in unmeasured samples.

Table 2. Showing t*-values (Baillie and Pilcher 1973) between 15 of the individual series from Burlescombe site BLC04 structure 678. These series were combined into the composite sequence used in Table 3*

	526	529	530	531	533	534	535	537	538	539	541	542	543	544
520	**18.85**	-	-	-	5.22	6.64	3.89	-	5.89	-	6.49	3.33	4.89	-
526		-	-	-	3.65	6.77	3.86	-	4.74	-	4.90	3.27	4.09	3.36
529			-	-	4.66	4.47	3.36	-	5.13	6.58	5.17	-	-	8.57
530				-	-	3.77	7.36	5.69	-	-	5.08	-	-	-
531					-	5.07	4.47	3.30	-	4.24	3.12	3.07	-	3.17
533						4.98	4.30	-	5.07	3.02	6.27	3.54	4.11	4.75
534							5.66	4.06	6.58	5.24	7.59	4.38	6.11	5.14
535								**9.70**	4.52	3.31	4.43	3.44	-	3.43
537									3.33	-	5.09	-	-	-
538										4.47	7.78	3.04	4.15	4.99
539											5.08	-	-	**14.27**
541												4.04	4.60	6.02
542													3.14	-
543														-

KEY Bold indicates same tree, – indicates *t*-values less than 3.0

Table 3. Showing t-values (Baillie and Pilcher 1973) between the composite sequence from Burlescombe site BLC04 structure 678 and contemporaneous reference data

Structure 678, 15 timbers/12 trees: AD 421–628	*t*-values
Cumbria, Carlisle Castle Street (Groves 1991)	5.49
Hampshire, Hamwic Six Dials (Hillam 1984)	5.43
Ireland, southern horizontal mills composite (Baillie pers comm)	5.49
London, Guildhall (Tyers 2001)	5.71
Staffordshire, Tamworth 72–4 Bolebridge Street (Baillie 1992)	8.13
Yorkshire East, Welham Bridge (Tyers 2007)	6.63
Yorkshire North, Coppergate (Groves and Hillam forthcoming)	5.88
Yorkshire North, West Heslerton (Hillam 1990)	5.94

Table 4. Showing t-value (Baillie and Pilcher 1973) between two of the individual series from Burlescombe site BLC04 structure 658. Sample 475 was the subject of the radiocarbon dating programme. These samples are from the same tree

	483
475	18.29

Table 5. Three sets of segmented correlation (r values) for the tree-ring series from 475 and 483, using different segment lengths. In each case segments including ring 123 and beyond are generally less well correlated than earlier segments. Calculations from Cofecha version 6.02P (R L Holmes, E R Cook, and P Krusic, and the Tree-Ring Laboratory at Columbia University)

a) Correlations of 20-year segments, lagged 10 years

	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160	170	180	190
	39	49	59	69	79	89	99	109	119	129	139	149	159	169	179	189	199	209
475	.94	.95	.89	.86	.69	.69	.89	.90	.90	.87	.84	.81	.72	.68	.40	.69	.77	.64
483	.94	.95	.89	.86	.69	.69	.89	.90	.90	.87	.84	.81	.72	.68	.40	.69	.76	.64

b) Correlations of 24-year segments, lagged 12 years

	24	36	48	60	72	84	96	108	120	132	144	156	168	180
	47	59	71	83	95	107	119	131	143	155	167	179	191	203
475	.93	.90	.86	.70	.69	.91	.91	.88	.82	.72	.78	.60	.68	.64
483	.93	.90	.86	.70	.69	.91	.91	.88	.82	.72	.78	.60	.68	.64

c) Correlations of 50-year segments, lagged 25 years

	25	50	75	100	125	150	175
	74	99	124	149	174	199	224
475	.81	.78	.88	.85	.73	.67	.65
483	.81	.78	.88	.85	.73	.67	.65

Table 6. Showing t*-values (Baillie and Pilcher 1973) between the 'short' individual series from samples 475 and 483 and the composite sequence constructed from them and contemporaneous reference data*

t-values	475s 1677–1556 BC	483s 1653–1556 BC	475s+483s 1677–1556 BC
Hampshire, Testwood3 (Tyers 2004b)	6.62	5.69	7.06
Hampshire, Testwood3 eval (Groves pers comm)	-	3.85	3.18
Somerset, Meare Heath (Hillam pers comm)	3.85	-	4.13
Somerset, Tinneys Ground (Hillam pers comm)	4.82	4.11	5.11
East Yorkshire, Hasholme bog oaks (Hillam 1987)	4.59	4.30	4.72

KEY: - = *t*-values less than 3.00.
Reference chronologies: Testwood3 (Tyers 2004b) and Testwood3 evaluation (Groves pers comm) are independent of each other, the latter was dated using the Testwood3 data (Tyers 2004b). Meare Heath and Tinneys sequences are derived from samples originally analysed by Ruth Morgan (Morgan 1978a; 1978b; 1979; 1980; 1982; 1989), and reworked by Jennifer Hillam (pers comm) this material was dated by the data from Testwood3 (Tyers 2004b), and is reported in Tyers (forthcoming)

Table 7. Showing t*-values (Baillie and Pilcher 1973) between the complete individual series from samples 475 and 483 and the composite sequence constructed from them and contemporaneous reference data*

t-values	475 1677–1433 BC	483 1653–1477 BC	475+483 1677–1433 BC
Hampshire, Testwood3 (Tyers 2004b)	4.25	4.00	4.78
Hampshire, Testwood3 eval (Groves pers comm)	-	4.33	3.54
Somerset, Meare Heath (Hillam pers comm)	3.58	-	3.98
Somerset, Tinneys Ground (Hillam pers comm)	4.78	3.30	4.61
East Yorkshire, Hasholme bog oaks (Hillam 1987)	-	3.07	-

KEY: - = *t*-values less than 3.00. Reference chronologies as Table 6

Table 8. Showing t*-values (Baillie and Pilcher 1973) between the complete and shortened individual series from samples 475 and 483 and the sequence from 474*

t-values	474 1588–1481 BC
475all	2.33
483all	3.73
475+483all	3.20
475short	4.94
483short	5.64
475+483short	5.55

Table 9. Showing t-*values (Baillie and Pilcher 1973) between the composite sequence constructed from the complete series from samples 475+483 and sample 474 and contemporaneous independent reference data*

Structure 654, 2 trees/3 samples: 1677–1433 BC	*t*-values
Hampshire, Testwood3 (Tyers 2004b)	6.62
Hampshire, Testwood3 eval (Groves pers comm)	3.76
Somerset, Meare Heath (Hillam pers comm)	4.57
Somerset, Tinneys Ground (Hillam pers comm)	4.28
East Yorkshire, Hasholme bog oaks (Hillam 1987)	3.59

Reference chronologies as Table 6

Table 10. Radiocarbon calibration data for decadal blocks of sample 475

Laboratory Code	Annual rings from 475	^{14}C Age BP	$\delta^{13}C$ (‰)	Calibrated Date Range (95% confidence)	*Posterior Density Estimate (95% probability)*
GrN-30162	18–27	3355 ±14	-26.1	1690–1610 cal BC	*1660–1625 cal BC*
GrN-30163	38–47	3341 ±21	-25.9	1690–1530 cal BC	*1640–1605 cal BC*
GrN-30164	58–67	3343 ±21	-25.6	1690–1530 cal BC	*1620–1585 cal BC*
GrN-30165	78–87	3305 ±17	-26.0	1630–1520 cal BC	*1600–1565 cal BC*
GrN-30166	98–107	3277 ±18	-25.8	1615–1495 cal BC	*1580–1545 cal BC*
GrN-30167	118–127	3291 ±25	-25.2	1630–1500 cal BC	*1560–1525 cal BC*
GrN-30168	138–147	3243 ±17	-25.8	1600–1455 cal BC	*1540–1505 cal BC*
GrN-30169	158–167	3243 ±20	-26.0	1605–1450 cal BC	*1520–1485 cal BC*
GrN-30170	178–187	3205 ±17	-25.9	1510–1430 cal BC	*1500–1465 cal BC*
GrN-30171	198 –207	3188 ±24	-26.6	1505–1410 cal BC	*1475–1455 cal BC*

Table 11. Bayesian analysis for decadal blocks of sample 475

Calibration Data	*Last Ring Date, cal BC (95% probability)*	Dendrochronology-Radiocarbon Agreement
Reimer *et al* (2004)	*1440–1400*	good
Pearson and Stuiver (1986)	*1455–1415*	good
Pearson and Stuiver (1993)	*1430–1390*	poor
Stuiver *et al* (1998)	*1440–1395*	good

APPENDIX 1

blc474

151	157	170	189	183	181	342	188	209	272
257	418	311	344	402	365	216	201	208	240
180	253	179	227	248	168	192	145	146	153
211	217	194	176	200	196	217	242	265	222
246	245	221	170	193	220	184	172	165	201
199	157	227	191	210	218	233	185	214	244
282	233	230	194	190	155	178	245	192	190
167	131	173	246	281	243	211	200	233	205
239	227	236	214	209	178	162	170	185	180
174	236	163	180	254	230	172	193	166	146
239	224	181	245	220	180	221	205		

blc474a

187	240	322	284	245	270	229	300	145	105
131	192	233	271	238	281	163	142	149	114
187	124	138	166	258	171	181	206	289	320
238	268	174	280	205	161	199	172	109	125
160	157	279	277	280	156	189	169	107	84
95	82	54	53	75	89	64	72	74	110
90	63	98	61	56	44	54	67	64	56
57	54	58							

blc475

114	118	98	117	177	134	175	145	105	152
106	120	103	195	343	177	233	209	210	142
166	203	253	210	118	209	254	206	88	113
111	174	193	150	178	125	92	96	115	213
213	487	360	191	102	111	159	138	120	277
133	119	111	113	123	197	79	119	105	232
106	154	91	99	116	109	121	98	87	107
71	110	102	140	105	112	79	114	92	62
87	107	87	84	105	113	196	193	133	88
154	131	115	84	128	124	81	95	111	125
244	161	193	140	182	99	123	112	172	120
153	102	145	162	95	153	137	134	117	137
119	98	64	56	53	37	37	48	77	58
37	42	44	59	53	68	64	62	35	38
52	45	58	88	51	38	38	41	50	30
28	40	60	74	63	71	79	71	41	37
38	45	46	44	38	35	50	72	88	91
72	76	98	134	82	82	73	129	85	148
137	136	138	181	153	150	92	68	56	45
91	99	106	151	109	68	52	66	71	66
44	68	71	81	69	85	60	92	92	122
118	112	92	98	115	87	54	49	46	42
39	52	62	49	66	71	85	72	82	107
54	76	51	81	72	40	43	34	52	83
67	55	74	53	49					

blc476

64	97	69	95	138	103	136	172	90	115
93	76	60	61	87	83	82	99	77	83
80	71	107	92	90	112	112	101	88	96
140	82	60	83	102	85	84	89	74	75
70	56	60	88	128	116	112	196	64	39
48	67	65	71	76	55	44	55	60	65
65	45	42	42	43					

blc483

126	283	293	176	99	102	126	172	191	152
167	116	111	89	105	147	170	388	344	220
107	117	195	172	141	204	154	107	102	101
108	160	81	152	82	198	96	133	95	117
147	149	140	134	100	135	98	94	121	110
96	111	93	101	93	65	95	164	112	97
112	130	218	259	171	131	152	142	146	88
120	126	77	102	129	116	199	134	169	134
208	96	133	140	192	155	203	138	226	215
115	202	153	178	145	166	177	148	96	71
63	61	71	80	86	78	40	46	38	51
49	57	57	63	37	33	40	31	42	72
49	53	49	51	44	36	48	50	45	53
50	49	63	62	40	33	30	32	45	44
42	32	43	48	52	54	57	54	65	78
77	74	79	103	114	162	127	103	90	140
120	120	61	55	48	44	63	62	59	69
71	58	40	50	49	46	40			

blc500

148	116	119	144	137	176	154	163	169	170
230	67	83	63	72	112	113	69	87	96
110	79	110	115	156	162	106	139	96	90
110	102	107	79	91	76	95	92	91	74
99	92	74	59	65	90	83	96	106	108

blc506

237	184	162	212	149	152	143	128	112	106
113	103	170	202	183	135	150	128	99	150
149	148	137	154	125	123	120	143	169	142
191	161	251	206	185	211	171	180	201	192
177	165								

blc507

87	100	117	56	61	76	59	69	67	74
89	88	84	96	61	72	57	59	52	52
54	65	82	60	76	69	77	65	71	59
66	67	65	81	59	59	64	62	41	29
35	39	43	32	31	34	25	20	22	20
20	25	25	43	48	63	53	39		

blc508

218	187	240	229	177	187	189	163	136	110
136	141	144	181	242	191	193	128	103	136
104	112	131	89	66	78	88	85	73	80
67	88	102	92	89	71	92			

blc520

260	343	252	355	331	282	209	243	205	254
195	207	261	334	282	284	171	267	275	256
191	210	173	206	197	245	140	135	178	130
241	255	236	280	225	163	133	162	213	236
296	300	184	168	183	216	295	317	321	329
278	276	275	302	239	236	280	332	353	279
198	208	191	221	216	209	224	193	156	170
133	101	83	100	88	72	92	81	88	126
120	111	118	126	129	110	106	123	135	135
139	133	119	130	159	166	185	139	170	176
170	136	103	104	113	121	129	117	130	157
116	119	126	108	120	119	105	134	144	117
122	131	124	132	143	168	156	127	96	88
83	104	105	104	100	107	108	89	71	74
103	134	106	122	90	75	65	91	94	92
97	128	108	90	91	97	79	79	54	77
73									

blc526

266	348	300	288	331	285	344	232	363	207
190	252	179	310	310	361	336	270	192	142
176	244	308	392	426	220	219	206	257	342
382	373	373	294	301	277	287	193	181	196
240	269	214	147	158	140	172	173	183	170
160	118	125	108	81	69	76	68	66	68
68	77	92	100	96	116	100	105	97	91
97	110	113	100	106	101	104	119	125	153
118	133	172	169	128	105	117	131	146	158
130	146	182	142	139	178	131	162	149	176
174	178	135	175	169	146	165	210	294	183
162	123	112	94	125	126	114	114	121	120
112	87	95	155	156	149	170	109	87	61
94	99	104	116	158	125	118	116	111	83
86	66	87	95	126	131	124	147	99	90
77	90	86	101	112	146	125	132	90	66
61	44	46	72	62	79	87	101	104	

blc529

89	105	80	74	95	53	57	77	110	105
117	120	123	109	122	136	110	92	102	47
43	37	46	45	40	59	61	75	57	66
58	55	78	62	64	75	94	83	59	54
75	85	72	79	59	96	65	55	59	73
57	73	71	76	60	60	44	41	63	53
62	71	83	68	52	48	62	73	83	91

blc530

172	203	139	176	186	302	268	410	338	308
279	162	94	220	239	167	183	161	153	130
121	199	154	146	127	119	75	93	75	86
100	60	44	39	71	59	80	59	41	48
49	47	81	78	146	113	112	126	82	100
129	74	88	166	189	227	177	153	127	129
111	124	162	149	100	72	54	59	52	65
66	58	66	86	97	115	136	160	109	103
125	137	156	188	164	147	126	125	146	90
94	102	81	72	71	69	101	101	104	92
55	60	68	75	84	57	71	67	73	65
89	66	84	63	55	51	59	47	63	52
46	41	35	31	33	43	39	44		

blc531

198	159	196	189	153	142	144	183	188	149
151	144	119	142	121	162	189	130	207	175
141	108	118	122	108	100	113	110	181	102
105	96	79	118	119	166	127	140	136	165
127	134	147	133	102	109	123	156	135	127
153	175	126	160						

blc533

177	224	192	194	188	265	201	237	337	266
291	201	196	141	130	122	139	136	169	158
129	129	135	128	207	250	210	250	203	139
109	139	161	200	166	165	143	257	232	134
259	245	218	314	259	164	145	176	114	126
202	161	150	159	156	160	100	92	148	126
176	267	222	175	159	116	101	90	92	118
189	205	208	188	182	141	134	168	124	125
164	177	114	131	148	101	81	67	64	86
92	102	102	84	68	73	74	99	102	94
101	106	108	104	120	136	94	64	89	94
52	63	67	84	103	101	99			

blc534

110	118	132	135	136	146	101	79	108	100
126	99	164	93	79	82	113	168	231	185
198	231	195	224	199	225	197	252	191	200
275	277	199	277	349	315	372	342	252	228
174	159	177	210	259	216	159	144	182	184
167	227	176	210	159	153	160	145	190	176
191	221	265	233	197	243	207	254	269	213
231	276	258	183	143	165	199	185	196	185
297	378	207	274	376	279	253	264	282	228
194	203	204	267	210	232	231	230	260	194
168	146	175	214	280	257	195	221	236	186
126	167	214	206	199	217	232	140	82	144
203	202	179	206	195	175	170	217	142	127
82	97	93							

blc535

303	322	287	258	227	229	160	91	176	208
208	186	226	167	198	145	217	160	132	124
128	83	93	83	135	137	76	60	52	81
81	98	81	45	58	55	50	68	65	94
101	126	143	101	100	136	105	129	146	163
180	221	281	125	144	161	190	243	143	111
117	166	102	99	81	72	80	85	94	113
110	108	117	116	114	141	139	151	177	140
143	87	88	75	64	61	59	59	71	71
67	60	66	56	69	68	53	66	72	69
60	62	62	70	71	77	62	92	80	43
64	52	49	53	75	61	63	38	39	44
47	37	39	44	28	47	37	35	32	46
47	42	38	31	38	30	30	25	28	35
40	40	49	45	46	30	39	31	36	36
45	35	34							

blc536

194	254	174	101	133	84	70	63	57	66
86	80	81	89	137	118	101	134	206	165
169	217	142	131	105	96	102	77	59	83
72	69	66	65	67	78	62	70	66	63
77	76	68	46	61	52	50	54	65	53
65	64	63	54	47	44	50	41	44	39
41	37	41	46	40	46	46	40	36	40
39	37	31	37	39	44	41	42	30	28
26	25	29	39	46	41	45	53	55	40
50	43	65							

blc537

413	421	309	390	395	315	330	332	277	268
172	212	182	278	292	292	302	251	265	180
114	197	174	174	196	166	148	153	133	166
148	111	141	117	77	77	62	80	98	76
48	51	63	59	75	67	47	55	41	43
68	50	53	64	71	78	56	100	80	76
108	121	133	154	163	185	116	108	138	133
149	128	68	115	226	177	147	102	81	67
79	74	84	78	92	73	95	122	140	123
131	149	137	125	86	83	77	67	67	57
65	62	66	48	67	55	52	63	66	72
67	86	87	64	64	71	65	59	81	56
79	70	52	58	42	54	60	68	67	60
53	47	56	61	47	42	36	33	38	48
42	45	38	33	40	41	33	40	42	30
27	39	39	43	44	40	36	35	23	29
33	31	29	32	41	48	31	36	32	37
30	33	27	35	33	31	29	26	29	41
41	52	57							

blc538

138	119	122	116	147	194	195	157	179	174
93	138	156	159	151	142	125	134	155	161
137	121	119	100	105	129	133	141	147	124
117	105	131	111	116	131	133	151	78	78
77	57	68	74	84	105	94	81	76	83
71	109	95	85	70	107	113	81	65	102
111	111	101	93	115	132	94	115	176	114
126	78	110	97	148	98	138	133	96	109
120	153	108	70	56	90	114	110	108	106
92	96	61	73	45	65	84	95	83	101
102	74	74	100	123	89	104	122	123	119
77	114	69	44	44	76	113	116	122	112
59	42	84	76	51	105	107	96	95	128
84	70	63	58	56	77	64	49	61	64
79	94	74	71	74	75	110			

blc539

131	64	48	71	140	149	139	147	123	101
126	130	48	84	103	51	40	37	42	44
49	70	75	93	98	82	115	109	119	98
74	72	91	102	61	73	78	111	69	103
62	81	95	50	74	116	85	94	140	147
97	95	90	110	136	77	91	67	88	96
67	65	96	98	109	155	93	80	75	64
65	60	70	101	121	100	143	113	105	85
81	104	125	109	134	136	144	99	86	51
38	34	34	42	56	55	65	60	36	38
31	27	29							

blc540

138	144	174	210	132	188	223	183	140	137
104	111	145	134	161	207	157	187	174	149
135	170	169	141	162	139	134	109	102	131
157	148	137	150	204	193	190	192	162	141
202	245	224	266	202	195	234	206	208	250
199	177	160	156	178	205	180	175	191	216
165	215								

blc541

210	301	312	225	343	260	269	256	251	242
209	177	139	166	106	67	101	117	145	105
155	180	131	88	86	70	128	90	93	124
125	102	97	76	117	145	139	119	123	112
140	138	141	101	86	84	62	119	112	108
99	74	103	81	60	79	112	136	108	62
65	81	110	131	103	123	159	151	155	159
157	139	209	147	130	132	90	60	79	87
83	103	96	96	106	79	93	85	119	124
98	123	129	148	160	158	233	207	260	104
103	103	71	101	94	133	145	120	92	97
93	113	157	142	144	128	172	130	86	100
136	158	142	124	99	110	99	83	88	117
73	117	114	129	78	104	73	95	109	83
50	38	32	41	40	44	41	41	44	54
44	45	41	37	41	44	50	80	87	73
73	71	50	44	55	80	59	57	80	95
74	47	77	43	42	40	59	58	79	56
70	53	41	52	60	42	54	61	66	61
64	59	62	42	32	28	49	53	48	47
88	97	144							

blc542

197	110	134	123	124	104	88	58	52	48
52	44	40	41	50	55	62	58	59	48
54	49	49	66	60	64	84	99	106	82
60	64	50	63	54	49	52	41	45	52
46	65	76	118	87	81	85	90	59	83
66	85	71	82	109	133	144	92	114	118
95	82	85	70	56	67	65	64	66	58
53	54	52	56	50	55	44	44	61	53
55	49	50	58	42	41	39	45	42	48
43	54								

blc543

202	236	291	221	191	287	200	163	193	183
178	234	167	163	160	169	209	233	177	203
207	163	166	266	199	168	220	203	172	139
144	149	96	78	70	76	58	65	81	75
64	50	51	57	57	66	80	114	96	83
130	147	109	97	128	110	139	114	130	111
90	90	103	89	73	83	87	65	86	79
79	82	103	105	89	62	87	109	173	155
164	144	128	138	130	112	160	207	206	182
215	214	149	124	141	155	150	102	120	97
77	87	101	96	86	99	95	99	160	160
134	145	89	95	91	93	86	95	102	108
109	91	86	108	102	97	136	122	88	84
94	92	102	79						

blc544

94	90	138	108	122	143	79	65	97	132
117	100	114	100	87	101	104	53	82	93
73	70	65	48	79	62	93	100	110	109
97	121	96	108	98	75	90	120	118	79
83	85	114	93	117	80	138	102	64	77
125	86	113	138	142	104	131	91	97	133
92	91	89	100	103	73	74	101	108	106
152	85	84	68	53	70	65	78	116	127
99	115	97	103	82	76	101	131	98	147
147	131	98	89	59	39	35	39	37	70
54									

blc616

81	56	49	38	43	69	58	57	81	75
73	55	67	98	57	61	42	35	44	55
72	58	50	72	65	92	101	96	105	87
119	111	110	150	124	140	219	89	86	98
88	100	138	126	97	74	94	91	70	64
57	61	98	84	80	68	77	78	86	77
47	100	84	79	112	103	111	65	81	76
75	88	135	130	135	134	133			