Scientific Dating

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Introduction

Fifty-five radiocarbon age determinations have been obtained on samples of charcoal, waterlogged macrofossils, wood, and charred residues on the interior of pottery sherds from Willington Quarry, Derbyshire.

Methods

The 16 charcoal samples submitted to the Scottish Universities Environmental Research Centre, East Kilbride (SUERC) were prepared using the methods outlined in Slota *et al* (1987), and measured by Accelerator Mass Spectrometry as described by Xu *et al* (2004).

Twenty-five samples were submitted to the Oxford Radiocarbon Accelerator Unit (ORAU). These were prepared according to methods given in Hedges *et al* (1989) and measured by Accelerator Mass Spectrometry as described in Bronk Ramsey *et al* (2004).

Seventeen samples were samples were submitted to the Centre for Isotope Research at the University of Groningen (GrA), The Netherlands, for Accelerator Mass Spectrometry (AMS) and gas proportional radiocarbon dating. The twelve samples for AMS dating (**GrA**-), all charcoal, were processed according to the procedures set out in Aerts-Bijma *et al* (1997; 2001) and van der Plicht *et al* (2000). The wood and charcoal samples were processed and measured at Groningen by gas proportional counting (**GrN**-), according to the procedures described by Mook and Streurman (1983).

The five charcoal samples submitted to the Poznań were prepared and measured by Accelerator Mass Spectrometry as described by Czernik and Goslar (2001).

All four laboratories maintain continual programmes of quality assurance procedures, in addition to participation in international inter-comparisons (Scott 2003). These tests indicate no laboratory offsets and demonstrate the validity of the measurements quoted.

Results

The radiocarbon results are given in Table 1, and are quoted in accordance with the international standard known as the Trondheim convention (Stuiver and Kra 1986). They are conventional radiocarbon ages (Stuiver and Polach 1977).

Calibration

The calibrations of the results, relating the radiocarbon measurements directly to calendar dates, are given in Tables 1-7 and in Figures 1–5, 7, 11 and 13. All have been calculated using the calibration curve of Reimer *et al* (2004) and the computer program OxCal (v3.10) (Bronk Ramsey 1995; 1998, 2001). The calibrated date ranges cited in the text are those for 95% confidence. They are quoted in the form recommended by Mook (1986), with the end points rounded outwards to 10 years if the error term is greater than or equal to 25 radiocarbon years, or to 5 years if it is less. The ranges quoted in italics are *posterior density estimates* derived from mathematical modelling of archaeological problems (see below). The ranges in plain type in Tables 1-7 have been calculated according to the maximum intercept method (Stuiver and Reimer 1986). All other ranges are derived from the probability method (Stuiver and Reimer 1993).

Methodological Approach

A Bayesian approach has been adopted for the interpretation of the chronology from the burnt mounds and Neolithic ceramic sequence from this site (Buck *et al* 1996). Although the simple calibrated dates

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are accurate estimates of the dates of the samples, this is usually not what archaeologists really wish to know. It is the dates of the archaeological events, which are represented by those samples, which are of interest. In the case of Willington, it is the chronology of the use of the burnt mounds and the start of the use of various pottery types that is under consideration, not the dates of samples or pottery residues. The dates of this activity can be estimated not only using the absolute dating information from the radiocarbon measurements on the samples, but also by using the stratigraphic relationships between samples and the relative dating information provided by ceramic typologies.

Fortunately, methodology is now available which allows the combination of these different types of information explicitly, to produce realistic estimates of the dates of archaeological interest. It should be emphasised that the *posterior density estimates* produced by this modelling are not absolute. They are interpretative *estimates*, which can and will change as further data become available and as other researchers choose to model the existing data from different perspectives.

The technique used is a form of Markov Chain Monte Carlo sampling, and has been applied using the program OxCal v3.10 (http://www.rlaha.ox.ac.uk/), which uses a mixture of the Metropolis-Hastings algorithm and the more specific Gibbs sampler (Gilks *et al* 1996; Gelfand and Smith 1990). Details of the algorithms employed by this program are available from the on-line manual or in Bronk Ramsey (1995; 1998; 2001). The algorithm used in the models described below can be derived from the structures shown in Figures 6, 8, 12, 14-15 and 20-21.

Objectives and sampling strategy
The radiocarbon programme was designed to achieve the following objectives:

- To provide a chronological framework for interpreting the environmental sequence from the palaeochannel deposits.
- To date and ascertain the significance of human activity in the vicinity of fallen trees.
- To date the fire-clearance of the floodplain.
- To provide overall estimates of the start, end, and duration of the use of the burnt mounds.
- To date alluviation.
- To provide precise dates for the Peterborough Ware (and its sub-styles) ceramic assemblage.

The first stage in sample selection was to identify short-lived material, which was demonstrably not residual in the context from which it was recovered. The taphonomic relationship between a sample and its context is the most hazardous link in this process, since the mechanisms by which a sample came to be in its context are a matter of interpretative decision rather than certain knowledge. The majority of samples consisted of single entities (Ashmore 1999), however, a number of waterlogged plant remains had to be "bulked" together to provide enough carbon from the palaeochannel samples. Material was selected only where there was evidence that a sample had been put fresh into its context. The main category of material, which met these taphonomic criteria, was charcoal from short-lived species — from contexts in which it seemed to have been freshly deposited.

Other samples with a less certain taphonomic origin submitted included:

- charcoal from the fill of post-holes; interpreted as relating to the use of structures rather than its construction, as suggested by experimental archaeology (Reynolds 1995), and from the primary fill of pits. Where possible duplicate samples from these contexts were submitted to test the assumption that the material was of the same actual age.
- charred residues adhering to the inside surface of ceramics. Sherds were selected that were large and unabraded suggesting that the residue/sherd had not been exposed to weathering for a long period of time.

Column 1 (Channel G) (Fig 1 and Table 1)
Samples and results
Channel G was a palaeochannel with a peaty infill on the southern edge of the excavations. Four samples were submitted from column 1 taken at the following depths; 0–10cm (two samples), 0.48–0.50cm and 96–98cm.

The two samples from 0–10cm comprised terrestrial seeds (GrA-31468; 4245±35 BP) and twig fragments (OxA-15897; 4395±36 BP). The two measurements are not statistically consistent (T'=8.9; ν=1; T'(5%)=3.8; Ward and Wilson 1978) and thus contain material of different ages. This is not surprising given that both samples contain material from within a 10cm section of the palaeochannel. The measurements at best therefore only provide a *terminus post quem (tpq)* for the top part of the column. The samples from 0.48–0.50 (SUERC-7350; 11405±45 BP) and 0.98–0.98m (SUERC-7351; 11780±45 BP) also comprised terrestrial seeds (see Table 1).

Fallen trees and associated features
Samples
Samples were submitted from 11 contexts that had some association with the root-void siltings (Fig 2 and Table 2**)**.

Group 802
A single fragment of charcoal (OxA-15116) was dated from [299] a homogenous burnt deposit above a silt [317] filling an irregular spread that may be part of a root-void silting [327].

Two single fragments of charcoal were dated from [291] the fill of a small pit that also contained Peterborough and Plain Bowl style pottery. Replicate measurements on the sample sent to Oxford are statistically consistent (T'=3.3; ν=1; T'(5%)=3.8; Ward and Wilson 1978) and thus a weighted mean can be taken before calibration (4649±22 BP). However, the three measurements from [291] (OxA-15127; 4790±32 BP; OxA-15128; 4709±31 BP and SUERC-7607; 4875±35 BP) are not statistically consistent (T'=33.5; ν=2; T'(5%)=6.0; Ward and Wilson 1978) and the context clearly contains material of different ages.

The four measurements from Group 802 are not statistically consistent (T'=33.5; ν=3; T'(5%)=7.8; Ward and Wilson 1978).

Group 803
Two samples were submitted from [458] the fill of a small pit-type feature to the west of a probable burnt [420]. The pit also contained Peterborough (Mortlake) Ware pottery. The two measurements are statistically consistent (T'=1.3; ν=1; T'(5%)=3.8; Ward and Wilson 1978) and could therefore be of the same actual age.

Group 809
Residue adhering to a sherd of Peterborough Ware (Mortlake/Fengate) pottery was submitted from [390] a probable root-void silting feature (OxA-15047; 4615±36 BP) forming part of Group 809.

Group 2503
A single fragment of hazel charcoal (GrA-31770) came from [1448] a lens of charcoal rich clay with the fill [1056] of pit [1447]. [1447] was one of two pits to the north east of a probable root-void silting.

A fragment of blackthorn (GrA-31786) came from [1453] the upper fill of [1455] a plausible post pit.

Two samples came from [1451] the fill of sausage-shaped pit [1452] classified as a root-void silting. The charcoal is thought to have been deposited while the *in-situ* roots were rotting and is not interpreted as evidence that the fallen tree was burned *in-situ*. Two fragments of the same piece of blackthorn charcoal [114a] were dated in Groningen (GrA-31785; 3800±40 BP) and Oxford (OxA-15110; 3714±29 BP) and gave statistically consistent results (T'=3.0; ν=1; T'(5%)=3.8; Ward and Wilson 1978) thus allowing a weighted mean to be calculated (3744±23 BP). The other sample dated was a fragment of hazel charcoal (SUERC-7597; 4510±35 BP). The three measurements from [1451] are not statistically consistent (T'=344.5; ν=2; T'(5%)=6.0; Ward and Wilson 1978) and the context clearly contains material of different ages.

Four samples came from [1328] a lens of charcoal within [102] the fill of pit [103]. Replicate measurements on sample 64A (OxA-15045; 3641±33 BP and OxA-15109; 3650±28 BP) are statistically consistent (T'=0.0; ν=1; T'(5%)=3.8; Ward and Wilson 1978) and allow a weighted mean to be calculated (3646±21 BP). The other samples from [1328] were SUERC-7596 (4455±35 BP) GrA-31803 (3650±40 BP) and OxA-15900 (4472±36 BP). The five measurements from [1328] are not statistically consistent (T'=693.5; ν=4; T'(5%)=9.5; Ward and Wilson 1978).

Group 2508

Two samples were submitted from [1499] the charcoal-rich fill of pit [1500] that cut and was sealed by deposits containing Peterborough (Fengate) Ware and lithics. The two measurements (OxA-15084; 4434±30 BP and SUERC-8156; 4500±40 BP) are statistically consistent (T'=1.7; ν=1; T'(5%)=3.8; Ward and Wilson 1978) and could therefore be of the same actual age.

In addition to the pit Group 2508 also contained five probable postholes and a spread of material interpreted as a midden surrounding a cooking pit.

Group 2509
Group 2509 comprised an area of up to 20 shallow circular features, possibly postholes, adjacent to a finds-rich spread. Residue adhering to a sherd of Peterborough Ware from [1004] a shallow pit or posthole cutting [1829] (OxA-14484; 4540±65 BP) was dated.

Group 2054
A single fragment of charcoal (GrA-31801; 4515±45 BP) came from [1477] a substantial spread with concentrations of charcoal and rich in Mortlake style Peterborough Ware sealing a small pit containing fire-cracked stones.

Group 2541
Group 2541 was an area of mixed archaeological and probable root-void silting features from which a sherd of Peterborough Ware (Ebbslfeet) with residue from [225] the fill of a wide gully or pit was dated (OxA-14483; 4550±45 BP).

Results
Figure 3 shows a clear phase of occupation in the vicinity of fallen trees lasting from *c* 3500-3000 cal BC. Those contexts (eg [1451 and 1328]) containing material dating to c 2000 cal BC is probably intrusive and related to clearance activity (see below).

The fire-clearance of the floodplain (Fig 4 and Table 3)
Samples
The clearance of woodland from the floodplain represents an important change in the local landscape development as it was a pre-cursor to providing increased grazing or land for cultivation or both.

Samples were submitted from eight contexts directly associated with the clearance of trees from the floodplain.

Two charcoal samples derived from a charcoal rich (albeit degraded) deposit [63] immediately related with pockets of more oxidised fire reddened clay appears to be derived from a fire used as part of tree clearance. The charcoal is thought to have been incorporated into the tree pit or hole during the felling of the tree. The two measurements (OxA-15898; 4535±38 BP and GrA-31797; 4670±45 BP) are not statistically consistent (T'=5.3; ν=1; T'(5%)=3.8; Ward and Wilson 1978) and therefore date material of different ages.

A single fragment of charcoal (GrA-31789; 3730±40 BP) was dated from [4108]. [4108]; derived from a charcoal rich (albeit degraded) deposit immediately related with pockets of more oxidised fire reddened clay that appears to be derived from a fire used as part of tree clearance. The charcoal is thought to have been incorporated into the tree pit or hole during the felling of the tree.

Two samples of charcoal from a 3m diameter deposit of fire-reddened charcoal and scorched clay [4156], filling [4159] a feature whose platform and profile are consistent with that of a tree pit. The two measurements (OxA-15083; 3508±28 BP and SUERC-7594; 3440±35 BP) are statistically consistent (T'=2.3; ν=1; T'(5%)=3.8; Ward and Wilson 1978) and could be of the same actual age.

A single fragment of blackthorn (GrA-31800) came from [302] the base of a small tree or shrub that had been burnt out.

A single fragment of charcoal (GrA-31787; 3410±40 BP) came from [78] a 2.1x1.0m area of charcoal rich soil with some scorched red clay pockets.

[134] a feature of extensive deposits of reddened clay representing an intense burning event overlay a more reduced deposit of charcoal rich clay [135] that was in places black with charcoal. Two measurements (OxA-15082; 3645±28 BP and SUERC-7593; 3700±35 BP) were obtained from fragments of charcoal from [135] that are statistically consistent (T'=1.5; ν=1; T'(5%)=3.8; Ward and Wilson 1978) and could be of the same actual age.

The two measurements (OxA-15081; 3981±27 BP and SUERC-7592; 3995±35 BP) from [4490] a deposit of charcoal rich clay (1.5m in diameter), overlain by reddened ?scorched clay, are statistically consistent (T'=0.1; ν=1; T'(5%)=3.8; Ward and Wilson 1978) and could be of the same actual age.

A single fragment of hazel charcoal (GrA-31796; 4425±45 BP) was dated from [4489] a 2.1x0.8m area of scorched red clay with charcoal pockets

Results
The results shown in Figure 4 suggest clearance of the floodplain was concentrated in the mid-third to mid-second millennia cal BC.

Burnt Mound 1 and stratigraphically related contexts (Groups 2550-01, 2550-02 and 2550-03)
Samples
Burnt Mound 1 (Fig 5 and Table 4) constituted a layer of fire cracked stone and charcoal with a series of central features. The burnt mound had been located over a spread of grey gravelly clay which sealed an earlier pit which cut remnants of more gravelly clay interpreted as a buried soil.

Duplicate samples from six contexts interpreted as forming part of Burnt Mound 1 and stratigraphically related layers were dated. A measurements from a residue dated sherd is also included.

Group 2550-01

Residue adhering to a sherd of Neolithic bowl was submitted from [1980] a grey gravely clay interpreted as a buried soil and sealed below all later layers (OxA-14481; 4849±35 BP).

Group 2550-02

The two measurements (OxA-15046; 4607±35 BP and SUERC-7605; 4695±35 BP) from [1817] a spread representing Neolithic activity pre-dating the burnt mound layer and central feature [1651] are statistically consistent (T'=3.2; ν=1; T'(5%)=3.8; Ward and Wilson 1978).

Group 2550-03

The two measurements (OxA-15115; 3649±33 BP and SUERC-7606; 4695±35 BP) from [1881] a charcoal-rich deposit post-dating the earliest spread [1817] are not statistically consistent (T'=473.1; ν=1; T'(5%)=3.8; Ward and Wilson 1978) and therefore date material of different ages.

The two measurements (OxA-15114; 3695±29 BP and SUERC-7604; 3740±35 BP) from [1653] a charcoal-rich fill of the central pit (trough) of the burnt mound are statistically consistent (T'=1.0; ν=1; T'(5%)=3.8; Ward and Wilson 1978) and could be of the same actual age.

The two measurements (OxA-15113; 3754±28 BP and SUERC-7909; 3780±50 BP) from [1691] a charcoal and fire-cracked stone rich fill of an adjacent pit (oven or hearth [[1704]) are statistically consistent (T'=0.2; ν=1; T'(5%)=3.8; Ward and Wilson 1978) and could be of the same actual age.

The two measurements (OxA-15112; 3721±30 BP and SUERC-7602; 3690±35 BP) from [1582] a primary fill of a substantial pit or tank adjacent to the hearth/oven [1704] and derived from an episode of burnt mound activity are statistically consistent (T'=0.5; ν=1; T'(5%)=3.8; Ward and Wilson 1978) and could be of the same actual age.

The two measurements (OxA-15111; 3610±29 BP and SUERC-7598; 3775±35 BP) from [1487] a charcoal-rich layer derived from spent fuel and stone cleaned out of the central features are not statistically consistent (T'=13.2; ν=1; T'(5%)=3.8; Ward and Wilson 1978) and therefore date material of different ages.

The results (Figure 5) clearly show that the base of the burnt mound incorporates residual material from earlier Neolithic activity (SUERC-7605–6 and OxA-15046). In fact these three measurements are statistically consistent (T'=4.2; ν=2; T'(5%)=6.0; Ward and Wilson 1978) and could be of the same actual age.

Results
We have chosen to exclude all the Neolithic samples from the model shown in Figure 6 (SUERC-7605–6; OxA-14481 and OxA-15046). SUERC-7607 clearly represent residual material that was incorporated into the basal layer of the burnt mound from the underlying Neolithic contexts. The model show good agreement between the sequence and radiocarbon measurements ($A_{overall}$=90.2%) and provides estimates for the start of burnt mound activity of *2340–2060 cal BC (95% probability*; Fig. 6: *start burnt mound*) and probably in *2260–2140 cal BC (68% probability)*. The end of use of the burnt mound is estimated at *2120–1840 cal BC (95% probability*; Fig. 6: *end burnt mound*) and probably in *2040–1920 cal BC (68% probability)*.

Burnt Mound 2
A sequence of three samples (Fig 7 and Table 5) came from the silty peat layers below the wood lined trough (Poz-18029; 3665±35 BP; Poz-18009; 2965±35 BP and GrN-30412; 2980±50 BP). The two measurements (GrN-30408; 2920±30 BP and GrN-30409; 2940±30 BP) from [4613] on timbers from the trough are statistically consistent (T'=0.2; ν=1; T'(5%)=3.8; Ward and Wilson, 1978) and could be of the same actual age. Two samples came from bottom (Poz-18007; 2845±35 BP) and top (Poz-18006; 2910±35 BP) of a column sample of the silty peat infill of the trough.

Poz-18010 (2875±35 BP) was from a lens of leaf litter [4466] sitting near the base of the adjacent palaeochannel without direct stratigraphic link to the trough. The two measurements (GrN-30410; 2880±50 BP and GrN-30411; 2990±50 BP) from [4613] on charcoal from a hearth type feature adjacent to the trough are statistically consistent (T'=1.3; ν=1; T'(5%)=3.8; Ward and Wilson, 1978) and could be of the same actual age.

Results
The model (Fig 8) show good agreement between the sequence and radiocarbon measurements ($A_{overall}$=88.6%) and provides estimates for trough construction of *1290-1100 cal BC* (*95% probability; Event trough construction*; Fig 8) and probably *1240-1150 cal BC* (*68% confidence*) and end of use of *1170-100 cal BC* (*95% probability; Event trough out of use*; Fig 8) and probably *1130-1040 cal BC* (*68% confidence*). The trough was in use for between *20-210 years* (*95% probability*) and probably *40-150 years* (*68% probability*).

Burnt mounds 1 and 2
Both burnt mounds were in use for a relatively short period of time (see Fig 9), although the gap between the end of use of burnt mound 1 and construction of the trough of burnt mound 2 is estimated to be *640-960 years (95% probability*; Fig 10) and probably *720-880 years (68% probability*).

The dating of alluviation
Samples
Duplicate samples from the base of a partly stone lined feature [2076], interpreted as an oven were dated to provide a *tpq* for the alluviation event that buried the whole site in a silty clay (Fig 11 and Table 6). The charcoal probably represents fuel from the last use of the oven, or material dumped into it following its final usage. Following collapse of the feature flooding washed some of the scorched fire-reddened clay roof [2068] down slope towards a nearby stream. This is clear evidence that the site had started to flood before the infilled feature had been integrated into the surrounding soils. The two measurements (OxA-15044; 4556±34 BP and SUERC-7595; 4740±35 BP) are not statistically consistent (T'=14.2; ν=1; T'(5%)=3.8; Ward and Wilson, 1978) and therefore date material of different ages.

Results
The latest date (OxA-15044) provides a *tpq* for the onset of alluvial conditions of 3490–3100 cal BC.

Discussion

In order to try and provide a more precise estimate for the date of aluviation event, attempts were made to model all measurements from the site on the basis of whether samples were either above or below alluvium. Ultimately this proved impossible for a number of reasons. Firstly detailed recording of the natural layers cut by features was not always been recorded in the field as at the time the importance of this relationship was not appreciated. Secondly, alluviation was not a simple time-transgressive event. However, modelling of those samples that were from features recorded as having alluvium below them allows a *terminus ante quem* for alluviation to be estimated of *2200-1980 cal BC* (*95% probability; First taq_alluviation*; Fig 12). A number of samples have been excluded from the model, OxA-14485, a residual sherd of Peterborough ware in a medieval/post-medieval context and OxA-15898 and GrN-31797 from a feature not definitively recorded as cutting alluvium.

Ceramics (Fig 13 and Table 7)
Samples
Six ceramic sherds with organic residues adhering to the interiors were submitted for dating. These comprised:

1. A Neolithic bowl from [1980] a grey gravely clay overlying undisturbed natural strata and sealed below [1817] a Neolithic layer below part of burnt mound 1 (OxA-14481; 4849±35 BP).
2. Peterborough Ware from [1040] a spread of material adjacent to a ?cooking pit and structure of Neolithic date (OxA-14482; 4416±36 BP)
3. Peterborough Ware (Ebbsfleet) from [225] the fill of a wide gully or pit associated with a root-void silting feature (OxA-14483; 4550±45 BP).
4. Peterborough Ware from [1004] a shallow pit or posthole cutting [1829] (OxA-14484; 4540±65 BP).
5. Peterborough Ware from [246] the fill of a medieval/post medieval linear ?drainage gully part of Group 815 (OxA-14485; 4500±50 BP).
6. Peterborough Ware (Mortlake/Fengate) from [390] a probable root-void silting feature (OxA-15047; 4615±36 BP).

Additionally three other contexts were dated that were associated with significant assemblages of Peterborough Ware ceramics.

1. The two measurements (GrA-31799; 4750±40 BP and OxA-15899; 4814±38 BP) on charcoal from [458], the rich fill of a pit that contained Peterborough Ware (Mortlake) ceramics, are statistically consistent (T'=1.3; ν=1; T'(5%)=3.8;). However, given the lack of recognisable relationship between the charcoal and ceramics the results only provide a *terminus post quem* for the associated ceramic assemblage.
2. The two measurements (OxA-15084; 4434±30 BP and SUERC-8158; 4500±40 BP) on single fragments of charcoal from [1499] are also statistically consistent (T'=1.7; ν=1; T'(5%)=3.8;) suggesting that the deposit is a single event. [1499] formed following an episode of burning possibly associated with a three-throw and post pits forming a structure and was sealed by spread that contains Peterborough Ware (Fengate) ceramics. The results therefore provide a *tpq* for the ceramics.
3. Charcoal from [1477] the rich fill of a probable cooking pit (GrA-31801; 4515±45 BP) that also contained Peterborough Ware (Mortlake) pottery also provides a *tpq* for the associated ceramics.

Further analysis
Modelling of the results from Willington together with the available radiocarbon measurements for finds of Peterborough ware from England and Wales (Marshall *et al* in prep) to try and provide more precise estimates for the date of Peterborough ware was undertaken using three different underlying assumptions.

Model A
Modelling the data as a single phase takes no account of the fact that the ceramic sherds are in some way related to each other, ie it treats them as each is chronologically independent. This model is shown in Figure 14 and shows good overall agreement ($A_{overall}$=84.4%), and provides estimates for the beginning of use of Peterborough Ware of *3600–3350 cal BC (95% probability*; Fig 14: *start Peterborough Ware*), and probably in *3510–3360 cal BC (68% probability).* The latest deposits of this style occurred in *3010–2860 cal BC (95% probability*; Fig 14: *end Peterborough Ware)*, and probably in *2970–2890 cal BC (68% probability).*

A number of results have been excluded from this and subsequent models; identified by a ?, they are from:

Cefn Bryn (Ward 1987; Gibson 1995). Three of the four measurements from Cefn Bryn appear to be anomalously late (Birm-1238, Birm-1236 and Birm-1235, with probabilities of 0.9%, 0.5% and 18.7% respectively of lying within this sequence of deposition). The samples in question came from beneath a Bronze Age cairn, and it is possible that later material was incorporated into these bulk samples.

Ogmore (Gibson 1995). OxA-5318 was a measurement made on organic residue adhering to a sherd of Peterborough Ware (Mortlake), however, it is anomalously old for the ceramic style. As a small sample with a very low carbon content (Gibson 1995, 38) a small amount of contamination might explain such an erroneous result. It has been suggested that clays may contain appreciable amounts of carbon which may remain in pottery even after firing (Nakanura *et al* 2001). Such a mechanism as this would introduce “old” carbon if some of the fabric of the vessel was removed with the residue and may therefore provide an explanation for the apparent erroneous measurement.

Sarn-y-bryn (Gibson 1994). These two samples (BM-2819 and BM-2820) are from the same context; a recut in a penannular ring ditch, containing cremations and some small Mortlake Ware sherds. The measurements are not statistically consistent (T’=9.0; ν=1; T’(5%)=3.8; Ward and Wilson 1978) and the context clearly contains material of different ages. As BM-2819 has a probability of 2.5% of lying within this sequence of deposition, it seems as though the sample contains some later intrusive material.

Wall Garden Farm, Sipson, Hillingdon (Meadows *et al* forthcoming). Duplicate measurements on an organic residue adhering to the interior of a sherd of Mortlake style Peterborough ware are clearly too old (see Ogmore above).

Horton (Ford and Pine 2003). The six measurements from F208 are not statistically consistent (T’=31.9; ν=6; T’(5%)=12.6; Ward and Wilson 1978), however, by excluding BM-2754 they are (T’=10.4; ν=5; T’(5%)=11.8; Ward and Wilson 1978). BM-2754 was a substantial red deer antler is very unlikely to be intrusive and also had a high and well preserved collagen content. It probably therefore represents a statistical outlier.

Model B

Further analysis, however, allows us to make use of more realistic underlying assumptions. In the first of these we make use of the fact that Peterborough ware can be differentiated into a number of styles. We do though make no assumptions about the interrelationship between each ceramic style and therefore postulate that each style (eg Ebbsfleet, Mortlake, Fengate) started at some definitive date, continued in use at a fairly uniform rate and then stopped (Buck *et al* 1992). Thus in the model shown in Figure 15 each style is treated as a uniform phase. For each phase we can estimate the age of the first and last dated objects and their span. However, taking into account that in all cases we probably only have a sample of the ceramics from that phase and therefore it is almost certain that both earlier and latter examples exist we can estimate the start, end and duration of these phases on the basis of two assumptions. Firstly, the examples we have are representative of the whole group (ie style) and secondly the pots were used (in the case of measurements on residues) or deposited uniformly through the phase.

Figures 16 and 17 and Table 8 give estimates for the first and last dated examples from each data set and the actual span of these dates. Estimates for the start, end and duration of these phases are shown in Figures 18 and 19 and in Table 9. The large estimates for these events are because of the limited amount of information we have.

Model C

The model is based on the purported sequential sequence of Peterborough Styles as defined by Smith (1956; 1974) with a succession from Ebbsfleet through Mortlake to Fengate. This model again assumes that each phase of use of a style is uniform and allows estimates to be calculated for the date of transition between the phases and their duration. This model (Fig 20) shows poor agreement between the radiocarbon evidence and sequential sequence of Peterborough ware styles

($A_{overall}$=38.7%). This though is not entirely unexpected given that Figure 19 suggests that Ebbsfleet, Fengate and Mortlake followed one after another.

Model D

The final model (Fig 21) based on the sequential sequence from Ebbsfleet through Fengate to Mortlake shows good agreement between the radiocarbon evidence and sequence ($A_{overall}$=67.5%). The results of this analysis are summarised in Figure 22 and Table 10.

Discussion

Model D suggests that the use of Peterborough ware was considerably shorter that the span of *c* 3400-2500 cal BC put forward by Gibson and Kinnes (1997). It provides estimates for the beginning of use of Peterborough Ware of *3690–3340 cal BC (95% probability*; Fig 21: *start Ebbsfleet*), and probably in *3500–3530 cal BC (68% probability).* The latest deposits of this style occurred in *3060–2880 cal BC (95% probability*; Fig 21: *end Mortlake)*, and probably in *3010–2880 cal BC (68% probability).*

All three models are extremely ‘conservative’ in that they treat all samples without a direct functional relationship to the Peterborough ware in a context (ie all non residue measurements) as only providing *tps* for the ceramics. The implications of not treating all non-residue dates results as *tps* for the chronology of Peterborough ware proposed above will be explored more fully in Marshall *et a*l (in prep).

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References

Abramson, P, 1996 Excavations along Caythorpe Gas Pipeline, North Humberside, *Yorkshire Archaeological Journal*, **68**, 1-89

Ambers, J, Burleigh, R, and Matthews, K, 1987 British Museum natural radiocarbon measurements XIX, *Radiocarbon*, **29**(1), 61-77

Aerts-Bijma, A T, Meijer, H A J, and van der Plicht, J, 1997 AMS sample handling in Groningen, *Nuclear Instruments and Methods in Physics Research B*, **123**, 221–5

Aerts-Bijma, A T, van der Plicht, J, and Meijer, H A J, 2001 Automatic AMS sample combustion and CO_2 collection, *Radiocarbon*, **43(2A)**, 293–8

Ashmore, P, 1999 Radiocarbon dating: avoiding errors by avoiding mixed samples, *Antiquity*, 73, 124–30

Bowman, S G E, Ambers, J C, and Leesem, M N, 1990 Re-Evaluation of British Museum Radiocarbon Dates Issued Between 1980 and 1984, **32**, 59-81

Bronk Ramsey, C, 1995 Radiocarbon calibration and analysis of stratigraphy, *Radiocarbon*, **36**, 425–30

Bronk Ramsey, C, 1998 Probability and dating, *Radiocarbon*, **40**, 461–74

Bronk Ramsey, C, 2001 Development of the radiocarbon calibration program, *Radiocarbon*, **43**, 355–63

Bronk Ramsey, C, Higham, T, and Leach, P, 2004 Towards high precision AMS: progress and limitations, *Radiocarbon*, **46(1)**, 17–24

Buck, C E, Litton, C D, and Smith, A F M, 1992 Calibration of radiocarbon results pertaining to related archaeological events, *J Archaeol Sci*, **19**, 497–512

Buck, C E, Cavanagh, W G, and Litton, C D, 1996 *Bayesian Approach to Interpreting Archaeological Data*, Chichester

Buckley, D G, Hedges, J D, and Brown, N, 2001 Excavations at a Neolithic cursus, Springfield, Essex, 1979–85, *Proceedings of the Prehistoric Society* **67**, 101–62.

Czernik, J, and Goslar, T, 2001 Preparation of graphite targets in the Gliwice Radiocarbon Laboratory for AMS 14C dating, *Radiocarbon*, **43** (2A) 282–91

Ford, S, and Pine, J, 2003. Neolithic ring ditches and Roman landscape features at Horton (1989 to 1996) in S Preston (ed.) *Prehistoric, Roman and Saxon Sites in Eastern Berkshire. Excavations 1989–1997*, 13–85. Thames Valley Archaeological Services Ltd Monograph 2. Reading: Thames Valley Archaeological Services Ltd.

Gelfand, A E, and Smith, A F M, 1990 Sampling approaches to calculating marginal densities, *Journal of the American Statistical Association,* **85**, 398–409

Gibson, A M, 1994 Excavations at the Sarn-y-byrn-caled cursus complex, Welshpool, Powys and the timber circles of Great Britain and Ireland, *Proceeding of the Prehistoric Society*, **60**, 143–223

Gibson, A M, 1995 First impressions: a review of Peterborough Ware in Wales, in I Kinnes and G Varndell (eds) *Unbaked Urns of Rudely Shape: Essays on British and Irish Pottery for Ian Longworth*, Oxford, 23–39

Gibson, A M, and Kinnes, I, 1997 On the urns of a dilemma: radiocarbon dating and the Peterborough problem, *Oxford Journal of Archaeology*, **16**, 65–72

Gilks, W R, Richardson, S, and Spiegelhalther, D J, 1996 *Markov Chain Monte Carlo in practice*, London: Chapman and Hall

Marshall, P D, Hamilton, W D, Woodward, A, and Beamish M, in prep A precise chronology for Peterborough Ware?

Meadows, J, Sidell, J, Swain, H, and Taylor, B, forthcoming *Absolute Dating: a Regional Review for London, vol 1; Physical and Chemical Methods*, Museum of London, London

Mook, W G, 1986 Business meeting: Recommendations/Resolutions adopted by the Twelfth International Radiocarbon Conference, *Radiocarbon*, **28**, 799

Mook, W G, and Steurman, H J, 1983 Physical and chemical aspects of radiocarbon dating, in W G Mook and H T Waterbolk (eds) *Proceeding of the Groningen Symposium*. ^{14}C and Archaeology. PACT 8, 31-55

Nakamura, T, Taniguchi, Y, Tsuji, S, and Oda, H, 2001 Radiocarbon dating of charred residues on the earliest pottery in Japan, *Radiocarbon*, **43**, 1129–38

Reimer, P J, Baillie, M G L, Bard, E, Bayliss, A, Beck, J W, Bertrand, C J H, Blackwell, P G, Buck, C E, Burr, G S, Cutler, K B, Damon, P E, Edwards, R L, Fairbanks, R G, Friedrich, M, Guilderson, T P, Hogg, A G, Hughen, K A, Kromer, B, McCormac, G, Manning, S, Bronk Ramsey, C, Reimer, R W, Remmele, S, Southon, J R, Stuiver, M, Talamo, S, Taylor, F W, van der Plicht, J, and Weyhenmeyer, C E, 2004 IntCal04 Terrestrial radiocarbon age calibration, 0–26 Cal Kyr BP, *Radiocarbon*, **46**, 1029–58

Reynolds, P, 1995 The life and death of a post-hole, *Interpreting Stratigraphy*, **5**, 21–5

Scott, E M (ed), 2003 The Third International Radiocarbon Intercomparison (TIRI) and the Fourth International Radiocarbon Intercomparison (FIRI) 1990–2002: results, analysis, and conclusions, *Radiocarbon*, **45**, 135–408

Slota, Jr P J, Jull, A J T, Linick, T W, and Toolin, L J, 1987 Preparation of small samples for ^{14}C accelerator targets by catalytic reduction of CO, *Radiocarbon*, **29**, 303–6

Smith, I F, 1956 *The Decorative Art of Neolithic Ceramics in South-East England*, unpubl PhD, University of London

Smith, I F, 1974 The Neolithic, In A C Renfrew (ed) *British Prehistory: A New Outline*, London, 100–36

Stuiver, M and Kra, R S 1986 Editorial comment, *Radiocarbon*, **28**(2B), ii

Stuiver, M, and Polach, H A, 1977 Reporting of ^{14}C data, *Radiocarbon*, **19**, 355–63

Stuiver, M, and Reimer, P J, 1986 A computer program for radiocarbon age calculation, *Radiocarbon*, **28**, 1022–30

Stuiver, M, and Reimer, P J, 1993 Extended ^{14}C data base and revised CALIB 3.0 ^{14}C age calibration program, *Radiocarbon*, **35**, 215–30

van der Plicht, J, Wijma, S, Aerts, A T, Pertuisot, M H, and Meijer, H A J, 2000 Status report: the Groningen AMS facility, *Nuclear Instruments and Methods in Physics Research B*, **172**, 58–65

Ward, G K, and Wilson, S R, 1978 Procedures for comparing and combining radiocarbon age determinations: a critique, *Archaeometry*, **20**, 19–31

Xu, S, Anderson, R, Bryant, C, Cook, G T, Dougans, A, Freeman, S, Naysmith, P, Schnabel, C, and Scott, E M, 2004 Capabilities of the new SUERC 5MV AMS facility for ^{14}C dating, *Radiocarbon*, **46**, 59–64

Table 1 Willington: environmental column radiocarbon results

Pollen Column	**Context & Sample**	**Material**	**$\delta^{13}C$ (‰)**	**Radiocarbon age BP**	**Calibrated date range (95% confidence)**
GrA-31468	0-0.1m	Waterlogged plant macrofossils: *Rannunculus* sect. *Rannunculus* (3), *Corylus avellana*, *Persicaria lapathifolia* (2), *Rumex* sp., *Prunella vulgaris* (2), *Sambucus nigra*, *Carex* (3)	-28.7	4245±35	2910-2750 cal BC
OxA-15897	0-0.1m	Waterlogged plant macrofossils: twig fragments	-28.7	4395±36	3270-2910 cal BC
SUERC-7350	0.48-0.50m	Waterlogged plant macrofossils: *Rannunculus* sect. *Rannunculus* (3), *Rannunculus flammula*, *Betula* sp., *Alnus glutinosa*, *Filipendula ulmaria*, *Apiaceae*, *Carex*	-26.2	11,405±45	11,410-11230 cal BC
SUERC-7351	0.96-0.98m	Waterlogged plant macrofossils: Betula sp., *Filipendula ulmaria*, *Apiaceae*, *Eleocharis* sp., *Schoenoplectus* sp. *Carex*	-27.4	11,780±45	11,820-11510 cal BC

Table 2 Willington: radiocarbon results associated with tree-throws

Tree-throw/usage	**Context & Sample**	**Material**	**Description**	**$\delta^{13}C$ (‰)**	**Radiocarbon age BP**	**Weighted mean**	**Calibrated date range (95% confidence)**
OxA-15116	[299]-<34A>	charcoal, *Prunus spinosa* (R Gale)	From a homogenous burnt deposit filling an irregular spread that may be part of a treethrow [327].	-25.4	4712±31		3640-3370 cal BC
OxA-15127	[291]-<25A>	charcoal, *Prunus spinosa* (R Gale)	From a deposit representing human activity within the pit of a treethrow	-26.9	4790±32	4649±22 BP (T'=3.3; ν=1; T'(5%)=3.8;) .	3515-3360 cal BC
OxA-15128	[291]-<25A>	*Prunus spinosa* (R Gale)	Replicate of OxA-15127	-26.4	4709±31		
SUERC-7607	[291]-<25B>	charcoal, *Corylus avellana* (R Gale)	As OxA-15127	-27.1	4875±35		3710-3630 cal BC
GrA-31799	[458]-<57A>	Charcoal, *Prunus spinosa* (R Gale)	From the rich fill of a pit that also contained Peterborough ware (Mortlake) pottery.	-25.0	4750±40		3640-3370 cal BC
OxA-15899	[458]-<57B>	Charcoal, Pomoideae (R Gale)	As GrA-31799	-27.7	4814±38		3660-3520 cal BC
GrA-31800	[302]-<28>	charcoal, *Prunus spinosa* (R Gale)	From the filling of the base of a burnt out small tree/shrub.	-25.6	3655±40		2140-1910 cal BC
GrA-31770	[1448]-<65A>	charcoal, *Corylus avellana* (R Gale)	Charcoal from the fill of a post-pit	-25.5	4490±40		3360-3020 cal BC
GrA-31786	[1453]-<112>	charcoal, *Prunus spinosa* (R Gale)	From an episode of burning redeposited in the base of a pit that held the post of a structure.	-25.8	3665±40		2200-1930 cal BC
OxA-15084	[1499]-<71A>	charcoal, *Prunus spinosa* (R Gale)	From an episode of burning possibly associated with a treethrow and post pits forming a structure. Contains Peterborough (Fengate) pottery	-26.1	4434±30		3330-2920 cal BC
SUERC-8156	[1499]-<71B>	charcoal, *Corylus avellana* (R Gale)	As OxA-15084	-25.2	4500±40		3370-3020 cal BC
GrA-31785	[1451]-<114A>	charcoal, *Prunus spinosa* (R Gale)	From a deposit of charcoal deposited in a treethrow.	-27.1	3800±40		2430-2130 cal BC
OxA-15110	[1451]-<114A>	charcoal, *Prunus spinosa* (R Gale)	From a deposit of charcoal deposited in a treethrow.	-25.4	3714±29		2200-2020 cal BC
SUERC-7597	[1451]-<114B>	charcoal, *Corylus avellana* (R Gale)	As OxA-15110	-26.5	4510±35		3370-3080 cal BC

GrA-31803	[1328]-<64>	charcoal, *Prunus spinosa* (R Gale)	From an episode of burning re-deposited in the base of a pit that held the post of a structure.	-26.1	3650±40		2140-1900 cal BC
OxA-15045	[1328]-<64A>	charcoal, *Prunus spinosa* (R Gale)	From an episode of burning redeposited in the base of a pit that held the post of a Neolithic structure.	-26.4	3641±33	3646±21 BP (T'=0.0; ν=1; T'(5%)=3.8;) .	2130-1945 cal BC
OxA-15109	[1328]-<64A>	charcoal, *Prunus spinosa* (R Gale)	Replicate of OxA-15045	-25.3	3650±28		
SUERC-7596	[1328]-<64B>	charcoal, *Prunus spinosa* (R Gale)	As OxA-15044	-25.5	4455±35		3340-2940 cal BC
OxA-15900	[1328]-<113>	charcoal, *Corylus avellana* (R Gale)	From an episode of burning re-deposited in the base of a pit that held the post of a structure.	-26.7	4472±36		3390-3020 cal BC
GrA-31801	[1477]-<68>	charcoal, *Prunus spinosa* (R Gale)	From the rich fill of a ?cooking pit that also contained Peterborough ware (Mortlake) pottery.	-25.5	4515±45		3370-3020 cal BC

Table 3 Willington: clearance radiocarbon results

Clearance	Context & Sample	Material	Description	$\delta^{13}C$ (‰)	Radiocarbon age BP	Calibrated date range (95% confidence)
GrA-31797	[63]-<3A>	charcoal, *Alnus/Corylus* (R Gale)	From a charcoal rich deposit related to an extensive fire reddened clay associated with a tree clearance	-27.1	4670±45	3630-3350 cal BC
OxA-15898	[63]-<3B>	Charcoal, *Betula* (R Gale)	As GrA-31797	-26.9	4535±38	3370-3090 cal BC
GrA-31789	[4108]-<183>	Charcoal, *Alnus* (R Gale)	From a charcoal rich deposit related to an extensive fire reddened clay associated with a tree clearance	-27.3	3730±40	2280-2020 cal BC
OxA-15083	[4156/7]-<187A>	charcoal, *Prunus spinosa* (R Gale)	From a charcoal rich deposit related to an extensive fire reddened clay associated with a treethrow.	-29.4	3508±28	1920-1740 cal BC
SUERC-7594	[4156/7]-<187B>	charcoal, *Prunus spinosa* (R Gale)	As OxA-15083	-25.8	3440±35	1880-1640 cal BC
GrA-31787	[78]-<6>	Charcoal, possible Rosaceae twig (R Gale)	From a charcoal rich deposit related to an extensive fire reddened clay associated with a tree clearance	-25.7	3410±40	1880-1610 cal BC
OxA-15082	[135]-<17A>	charcoal, *Prunus spinosa*, stems (R Gale)	From a charcoal rich deposit related to an extensive fire reddened clay associated with a treethrow.	-26.3	3645±28	2140-1930 cal BC
SUERC-7593	[135]-<17B>	charcoal, *Prunus spinosa*, stems (R Gale)	As OxA-15082	-24.6	3700±35	2200-1970 cal BC
OxA-15081	[4490]-<278A>	charcoal, *Fraxinus*, probably root (R Gale)	From a charcoal rich deposit related to an extensive fire reddened clay associated with a treethrow.	-25.3	3981±27	2580-2460 cal BC
SUERC-7592	[4490]-<278B>	charcoal, *Fraxinus excelsior*	As OxA-15081	-25.3	3995±35	2580-2460 cal BC
GrA-31796	[4489]-<276>	Charcoal, *Corylus avellana* (R Gale)	From a charcoal rich deposit related to an extensive fire reddened clay associated with a tree clearance	-27.9	4425±45	3340-2910 cal BC

Table 4 Willington: burnt mound 1 and associated contexts radiocarbon results

Laboratory code	Context & Sample	Material	Description	$\delta^{13}C$ (‰)	Radiocarbon age BP	Calibrated date range (95% confidence)	***Posterior Density Estimate (95% probability)***
OxA-15111	[1487]-<111A>	charcoal, *Prunus spinosa* (R Gale)	From a charcoal rich deposit derived from spent fuel cleaned out of the central features	-26.8	3610±29	2040-1880 cal BC	*2140-2080 (28%) or 2050-1930 (67%)*

							cal BC
SUERC-7598	[1487]-<111B>	charcoal, *Fraxinus excelsior* (R Gale)	As OxA-15111	-25.9	3775±35	2300-2040 cal BC	*2270-2030 cal BC*
OxA-15112	[1582]-<81A>	charcoal, *Corylus avellana* (R Gale)	From the base of a substantial pit adjacent to the hearth/oven [1704] and derived from an episode of burnt mound activity.	-24.3	372 ±30	2210-2020 cal BC	*2200-2030 cal BC*
SUERC-7602	[1582]-<81B>	charcoal, *Fraxinus excelsior* (R Gale)	As OxA-15112	-26.2	3690±35	2200-1960 cal BC	*2200-1980 cal BC*
OxA-15113	[1653]-<152A>	charcoal, Pomoideae (R Gale)	From a charcoal rich deposit (trough) near the base of the central burnt mound	-24.9	3754±28	2280-2040 cal BC	*2210-2030 cal BC*
SUERC-7909	[1653]-<152B>	charcoal, Pomoideae (R Gale)	As OxA-15113	-25.8	3780±50	2400-2030 cal BC	*2250-2030 cal BC*
OxA-15114	[1691]-<91A>	charcoal, Pomoideae (R Gale)	From a charcoal and fire cracked stone rich deposit (?oven/hearth)	-26.2	3695±29	2200-1970 cal BC	*2200-2010 cal BC*
SUERC-7604	[1691]-<91B>	charcoal, *Fraxinus excelsior* (R Gale)	As OxA-15114	-24.4	3740±35	2280-2030 cal BC	*2210-2010 cal BC*
OxA-15115	[1881]-<122A>	charcoal, *Fraxinus excelsior* (R Gale)	From a charcoal rich deposit post-dating the lower burnt mound activity	-24.7	3649±33	2140-1920 cal BC	*2140-1960 cal BC*
SUERC-7606	[1881]-<122B>	charcoal, *Corylus avellana* (R Gale)	As OxA-15115	-24.6	4695±35	3630-3360 cal BC	-
OxA-15046	[1817]-<123A>	charcoal, *Prunus spinosa* (R Gale)	From a charcoal rich deposit pre-dating the upper burnt mound layer and central trough [1651]	-24.1	4607±35	3500-3340 cal BC	-
SUERC-7605	[1817]-<123B>	charcoal, *Prunus spinosa* (R Gale)	As OxA-15046	-25.1	4695±35	3630-3360 cal BC	-

Table 5 Willington: burnt mound 2 radiocarbon results

Burnt Mound 2	**Context & Sample**	**Material**	**Description**	**Radiocarbon age BP**	**Calibrated date range (95% confidence)**	***Posterior Density Estimate (95% probability)***
GrN-30408	[4613] <T31>	Waterlogged wood; *Fraxinus*	Timbers forming trough within pit [4468]	2920±30	1260-1000 cal BC	*1210-1050 cal BC*
GrN-30409	[4613] <T61>	Waterlogged wood; *Alnus*	Timbers forming trough within pit [4468]	2940±30	1270-1020 cal BC	*1220-1050 cal BC*
GrN-30410	[4477] <272A>	Charcoal; 46 (12g) *Alnus/Corylus*, 2r (<1g) *Fraxinus*, 3r (2g) Pomoideae, 1 (<1g) *Prunus*, 1 *Quercus*	Fragmentary fire cracked stones and charcoal	2880±50	1260-910 cal BC	*1260-930 cal BC*
GrN-30411	[4477] <272B>	Charcoal; 4 (4g) *Alnus*, 11 (4g) *Alnus/Corylus*, 5 (4g) *Fraxinus*, 5 (3g) Pomoideae, 1 (<1g) *Prunus*, 1h, 6 (4g) *Rhamnus cathartica*,	Fragmentary fire cracked stones and charcoal	2960±50	1380-1010 cal BC	*1380-1340 cal BC (2%) or 1320-1010 cal BC (93%)*
GrN-30412	[4483] <284>	Charcoal; 12 (2g) *Alnus*, 4 (1g) Pomoideae, -, 9r (1g) *Quercus*, 2 (<1g) *Rhamnus cathartica*, 3r (<1g> *Ulmus*	Silty peat layer	2980±50	1390-1040 cal BC	*1320-1130 cal BC*
Poz-18010	[4466] <S 270>	Waterlogged plant macrofossils: *Ranunculus* sect. *Ranunculus*, (3), *Urtica dioica* L., (20), *Urtica urens* L., (1), *Alnus glutinosa* L. catkin, (2), *Alnus glutinosa* L. seeds, (13),	From leaf litter horizon within channel filling	2875±35	1200-920 cal BC	*1200-930 cal BC*

		Chenopodium sp., (1), *Atriplex* sp., (2), *Stellaria media* (L.) *Villars*, (3)				
Poz-18006	[4462]	Waterlogged plant macrofossils: *Rannunculus* sect. *Rannunculus* (2), *Alnus glutinosa* L. seeds (2), *Persicaria hydopiper* (L.) *Spach* (3), *Rumex* sp.(1), *Filipendula ulmaria* (3), *Potentilla anserina* L. (1), *Lycopus europaeus* L.) (1), *Scirpus sylvaticus* L. (4),	Top of shallow column.	2845±35	1260-1000 cal BC	*1100-930 cal BC*
Poz-18007	[4463]	Waterlogged plant macrofossils: *Rannunculus* sect. *Rannunculus* (1), *Urtica dioica* L. (1), *Alnus glutinosa* L. catkin (1),*Alnus glutinosa* L. seeds (1),*Chenopodium* sp. (1), *Stellaria media* (L.) *Villars* (4), *Lychnis flos-cuculi* L. (2), *Filipendula ulmaria* (1),	Base of shallow column.	2910±35	1130-910 cal BC	*1130-970 cal BC*
Poz-18029	[4498]	Waterlogged plant macrofossils: *Rannunculus* sect. *Rannunculus* (20), *Urtica dioica* L. (1), *Alnus glutinosa* L. seeds (3), *Chenopodium* sp. (2), *Lychnis flos-cuculi* L. (4), *Persicaria* cf. *maculosa* Gray (3),*Persicaria hydropiper* (L.) *Spach* (8), *Rumex acetosell*	From channel deposit (column)	3665±35	2150-1940 cal BC	*2130-1920 cal BC*
Poz-18009	[4454}	Waterlogged plant macrofossils: *Urtica dioica* L. (1),*Alnus glutinosa* L. seeds (2), *Persicaria* cf.*maculosa* Gray (1),*Persicaria hydropiper* (L.) *Spach* (8), *Bidens* sp.(1) *Eupatorium cannabinum* L. (1) *Qlismatacaeae* (7) *Eleocharis* sp. (1), *Scirpus sylvaticus* L.	From channel deposit (column)	2965±35	1320-1050 cal BC	*1390-1180 cal BC*

Table 6 Willington: alluviation radiocarbon results

Laboratory code	**Context & Sample**	**Material**	**Description**	**δ^{13}C (‰)**	**Radiocarbon age BP**	**Calibrated date range (95% confidence)**
OxA-15044	[2076]-<149A>	charcoal, *Prunus spinosa* (R Gale)	From the base of a partly stoned lined oven	-24.3	4556± 34	3490-3100 cal BC
SUERC-7595	[2076]-<149B>	charcoal, *Prunus spinosa* (R Gale)	As OxA-15044	-24.2	4740±35	3640-3370 cal BC

Table 7 Willington: ceramic residue radiocarbon results

Laboratory code	**Context & Sample**	**Material**	**Description**	**δ^{13}C (‰)**	**Radiocarbon age BP**	**Calibrated date range (95% confidence)**
OxA-15047	[390]	carbonised residue	Peterborough ware, Mortlake/Fengate vessel	-27.4	4615±36	3510-3340 cal BC
OxA-14481	[1980]	carbonised residue	Neolithic bowl	-26.5	3489±35	3700-3530 cal BC
OxA-14482	[1040]	carbonised residue	Peterborough ware	-27.2	4416±36	3330-2910 cal BC

OxA-14483	[225]	carbonised residue	Peterborough ware (Ebbslfeet)	-29.0	4550±45	3500-3090 cal BC
OxA-14484	[1004]	carbonised residue	Peterborough ware	-28.1	4540±65	3500-3020 cal BC
OxA-14485	[246]	carbonised residue	Peterborough ware	-26.6	4500±50	3370-3020 cal BC

Table 8 Estimates for first and last dates and span of each ceramic style

Peterborough style dated	***First (95% probability)***	***Last (95% probability)***	**Span**
Ebbsfleet	*3520-3340 cal BC*	*3270-2900 cal BC*	60-540 years
Fengate	*3380-3110 cal BC*	*3090-2980 cal BC*	20-370 years
Mortlake	*3330-3210 (17%) or 3190-3150 (3%) or 3130-2920 (75%) cal BC*	*3060-2870 cal BC*	1-310 years

Table 9 Estimates for start and end dates and duration of each ceramic style

Phase includes Peterborough style dated material	***Start (95% probability)***	***End (95% probability)***	**Duration**
Ebbsfleet	*4290-3340 cal BC*	*3300-2670 cal BC*	50-1400 years
Fengate	*3890-3100 cal BC*	*3090-2780 cal BC*	30-1000 years
Mortlake	*4430-2920 cal BC*	*3070-2740 cal BC*	1-1560 years

Table 10 Estimates for Peterborough ware styles based on a sequential model in which the end of one style is assumed to be the start of the next

Phase includes Peterborough style dated material	***Start (95% probability)***	***End (95% probability)***	**Duration**
Ebbsfleet	*3690-3340 cal BC*	*3320-3110 cal BC*	40-490 years
Fengate	*3320-3110 cal BC*	*3130-2930 cal BC*	30-320 years
Mortlake	*3130-2930 cal BC*	*3060-2880 cal BC*	1-240 years

Figure 1 Probability distributions of dates from Column 1 (Channel G). Each distribution represents the relative probability that an event occurred at a particular time. These distributions are the result of simple radiocarbon calibration (Stuiver and Reimer 1993).

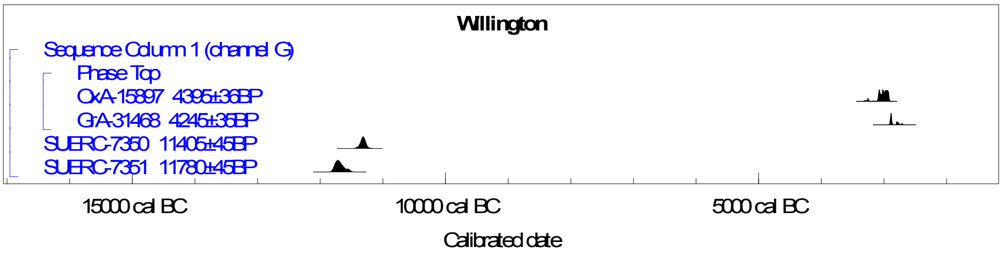


Figure 2 Probability distributions of dates from root-void siltings and potentially associated occupation features. Each distribution represents the relative probability that an event occurred at a particular time. These distributions are the result of simple radiocarbon calibration (Stuiver and Reimer 1993).

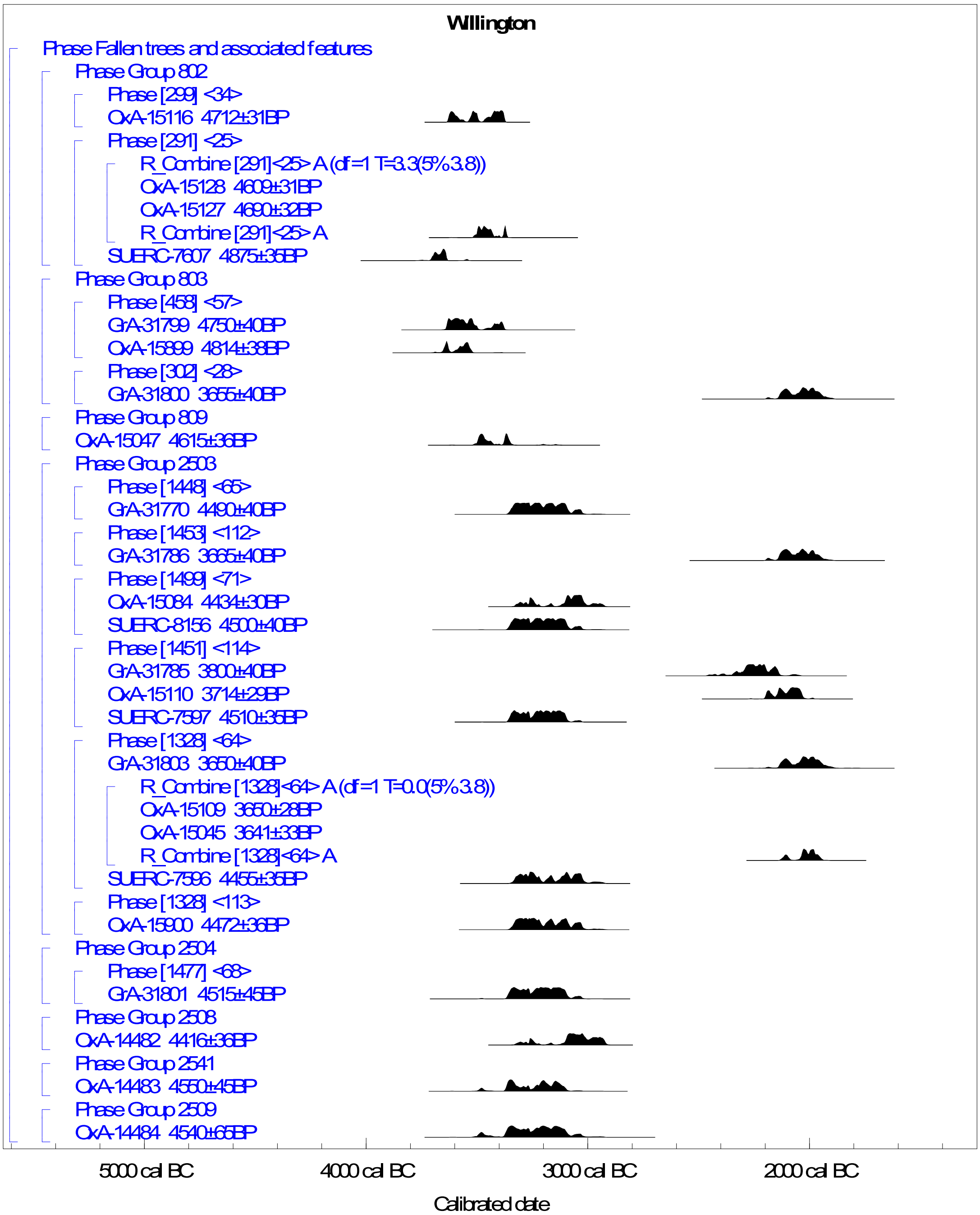


Figure 3 Probability distributions of dates from occupation in the vicinity of fallen trees. Each distribution represents the relative probability that an event occurred at a particular time. These distributions are the result of simple radiocarbon calibration (Stuiver and Reimer 1993).

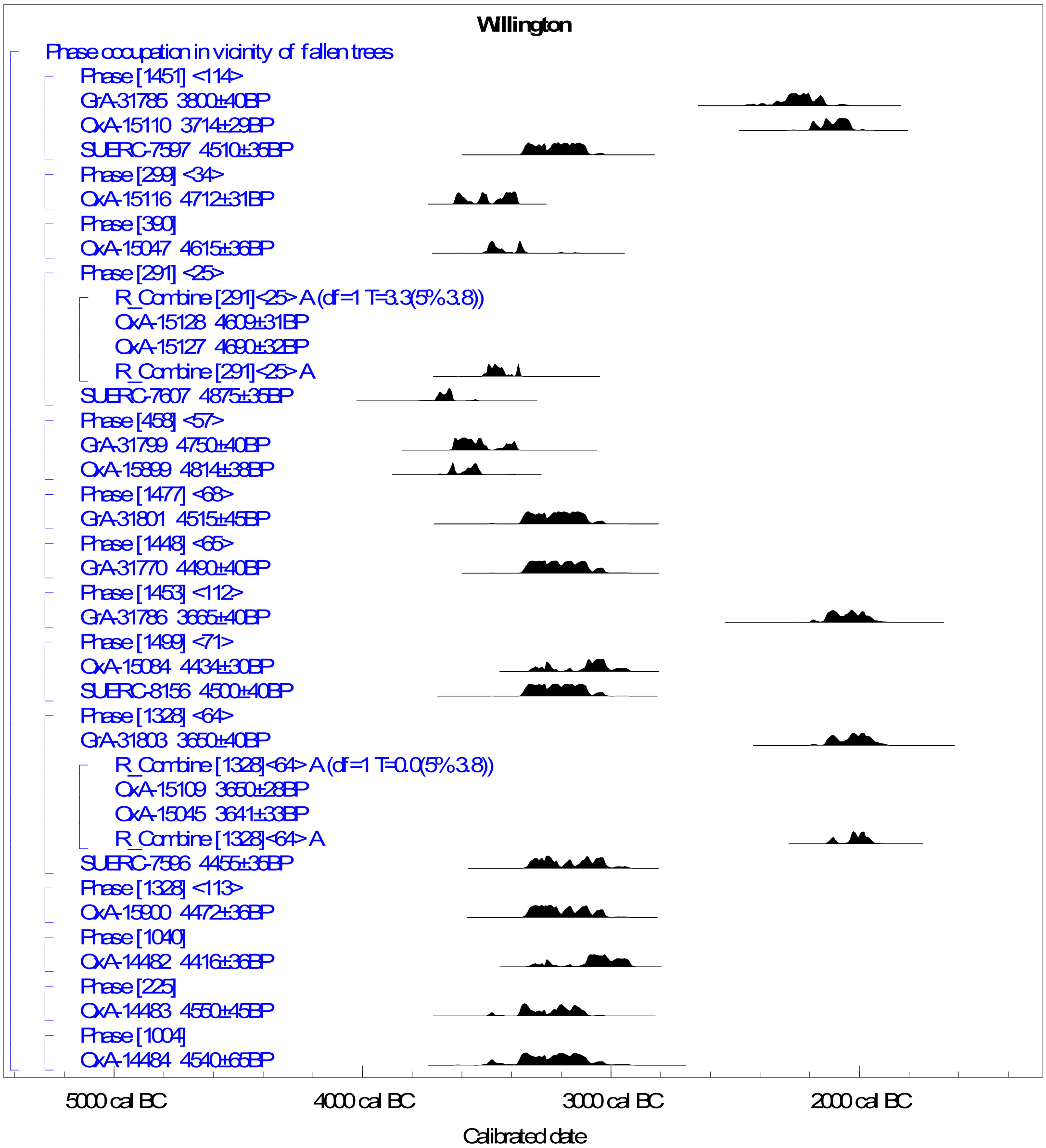


Figure 4 Probability distributions of dates for fire clearance of the floodplain. Each distribution represents the relative probability that an event occurred at a particular time. These distributions are the result of simple radiocarbon calibration (Stuiver and Reimer 1993).

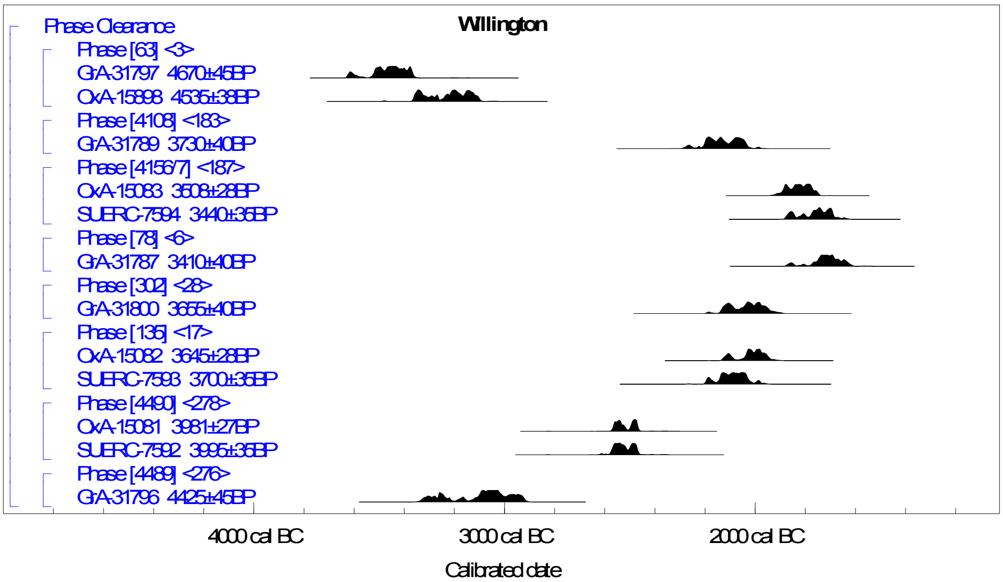


Figure 5 Probability distributions of dates from burnt mound 1. Each distribution represents the relative probability that an event occurred at a particular time. These distributions are the result of simple radiocarbon calibration (Stuiver and Reimer 1993).

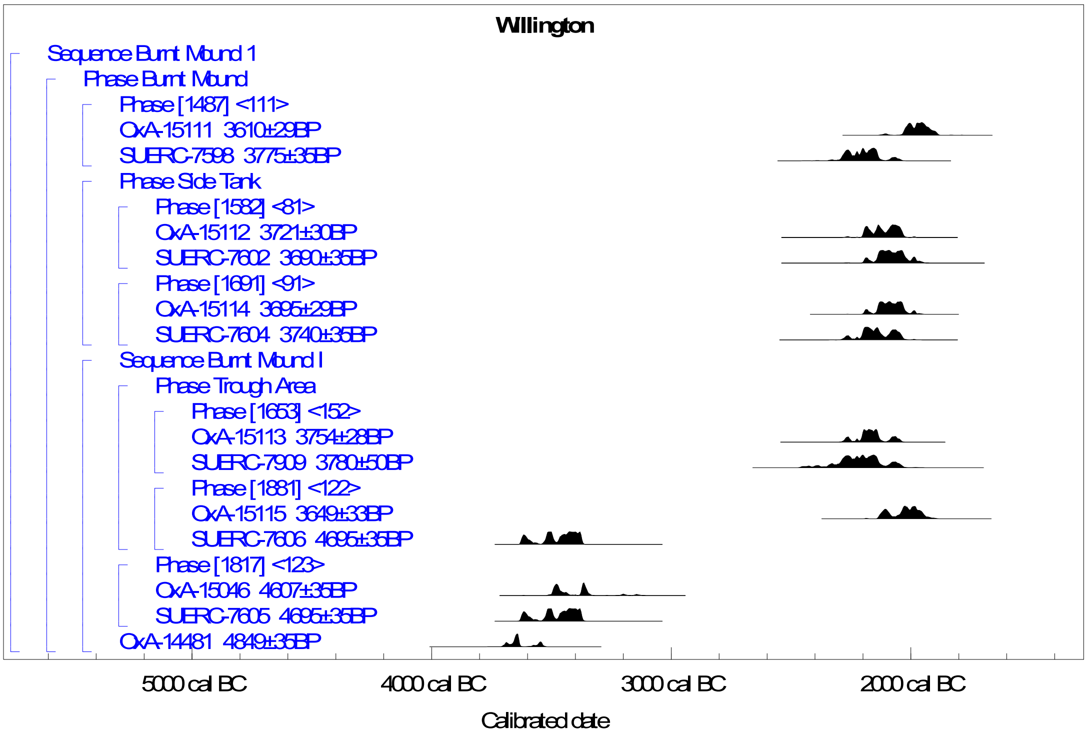


Figure 6 Probability distributions of dates from burnt mound I: each distribution represents the relative probability that an event occurs at a particular time. For each of the radiocarbon dates two distributions have been plotted, one in outline, which is the result of simple radiocarbon calibration, and a solid one, which is based on the chronological model used. The large square brackets down the left hand side along with the OxCal keywords define the model exactly.

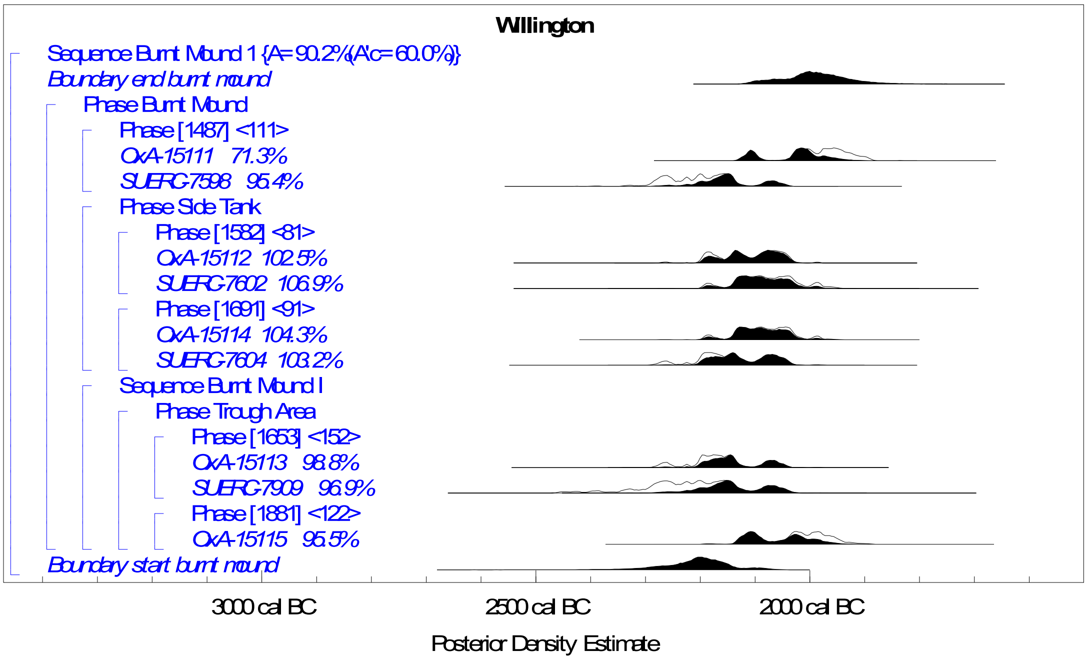


Figure 7 Probability distributions of dates from burnt mound 2. Each distribution represents the relative probability that an event occurred at a particular time. These distributions are the result of simple radiocarbon calibration (Stuiver and Reimer 1993).

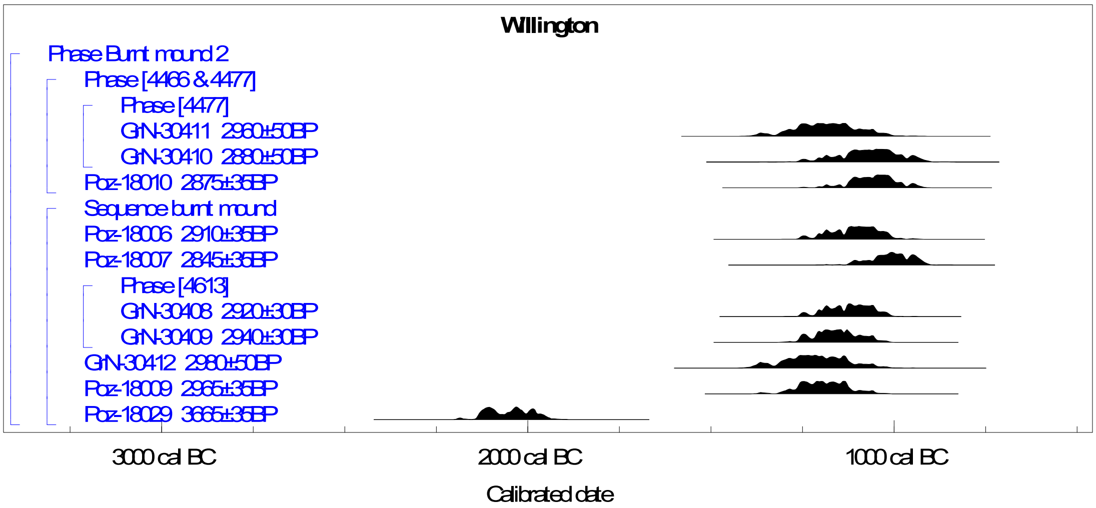


Figure 8 Probability distributions of dates from burnt mound 2: each distribution represents the relative probability that an event occurs at a particular time. For each of the radiocarbon dates two distributions have been plotted, one in outline, which is the result of simple radiocarbon calibration, and a solid one, which is based on the chronological model used. The large square brackets down the left hand side along with the OxCal keywords define the model exactly.

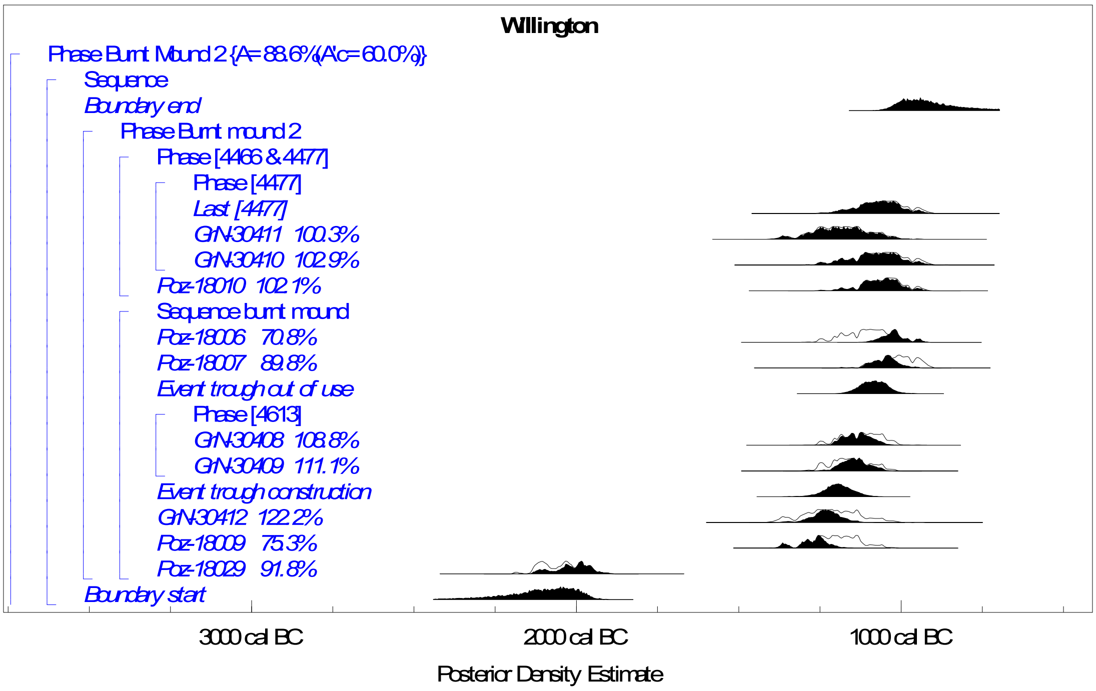


Figure 9 Probability distribution of the numbers of years during which activities occurred at burnt mounds 1 and 2 (derived from Figs 6 and 8)

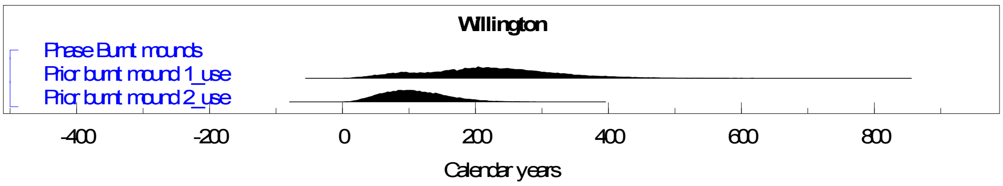


Figure 10 Estimated difference between the end of use of Burnt mound 1 (*Boundary end burnt mound*; Fig 6) and construction of the burnt mound 2 trough (*Event trough construction*; Fig 8)

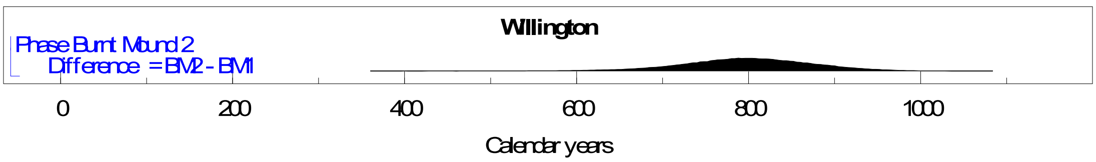


Figure 11 Probability distributions of dates for alluviation. Each distribution represents the relative probability that an event occurred at a particular time. These distributions are the result of simple radiocarbon calibration (Stuiver and Reimer 1993).

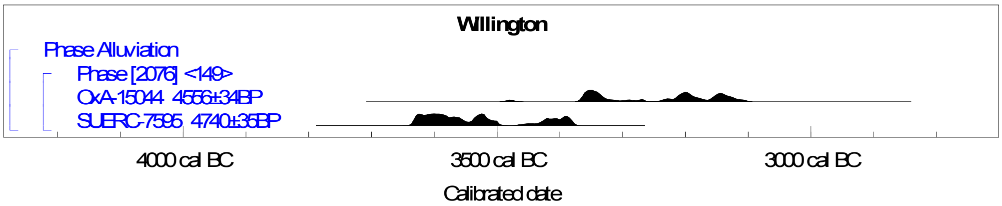


Figure 12 Probability distributions of dates from features cutting alluvium: each distribution represents the relative probability that an event occurs at a particular time. For each of the radiocarbon dates two distributions have been plotted, one in outline, which is the result of simple radiocarbon calibration, and a solid one, which is based on the chronological model used. A question mark (*?*) indicates that the result has been excluded from the model. The large square brackets down the left hand side along with the OxCal keywords define the model exactly.

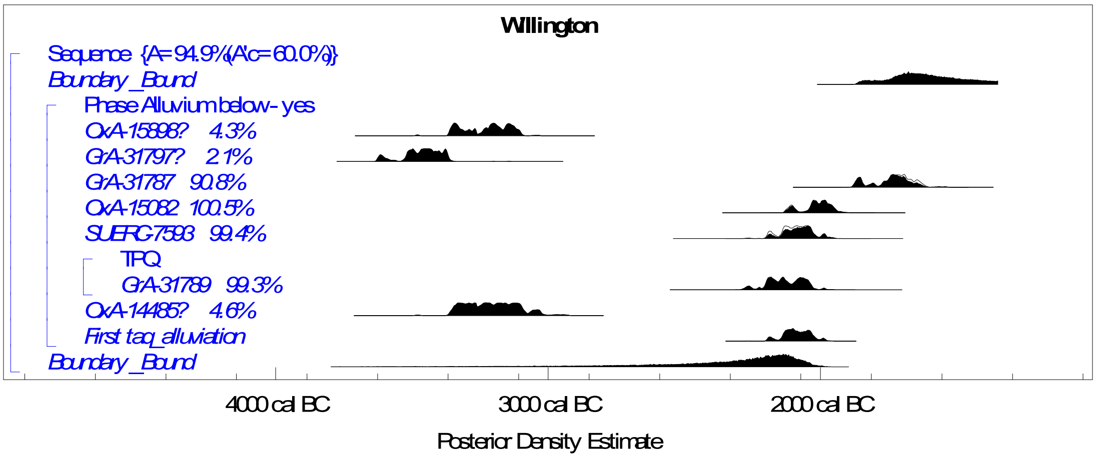


Figure 13 Probability distributions of dates for Neolithic ceramics: Each distribution represents the relative probability that an event occurred at a particular time. These distributions are the result of simple radiocarbon calibration (Stuiver and Reimer 1993).

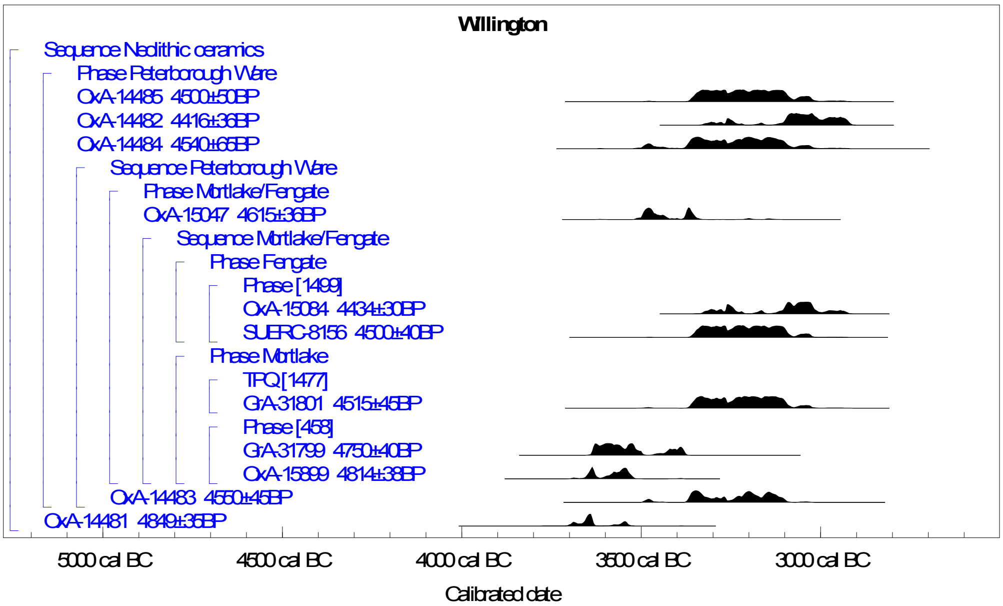
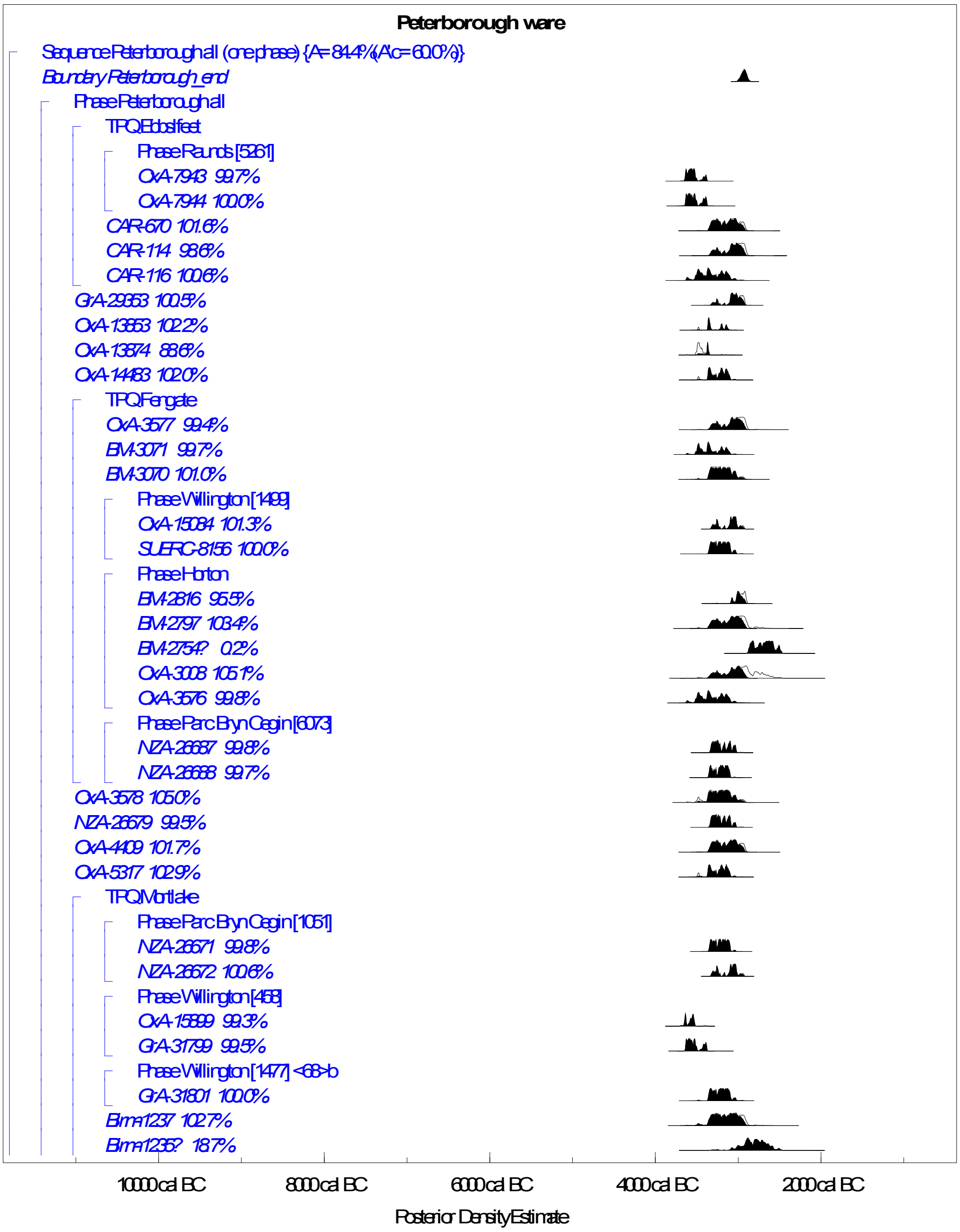


Figure 14 Probability distributions of dates Peterborough ware (model A): each distribution represents the relative probability that an event occurs at a particular time. For each of the radiocarbon dates two distributions have been plotted, one in outline, which is the result of simple radiocarbon calibration, and a solid one, which is based on the chronological model used. The other distributions correspond to aspects of the model. For example, the distribution '*Boundary Peterborough_end'* is the estimated date for the end of use of Peterborough ware. A question mark (*?*) indicates that the result has been excluded from the model. The large square brackets down the left hand side along with the OxCal keywords define the model exactly.



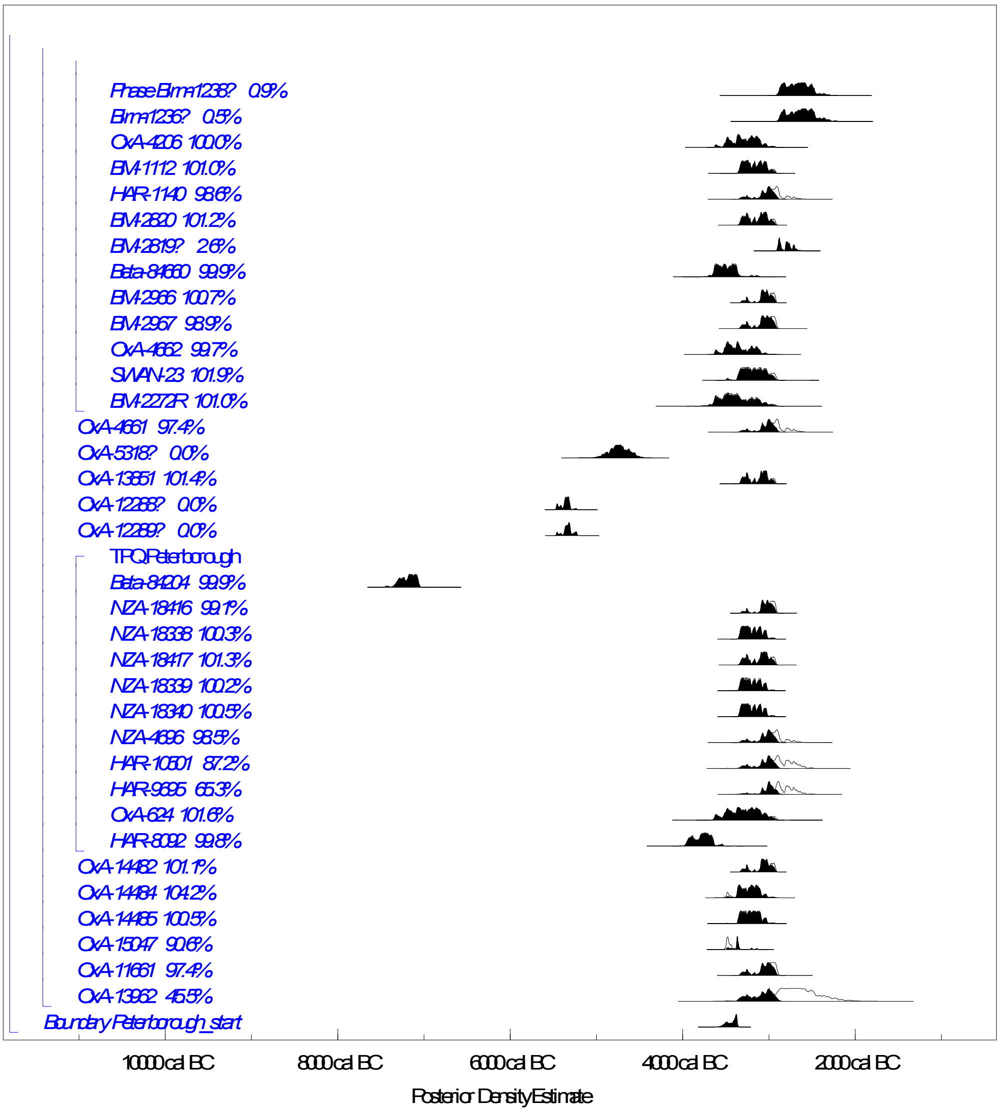
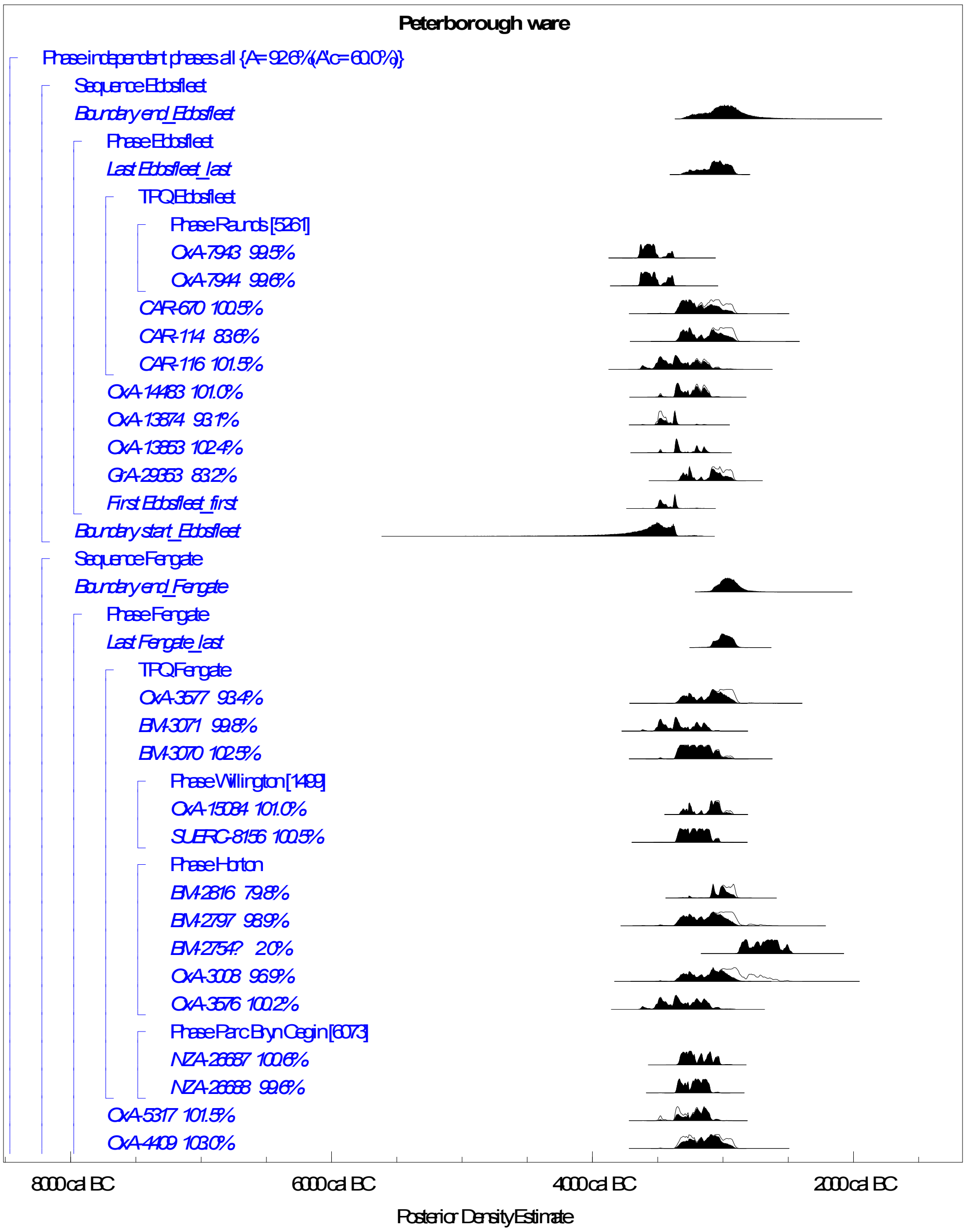

Phase Bmm1238? 0.9%
Bmm1236? 0.5%
OxA-4206 100.0%
BM-1112 101.0%
HAR-1140 98.6%
BM-2820 101.2%
BM-2819? 2.6%
Beta-84660 99.9%
BM-2966 100.7%
BM-2967 98.9%
OxA-4662 99.7%
SWAN-23 101.9%
BM-2272R 101.0%
OxA-4661 97.4%
OxA-5318? 0.0%
OxA-13851 101.4%
OxA-12288? 0.0%
OxA-12289? 0.0%
TPQ Peterborough
Beta-84204 99.9%
NZA-18416 99.1%
NZA-18338 100.3%
NZA-18417 101.3%
NZA-18339 100.2%
NZA-18340 100.5%
NZA-4696 98.5%
HAR-10501 87.2%
HAR-9695 65.3%
OxA-624 101.6%
HAR-8092 99.8%
OxA-14482 101.1%
OxA-14484 104.2%
OxA-14485 100.5%
OxA-15047 90.6%
OxA-11661 97.4%
OxA-13962 45.5%
Boundary Peterborough_start
10000 cal BC
8000 cal BC
6000 cal BC
4000 cal BC
2000 cal BC
Posterior Density Estimate

Figure 15 Probability distributions of dates Peterborough ware (model B): each distribution represents the relative probability that an event occurs at a particular time. For each of the radiocarbon dates two distributions have been plotted, one in outline, which is the result of simple radiocarbon calibration, and a solid one, which is based on the chronological model used. The other distributions correspond to aspects of the model. For example, the distribution '*Boundary end_Fengate'* is the estimated date for the end of use of the Fengate style of Peterborough ware. A question mark (*?*) indicates that the result has been excluded from the model. The large square brackets down the left hand side along with the OxCal keywords define the model exactly.



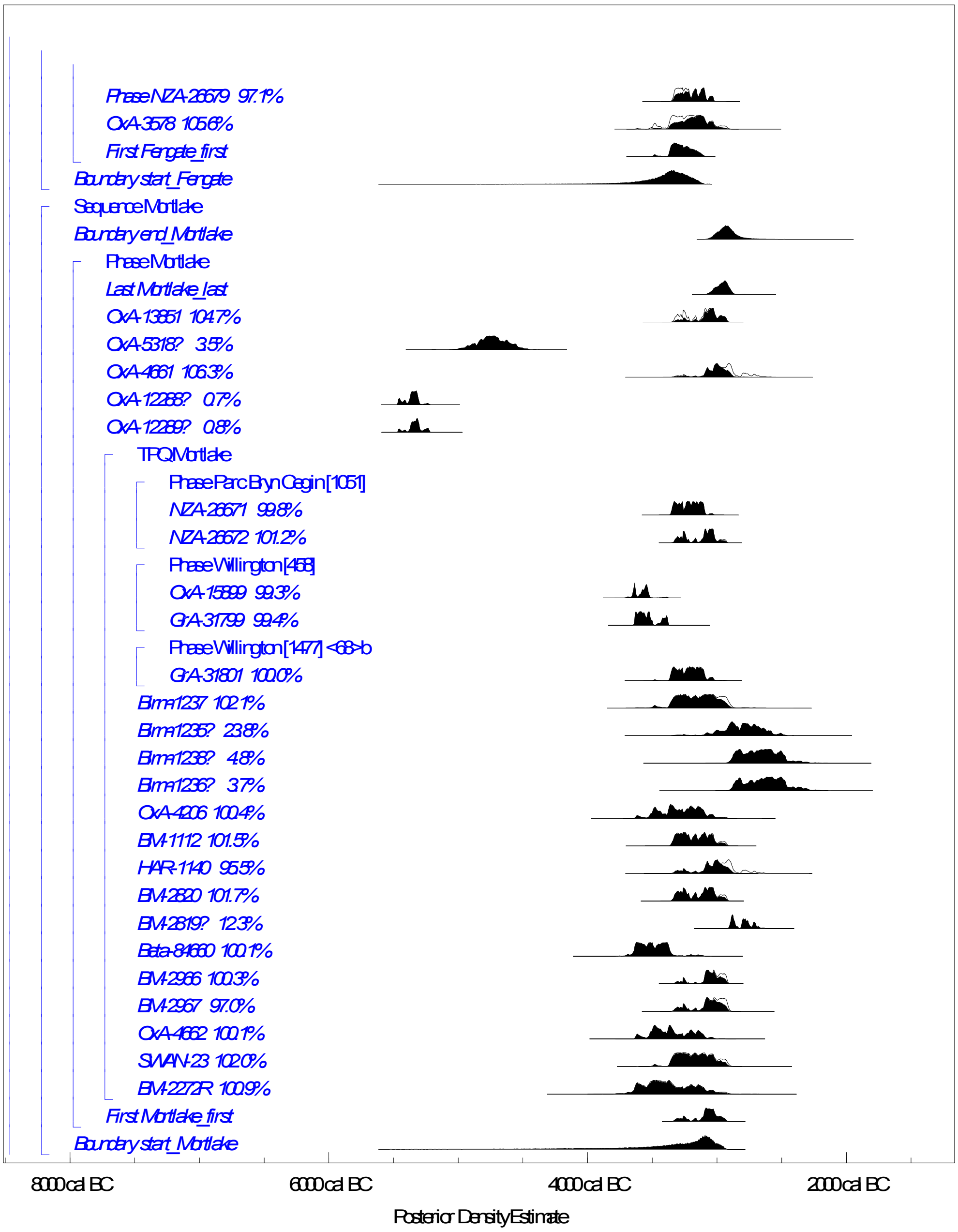

Phase NZA-26679 97.1%
OxA-3578 105.6%
First Fengate_first
Boundary start_Fengate
Sequence Mortlake
Boundary end_Mortlake
Phase Mortlake
Last Mortlake_last
OxA-13851 104.7%
OxA-5318? 3.5%
OxA-4661 106.3%
OxA-12288? 0.7%
OxA-12289? 0.8%
TPQ Mortlake
Phase Parc Bryn Cegin [1051]
NZA-26671 99.8%
NZA-26672 101.2%
Phase Willington [458]
OxA-15899 99.3%
GrA-31799 99.4%
Phase Willington [1477] <63>b
GrA-31801 100.0%
Birm-1237 102.1%
Birm-1235? 23.8%
Birm-1238? 4.8%
Birm-1236? 3.7%
OxA-4206 100.4%
BM-1112 101.5%
HAR-1140 95.5%
BM-2820 101.7%
BM-2819? 12.3%
Beta-84660 100.1%
BM-2966 100.3%
BM-2967 97.0%
OxA-4662 100.1%
SWAN-23 102.0%
BM-2272R 100.9%
First Mortlake_first
Boundary start_Mortlake
8000cal BC
6000cal BC
4000cal BC
2000cal BC
Posterior Density Estimate

Figure 16 Probability distributions for estimated first and last dates in each phase derived from the model shown in Figure 15

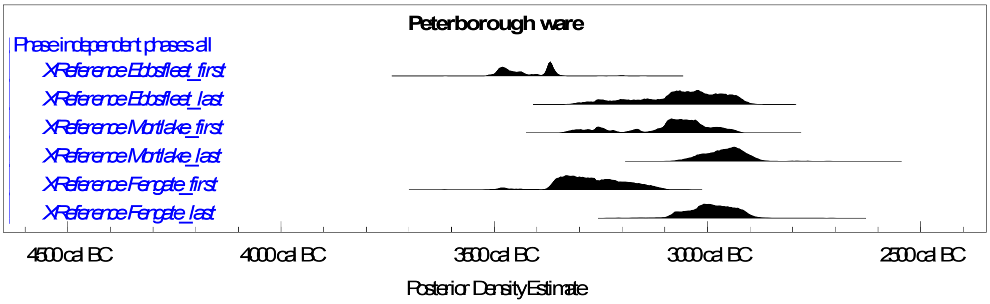


Figure 17 Probability distributions for the span of dated objects from each phase derived from the model shown in Figure 15

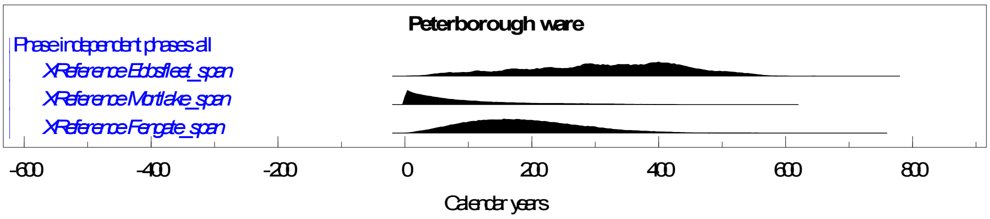


Figure 18 Probability distributions for estimated start and end dates for the postulated phases during which each style was used assuming that they might overlap derived from the model shown in Figure 15

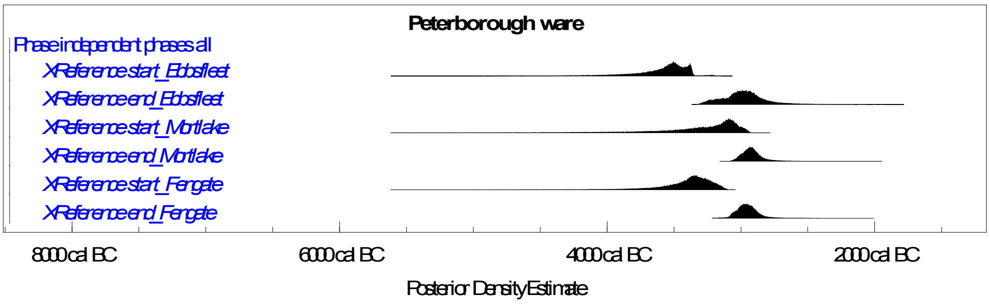


Figure 19 Probability distributions for the duration of phases assuming that they might overlap derived from the model shown in Figure 15

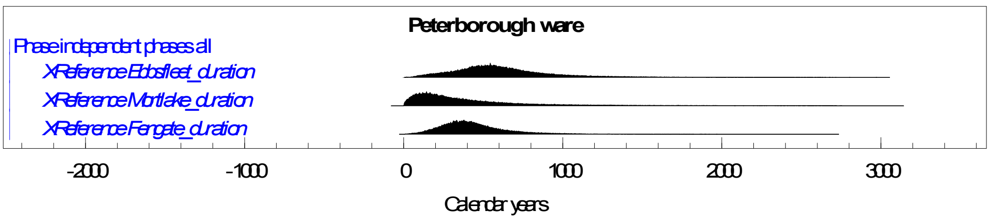
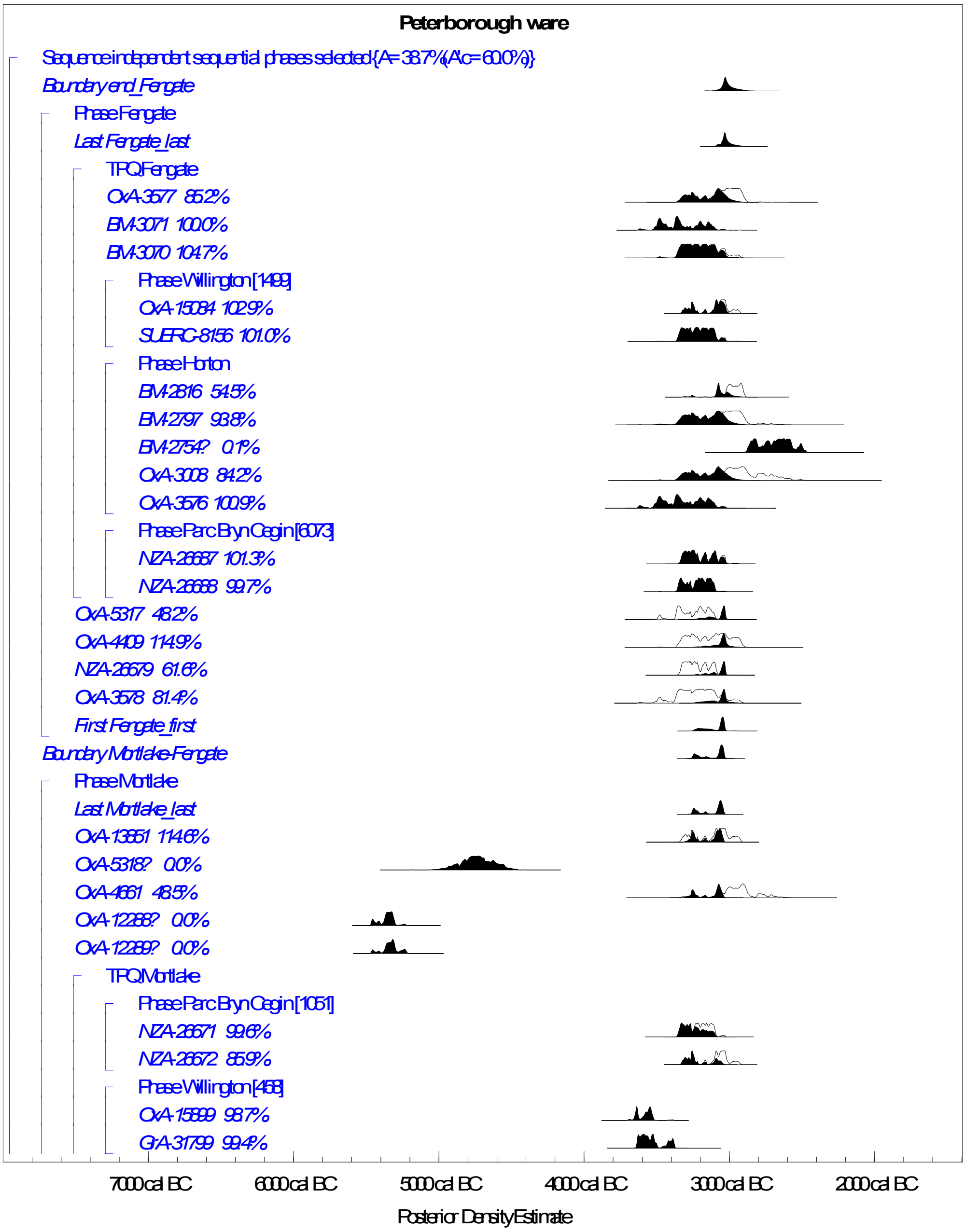


Fig 20 Probability distributions of dates Peterborough ware (model C): each distribution represents the relative probability that an event occurs at a particular time. For each of the radiocarbon dates two distributions have been plotted, one in outline, which is the result of simple radiocarbon calibration, and a solid one, which is based on the chronological model used. A question mark (*?*) indicates that the result has been excluded from the model. The large square brackets down the left hand side along with the OxCal keywords define the model exactly.



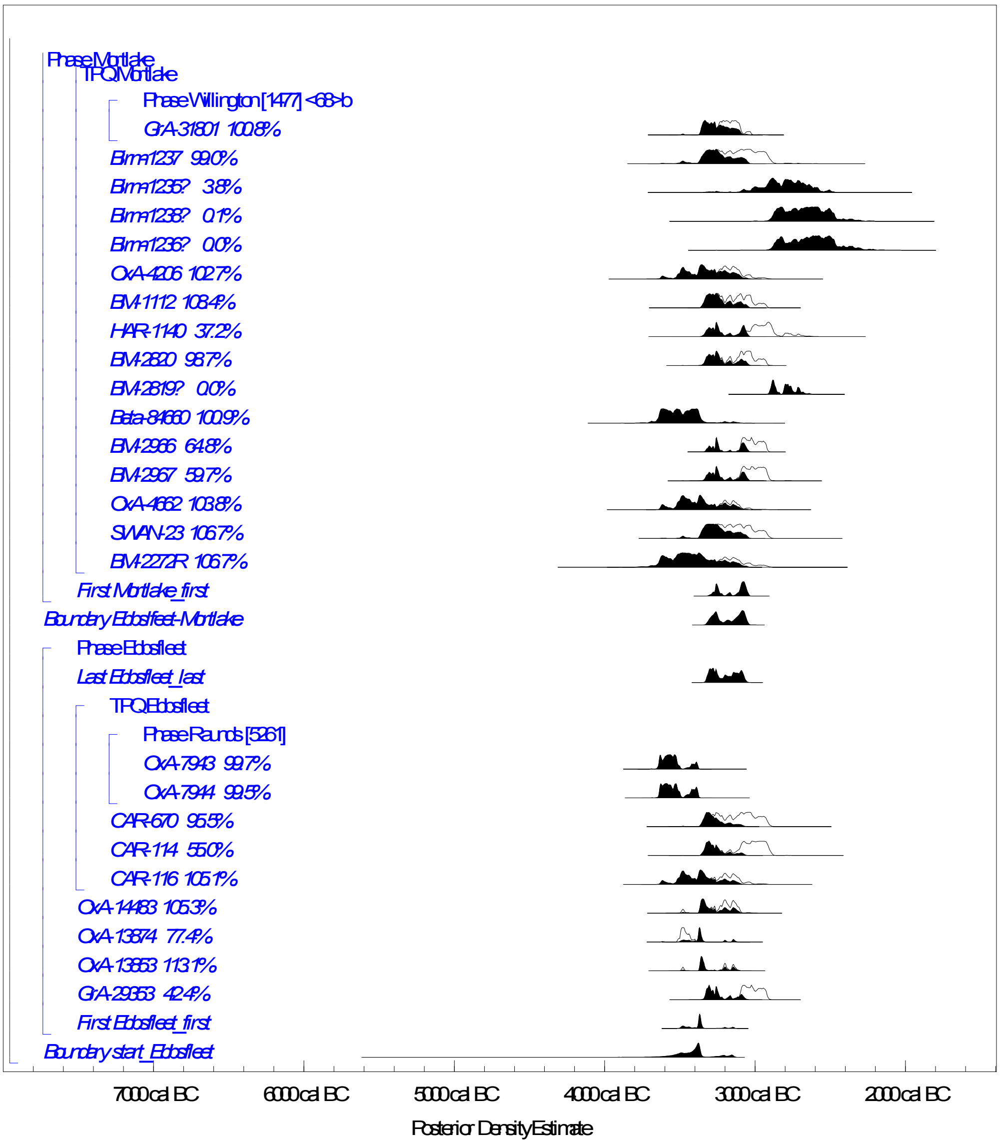
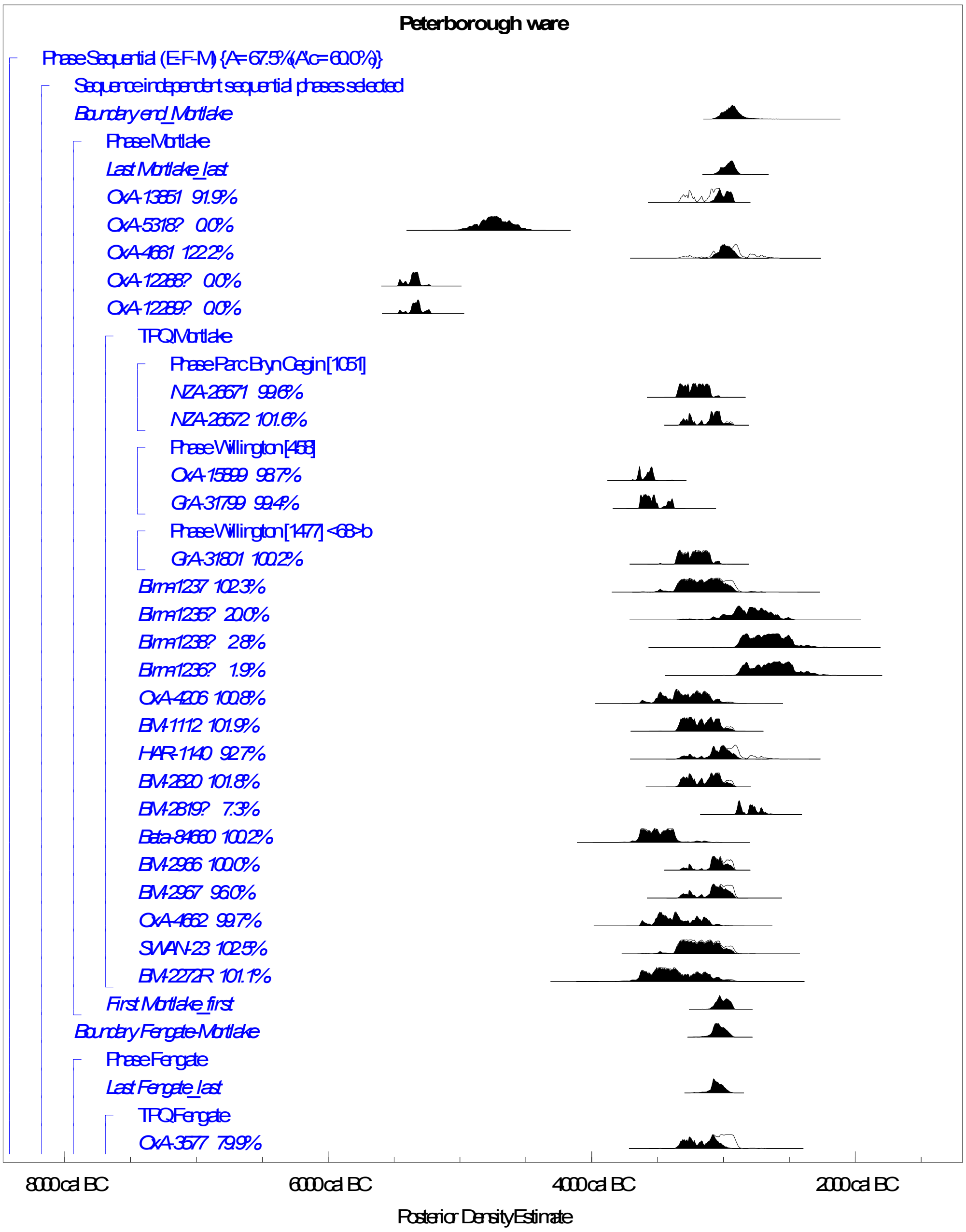

Phase Mortlake
TPQ Mortlake
Phase Willington [1477] <68>b
GrA-31801 100.8%
Birm-1237 99.0%
Birm-1235? 3.8%
Birm-1238? 0.1%
Birm-1236? 0.0%
OxA-4206 102.7%
BM-1112 108.4%
HAR-1140 37.2%
BM-2820 98.7%
BM-2819? 0.0%
Beta-84660 100.9%
BM-2966 64.8%
BM-2967 59.7%
OxA-4662 103.8%
SWAN-23 106.7%
BM-2272R 106.7%
First Mortlake_first
Boundary Ebbsfleet-Mortlake
Phase Ebbsfleet
Last Ebbsfleet_last
TPQ Ebbsfleet
Phase Raunds [5261]
OxA-7943 99.7%
OxA-7944 99.5%
CAR-670 95.5%
CAR-114 55.0%
CAR-116 105.1%
OxA-14483 105.3%
OxA-13874 77.4%
OxA-13853 113.1%
GrA-29353 42.4%
First Ebbsfleet_first
Boundary start_Ebbsfleet
7000cal BC
6000cal BC
5000cal BC
4000cal BC
3000cal BC
2000cal BC
Posterior Density Estimate

Figure 21 Probability distributions of dates Peterborough ware (model D): each distribution represents the relative probability that an event occurs at a particular time. For each of the radiocarbon dates two distributions have been plotted, one in outline, which is the result of simple radiocarbon calibration, and a solid one, which is based on the chronological model used. The other distributions correspond to aspects of the model. For example, the distribution '*Boundary Fengate'_Mortlake* is the estimated date for the end of use of the Fengate style of Peterborough ware and the start of the Mortlake style. A question mark (*?*) indicates that the result has been excluded from the model. The large square brackets down the left hand side along with the OxCal keywords define the model exactly.



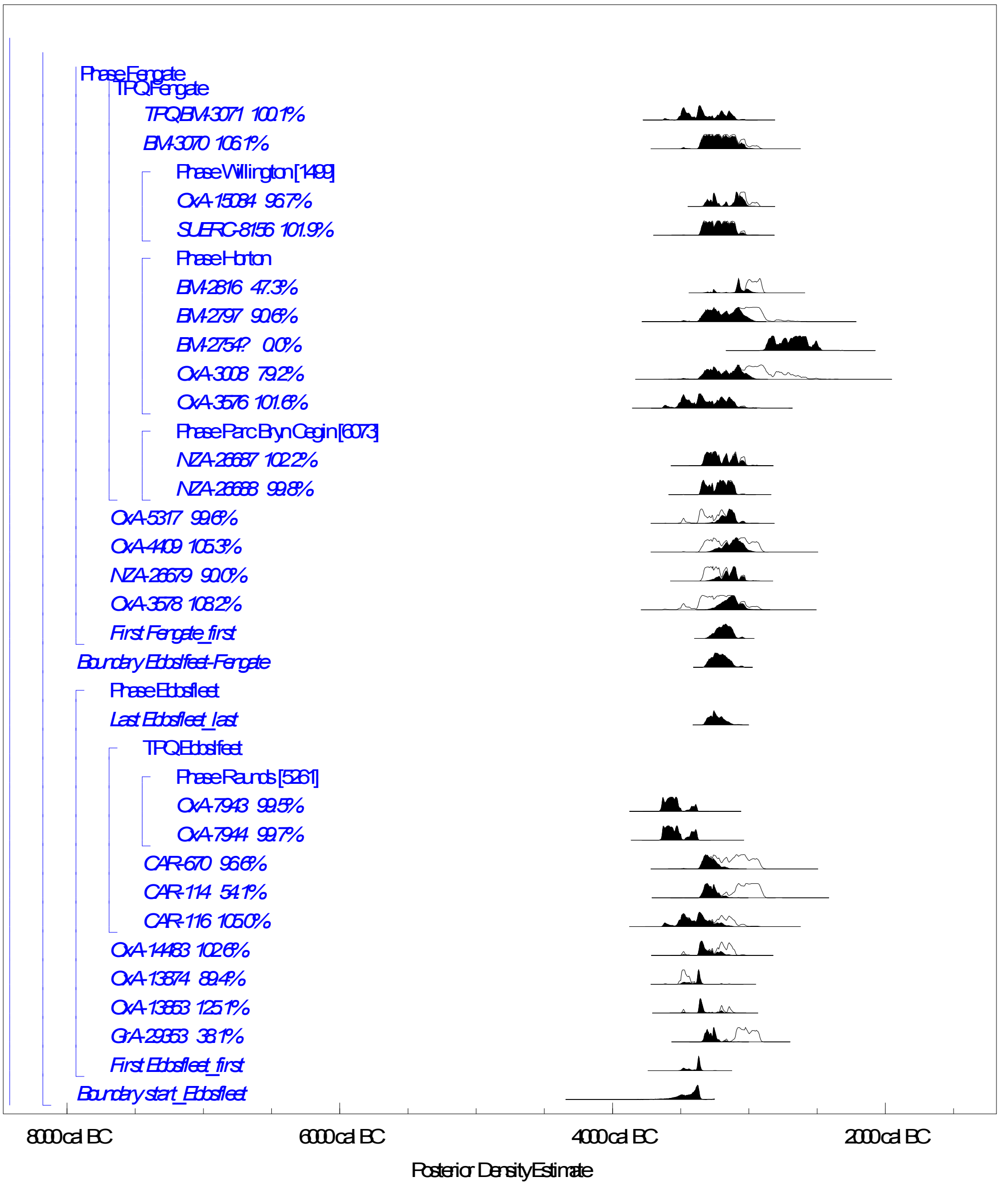

Phase Fengate
TPQ Fengate
TPQ BM-3071 100.1%
BM-3070 106.1%
Phase Willington [1499]
OxA-15084 96.7%
SUERC-8156 101.9%
Phase Horton
BM-2816 47.3%
BM-2797 90.6%
BM-2754? 0.0%
OxA-3008 79.2%
OxA-3576 101.6%
Phase Parc Bryn Cegin [6073]
NZA-26687 102.2%
NZA-26688 99.8%
OxA-5317 99.6%
OxA-4409 105.3%
NZA-26679 90.0%
OxA-3578 108.2%
First Fengate_first
Boundary Ebbsfleet-Fengate
Phase Ebbsfleet
Last Ebbsfleet_last
TPQ Ebbsfleet
Phase Raunds [5261]
OxA-7943 99.5%
OxA-7944 99.7%
CAR-670 96.6%
CAR-114 54.1%
CAR-116 105.0%
OxA-14483 102.6%
OxA-13874 89.4%
OxA-13853 125.1%
GrA-29353 38.1%
First Ebbsfleet_first
Boundary start_Ebbsfleet
8000cal BC
6000cal BC
4000cal BC
2000cal BC
Posterior Density Estimate

Figure 22 Probability distributions for the transitions between phases (model D) assuming a sequential sequence derived from the model shown in Figure 21