APPENDIX 2: RADIOCARBON DATING

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An integral element of the post-excavation analysis at both Cutacre and Kingsway involved the selection of suitable samples, which could be subjected to radiocarbon assay. At Cutacre, 14 samples were dated from Cinder Hill (Site 42), which, it was anticipated, would provide robust chronologies for the prehistoric roundhouse and associated four-post structures in the southern part of the site, and also secure dates for the bloomery site to the north. This programme of dating followed those recommendations set out by Patrick Ashmore (1999), in that single-entity short-lived samples were selected, specifically single charred plant remains or individual fragments of charcoal. This selection technique, whereby appropriate single-entity samples are selected from reliable contexts, is now viewed as essential to avoid any disturbance from older fragments of charcoal, which may be present in bulk samples (*ibid*). In addition, multiple radiocarbon assays were obtained, to provide more reliable dates and, where possible, the selected samples were derived from sealed deposits located close to the base of a feature, and from deposits which contained diagnostic artefacts, to confirm the suspected date of these contexts.

In addition to the short-lived materials from Cinder Hill, organic elements from two monoliths were also subjected to radiocarbon assay, to provide a chronological framework for pollen analysis (*Appendix 1*). One of these monoliths was extracted from a palaeochannel (***1305***) at Wharton Hall (Site 70), at Cutacre. An indeterminate fragment of waterlogged wood and the humic and humin fractions from a sample of waterlogged clay were subjected to radiocarbon assay. The other monolith was extracted from an area of peat identified at the Kingsway Business Park, and from this humic and humin acid samples of peat, organic silt, and silty peat, along with a fragment of charcoal, were subjected to radiocarbon assay.

All of the selected samples were dated using the accelerator mass spectrometry (AMS) technique, which allows small quantities of carbon to be dated (Gowlett and Hedges 1986). This was undertaken at the Scottish Universities Environmental Research Centre (SUERC; full details of methods and procedures can be obtained from the Centre).

Results and Calibration

The radiocarbon results derived from the programme of dating are presented as conventional radiocarbon ages (Table 9; Stuiver and Polach 1977), and are quoted in accordance with the international standard known as the Trondheim convention (Stuiver and Kra 1986). The results have been calibrated using IntCal13 (Reimer *et al* 2013), and OxCal v4.2 (Bronk Ramsey 1995; 1998; 2001; 2009), and the date ranges have been calculated using the maximum intercept method (Stuiver and Reimer 1986). The calibrated date ranges have been rounded outwards to ten years (*cf* Mook 1986), using the 'round-up' function in OxCal v4.2. The probability distributions shown in the figures were obtained by the probability method (Stuiver and Reimer 1993).

The calibrated results indicate that the roundhouse and four-post structures at Cinder Hill, Cutacre (*Ch 2, pp 25, 28*), all date to the latter half of the second millennium cal BC (Fig 123). Thus, the features clearly all date to the Middle Bronze Age (*c* 1500-1150 cal BC).

The other dated material from Cinder Hill all produced medieval dates (Fig 124). Of these, one (SUERC-56416), a fragment of alder charcoal from gully ***700*** (*Ch 3, p 49*), produced a date in the early medieval period, though this appears to represent residual material, since this gully also produced late medieval pottery (*Appendix 4, p 337*). The remaining dates span the earlier part of the later medieval period, suggesting activity in the northern part of the site occurred sometime between the late eleventh and early fifteenth centuries.

The remaining radiocarbon assays relate to the pollen monoliths that were extracted from a palaeochannel

Area/site/ association	Laboratory code	Material	Context/depth	Radiocarbon age (BP)	δ^{13}C (‰)	Calibrated date range (95% confidence)
Cutacre: Cinder Hill (Site 42S): roundhouse	SUERC-56655	Alder/hazel (*Alnus*/*Corylus*) charcoal	Fill (*848*) of post-pipe ***846***, in posthole ***844***, one of the posts in the post-ring	3035±32	-27.1	1410-1200 cal BC
	SUERC-56427	Alder/hazel (*Alnus*/*Corylus*) charcoal	Fill (***843***) of post-pipe ***842***, in posthole ***828***, one of the posts in the post-ring	2989±38	-27.7	1390-1050 cal BC
	SUERC-56428	Hazel (*Corylus avellana*) charcoal	Fill (***872***) of post-pipe ***871***, in posthole ***869***, part of the porch	2968±38	26.4	1370-1050 cal BC
Cutacre: Cinder Hill (Site 42S): four-post structures and fence/ windbreak	SUERC-56418	Charred barley (*Hordeum* sp) grain	Fill (***554)*** of posthole ***555***, part of the primary four-post structure	3091±38	-24.5	1440-1230 cal BC
	SUERC-56419	Charred barley (*Hordeum* sp) grain	Fill (***834***) of post-pipe ***849***, in posthole ***836***, part of the primary four-post structure	3075±38	-24.7	1430-1230 cal BC
	SUERC-56420	Alder (*Alnus glutinosa*) charcoal	Fill (***850***) of post-pipe ***851***, in posthole ***853***, part of replacement four-post structure	3052±38	-28.3	1420-1210 cal BC
	SUERC-56425	Charred wheat (*Triticum* sp) grain	Fill (***552***) of posthole ***553***, part of possible fence/ windbreak surrounding four-post structure(s)	3092±38	-24.3	1440-1250 cal BC
Cutacre: Cinder Hill (Site 42S): charcoal clamp	SUERC-56421	Alder (*Alnus glutinosa*) charcoal	Fill (***865***) of charcoal-burning pit ***864***	720±38	-29.3	cal AD 1220-1390
Cutacre: Cinder Hill (Site 42N): bloomery site	SUERC-56410	Alder/hazel (*Alnus*/*Corylus*) charcoal	Fill (***591***) of furnace ***588***	828±38	-26.9	cal AD 1050-1280
	SUERC-56411	Hazel (*Corylus avellana*) charcoal	Fill (***702***) of pit ***703***	698±38	-26.1	cal AD 1250-1400
	SUERC-56415	Alder/hazel (*Alnus*/*Corylus*) charcoal	Fill (***587***) of tapping pit ***581***; associated with furnace ***588***	817±38	-27.4	cal AD 1150-1280

Table 9: Radiocarbon results from Cutacre and Kingsway

Area/site/ association	Laboratory code	Material	Context/depth	Radiocarbon age (BP)	$\delta^{13}C$ (‰)	Calibrated date range (95% confidence)
Cutacre: Cinder Hill (Site 42N): bloomery site	SUERC-56416	Alder (*Alnus glutinosa*) charcoal	Fill (***701***) of gully/ditch ***700***	1451±38	-25.9	cal AD 540-660
	SUERC-56417	Hazel (*Corylus avellana*) charcoal	Fill (***721***) of tapping pit ***720***; associated with furnace ***722***	832±38	-26.6	cal AD 1050-1280
	SUERC-56426	Alder/hazel (*Alnus*/*Corylus*) charcoal	Fill (***503***) of pit ***715***	544±38	-25.8	cal AD 1300-1440
Cutacre: Wharton Hall (Site 70): palaeochannel ***1305***	SUERC-56429	Waterlogged wood (indeterminate)	Pollen core: 0.37-0.38 m depth	118±38	-24.8	cal AD 1670-1940
	SUERC-58092	Organic clay; humic acid	Pollen core: 0.39-0.40 m depth	1139±30	-30.0	cal AD 770-990
	SUERC-58093	Organic clay; humin	Pollen core: 0.39-0.40 m depth	2508±30	-25.0	790-540 cal BC
	SUERC-58647	Organic clay; humin	Pollen core: 0.39-0.40 m depth	2415±29	-29.1	750-400 cal BC
Kingsway: peat deposit	SUERC-7791	Peat: humic acid	Pollen core: 0.76-0.77 m depth	4230±50	-28.8	2920-2630 cal BC
	SUERC-7792	Organic silt: humic acid	Pollen core: 1.32 m depth	5425±50	-29.8	4360-4060 cal BC
	SUERC-7793	Charcoal	Pollen core: 1.635-1.645 m depth	6305±50	-28.8	5470-5110 cal BC
	SUERC-7794	Silty peat: humic acid	Pollen core: 1.71-1.72 m depth	6545±50	-28.8	5620-5380 cal BC

Table 9: Radiocarbon results from Cutacre and Kingsway (cont'd)

at Wharton Hall (Site 70; Fig 125; *Appendix 1*), Cutacre, and the deposit of peat at the Kingsway Business Park (Fig 126; *Appendix 1*). Initially, during the early stages of the post-excavation analysis, a fragment of indeterminate waterlogged wood from the monolith from Wharton Hall was selected for dating (SUERC-56429). However, this returned a modern date and was thus thought to

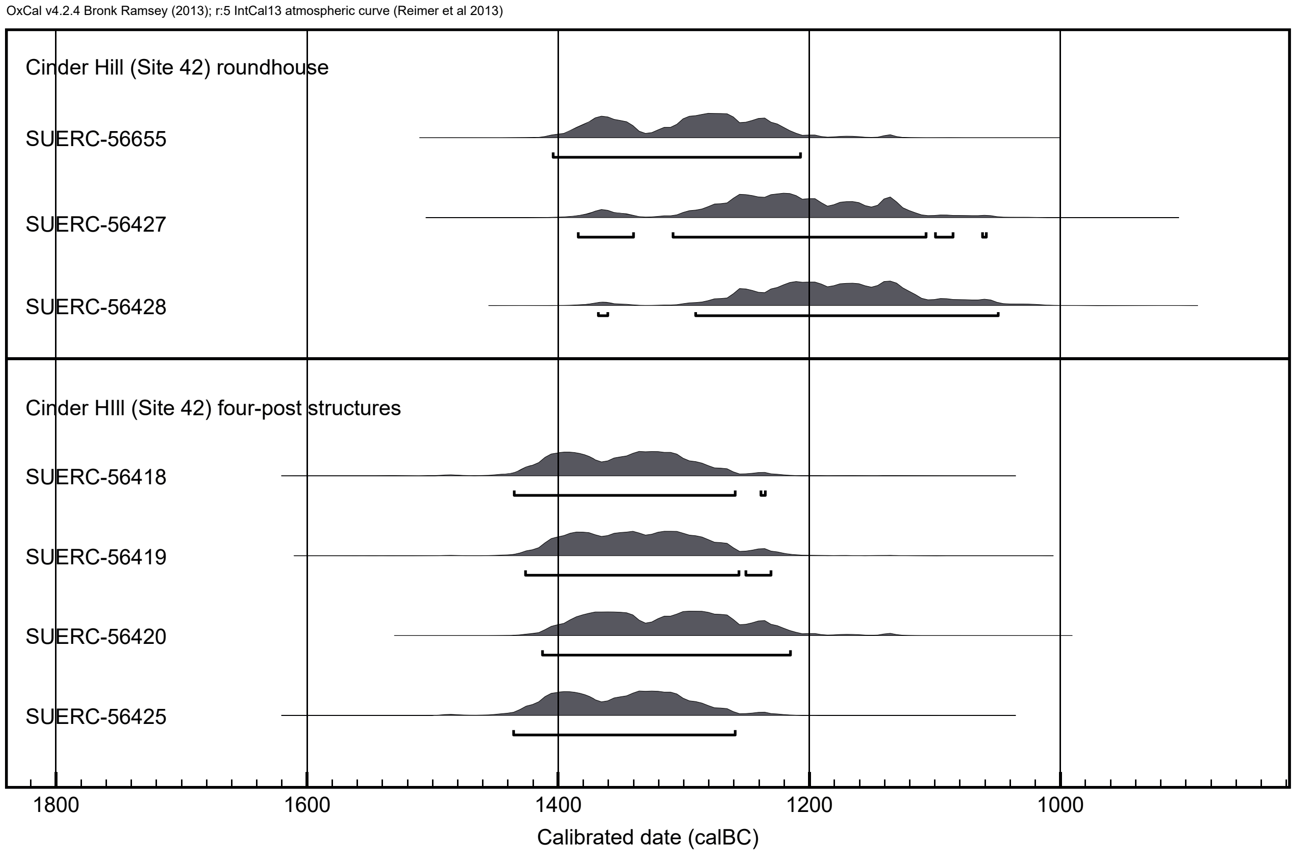

Figure 123: Probability distributions of the Bronze Age calibrated radiocarbon (AMS) assays from Cinder Hill (Site 42), Cutacre

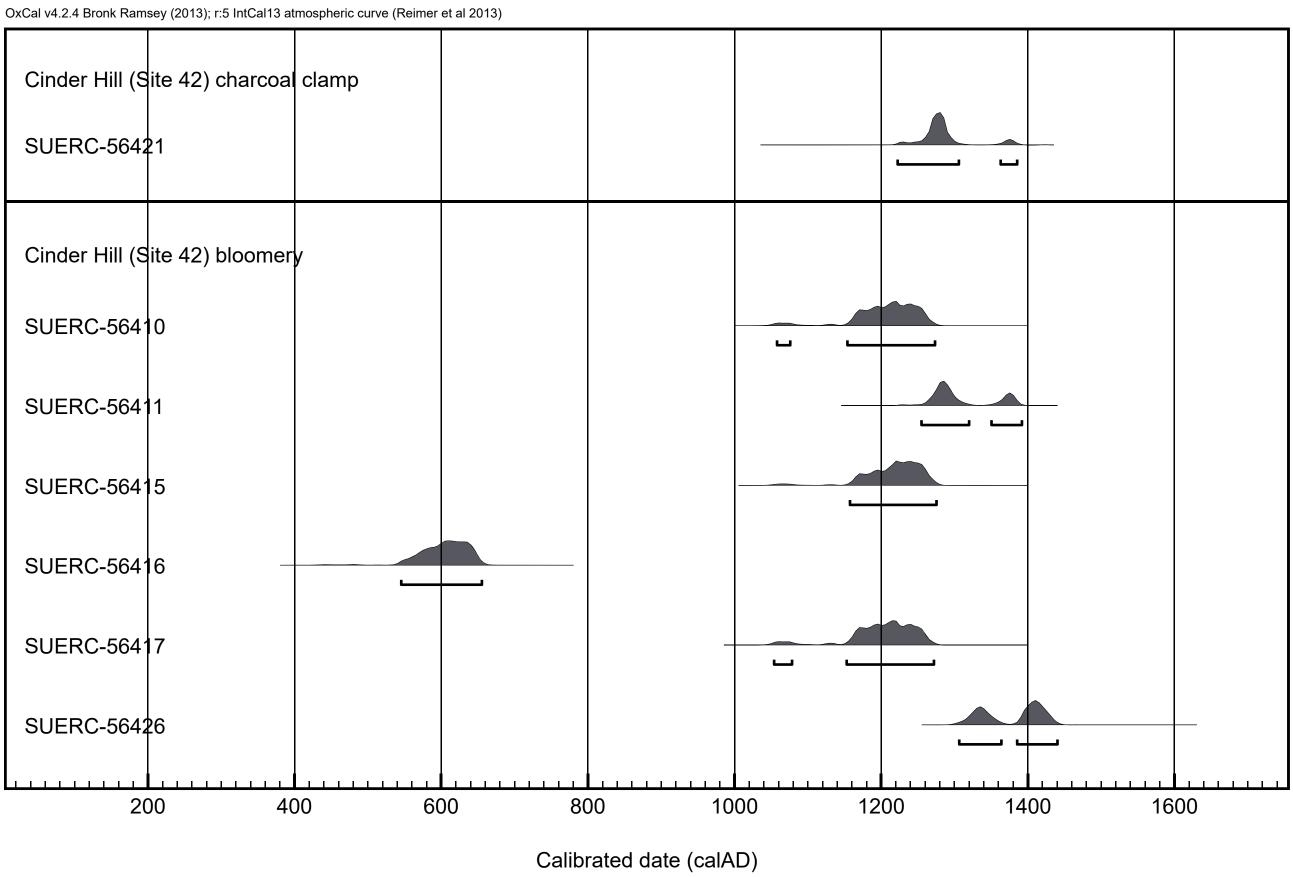

Figure 124: Probability distributions of the calibrated medieval radiocarbon (AMS) assays from Cinder Hill (Sites 42), Cutacre

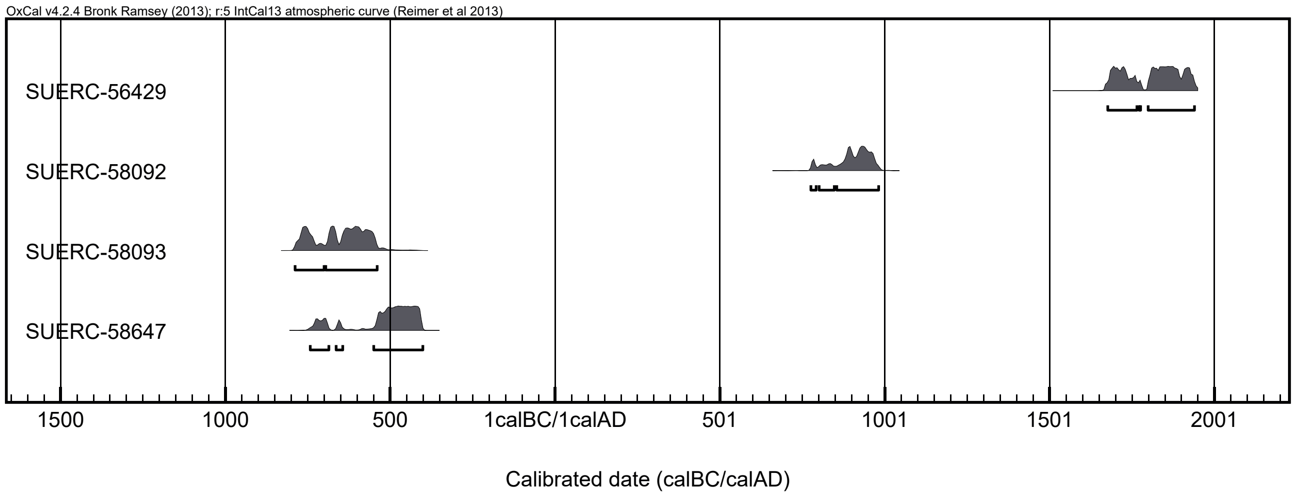

Figure 125: Probability distributions of the calibrated radiocarbon (AMS) dates from palaeochannel **1305**, *Wharton Hall (Site 70), Cutacre*

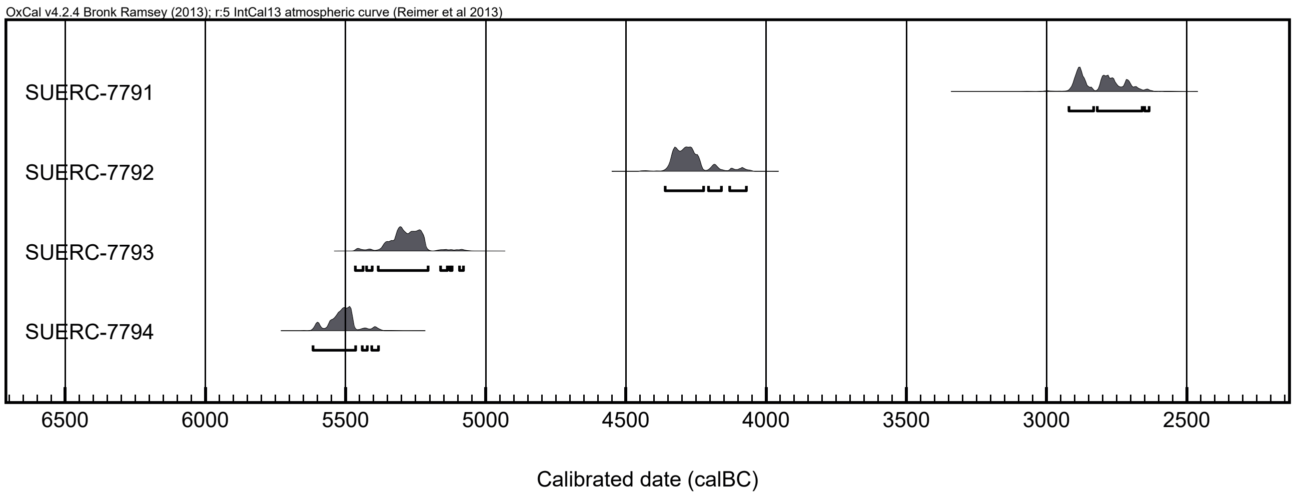

Figure 126: Probability distributions of the calibrated radiocarbon (AMS) dates from the peat deposit, Kingsway

have been an intrusive item. Therefore, sediment dates were obtained on a sample of organic clay from the monolith, derived from both the humic acid and humin within the sample (SUERC-58093 and SUERC-58093). However, these returned incongruous results, with the humic acid dating to the early medieval period and the humin to the early Iron Age. Given the presence of this older date from the humin, the radiocarbon-dating laboratory repeated the dating of the humin fraction (SUERC-58647). This confirmed the earlier result, as it again produced an early Iron Age date, and the radiocarbon-dating laboratory has suggested that the age difference may be due to the combustion of older clay forming residual material within the humin. Given this, the early medieval date is treated as the more reliable date, and this has been used to date the pollen sequence. The Kingsway peat deposit produced three late Mesolithic dates (SUERC-7972-4) from lower down in the sequence, and one late Neolithic date (SUERC-7971) from the upper part of the sequence.

Chi-square Testing

Following the completion of the radiocarbon-dating programme, some of the dates were statistically tested, to establish their consistency and, in turn, to assist in the formulation of a chronological hypothesis. The statistical technique employed was the non-Bayesian chi-square (χ^2) test of Ward and Wilson (1978), which can be used to determine whether duplicate dates are actually of the same age. The analysis was performed using the 'R_Combine' function in OxCal v4.2, with v representing the degree of freedom, and with the level of significance being set at 0.05 (T′(5%)). In this test, radiocarbon dates are considered statistically consistent when the T value (T′) is lower than the critical value (T′(5%)).

Cinder Hill, Bronze Age settlement

The radiocarbon dates from the roundhouse were statistically consistent (Table 10). Although two

Radiocarbon assay	Radiocarbon age (BP)	χ^2 test
SUERC-56655	3035±32	T′=2.0; T′(5%)=6.0; v=2 (statistically consistent)
SUERC-56427	2989±38	
SUERC-56428	2968±38	

Table 10: Chi-square test on the radiocarbon assays from the Bronze Age roundhouse, Cinder Hill

Radiocarbon assay	Radiocarbon age (BP)	χ^2 test
SUERC-56418	3091±38	T′=0.7; T′(5%)=7.8; v=3 (statistically consistent)
SUERC-56419	3075±38	
SUERC-56420	3052±38	
SUERC-56425	3092±38	

Table 11: Chi-square test on the radiocarbon assays from the Bronze Age four-post structures and fence/windbreak, Cinder Hill

Radiocarbon assay	Radiocarbon age (BP)	χ^2 test
SUERC-56655	3035±32	T′=10.0; T′(5%)=12.6; v=6 (statistically consistent)
SUERC-56427	2989±38	
SUERC-56428	2968±38	
SUERC-56418	3091±38	
SUERC-56419	3075±38	
SUERC-56420	3052±38	
SUERC-56425	3092±38	

Table 12: Chi-square test on the radiocarbon assays from the Bronze Age features, Cinder Hill

Radiocarbon assay	Radiocarbon age (BP)	χ^2 test
SUERC-56410	828±38	T′=0.0; T′(5%)=3.8; v=1 (statistically consistent)
SUERC-56415	817±38	

Table 13: Chi-square test on the radiocarbon assays from furnace **588**, *Cinder Hill*

successive buildings were identified in the four-post structures, the dates derived from each are also statistically consistent. This appears to indicate that either the original structure was replaced after a comparatively short period of time, or that the dated material from the secondary structure derived from the primary structure. The possible windbreak, or fence, surrounding the four-post structures was also consistent with both sets of dates (Table 11). Moreover, it is highly probable that the four-post structures and the windbreak/fence were contemporary with the roundhouse.

Tellingly, when all of these dates were subjected to the chi-square test, these were also statistically consistent (Table 12).

Cinder Hill, late medieval activity

One of the late medieval furnaces (***588***; *Ch 5, pp 44-8*) produced two radiocarbon dates. When subjected to chi-square testing, these dates are also statistically consistent (Table 13). When combined, these produce a date of cal AD 1160-1270 (based on a weighted mean of 823±27 BP), for the use of the furnace.

Chronological Modelling: the Bronze Age Settlement at Cutacre

Following statistical testing, chronological modelling was performed using OxCal v4.2 (Bronk Ramsey 2009). The aim was to produce more robust chronologies for the Bronze Age settlement at Cutacre, as represented by the dates from the roundhouse, and the four-post structures and windbreak, which were probably in existence when the house was occupied.

Modelling adopted a Bayesian approach (*cf* Lindley 1985; Buck *et al* 1996; Bayliss 2007; Bayliss *et al* 2007), which allows for the calculation of 'posterior beliefs', following consideration of 'standardised likelihoods' (*ie* radiocarbon dates) and 'prior beliefs' (*ie* the archaeological remains). Following standard practice, the outputs from this modelling (posterior-density estimates) are quoted in italics.

In the output plot of the models, two probability distributions are shown for each result. That in outline is the calibrated radiocarbon date, whilst the dark distribution represents the posterior-density estimate produced by the Bayesian statistical model. Within the plot, the brackets and OxCal Command Query Language keywords define the model exactly (Bronk Ramsey 2009).

The model for the Bronze Age features (Fig 127) has a good overall agreement value (Amodel: 87), and it passes the acceptable agreement indices (*ie* Amodel value is above 60; *ibid*). Based on the features dated from the site, this model suggests that the settlement was established in *1480-1260 cal BC* (*95% probability*) or *1420-1300 cal BC* (*68% probability*; *Boundary Start Bronze Age settlement*) and ended in *1380-1080 cal BC* (*95% probability*) or *1290-1170 cal BC* (*68% probability*; *Boundary End Bronze Age settlement*). The model estimates that the activity sampled at the settlement spanned *0-350 years* (*95% probability*) or *0-180 years* (*68% probability*; *Settlement Span*; Fig 128).

Order Analysis: the Medieval Bloomery at Cutacre

The late medieval radiocarbon dates from Cinder Hill indicate that the bloomery activity broadly occurred between the eleventh and fifteenth centuries. However, it is also possible to order the radiocarbon dates from each of the features to determine a possible sequence. This analysis was performed using the 'Order' function in OxCal v4.2, which provides a probability for a specific date being earlier than (<) another specific date (Table 14). As two statistically consistent dates were derived from furnace ***588*** (Table 13; *Ch 3, p 44*), these dates were modelled and the estimated date (prior) relating to its first use was used in the analysis. This modelling suggests that the furnace was used in *cal AD 1150-1260* (*95% probability*) or *cal AD 1170-1240* (*68% probability*; *First_588*).

The analysis suggests that the earliest dated features associated with the bloomery site were furnaces ***588*** and ***722*** (*Ch 3, p 44*), as there are low probabilities that any of the other dated features were earlier in date. It is highly likely that these were broadly contemporary, as there is a 52.07% chance that the use of furnace ***588*** was earlier than furnace ***722***. Charcoal clamp ***864*** (*Ch 3, p 49*) was the next dated feature in the sequence, as this was clearly later than furnaces ***588*** or ***722***. It is also possible that this clamp was broadly contemporary with the activity that produced the dated material derived from pit ***703*** (*Ch 3, p 50*). There is, for instance, a 30.39% probability that charcoal from pit ***703*** was earlier than the charcoal clamp. The latest dated activity at the site relates to the charcoal derived from pit ***715*** (*Ch 3, p 50*), as there is only an 11.41% probability that the dated material from this is earlier than that from ***703***, suggesting that the charcoal from pit ***715*** relates to a later phase of activity at the site. Based on the possible ordering of the radiocarbon dates there appear, therefore, to be a least three phases of activity at the site.

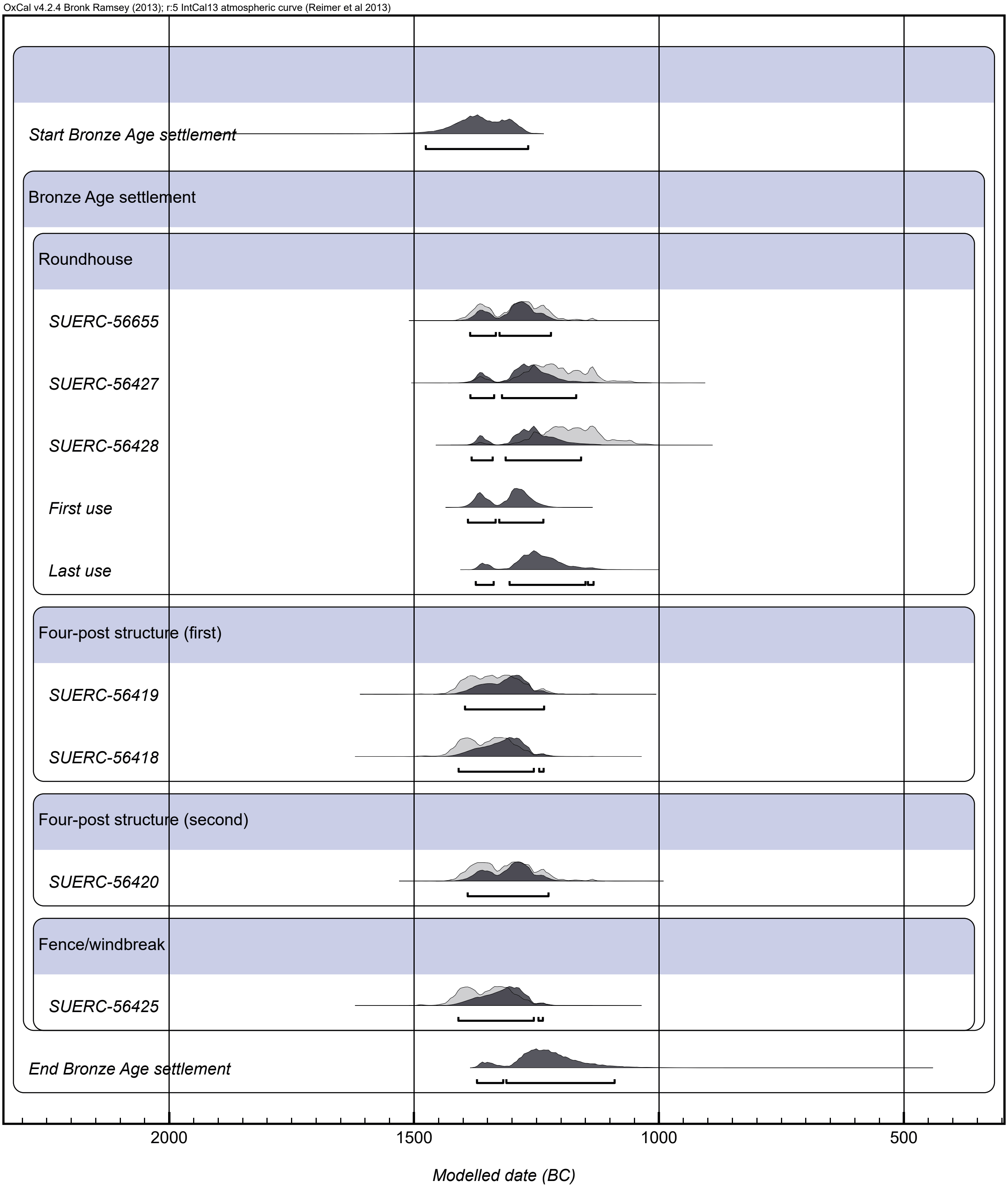

Figure 127: The modelled radiocarbon (AMS) assays relating to the Cinder Hill Bronze Age settlement (Site 42S)

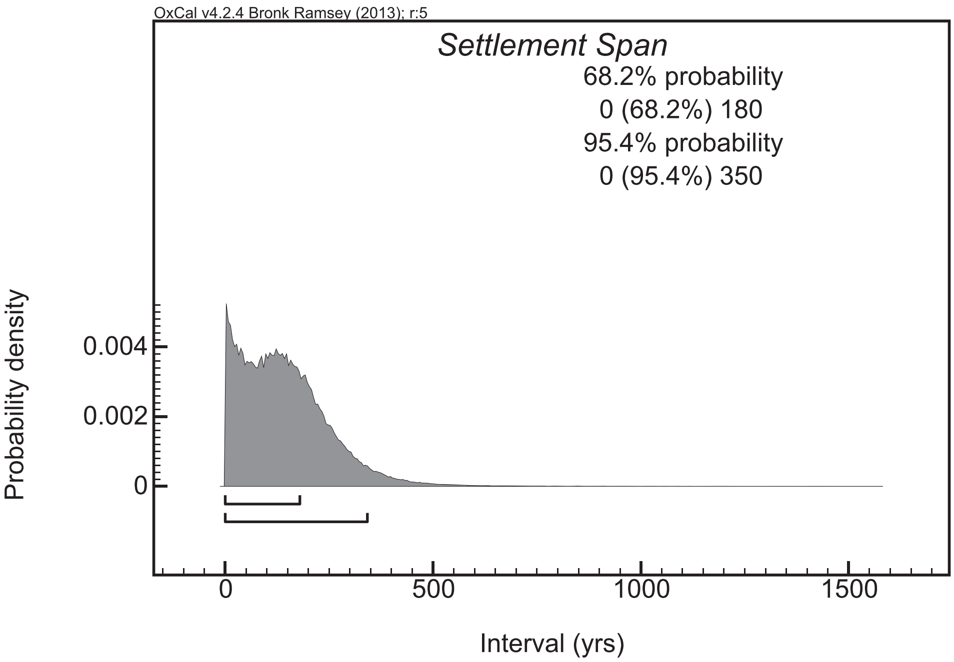

Figure 128: The modelled span of the Cinder Hill Bronze Age settlement (Site 42S)

Probability $t_1<t_2$					
t_1	**t_2**				
	Charcoal clamp ***864***	Furnace ***588*** (prior)	Pit ***703***	Furnace ***722***	Pit ***715***
Charcoal clamp ***864***	-	1.76%	69.6%	2.88%	95.12%
Furnace ***588*** (prior)	98.24%	-	99.63%	52.07%	100%
Pit ***703***	30.39%	0.36%	-	0.71%	88.60%
Furnace ***722***	97.12%	47.93	99.28%	-	100%
Pit ***715***	4.88%	0%	11.41%	0%	-

Table 14: Order analysis on late medieval radiocarbon dates from Cinder Hill