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Section 6:
The radiocarbon dating

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20. Interpreting the chronology of the cist

Peter Marshall, Christopher Bronk Ramsey, Nicola Russell, Fiona Brock and Paula Reimer

The wide range of organic material preserved in the cist provided the opportunity for determining a robust chronology for the cremation and its associated grave goods. In addition, the peat mound into which the cist had been placed had the potential to provide an environmental setting and context for the burial.

Radiocarbon dating

Cist

Twelve radiocarbon determinations have been produced on samples of cremated bone, waterlogged wood, plant material and charcoal from the cist (Table 20.1). These were dated between 2012 and 2014 by Accelerator Mass Spectrometry (AMS) at the Scottish Universities Environmental Research Centre in East Kilbride (SUERC), Queen's University, Belfast (UBA), and the Oxford Radiocarbon Accelerator Unit (OxA).

At SUERC the waterlogged wood and plant macrofossils were pre-treated as described by Stenhouse and Baxter (1983) and the cremated bone followed Lanting *et al.* (2001). CO_2 obtained from the pre-treated samples was combusted in pre-cleaned sealed quartz tubes (Vandeputte *et al.* 1996) and then converted to graphite (Slota *et al.* 1987). The samples were dated by AMS as described by Freeman *et al.* (2010).

The samples dated at Queen's University Belfast were processed using an acid-alkali-acid pre-treatment as first outlined in de Vries and Barendsen (1952). The pre-treated and dried samples were placed in quartz tubes with a strip of silver ribbon to remove nitrates, chlorides and CuO. The samples were then sealed under vacuum and combusted to CO_2 overnight at 850°C. The CO_2 was converted to graphite on an iron catalyst using the zinc reduction method (Vogel *et al* 1984). The graphite samples were analysed with an 0.5MeV NEC pelletron compact accelerator, with the $^{14}C/^{12}C$ ratios corrected for fractionation using the on-line measured $^{13}C/^{12}C$ ratio and in accordance with Stuiver and Polach (1977).

Those dated at Oxford were prepared and dated as described by Brock *et al.* (2010), Dee and Bronk Ramsey (2000) and Bronk Ramsey *et al.* (2004).

Three samples failed: at SUERC a fragment of cremated bone (GU-27037) did not produce sufficient CO_2; at Oxford a fragment of pelt/fur (P31392) completely dissolved in the base wash and leather (P31393) from the textile and animal-skin object survived pre-treatment until the bleach step, when it completely dissolved.

Peat monoliths

The eight radiocarbon measurements obtained on samples from the peat monoliths were dated by AMS at SUERC in 2006 and 2012.

The samples dated at SUERC were pre-treated using methods outlined in Stenhouse and Baxter (1983), combusted following Vandeputte *et al.* (1996), graphitised as described by Slota *et al.* (1987) and measured by AMS (Freeman *et al.* 2010; Xu *et al.* 2004). For each of the 'bulk' peat samples both the alkali-soluble ('humic acid') and alkali- and acid-insoluble ('humin') fractions were dated.

Radiocarbon quality assurance

Internal quality assurance procedures and international inter-comparisons (Scott 2003; Scott *et al.* 2010) indicate no laboratory offsets and validate the measurement precision quoted.

The results reported (Tables 20.1 and 20.2) are conventional radiocarbon ages (Stuiver and Polach 1977).

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Table 20.1: Whitehorse Hill cist; radiocarbon dates.

Laboratory number	*Sample reference*	*Material and context*	*Radiocarbon age (BP)*	*$\delta^{13}C$ (‰)*	*Calibrated date (95% confidence) cal BC*	*PDE (95% probability) cal BC*
Stakes						
SUERC-40124	WH11 – SF1	Wood, *Corylus* <10 yrs old (R Brunning). Horizontal stake found on eastern side of cist, parallel & level with cist's basal stone.	3500±30	−27.8	1920–1700	*1895–1740 (92%) or 1715–1695 (3%)*
OxA-26377	WH11 – SF2	Wood, *Corylus* <10 ys old (R Brunning). Vertical stake found on north side of cist, running up length of cist stone M.	3437±28	−25.6	–	
OxA-27447	WH11 – SF2	As OxA-26377	3457±27	−25.4	–	
	WH11 – SF2	Weighted mean OxA-26377 & OxA-27447 (T'= 0.3; T'(5%)= 3.8; ν= 1; Ward and Wilson 1978).	3447±20		1875–1690	*1875–1840 (7%) or 1815–1795 (3%) or 1780–1685 (85%)*
Cremation						
OxA-26376	WH11 – cremation (sample A)	Cremated human long bone fragment (S Mays), spit D, quadrant 3.	3511±29	−21.5	1930–1740	*1905–1740*
GU-27037	WH11 – cremation (sample B)	As OxA-26376	Failed to produce enough CO_2			
SUERC-52451	WH11 – cremation charcoal (sample A)	Charcoal *Corylus* sp., moderate ring curvature, 4 growth rings (20mg) (Z Hazell).	3528±29	−28.0	1950–1750	*1925–1755*
UBA-25300	WH11 – cremation charcoal (sample B)	Charred grass culm base (30mg) (Z Hazell).	3423±34	−27.3	1880–1630	*1870–1845 (3%) or 1815–1795 (2%) or 1780–1635 (91%)*
P31393	WH11 – leather and textile object	Leather (E Cameron) from textile & animal-skin object, from spit C (2–3cm).	Failed in pre-treatment			
P31392	WH11 – pelt/fur	Pelt/fur (E Cameron) from animal pelt.	Failed in pre-treatment			
OxA-27446	WH11 – pelt/fur	As P31392	3358±30	−20.9	1740–1560	*1745–1620*
OxA-27543	WH11 – basketry container	Unidentified plant remains from basketry container.	3405±33	−27.9	1870–1620	*1770–1630*
OxA-27915	WH11 – wooden stud	*Euonymus europaeus* (spindle) stud (G Campbell).	3709±33	−26.8	2210–1980	*2200–2010 (90%) or 2000–1975 (5%)*
Matted vegetation						
SUERC-52450	WH11 – matted vegetation – spit C (2–3cm)	*Molinia* stem (20mg) (G Campbell).	3433±29	−25.0	1880–1660	*1875–1840 (7%) or 1815–1795 (3%) or 1780–1645 (88%)*
OxA-30025	WH11 – matted vegetation – spit J (11–12cm) sample A	*Molinia* stem (20mg) (G Campbell).	3357±30	−25.3	1740–1560	*1740–1710 (12%) or 1700–1620 (77%)*
UBA-25301	WH11 – matted vegetation – spit J (11–12cm) sample B	*Molinia* stem (20mg) (G Campbell).	3378±37	–	1760–1560	*1750–1620*

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Table 20.2: Whitehorse Hill monoliths: radiocarbon dates.

Laboratory Number	*Sample reference*	*Material*	*Radiocarbon Age (BP)*	*$\delta^{13}C$ (‰)*	*Calibrated date (95% confidence) cal BC*
SUERC-40113	WH05 (45–46cm)	Peat: humic acid	3370±30	−28.6	1750–1540
SUERC-40114	WH05 (45–46cm)	Peat: humin fraction	3410±30	−29.2	1870–1620
SUERC-10198	WHH45 (45–46cm)	Plant macrofossils: *Eriophorum vaginatum* (hare's-tail cotton-grass) sclerenchymatous spindles	3650±50	−27.0 (assumed)	2200–1890
SUERC-40118	WH05 (101–102cm)	Peat: humic acid	4280±30	−28.2	2920–2880
SUERC-40119	WH05 (101–102cm)	Peat: humin fraction	4345±30	−29.0	3080–2890
SUERC-10199	WHH45 (101–102cm)	Plant macrofossils: *Eriophorum vaginatum* (hare's-tail cotton-grass) sclerenchymatous spindles	4625±50	−27.0 (assumed)	3630–2140
SUERC-40120	WH11 monolith 3 (1.04–1.05m) bottom	Peat: humic acid	5080±30	−28.1	3970–3790
SUERC-40121	WH11 monolith 3 (1.04–1.05m) bottom	Peat: humin fraction	5200±30	−28.9	4050–3960
SUERC-40122	WH11 monolith 1 (24–25cm)	Peat: humic acid	3205±30	−28.6	1530–1410
SUERC-40123	WH11 monolith 3 (24–25cm)	Peat: humin fraction	3330±30	−28.9	1690–1520

The calibrated date ranges have been calculated by the maximum intercept method (Stuiver and Reimer 1986), using the program OxCal v4.2 (Bronk Ramsey 1995; 1998; 2001; 2009) and the IntCal13 data set (Reimer *et al.* 2013). They are quoted in the form recommended by Mook (1986), rounded outwards to 10 years. The probability distributions of the calibrated dates have been calculated using the probability method (Stuiver and Reimer 1993) and the same data.

The samples

Construction and contents of the cist

The cist was set into a mound of peat and although a cut for the cist was not identified in section it seems improbable that it was a free-standing structure (Chapter 2). It seems conceivable that prior to the construction of the cist the two hazel (*Corylus avellana*) stakes were pushed into the peat to mark the site. SF1 (SUERC-40124) and SF2 (OxA-26377 and OxA-27447) were respectively found lying horizontally and vertically outside the cist. The two measurements on SF2 are statistically consistent (T'=0.3; T'(5%)=3.8; ν=1) and a weighted mean (WH11 – SF2; 3447±20 BP) has been taken as providing the best estimate for the age of the stake.

After the cist was constructed, the burial deposit and the accompanying items were placed inside it. The key questions identified were as follows:

- At what point in time was the site marked by the stakes and how does this relate to the finds and burial horizon within the cist?
- What is the date of the cremation burial and is there evidence for the curation of bone?
- How do the dates of the artefacts relate to the burial deposit and were the artefacts contemporary with one another and with the burial? Were any of the objects heirlooms or were they made for the grave?

The cist was block lifted and taken for excavation in the laboratory at Chippenham, where it was excavated in spits and by quadrant. This detailed excavation established that the cremation was located beneath a layer of matted plant material and had been placed within an animal hide or pelt. A second matted layer of plant material approximately 325 × 250mm, with fibres running roughly in the same direction, appeared to have been deliberately placed on the granite slab. The two radiocarbon measurements on *Molinia* stems from the matting in spit J (see Chapter 9) below the organic artefacts (OxA-30025 and UBA-25301) are statistically consistent (T'=0.2; T'(5%)=3.8; ν=1) and could therefore be of the same actual age.

A *Molinia* stem (SUERC-52450) from spit C (see Chapter 9) above the organic artefacts was also dated. As it appear that clumps of purple moor-grass were collected for use as matting around the cremated burial deposit and its associated organic artefacts (Chapters 9 and 21) the dates do not provide a constraint for deposition.

Samples from the following objects recovered from within the block were dated:

- Basketry object (OxA-27543) partially overlying the bear pelt/fur.
- Pelt/fur (OxA-27446) containing the cremation.

Two pairs of wooden studs, one pair smaller than the other, were recovered from within the basketry container during

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excavation in the laboratory at Chippenham. Fragments of wood had become detached from one of the larger ear-studs and these fragments were dated (OxA-27915).

Two fragments of cremated human bone, a fragment of charcoal (*Corylus* sp.) and a charred grass culm base were submitted for dating from the cremation. One fragment of cremated bone failed during pre-treatment. The determinations on the other three samples – calcined bone (OxA-26376), pyre fuel (UBA-25300 and SUERC-52451) – are statistically consistent (T'=6.0; T'(5%)=6.0; ν=2; Ward and Wilson 1978) and could therefore be of the same actual age.

The monoliths

The integration of archaeological and palaeoenvironmental chronologies is vital to produce meaningful reconstructions of the environmental context of past human activities (for example, Baillie 1991; Gearey *et al.* 2009; Kintigh *et al.* 2014). Producing robust chronologies for palaeoenvironmental sequences, such as pollen diagrams (Chapter 19), presents a specific set of problems. The formation processes of peat, which are the archive for palaeoenvironmental data, may show considerable complexity, including variations in sediment accumulation rates and bioturbation. Although these processes may sometimes be evident in the stratigraphy or biostratigraphy, this is by no means always the case. This has resulted in considerable debate regarding 'best practice' in radiocarbon sub-sampling procedures, in terms of the sediment fractions which might yield the most reliable estimation of the age of the horizon in question (Brock *et al.* 2011; Howard *et al.* 2009; Lowe and Walker 2000; Shore *et al.* 1995; Walker *et al.* 2001).

Environmental sampling of the peat mound into which the cist was set was initially carried out by English Heritage in 2005 (Straker 2006). Two samples were submitted for dating comprising Ericaceous leaves, stems and flower heads, and *Eriophorum vaginatum* (hare's-tail cottongrass) sclerenchymatous spindles from the level of the base of the cist (as it was believed to be in 2005) and the top of the cist.

Given the paucity of identifiable plant macrofossils in the samples assessed from the 2011 monoliths and the lack of radiometric sized bulk peat samples (Howard *et al.* 2009) due to the on-site sampling programme, the dating of bulk AMS-sized peat samples offered the only potential means of providing a chronology for the sequence adjacent to the cist. Given the inherent difficulties in obtaining accurate results from the dating of bulk AMS-sized peat samples (Bayliss 2008, fig. 9), the following samples were dated:

- From the 2005 monolith sequence, two bulk peat samples (humic and humin fractions) to determine whether consistent results could be obtained with those from 'bulk' plant macrofossils from the same horizons dated in 2005 (SUERC-10198 and SUERC-10199).
- From the 2011 monolith sequence, two bulk peat samples (humic and humin fractions) to determine the consistency of measurements on these fractions.

Results

Construction of the cist

The 12 determinations from the cremation, organic remains buried with the cist, wooden stakes and purple moor-grass (*Molinia*) are not statistically consistent (T'=84.4, T'(5%)=19.7, ν=11) and the samples clearly represent material of different ages. This is, however, entirely expected, given the range of materials dated, all of which can be expected to have 'life histories' prior to burial. The wooden stud is clearly older than the majority of material in the cist; as common spindle does not grow to excessive ages a significant age-at-death offset (Bowman 1990) can be discounted as an explanation. Even excluding the wood stud the remaining measurements are statistically inconsistent (T'=29.9, T'(5%)=18.3, ν=10).

Simple visual inspection of the calibrated radiocarbon dates does not allow us to assess the date of funerary activity at Whitehorse Hill accurately, since the calibration process does not allow for the fact that the radiocarbon dates in this group are related: they all come from the same site. Bayesian statistical modelling is required to account for this dependence (Buck *et al.* 1992; Bronk Ramsey 2000), which we have undertaken using OxCal v.4.1.2 (Bronk Ramsey 1995; 1998; 2001; 2009). The date ranges from the model defined below are given *in italics* to distinguish them from simple, calibrated radiocarbon dates.

The date for the burial of the cremation and its associated grave goods is most likely that for the latest item deposited in the cist. However, it is actually most likely that the material found within it derives mainly from close to this event, with a few older items being incorporated into it. This can be modelled by an exponential distribution – rising to greatest concentration of samples found from the end of collection, as in the model shown in Figure 20.1. Such a model makes more sense from an archaeological perspective (that is to say, a few items not collected/ made for the burial) than assuming that the dated samples represent material derived from a uniform phase of activity (Buck *et al.* 1992) associated with the burial.

The model shown in Figure 20.2 has good overall agreement (A_{model}=112) and provides an estimate for the deposition of the cremation and its associated grave goods in the cist of *1720–1615 cal BC* (*95% probability*; *burial*) and probably *1675–1615 cal BC* (*68% probability).* The wooden stud could have been as much as *315–570 years (95% probability)* old when it was deposited in the cist. Estimating the potential age of the other finds within the cist, contributing to understanding their 'biography', is, however, fraught with difficulties and has therefore not been undertaken. Although the cremation could have been 'old' when it was buried with the organic materials in the

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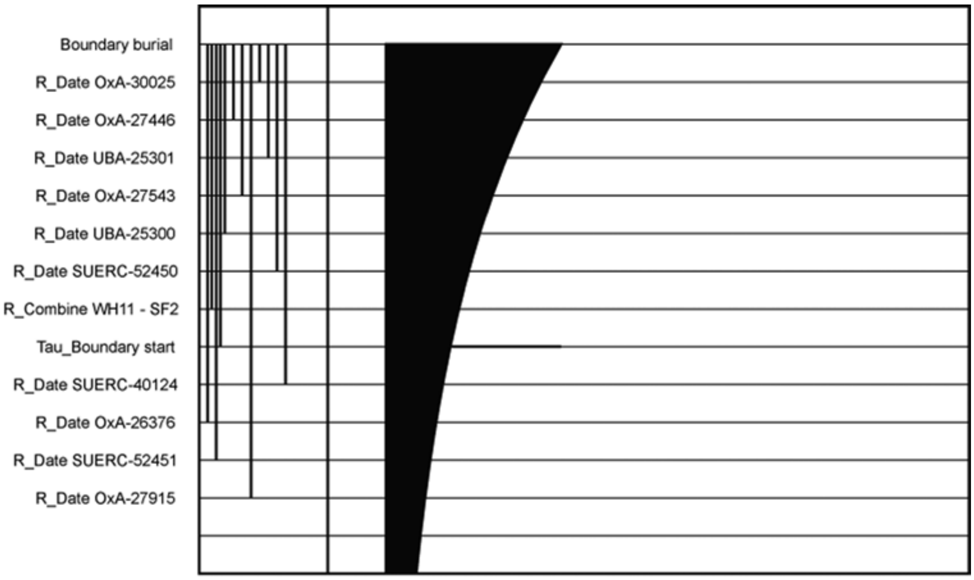

Figure 20.1: Schematic for the model shown in Figure RC2.

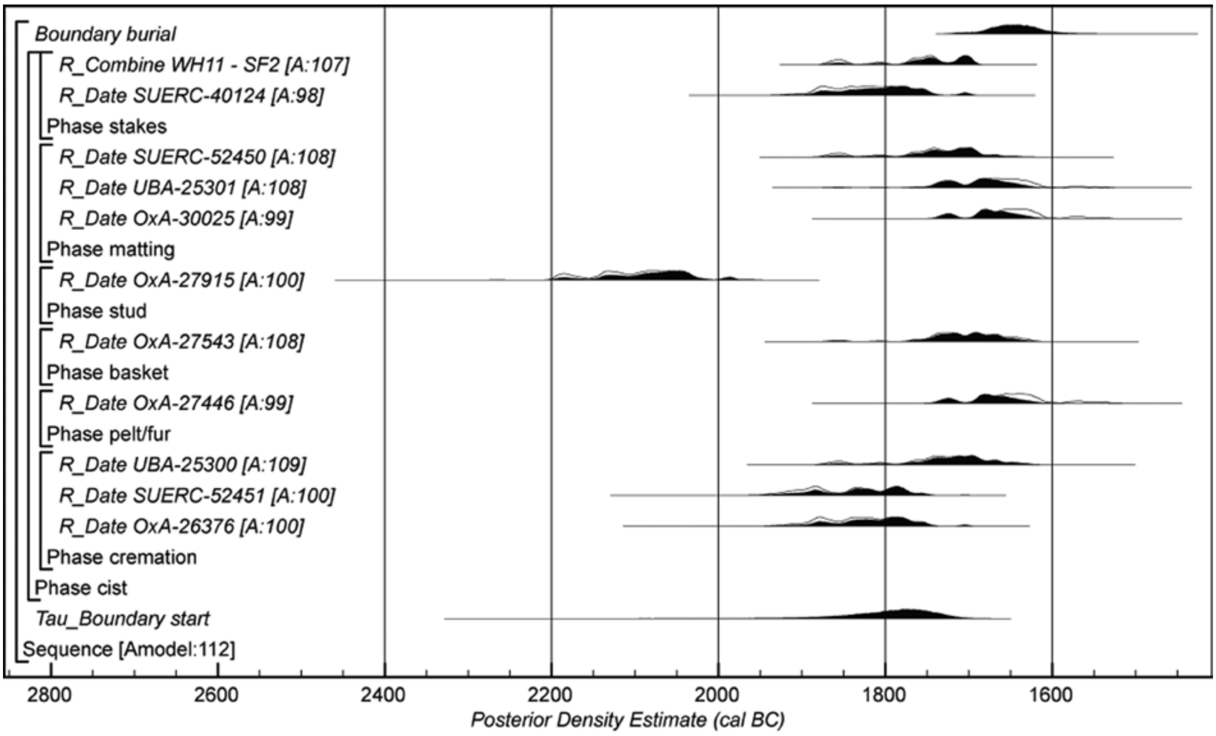

Figure 20.2: Probability distributions of dates from the Whitehorse Hill cist. An exponential distribution has been used for the collection of material associated with the cist. Each distribution represents the relative probability that an event occurs at a particular time. For each radiocarbon date, two distributions have been plotted: one in outline, which is the result of simple radiocarbon calibration, and a solid one based on the chronological model used. The other distributions correspond to aspects of the model. For example, the distribution 'burial' is the estimate for when the burial took place. The large square brackets down the left-hand side of the diagram and the OxCal keywords define the overall model exactly.

cist, it is impossible to determine whether this is just a reflection of a small offset due to an old-wood effect from the fuel (Snoeck *et al.* 2014).

The monoliths

2005 monoliths

The humic and humin fractions from both samples are

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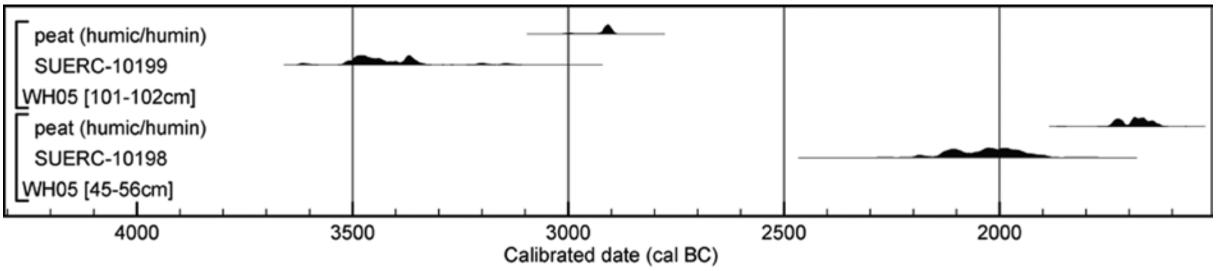

Figure 20.3: Probability distribution of radiocarbon dates from the Whitehorse Hill 2005 monolith.

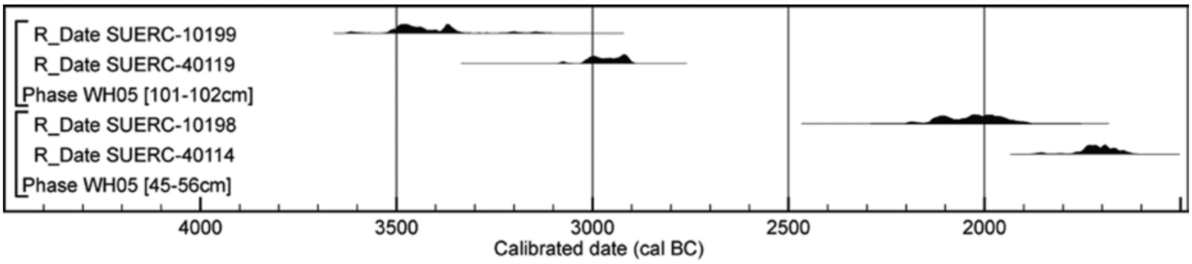

Figure 20.4: Probability distribution of radiocarbon dates on the humin fraction (SUERC-40114 and SUERC-40119) and bulk plant macrofossils (SUERC-10198–9) from the Whitehorse Hill 2005 monolith.

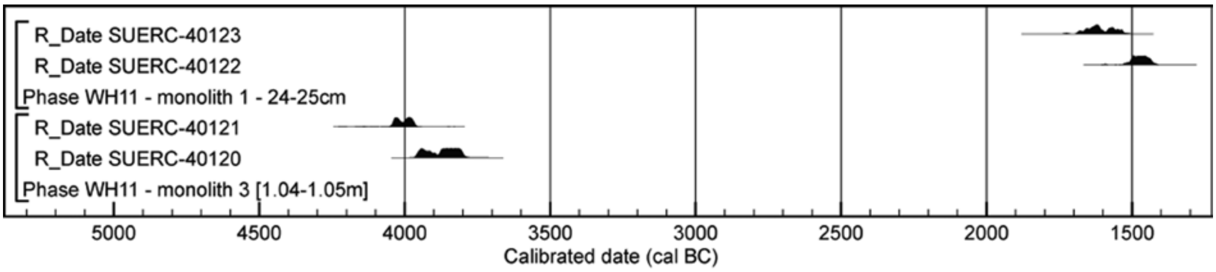

Figure 20.5: Probability distribution of radiocarbon dates on humic (SUERC-40120 and SUERC-40122) and humin (SUERC-40121 and SUERC-40123) fractions from the Whitehorse Hill 2011 monolith.

statistically consistent and the weighted mean of these samples therefore provides the best estimate for their ages; WHH05 (45–46cm); 3390±22 BP (T'=0.9, T'(5%)=3.8, ν=1; Ward and Wilson 1978) and WHH05 (101–102cm); 4313±22 BP (T'=2.3, T'(5%)=3.8, ν=1).

But at both depths, the weighted mean of the humic and humin fractions of these samples is significantly younger than the bulk plant macrofossils (Fig. 20.3) 3390±22 BP (WHH5: 45–46cm) and 3650±50 BP (SUERC-10198); (T'=23.2, T'(5%)=6.0, ν=2); 4313±22 BP (WHH5: 101–102cm and 4625±50 BP (SUERC-10199); (T'=33.5, T'(5%)=6.0, ν=2).

Although the humin (acid and alkali-insoluble) fraction is thought to be most representative of the original plant material (Shore *et al.* 1995), it is clearly much younger than the bulk plant macrofossils dated from these horizons (Fig. 20.4), and we are unable to say with any confidence which, if any, measurement provides a reliable estimate of the age of the deposits.

2011 monoliths

The humic and humin fractions from the two samples dated from the 2011 monoliths are not statistically consistent; WH11 (24–25cm) (T'=8.7, T'(5%)=3.8, ν=1) and WH11 (1.04–1.05cm) (T'=8.0, T'(5%)=3.8, ν=1). In both cases the humic acid fraction is younger than the humin fraction (Fig. 20.5). This is in agreement with much previously published work (for example, Brock *et al.* 2011; Bayliss *et al.* 2008), and suggests the downward movement of humic acids (Shore *et al.* 1995). However, given that from the 2005 core we know the humin date is not statistically consistent with the plant macrofossils, we are unable to say with any confidence which measurement provides a reliable age estimate for the formation of the deposits.

Tephra

Further independent scientific dating evidence with which to evaluate the radiocarbon results from the 2011 monoliths exists at Whitehorse Hill from tephra dating (Chapter 19).

Estimates for the Lairg A, Lairg B and OMH-185 tephra

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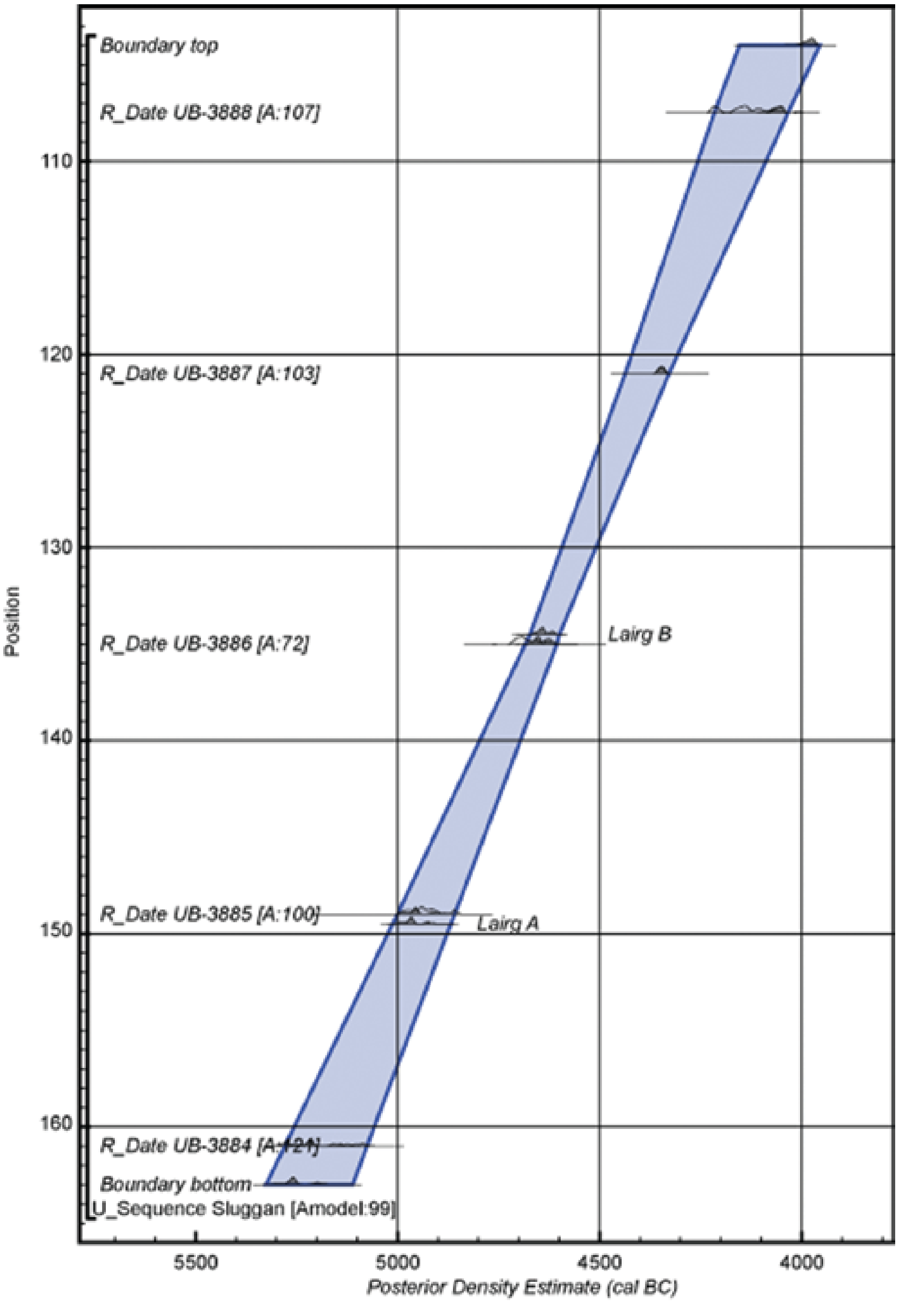

Figure 20.6: Bayesian age-depth model of the chronology of the sediment sequence at Sluggan Bog (U_Sequence model; Bronk Ramsey 2008) and estimates for the dates of the Lairg A and B tephra horizons. The coloured band shows the estimated date of the sediment at the corresponding depth, at 95% probability. For radiocarbon dates the lighter distribution is the result of simple calibration and the darker distribution is the posterior density estimate provided by the model.

horizons identified in the 2011 monoliths were derived from age-depth modelling the individual radiocarbon dated sequences from Sluggan Bog (Pilcher *et al.* 1996) and Glen West (Plunkett *et al.* 2004).

Revised age estimates for the Lairg A and Lairg B tephras

A uniform aged depth model (U-Sequence, Bronk Ramsey 2008; Fig. 20.6), in which the accumulation rate is unknown but assumed to be constant (Christen *et al.* 1995), shows good overall agreement (A_{model}=99) between the radiocarbon dates (Pilcher *et al.* 1996) and stratigraphy.

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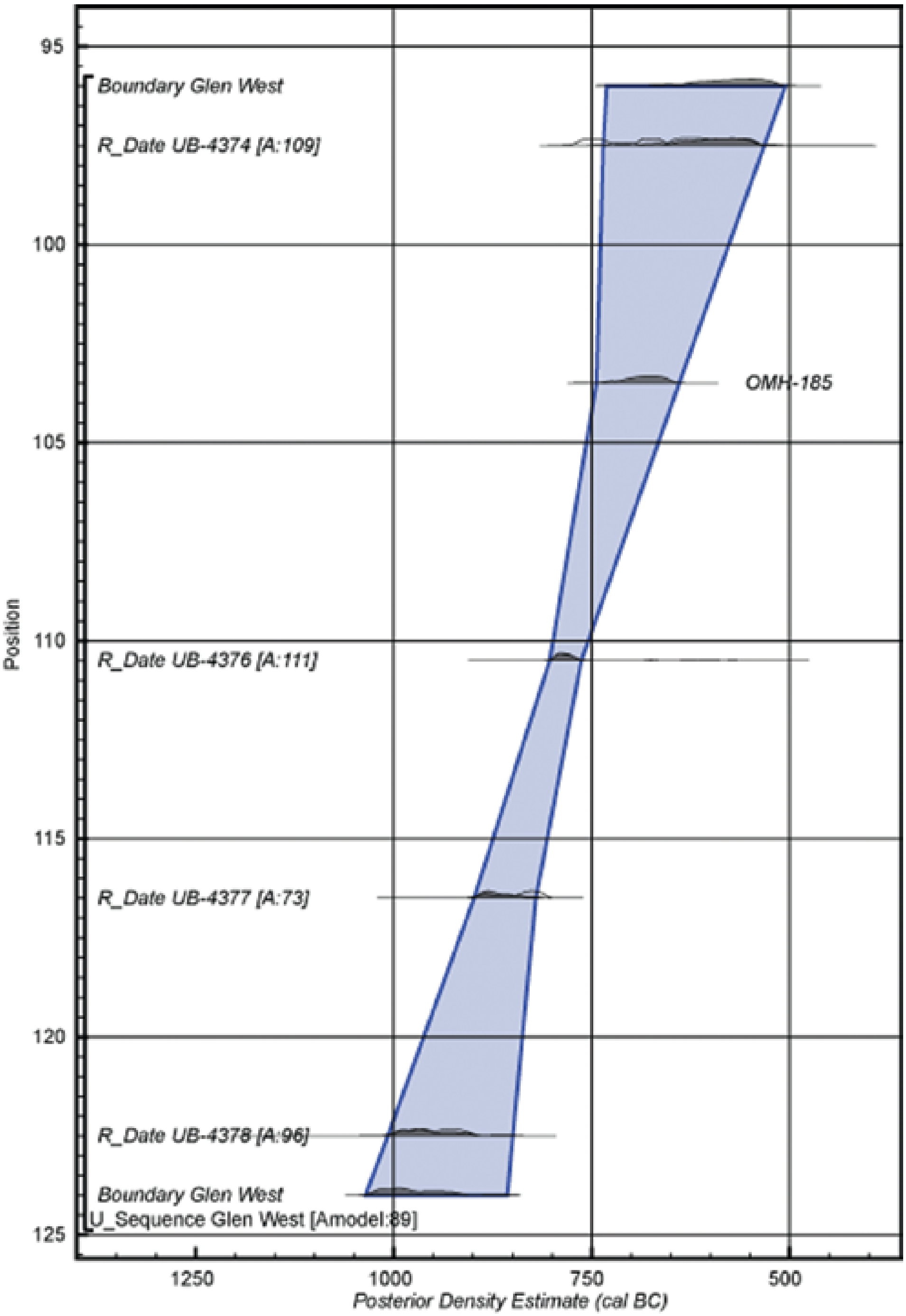

Figure 20.7: Bayesian age-depth model of the chronology of the sediment sequence at Glen West (U_Sequence model; Bronk Ramsey 2008) and estimates for the date of the OMH-185 tephra. The format is identical to Figure RC6.

The model provides estimates for the date of the Lairg A tephra of *5020–4895 cal BC* (*94% probability; Lairg A;* Fig. 20.6) and Lairg B of *4675–4600 cal BC* (*95% probability; Lairg B;* Fig. 20.6*)*. The estimate for the Lairg B event is in agreement with that obtained from the annual laminated record of Lake Belau, Germany (Dörfler *et al.* 2012), of *4980–4760 cal BC* (*95% probability*) and suggests the age-depth model (Fig. 20.6) is robust and accurate.

Revised age estimate for the OMH-185 tephra

A uniform-aged depth model (U-Sequence, Bronk Ramsey 2008; Fig. 20.7) shows good overall agreement (A_{model}=89) between the radiocarbon dates (Plunkett *et al.* 2004) and stratigraphy. The model provides an estimate for the date of the OMH-185 tephra of *745–640 cal BC* (*94% probability;* OMH-185; Fig. 20.7).

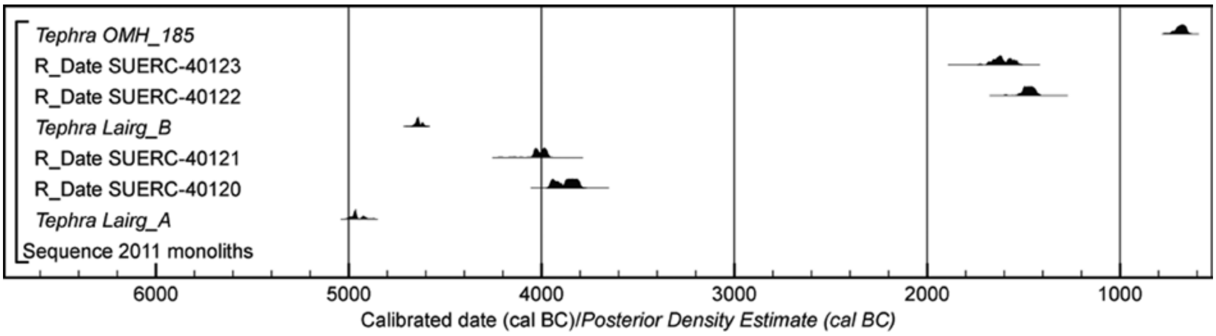

Figure 20.8: Probability distribution of radiocarbon dates on peat: humic (SUERC-40120 and SUERC-40122) and humin (SUERC-40121 and SUERC-40123) fractions from the Whitehorse Hill 2011 monolith, and estimates for the dates of the Lairg A, Lairg B, and OMH-185 tephras derived from the models shown in Figures RC6 and RC7.

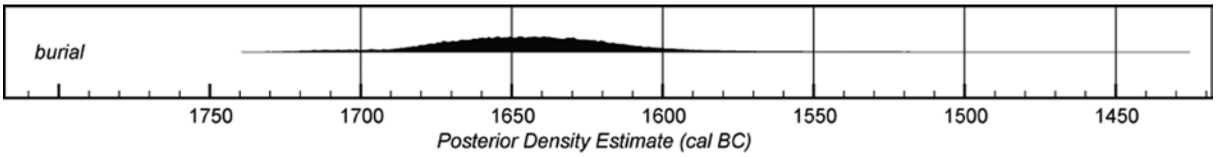

Figure 20.9: Probability distribution for the 'burial' in the cist. The distribution is derived from the model shown in Figure RC2.

Tephra and radiocarbon results

Figure 20.8 shows the radiocarbon results from the 2011 monoliths and estimates for the dates of three tephras (Chapter 19) derived above. The results suggest that the radiocarbon measurements from near the base of the core (104–105 cm) are too young by as much as 800 years. Explaining such a large offset in both the humic and humin fractions is difficult, although downward movement of water soluble organic materials would lead to the age of the humic fraction being too young and downward penetration of rootlets could result in the humin sediment fraction also being too young. Given that the radiocarbon measurements were from AMS size bulk samples this remains a possibility.

Conversely, the radiocarbon determinations from near the top of the monoliths (24–25 cm) may be too old!

Discussion

The independent dating evidence provided by the tephra analysis – although the fact that the age of the tephra horizons is derived from radiocarbon dating might argue for a degree of circularity – clearly demonstrates the difficulties in providing reliable chronologies for peat sequences when AMS size samples are used.

The chronology

Given that we have no reason *a priori* to expect all the dated samples from the cist and its construction to be of the same actual age (*cf* Hamilton and Kenney 2015), a model such as that shown in Figure 20.2 will inherently produce a less precise but more robust estimate for the archaeological date of interest (the burial event) than other methods (for example, simply combining all the measurements). The estimated date for the burial is *1675–1615 cal BC* (*68% probability; burial*).

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Interpreting the chronology of the cist

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