Quaternary Science Reviews 28 (2009) 2551–2556

Contents lists available at ScienceDirect

Quaternary Science Reviews

journal homepage: www.elsevier.com/locate/quascirev

Rapid Communication

Revised radiocarbon ages on woolly rhinoceros (*Coelodonta antiquitatis*) from western central Scotland: significance for timing the extinction of woolly rhinoceros in Britain and the onset of the LGM in central Scotland

Roger M. Jacobi [a,b], James Rose [c,d,*], Alison MacLeod [c], Thomas F.G. Higham [e]

[a] Department of Prehistory and Europe, Franks House, The British Museum, London N1 5QJ, UK
[b] Department of Palaeontology, Natural History Museum, London SW7 5BD, UK
[c] Department of Geography, Royal Holloway, University of London, Egham, Surrey, TW20 0EX, UK
[d] British Geological Survey, Keyworth, Notts, NG12 5GG, UK
[e] Oxford Radiocarbon Accelerator Unit, RLAHA, Dyson Perrins Building, University of Oxford, Oxford OX1 3QY, UK

ARTICLE INFO

Article history:
Received 10 June 2009
Received in revised form
13 August 2009
Accepted 17 August 2009

ABSTRACT

Woolly rhinoceros bones, from a number of sites in Britain, have been AMS radiocarbon dated following ultrafiltration pre-treatment. These determinations give a coherent set of ages between >50 and c. 35 cal ka BP. The youngest (35,864–34,765 cal BP) come from the area around Bishopbriggs in western central Scotland and are derived from glaciofluvial sand and gravel overlain by till, both deposited during the Last Glacial Maximum (LGM) glaciation. A previous radiocarbon date from the site suggested that woolly rhinoceros lived c. 27 ^{14}C ka BP and the region was ice-free at the time. This date has had significant influence on the timing of extinction of woolly rhinoceros and the onset of glaciation over Britain during the LGM. The new dates revise this earlier determination and confirm that woolly rhinoceros became extinct in Britain after c. 35 cal ka BP, that central Scotland was ice-free at this time, and glaciation extended across this region sometime after 35 cal ka BP.

1. Introduction

As part of the Ancient Human Occupation of Britain project (AHOB, 2001–2012; Stringer, 2006), bones from a large number of sites have been re-dated by radiocarbon using ultrafiltration pre-treatment (Higham et al., 2006). Amongst these sites are many associated with evidence of Middle or Upper Palaeolithic human activity, whilst the fauna from other sites contributes to understanding the landscape occupied by humans. These new AMS radiocarbon determinations have yielded ages with a reliability and resolution not previously accessible and have already made significant contributions to our understanding of human presence and absence during the later part of MIS 3 and the Lateglacial (Jacobi et al., 2006; Jacobi and Higham, 2009). In addition, dates from localities that have been over-ridden by ice during the Last Glaciation (MIS 2) are able to contribute to dating of the onset of ice-cover, a topic that has received considerable attention in recent years (Bowen et al., 2002; Carr et al., 2006; Hubbard et al., 2009; Sejrup et al., 2009; Hibbert et al., in press).

This Rapid Communication reports the new AMS radiocarbon determinations for bones from woolly rhinoceros (*Coelodonta antiquitatis*) following ultrafiltration pre-treatment. These results are discussed with respect to the timing of the extinction of woolly rhinoceros from the British Isles and the onset of glaciation in central Scotland, prior to the Last Glacial Maximum (LGM).

The two dates that are key to the main issues of this paper come from bones of woolly rhinoceros found near Bishopbriggs, north of Glasgow in western central Scotland (Fig. 1A). The dated material is from two localities in the area: Hungryside and Wilderness (Swinton, 1927; Rolfe, 1966). The bones at both sites are from glaciofluvial sands and gravels that underlie till which forms drumlins, irregular hills and depressions (Flett, 1927; Rolfe, 1966; Rose and Smith, 2008) (Fig. 1C). Both the sands and gravels and till were laid down during the LGM; indeed the Wilderness site is a stratotype for Devensian glacial deposits in Scotland (Rose, 1981, 1989; Browne and McMillan, 1989; Sutherland, 1999). There has been some debate about derivation of the materials, but sedimentology (observed in 1965 soon after the bone at the Wilderness site was discovered) and the quality of preservation suggest that recycling was unlikely, transport distances were small and deposition was

* Corresponding author at: Department of Geography, Royal Holloway, University of London, Egham, Surrey, TW20 0EX, UK.
E-mail address: j.rose@rhul.ac.uk (J. Rose).

0277-3791/$ – see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.quascirev.2009.08.010

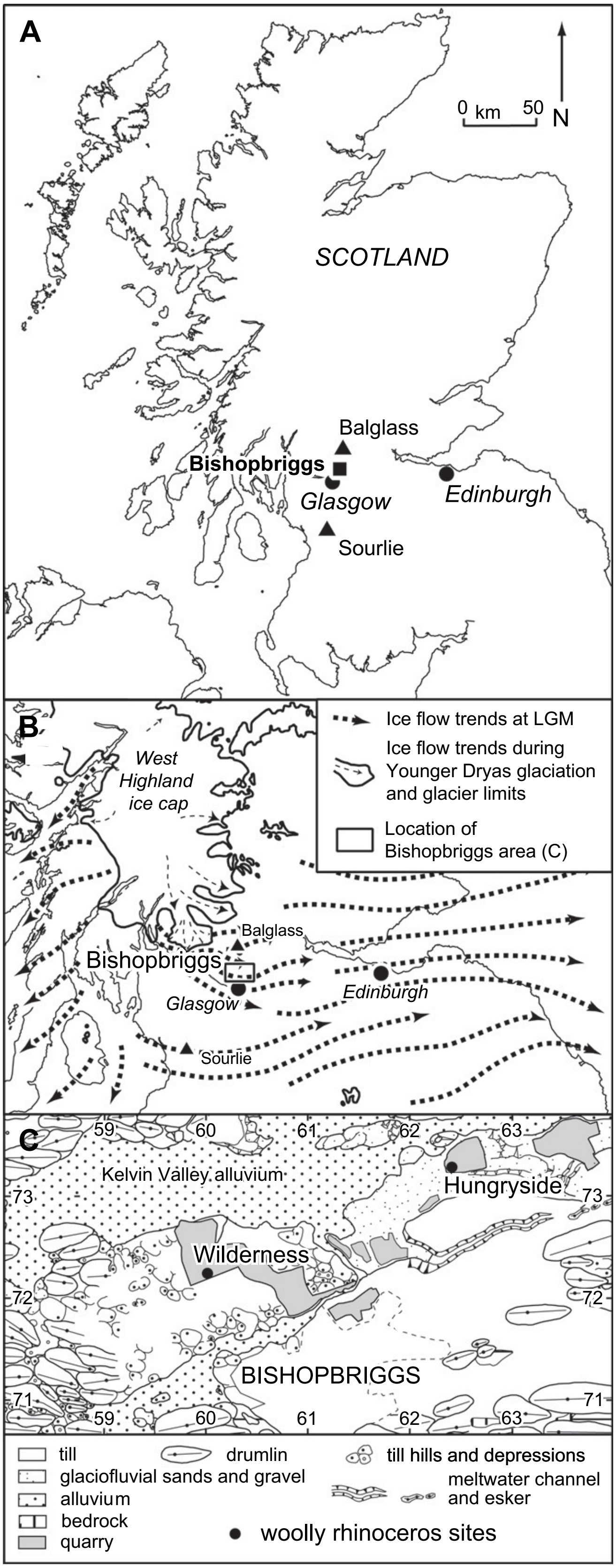

Fig. 1. Location of the finds of woolly rhinoceros in the Bishopbriggs area of western central Scotland, north of Glasgow. A) The location of Bishopbriggs, Balglass Burn and Sourlie which are sites with radiocarbon dated organic material below LGM till. B) Relationship of the sites to patterns and directions of ice movement across Scotland during the LGM. C) Geomorphological map of the Bishopbriggs area, showing the location of the Wilderness and Hungryside Quarries and the position of the finds. Based on 10:10,560 scale field mapping carried out in 1965–1966 and published electronically at 1:25,000 scale in Rose and Smith (2008).

rapid, along with other clastic material. The glacier that covered the site moved from west to east (Fig. 1B, C).

The bone from the Wilderness site has previously been dated by radiocarbon to 27,550 + 1370, −1680 ^{14}C BP (GX-0597) (Rolfe, 1966), providing a constraint on the presence of glacier ice-cover in Scotland (Sissons, 1974, 1981; Sutherland, 1984; Boulton et al., 2002). However, this age has been questioned, because of potential unreliability (Sutherland, 1984), or overlooked (Bowen et al., 2002), probably reflecting a lack of confidence in the determination. The calibrated age for this date (37,970–29,478 cal BP, 8492 years range) highlights the uncertainty of this determination.

2. Methods

All the radiocarbon determinations cited in this study have been carried out at the Oxford Radiocarbon Accelerator Unit (ORAU). Until recently, pre-treatment of bone at the ORAU comprised acidification to remove the mineral carbonate fraction, leaving raw collagen. This was then washed in alkali to remove humic substances, then acidified and filtered. Finally, the sample was gelatinised to enable insoluble particulates to be removed from the collagen targeted for dating. This pre-treated material is termed filtered gelatin and is used by most laboratories that date bone. From 2000, the ORAU has added an additional step to the pre-treatment process – that of ultrafiltration (Brown et al., 1988). After decalcification and gelatinisation, the soluble gelatin is transferred to an ultrafilter – a molecular sieve which retains the >30 kDalton (Da) molecular weight fraction which will include undegraded collagen. The <30 kDa fraction contains low molecular weight components such as salts, degraded collagen fragments and sometimes soil-derived contaminants and is discarded. It is the >30 Da fraction which is freeze-dried and dated.

Where bones, which were dated prior to ultrafiltration pre-treatment, have been re-dated using this technique, age-shifts have frequently been observed, often giving statistically different results. These age-shifts are attributed to the more successful removal of contaminants by means of ultrafiltration, and where it is possible independently to access the two sets of results there are usually good reasons to prefer those obtained by ultrafiltration (Higham et al., 2006; Jacobi et al., 2006; Jacobi and Higham, 2008, 2009).

Radiocarbon age determinations have been converted to the calendar timescale using OxCal v4.1.1 (Bronk Ramsey, 2001, in press). We have tentatively compared our data with the Hughen et al. (2006) curve, of Cariaco Basin vs. Hulu Cave, as the most appropriate means of calibrating ^{14}C dates covering the period 30–50 ^{14}C ka BP (Svensson et al., 2008). It is acknowledged that there is currently no official consensus on calibration prior to the IntCal04 curve of Reimer et al. (2004) and van der Plicht et al. (2004) Dates are presented as radiocarbon ages at $\pm 1\sigma$ (Table 1) and as calibrated ranges at the 2σ (95.4%) confidence interval and reported according to the method used: ^{14}C years BP, cal years BP, using the appropriate age units (Renne et al., 2006).

3. Results

The AMS radiocarbon determinations for woolly rhinoceros from the British Isles are given in Table 1. In all cases these are determinations on ultrafiltrated gelatin. This is particularly important for bones of the age considered here, because even very

Table 1

AMS Radiocarbon determinations for single fossils of woolly rhinoceros (*C. antiquitatis*) from the British Isles. The table gives both the AMS age and the calibrated ages using OxCal v4.1.1. and, prior to the applicability of OxCal v4.1.1 (26,000), we are comparing the radiocarbon ages against the Cariaco Basin record tuned to Hulu Cave. The ages given in grey are near one end of the comparison curve and so it is not certain if the range quoted includes all possible dates. *, **, ***, **** indicate repeat measurements on the same specimen. # are the two determinations which are the focus of this paper. Stable isotope ratios are expressed in ‰ relative to vPDB and nitrogen to AIR. Mass spectrometric precision is ±0.2‰ for carbon and ±0.3‰ for nitrogen. 'Used' is the amount of bone pre-treated and the yield represents the weight of gelatin or ultrafiltered gelatin in milligrams. %yield is the wt% collagen which ideally should not be <1 wt% at ORAU. This is the amount of collagen extracted as a percentage of the starting weight. %C is the carbon present in the combusted gelatin. For ultrafiltered gelatin this averages 41.0 ± 1%. CN is the atomic ratio of carbon to nitrogen, at ORAU this is acceptable if it ranges between 2.9 and 3.5. 1 refers to Jacobi and Higham (2008, Tables 6 and 7). 2 refers to Higham et al. (2006, Table 5). 3 refers to Jacobi (2007, p 280). 4 refers to Higham et al. (2006, Table 3).

Laboratory code	Locality	Element dated	Radiocarbon age (years BP, 1σ)	Comparison age range based on Cariaco–Hulu (years BP, 2σ)	Range (years)	Ref	Used (mg)	Yield (mg)	%Yld	%C	$\delta^{13}C$ (per mille)	$\delta^{15}N$ (per mille)	CN
OxA-19560	Wilderness Pit, Bishopbriggs, Dunbartonshire	Distal left humerus	31,140 ± 170	35,864–34,675	1189	#	1080	44.2	4.1	46.5	−19.5	0.7	3.3
OxA-X-2288-33	Hungryside, Bishopbriggs, Dunbartonshire	Left metacarpal 2	32,250 ± 700	38,727–35,014	3713	#	780	5.31	0.7	45.2	−19.5	0.8	3.3
OxA-13437	Goat's Hole (Paviland), Swansea	Mid-shaft of right humerus	32,870 ± 200	38,540–36,255	2285	1	900	5	0.6	44.3	−20.2	5.3	3.2
OxA-13377	Goat's Hole (Paviland), Swansea	Mid-shaft of right humerus	33,800 ± 200	39,970–37,610	2360	1	800	50.2	6.3	43.9	−20.2	5.4	3.4
OxA-14715	Kent's Cavern, Torquay, Devon	Distal right tibia	35,150 ± 330	41,161–39,242	1919	2	704	24.2	3.4	41.8	−19.4	6.5	3.3
OxA-14701*	Kent's Cavern, Torquay, Devon	Right metacarpal 4	35,650 ± 330	41,782–39,511	2271	2	552	32	5.8	43.7	−19.4	7.4	3.3
OxA-13921	Kent's Cavern, Torquay, Devon	Right metacarpal 3	36,040 ± 330	41,930–40,328	1602	2	560	31.1	5.6	36.7	−19.8	6.4	3.3
OxA-14201*	Kent's Cavern, Torquay, Devon	Right metacarpal 4	36,370 ± 320	42,110–40,461	1649	2	980	87.2	8.9	44.3	−20.8	5.7	3.3
OxA-13965	Kent's Cavern, Torquay, Devon	Cranial fragment	37,200 ± 550	42,872–40,895	1977	2	580	15.05	2.6	40.2	−20.1	6.2	3.2
OxA-14196	Ash Tree Cave, Whitwell, Derbyshire	Left ulna	37,540 ± 370	42,930–41,205	1725		698	32.9	4.7	42.6	−19.5	4.6	3.2
OxA-10804	Picken's Hole, Compton Bishop, Somerset	Shaft of left femur	40,200 ± 700	45,293–42,642	2651	3	494.6	17.9	3.6	41.6	−19.7	5.3	3.3
OxA-15484	Robin Hood Cave, Creswell Crags, Derbyshire	Shaft of left tibia	40,550 ± 400	45,209–43,173	2036		1000	63	6.3	41.4	−19.5	3.7	3.3
OxA-13682**	Pin Hole, Creswell Crags, Derbyshire	Right P4	41,900 ± 900	47,239–43,204	4035		461	15	3.3	44.8	−19.4	5.2	3.2
OxA-13657	Goat's Hole (Paviland), Swansea	Mid-shaft of right humerus	42,650 ± 800	48,036–43,306	4730	1	570	20.2	3.5	42.8	−19.8	6.0	3.2
OxA-13592	Pin Hole, Creswell Crags, Derbyshire	Partial right P4	43,350 ± 650	51,506–45,077	6429	4	492	35.4	7.2	44.2	−19.8	1.8	3.1
OxA-15521	Pin Hole, Creswell Crags, Derbyshire	Worn upper cheek tooth	43,700 ± 1000	51,928–44,298	7630		600	18.1	3	41	−19.2	6.0	3.3
OxA-13881**	Pin Hole, Creswell Crags, Derbyshire	Right P4	45,000 ± 750	55,100–45,492	9608	4	700	35	5	44.6	−19.2	4.7	3.2
OxA-14761	Kent's Cavern, Torquay, Devon	Left unciform	45,000 ± 2200	62,791–44,282	18,509	2	503.1	8.5	1.7	42	−19.9	6.4	3.4
OxA-16647	Coygan Cave, Laugharne, Carmarthenshire	Proximal left radius	45,800 ± 1400	55,426–45,678	9748		1010.1	16.8	1.7	45.3	−20.0	2.6	3.2
OxA-X-2116-6***	Pin Hole, Creswell Crags, Derbyshire	Proximal right radius	49,000 ± 800	62,653–48,795	13,858	4	590	15.9	2.7	41.6	−20.2	2.7	3.1
OxA-14719	Pin Hole, Creswell Crags, Derbyshire	Ulna	49,000 ± 1300	63,003–48,359	14,644		713.5	33.4	4.7	42.8	−19.6	3.2	3.2
OxA-19559	Clifford Hill (Little Houghton), Northamptonshire	Mandible	49,800 ± 1000	63,087–49,236	13,851		930	62.7	6.7	44.8	−20.0	4.7	3.3
OxA-14212***	Pin Hole, Creswell Crags, Derbyshire	Proximal right radius	50,200 ± 1400	63,450–49,391	14,059	4	800	33.6	4.2	49.8	−19.4	4.0	3.1
OxA-13880****	Pin Hole, Creswell Crags, Derbyshire	Shaft of right tibia	52,500 ± 2800	Out of Range – 50,995	N/A	4	520	18.2	3.5	42.5	−19.8	3.5	3.3
OxA-14717	Pin Hole, Creswell Crags, Derbyshire	Left navicular	52,900 ± 1900	Out of Range – 52,155	N/A		504.3	37.6	7.5	42.9	−19.5	2.5	3.3
OxA-14720	Pin Hole, Creswell Crags, Derbyshire	Tibia	53,300 ± 3400	Out of Range – 51,004	N/A		624.7	17.1	2.7	42.6	−19.9	3.8	3.2
OxA-14211***	Pin Hole, Creswell Crags, Derbyshire	Proximal right radius	53,400 ± 1700	Out of Range – 52,297	N/A	4	589	49.2	8.4	44.5	−19.6	3.1	3.4
OxA-12808	Pin Hole, Creswell Crags, Derbyshire	Partial ulna	54,000 ± 2900	Out of Range – 52,167	N/A	4	600	24.8	4.1	42.2	−20.1	2.4	3.2
OxA-14197	Pin Hole, Creswell Crags, Derbyshire	Calcaneum	55,900 ± 4000	77,074–50,625	26,449	4	544.5	20.9	3.8	44.2	−20.0	4.4	3.2
OxA-13564****	Pin Hole, Creswell Crags, Derbyshire	Shaft of right tibia	>43,000	NOT CALIBRATED	N/A	4	486	3.5	0.7	43.1	−19.7	8.3	3.2
OxA-10805	Picken's Hole, Compton Bishop, Somerset	Mandibular symphysis	>44,000	NOT CALIBRATED	N/A	3	507	4	0.8	43.6	−20.1	5.0	3.4
OxA-11979***	Pin Hole, Creswell Crags, Derbyshire	Proximal right radius	>51,400	NOT CALIBRATED	N/A	4	590	41.9	7.1	41	−19.7	3.4	3.3

small amounts of modern contamination can make a significant difference to the age obtained. The age models for the OxCal v4.1.1 calibrations are shown in Fig. 2B.

The youngest determination is 35,864–34,675 cal BP on the humerus from Wilderness at Bishopbriggs, and this shows a 2σ range of only 1189 calendar years. Other determinations are not so precise but the majority of those with radiocarbon ages of less than 41 ka have a range of 2000 years or less. The second youngest date, from Hungryside near Bishopbriggs was obtained from a sample with low collagen yield. 640 mg of bone only yielded 4.7 mg of gelatin, which is below the laboratory threshold of 10 mg, and 1% collagen. However, the other parameters including the CN atomic ratio (3.3) were acceptable, and the date is included in this study, although the 2σ age range is 3713 years (the OxA-X in the number identifies this issue) (Table 1, Fig. 2).

4. Discussion

4.1. Timing the extinction of woolly rhinoceros in Britain

The results of all the woolly rhinoceros determinations are truly remarkable for their coherence and the complete absence of outliers. They demonstrate the presence of woolly rhinoceros in the British Isles for more than 23,000 years of MIS 3, and confirm the

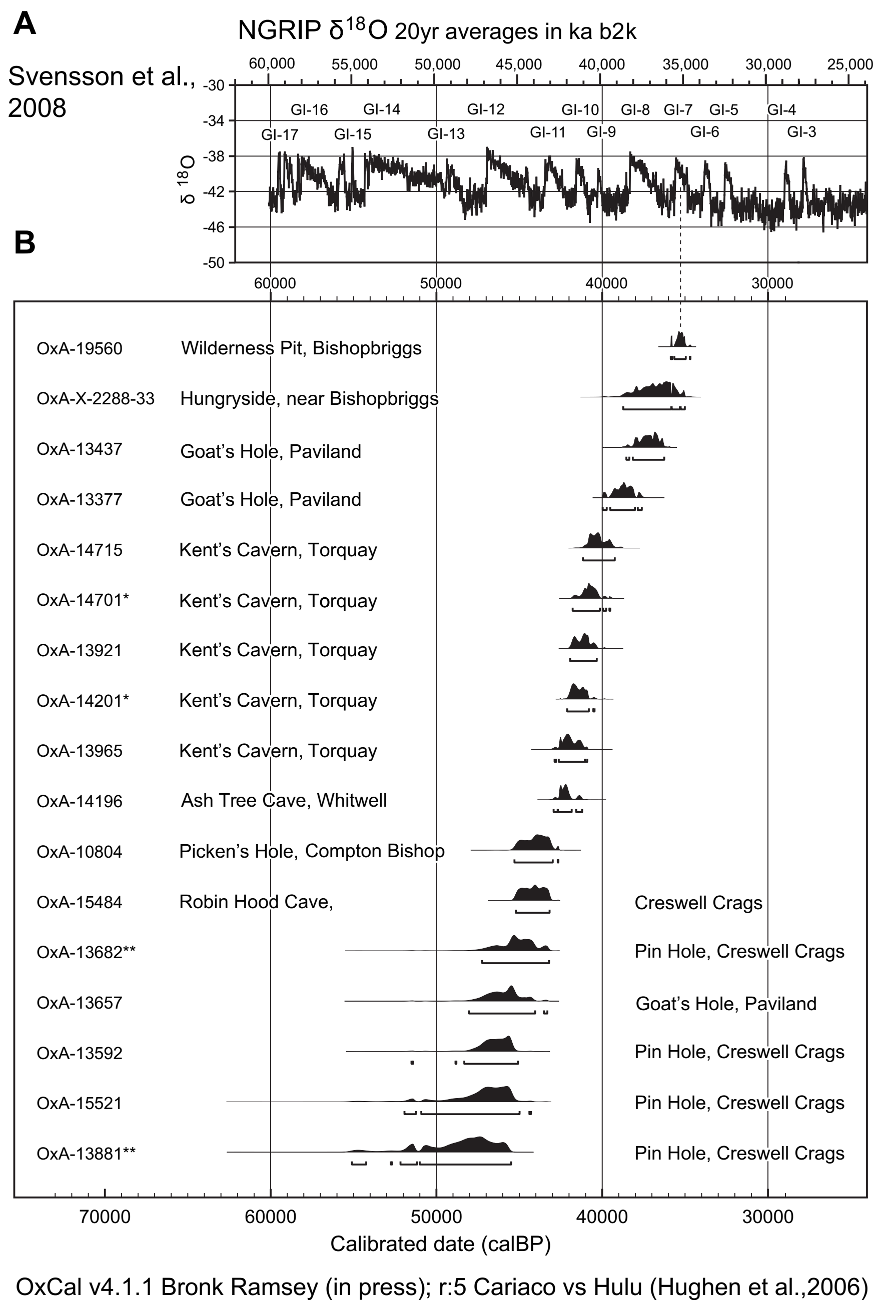

Fig. 2. A) The NGRIP $\delta^{18}O$ curve for the period 60–28 ka b2k. B) Age models for the AMS radiocarbon ages on bone of woolly rhinoceros. Further details of the determinations can be found in Table 1. The determinations that are outside the range of the Hughen et al. (2006) calibration curve are not included in this figure. The probability distributions for each radiocarbon sample are shown with a range beneath representing the age ranges at 95.4% probability. Note that the two timescales are offset by 50 years to represent the difference between b2k and cal BP. It can be seen that the youngest occurrence of woolly rhinoceros coincides with Greenland Interstadial 7, before the deterioration of the climate into the forthcoming stadial.

species as a useful marker for faunas of this period (Currant and Jacobi, 2001). However, it should be noted that the determinations come from relatively few localities and that, with the exception of Clifford Hill and the sites in western central Scotland, all are cave sites. Most of the rhinoceros bones from the cave sites show the characteristic pattern of gnawing associated with the activities of spotted hyaenas (*Crocuta crocuta*), thereby demonstrating that they were from prey. This is an important observation because the radiocarbon records for the two species are strikingly similar and it may be that the fossil record for woolly rhinoceros has been heavily biased by the presence of spotted hyaenas who introduced bones into caves where they could be preserved.

There are determinations for woolly rhinoceros, which we do not cite, that are younger than those from Bishopbriggs. However all of there were obtained prior to the use of ultrafiltration and therefore subject to the qualifications outlined above. Amongst these, is what could have been Britain's youngest rhinoceros from Ogof-yr-Ychen on Caldey in west Wales, with an age of $22{,}350 \pm 620$ ^{14}C BP (Nédervelde et al., 1973). The reason why this, and other samples, have not been re-dated is that no left-over bones can be traced (a problem that is frequently a consequence of conventional radiocarbon dating procedures). However, wherever such bone may still exist, we will continue, as part of AHOB 3, to attempt to carry out re-dating using ultrafiltration.

Woolly rhinoceros and spotted hyaena are the only large mammals found in the Middle Devensian for which we possess a reasonable number of radiocarbon determinations. While, as already suggested, the radiocarbon record of the woolly rhinoceros may have been artificially truncated by the local extinction of its principal hunter and scavenger, it is also possible that the disappearance of both species was as part of a wider pattern of faunal loss attributable to the onset of more rigorous climate conditions in MIS 2 (Dimlington Stadial, LGM, Rose, 1985). However, before we can generalise we need many more radiocarbon determinations for species such as mammoth (*Mammuthus primigenius*) (Stuart et al., 2002), wild horse (*Equus ferus*) (Stuart and Lister, 2007) and giant deer (*Megaloceros giganteus*) (Stuart et al., 2004) which may have been absent from the British Isles during the LGM.

While there is evidence that woolly rhinoceros returned to some areas of western Europe, for example the Rhine valley, during the early part of the Lateglacial (Street and Terberger, 2004), there presently is no suggestion that this happened in the British Isles. Thus, the new radiocarbon determinations from Bishopbriggs, and especially that from Wilderness (35,864–34,675 cal BP), are the most recent reliable evidence for the presence of this species in the British Isles. At the present state of knowledge, woolly rhinoceros became extinct in Britain after this time.

4.2. Timing of onset of the LGM in central Scotland

The issue of the timing of the LGM in central Scotland has received attention in recent years largely because of the use of a new dating method (cosmogenic radionuclide dates, Bowen et al., 2002), new micromorphological interpretations of North Sea sediments (Carr et al., 2006), new radiocarbon dates from the Norwegian sector of the North Sea region (Sejrup et al., 2009), long sequences with ice rafted detritus (IRD) from marine records off western Scotland (Knutz et al., 2001, 2007; Hibbert et al., in press) and glacier modelling tuned to the NGRIP δ^{18}O record (Hubbard et al., 2009). These works have in varying degrees challenged the view, based on early radiocarbon dates, that Scotland was ice-free during MIS 3 and that the LGM reached its limit after c. 22 ka cal BP (Rose, 1985). The most extreme case for the new view is Bowen et al. (2002, p 99) who envisaged that 'all of Ireland and Scotland were ice covered' 'between isotope stage 5e and ~37.5 ka'. IRD records are taken to imply that glaciation persisted in Scotland throughout the period from c. 41 ka BP to the LGM, but the extent of the ice in central Scotland is not implied (Hibbert et al., in press). Similar implications are presented as a result of glaciological modelling (Hubbard et al., 2009), although ice is shown to cross the Bishopbriggs region on a number of occasions between 35 and 24 cal ka BP. Recent models by Sejrup et al. (2009) take into consideration the recent radiocarbon dates from Sourlie (Bos et al., 2004) and Balglass (Brown et al., 2007) (Fig. 1A, B).

The radiocarbon dates from Bishopbriggs presented here confirm the findings presented in Brown et al. (2007) and reinforce the model of Sejrup which proposed that central Scotland was ice-free from c. 40 to 32 cal ka BP. The results also constrain the evidence from the IRD records that ice was probably restricted to the western highland regions over the period concerned. The modelling of Hubbard et al. (2009) is most revealing: stressing the dynamics of the glacial systems and indicating that glacier fluctuations across the Bishopbriggs area may have occurred at Greenland Stadial/Interstadial timescales in the order of a few thousand years (Fig. 2A). In this case it is possible that the woolly rhinoceros were living in a landscape that was close to glaciated highlands with oscillating glacier margins, but became extinct in association with the climatic deterioration that forced glacier expansion after c. 34 cal ka BP.

5. Conclusions

- New radiocarbon dates on bones using ultrafiltration pretreatment provide a series of ages for woolly rhinoceros in Britain over the period from before 55 to around 35 cal ka BP, ten of which are published here for the first time.
- The youngest of the ages indicate that woolly rhinoceros became extinct in Britain after 35,864–34,765 at 2σ cal BP and that western central Scotland was ice-free at this time.
- Independent evidence from IRD from ocean cores off western Scotland, and glaciological modelling indicate that ice existed in the highlands of Scotland when the woolly rhinoceros lived in western central Scotland.

Acknowledgements

The work recorded here is part of the Leverhulme Trust funded "Ancient Human Occupation of Britain" (AHOB) Project which funded the dating. The Hunterian Museum of the University of Glasgow is thanked for permission to sample the bones from Wilderness and Hungryside, as are the staff of the ORAU, University of Oxford, for their careful laboratory work. Both referees: Richard Gillespie and one who wishes to remain anonymous are thanked for their comments on the manuscript and the advice they have provided.

References

AHOB, 2001–2012. Ancient Human Occupation of Britain Project. http://www.nhm.ac.uk/hosted_sites/ahob/index_2.html.

Bos, J.A.A., Dickson, J.H., Coope, G.R., Jardine, W.G., 2004. Flora, fauna and climate of Scotland during the Weichselian Middle Pleniglacial – Palynological, macrofossil and coleopteran investigations. Palaeogeography, Palaeoclimatology, Palaeoecology 204, 65–100.

Boulton, G.S., Peacock, J.D., Sutherland, D.G., 2002. Quaternary. In: Trewin, N.H. (Ed.), Geology of Scotland, fourth ed.The Geological Society, London, pp. 409–430.

Bowen, D.Q., Philips, F.M., McCabe, A.M., Knutz, P.C., Sykes, G.A., 2002. New data for the Last Glacial Maximum in Great Britain and Ireland. Quaternary Science Reviews 21, 89–101.

Bronk Ramsey, C., 2001. Development of the radiocarbon calibration program OxCal. Radiocarbon 43 (2A), 355–363.

Bronk Ramsey, C. Bayesian analysis of radiocarbon dates. Radiocarbon, in press.

Brown, T.A., Nelson, D.E., Vogel, J.S., Southon, J.R., 1988. Improved collagen extraction by modified longin method. Radiocarbon 30, 171–177.
Brown, E.J., Rose, J., Coope, R.G., Lowe, J.J., 2007. An MIS 3 age organic deposit from Balglass Burn, central Scotland: significance for the palaeoenvironment of Scotland, and for the timing of the onset of the LGM in Britain and the adjacent seas. Journal of Quaternary Science 22, 295–308.
Browne, M.A.E., McMillan, A.A., 1989. Quaternary Geology of the Clyde Valley. British Geological Survey Research Report SA/89/1, Onshore Geology Series, pp. 1–63.
Carr, S.J., Holmes, R., van der Meer, J.J.M., Rose, J., 2006. The Last Glacial maximum in the North Sea basin: micromorphological evidence of extensive glaciation. Journal of Quaternary Science 21, 131–153.
Currant, A.P., Jacobi, R.M., 2001. A formal mammalian biostratigraphy for the Late Pleistocene of Britain. Quaternary Science Reviews 20, 1707–1716.
Flett, W.R., 1927. Description of the sand deposits at Hungryside, Torrance. Transactions of the Geological Society of Glasgow 17, 396–397.
Hibbert, F.D., Austin, W.E.N., Leng, M., Gatliff, R. British Ice Sheet dynamics inferred from North Atlantic ice rafted debris records spanning the last 170,000 years. Journal of Quaternary Science, in press.
Higham, T.F.G., Jacobi, R.M., Bronk Ramsey, C., 2006. AMS radiocarbon dating of ancient bone using ultrafiltration. Radiocarbon 48, 179–195.
Hubbard, A., Bradwell, T., Golledge, N., Hall, A., Patton, H., Sugden, D., Cooper, R., Stoker, M., 2009. Dynamic cycles, ice systems and their impact on the extent, chronology and deglaciation of the British-Irish ice sheet. Quaternary Science Reviews 28, 758–776.
Hughen, K., Southon, J., Lehman, S., Bertrand, C., Turnbull, J., 2006. Marine-derived 14C calibration and activity record for the past 50,000 years updated from the Cariaco Basin. Quaternary Science Reviews 25, 3216–3227.
Jacobi, R., 2007. A collection of Early Upper Palaeolithic artefacts from Beedings, near Pulborough, West Sussex, and the context of similar finds from the British Isles. Proceedings of the Prehistoric Society 73, 229–325.
Jacobi, R.M., Higham, T.F.G., 2008. The ‘‘Red Lady’’ ages gracefully: new ultrafiltration AMS determinations from Paviland. Journal of Human Ecology 55, 898–907.
Jacobi, R.M., Higham, T.F.G., 2009. The early Lateglacial re-colonization of Britain: new radiocarbon evidence from Gough’s Cave, southwest England. Quaternary Science Reviews 28, 1895–1913.
Jacobi, R.M., Higham, T.F.G., Bronk-Ramsey, C., 2006. AMS radiocarbon dating of Middle and Upper Palaeolithic bone in the British Isles: improved reliability using ultrafiltration. Journal of Quaternary Science 21, 557–573.
Knutz, P.C., Austin, W.E.N., Jones, E.J.W., 2001. Millennial-scale depositional cycles related to British Ice Sheet variability and North Atlantic paleocirculation since 45 kyr B.P., Barra Fan, U.K. margin. Paleoceanography 16, 53–64.
Knutz, P.C., Zahn, R., Hall, I.R., 2007. Centennial-scale variability of the British Ice Sheet: implications for climate forcing and meridional overturning circulation during the last glaciation. Paleoceanography 22:PA1207, doi:10.1029/2006PA001298.
Reimer, P.J., Baillie, M.G.L., Bard, E., Bayliss, A., Beck, J.W., Bertrand, C.J.H., et al., 2004. IntCal04 terrestrial radiocarbon age calibration, 0–26 cal kyr BP. Radiocarbon 46, 1029–1058.
Renne, P.R., Bonardi, M., DeBièvre, P., Fajgelj, A., Holden, N., Liu, D.Y., Villa, I.M., 2006. IUPAC-IUGS Task Group 2006-016-1-200: recommendations for isotope data in geosciences. http://www.iupac.org/projects/2006/2006-016-1-200.html.
Rolfe, W.D.I., 1966. Woolly rhinoceros from the Scottish Pleistocene. Scottish Journal of Geology 2, 253–258.
Rose, J., 1981. Field Guide to the Quaternary geology of the south-eastern part of the Loch Lomond basin. 1980–81. Proceedings of the Geological Society of Glasgow, 1–19.
Rose, J., 1985. The Dimlington Stadial/Dimlington Chronozone: a proposal for naming the main glacial episode of the Late Devensian in Britain. Boreas 14, 225–230.
Rose, J., 1989. Stadial type sections in the British Quaternary. In: Rose, J., Schlüchter, Ch (Eds.), Quaternary Type Sections: imagination or Reality? Balkema, Rotterdam, pp. 45–67.
Rose, J., Smith, M.J., 2008. Glacial geomorphological maps of the Glasgow region, western central Scotland. Journal of Maps 2008, 399–416.
Sejrup, H.P., Nygård, A., Hall, A.M., Haflidason, H., 2009. Middle and Late Weichselian (Devensian) glaciation history of south-western Norway, North Sea and eastern UK. Quaternary Science Reviews 28, 370–380.
Sissons, J.B., 1974. The Quaternary of Scotland: a review. Scottish Journal of Geology 10, 311–337.
Sissons, J.B., 1981. The last Scottish ice sheet: facts and speculative discussion. Boreas 10, 1–17.
Street, M., Terberger, T., 2004. The radiocarbon chronology of the German Upper Palaeolithic: fifteen years of cooperation with ORAU. In: Higham, T., Bronk-Ramsey, C., Owen, C. (Eds.), Radiocarbon and Archaeology, Proceedings of the 4th Symposium, vol. 2002. Oxford, pp. 281–302.
Stringer, C., 2006. Homo Britannicus. Penguin Group, London, p. 319.
Stuart, A.J., Lister, A.M., 2007. Patterns of Late Quaternary megafaunal extinctions in Europe and northern Asia. Courier Forschungsinstitut Senckenberg 259, 287–297.
Stuart, A.J., Sulerzhitsky, L.D., Orlova, L.A., Kuzmin, Y.V., Lister, A.M., 2002. The latest woolly mammoths (*Mammuthus primigenius* Blumenbach) in Europe and Asia: a review of the current evidence. Quaternary Science Reviews 21, 1559–1569.
Stuart, A.J., Kosintsev, P.A., Higham, T.F.G., Lister, A.M., 2004. Pleistocene and Holocene extinction dynamics in giant deer and woolly mammoth. Nature 431, pp. 684–689.
Sutherland, D.G., 1984. The Quaternary deposits and landforms of Scotland and the neighbouring shelves: a review. Quaternary Science Reviews 2, 157–254.
Sutherland, D.G, 1999. Scotland. In: Bowen, D.Q. (ed.), A Revised Correlation of Quaternary Deposits in the British Isles. The Geological Society Special Report No 23, London, 174 pp.
Svensson, A., Andersen, K.K., Bigler, M., Clausen, H.B., Dahl-Jensen, D., Davies, S.M., Johnsen, S.J., Muscheler, R., Parrenin, F., Rasmussen, S.O., Röthlisberger, R., Seierstad, I., Steffensen, J.P., Vinther, B.M., 2008. A 60,000 year Greenland stratigraphic ice core chronology. Climate of the Past 4, 47–57.
Swinton, W.E., 1927. Note on a rhinoceros bone from the glacial sands of cadder. 1927 (for 1925-26). Transactions of the Geological Society of Glasgow 17, 395.
van der Plicht, J., Beck, J.W., Bard, E., Baillie, M.G.L., Blackwell, P.G., Buck, C.E., et al., 2004. NotCal04-Comparison/calibration C-14 records 26–50 cal kyr BP. Radiocarbon 46, 1225–1238.
van Nédervelde, J., Davies, M., John, B.J., 1973. Radiocarbon dating from Ogof-yr-Ychen, a new Pleistocene site in west Wales. Nature 245, 453–454.