ANTHROPOLOGIE • XLVI/2–3 • pp. 125–134 • 2008

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THE AGE OF THE VEDROVICE CEMETERY: THE AMS RADIOCARBON DATING PROGRAMME

ABSTRACT: An ambitious radiocarbon dating programme was applied to the human skeletal material from the Vedrovice cemetery. Results suggest that the burials span the 53rd century BC, confirming that the Vedrovice cemetery (and by extension settlement) belongs to the end of the early phase of the regional LBK. The use of the cemetery therefore spanned some five or six generations. Insufficient data on the ceramic phasing of the cemetery precluded refinement of the phasing model although results suggest that a major transition occurred around 5200 BC.

KEY WORDS: Radiocarbon – Neolithic – Vedrovice – Calibration – OxCal

INTRODUCTION

Establishing the chronology and duration of deposition of the Vedrovice cemetery death assemblage was a critical element of the Vedrovice bioarchaeology project. Not only would such information further an understanding of the nature of the Vedrovice settlement (at least in terms of the dead in its cemetery) but this would also refine our understanding of the relative position of the settlement within the chronology of the Central European LBK as a whole. Prior to our programme, artefacts – particularly ceramics – from Vedrovice settlement contexts as well as those placed as grave goods within burials in the Vedrovice cemetery, in addition to two existing radiocarbon measurements (see below), suggested that Vedrovice was relatively early in the LBK chronology, and could be placed in the last part of the Earliest LBK of Central Europe or the first part of the Middle phase, but independent verification of these suggestions was felt to be critical. As the existing chronology was based only on four ^{14}C dates from the settlement, it was clear that the only way to gain a precise understanding of both the chronology and duration of the cemetery was to subject a statistically meaningful number of burials to direct AMS radiocarbon dating.

EXISTING RADIOCARBON DATES

Two dates on unspecified human bone from the Vedrovice cemetery were published previously. These were pre-treated and measured at the Vienna radiocarbon laboratory, using their standard procedures for bone (E. M. Wild pers. comm.) and have been published by Podborský (2002a, 2002b). These are: VERA-1831 Human bone, 6220 ± 35 BP and VERA-1832 Human bone, 6155 ± 35 BP.

When calibrated using OxCal (see below for references) the resulting age ranges at 2σ are 5300–5050 BC and 5220–5000 BC respectively. As will be seen below, these are fully consistent with the suite of Oxford dates analyzed here.

METHODOLOGY

The sampling for AMS Radiocarbon dating was undertaken by one of us (PP) and the pre-treatment and measurement of samples was conducted at the Oxford Radiocarbon Accelerator Unit. Of the 81 inhumations from the Vedrovice cemetery available for study, we removed samples from 43. Five of these failed to yield sufficient Carbon for dating (burials 42/77, 51/77, 86/80, 89/80 and 100/81). We were successful in dating the remaining 38, representing 47% of the available burials. Of these, duplicate samples were pre-treated and measured separately from four burials (48/77; 50/77; 90/80; and 107/82) for quality control purposes. Where this has been undertaken it can be seen that both results for each single burial are statistically identical at 2σ. In addition to the samples of human bone from the cemetery, we also measured one animal bone available to us from a pit context in the settlement. All samples taken are listed in *Table 1*.

We drilled samples from areas of dense bone, usually from long bones, ribs, or, seldomly, crania where preservation was poor on the preferred elements. Sampling was carried out in tandem with that required for stable isotope analyses. The AMS Radiocarbon dating was carried out on Carbon derived from the surviving bone collagen using the best available standard methods (Bronk Ramsey *et al*. 2004, Brock *et al*. 2007, Higham *et al*. 2006). This is a well developed approach, in which inaccuracies are only liable to arise if the preservation of collagen is unusually poor, or if the bone has been treated, e.g. during conservation, with organic material that might contaminate the collagen being dated. Neither of these were problematic for the Vedrovice samples. The collagen extraction and purification (pre-treatment) used is detailed in Higham *et al*. (2006). Briefly, the bone calcium phosphate is dissolved in dilute acid, the solid insoluble collagen is collected, washed, solubilised to gelatine in warm water, filtered, and then ultrafiltered to retain only high molecular weight material. In practice, this has been found to be a highly effective procedure to remove material which is physically or chemically associated with porous bone during its burial. Collagen is oxidized to CO_2 in a continuous flow elemental analyser, in which the gaseous products are purified by gas chromatography, an aliquot is split off for stable isotope mass spectrometric measurement (for $\delta^{13}C$ and $\delta^{15}N$), while the remainder is reduced to graphite targets suitable for AMS measurements. This routine method is standard among many AMS laboratories. The radiocarbon date (radiocarbon years BP) is calculated from the relative ion beam intensities of the carbon isotopes from sample and standard, making the appropriate correction for carbon isotopic fractionation according to international convention.

Three tests can be performed on the purified collagen to give reassurance that substantial contamination is absent. These are: the measured atomic Carbon to Nitrogen ratio (which should lie between 2.9 and 3.4, and here lies entirely between 3.18 and 3.4); the measured yield of collagen (which is more susceptible to contamination when the % collagen is <1%; here over 60% of the bones retained more than 3% collagen, and none had less than 1%): and the value for $\delta^{13}C$, where outlying measurements may be suspect (and here there was a remarkable uniformity in $\delta^{13}C$). Three bones however yielded so little collagen that they were undatable. A final test is to look for any correlation of ^{14}C dates with preservation (such as % collagen yield), which might indicate any bias arising from the possibility of contamination. In fact the dates are rather uniform, and show no correlation with any diagenetic indicator.

In summary, the assemblage of human bone at Vedrovice is well, and rather uniformly, preserved. The standard best practice method of collagen purification for every sample dated gave very satisfactory yields with reassuring values for measurements diagnostic for possible contamination. There is every reason to suppose that the dates are therefore correct within the quoted random errors.

RESULTS

The radiocarbon content of human bone collagen is an average of the content of the human diet (mainly its protein content) over the last few years of life. A complication that can arise in dating is if dietary components are depleted in radiocarbon for any reason. The main reason in archaeological contexts would be reservoir effects in aquatic systems, that is, where marine or freshwater fish may be consumed. A marine reservoir effect for the Vedrovice bone can be dismissed on the grounds of geography (not near to marine environments) and from the terrestrial values found for collagen $\delta^{13}C$ (which do not indicate any significant consumption of marine foodstuffs). A freshwater reservoir cannot be entirely dismissed, but is in fact highly unlikely given that the human collagen $\delta^{15}N$ values of the Vedrovice bone show no sign of the elevation characteristic of freshwater animal consumption (see, for example, Cook *et al.* 2001), and given the generally tight distribution in both stable isotopes for humans. Therefore the dates can be assumed to be unaffected by reservoir effects and thus calibratable by normal procedures (see Bronk Ramsey 2001).

Table 1 presents information on the samples dated: $\delta^{13}C$ ratios, measurements, laboratory numbers, and the resulting calibrated age ranges at 2σ. With regards to the calibration of the measurements, the results are somewhat affected by the existence of several radiocarbon plateaux in the relevant area of the calibration curve. *Figure 1* plots the Vedrovice AMS measurements as boxes onto the curve. It can be seen quite clearly that three large plateaux (horizontal stretches) fall onto the curve at ~5480–5400, ~5300–5220 and ~5180–5080 BC. While results may therefore not be as precise as desired, they nevertheless allow us to place the deposition of the dead in the Vedrovice cemetery to within one century, as discussed below.

Figure 2a, b, c presents the calibrated age ranges of each sample measured, and numerical age ranges at 2σ are shown in *Table 1*. Overall the dates range between 5480 and 4940 BC, in agreement with the existing two dates from Vedrovice measured at Vienna. The availability of a large sample of dates does, however, enable us to narrow down within this the probable range of deposition. A parsimonious interpretation of the probability distributions of *Figure 2* would narrow the range down to ~5300–5100 BC. We

TABLE 1. Vedrovice bones sampled and dated by AMS Radiocarbon at Oxford. With the exception of the 179/3 animal bone (full details 179/3 2D 0–20, 2000) all samples are identified to *Homo sapiens.* Samples are listed by burial number. "Duplicate" in notes column indicates quality control duplicate samples where these exist. In such cases both measurements are listed.

Sample	Material	Lab. No.	$\delta^{13}C$ (per mil)	Measurement (^{14}C BP)	Calibrated age range (2σ)	Notes
15/75	Bone	OxA–16650	–18.81	6299±35	5360BC–5210BC	Phase 1B1
16/75	Bone	OxA–16651	–19.43	6164±35	5220BC–5000BC	
22/75	Bone	OxA–15427	–19.08	6280±38	5360BC–5200BC	
23/75	Bone	OxA–15384	–19.01	6199±37	5300BC–5040BC	
28/76	Bone	OxA–15366	–19.23	6159±35	5220BC–5000BC	
30/76	Bone	OxA–15367	–18.71	6219±35	5300BC–5050BC	Phase 1B1
31/76	Bone	OxA–15428	–19.42	6253±36	5320BC–5070BC	
37/76	Bone	OxA–15385	–18.88	6332±37	5470BC–5210BC	Phase 1B1
38/76	Bone	OxA–15386	–19.55	6300±36	5360BC–5210BC	
42/77	Bone	–	–	–	–	Failed
43/77	Bone	OxA–15368	–19.64	6146±34	5210BC–5000BC	
44/77	Bone	OxA–15369	–19.25	6216±36	5300BC–5050BC	
48/77	Bone	OxA–16653	–19.30	6290±37	5360BC–5210BC	Duplicate
48/77	Bone	OxA–16652	–19.29	6248±35	5310BC–5070BC	Duplicate
50/77	Bone	OxA–15432	–19.05	6108±36	5210BC–4940BC	Phase 2A Duplicate
50/77	Bone	OxA–15433	–19.01	6069±36	5210BC–4850BC	Phase 2A Duplicate
51/77	Bone	–	–	–	–	Failed
54/78	Bone	OxA–16617	–18.88	6240±45	5320BC–5050BC	Phase 1B1
57/78	Bone	OxA–15387	–18.91	6160±35	5220BC–5000BC	
59/78	Bone	OxA–15388	–18.58	6246±36	5310BC–5070BC	
62/78	Bone	OxA–15131	–19.17	6266±36	5330BC–5070BC	Phase 1B1
66/78	Bone	OxA–16618	–19.00	6251±39	5320BC–5070BC	Phase 2A
71/79	Bone	OxA–15424	–18.50	6263±34	5320BC–5070BC	
72/79	Bone	OxA–15429	–19.30	6268±37	5330BC–5070BC	Phase 1B
77/79	Bone	OxA–15425	–18.61	6298±34	5350BC–5210BC	Phase 1B2
73/79	Bone	OxA–16619	–19.27	6169±38	5220BC–5000BC	
75/79	Bone	OxA–16620	–18.88	6289±37	5360BC–5200BC	
79/79	Bone	OxA–16621	–19.18	6244±40	5320BC–5060BC	Phase 1B1
81b/79	Bone	OxA–15370	–19.07	6234±36	5310BC–5060BC	
82/79	Bone	OxA–16622	–18.63	6250±40	5320BC–5060BC	
86/80	Bone	–	–	–	–	Failed
84/80	Bone	OxA–16623	–19.36	6297±38	5360BC–5210BC	
89/80	Bone	–	–	–	–	Failed
90/80	Bone	OxA–15430	–19.45	6407±37	5480BC–5320BC	Duplicate
90/80	Bone	OxA–15362	–19.24	6375±50	5480BC–5220BC	Duplicate
91/80	Bone	OxA–15363	–19.12	6305±40	5370BC–5210BC	Phase 1B1
93a/80	Bone	OxA–16624	–19.06	6226±37	5310BC (49.2%) 5190BC–5060BC	
96/80	Bone	OxA–15431	–19.21	6224±36	5310BC–5060BC	
99/81	Bone	OxA–15426	–19.41	6272±37	5330BC–5070BC	Phase 1B
100/81	Bone	–	–	–	–	Failed
101/81	Bone	OxA–15364	–18.92	6182±35	5230BC–5010BC	
102/81	Bone	OxA–16625	–19.42	6195±35	5300BC–5040BC	
104/81	Bone	OxA–16626	–19.06	6249±36	5320BC–5070BC	
105/81	Bone	OxA–16627	–19.33	6220±36	5310BC–5050BC	
106/82	Bone	OxA–15365	–19.16	6141±34	5220BC–4990BC	Phase 2A
107/82	Bone	OxA–16629	–19.26	6175±37	5220BC–5000BC	Duplicate
107/82	Bone	OxA–16628	–19.28	6125±37	5210BC–4960BC	Duplicate
179/3	Animal Bone	OxA–15553	–20.18	6410±65	5490BC–5220BC	(Settlement)

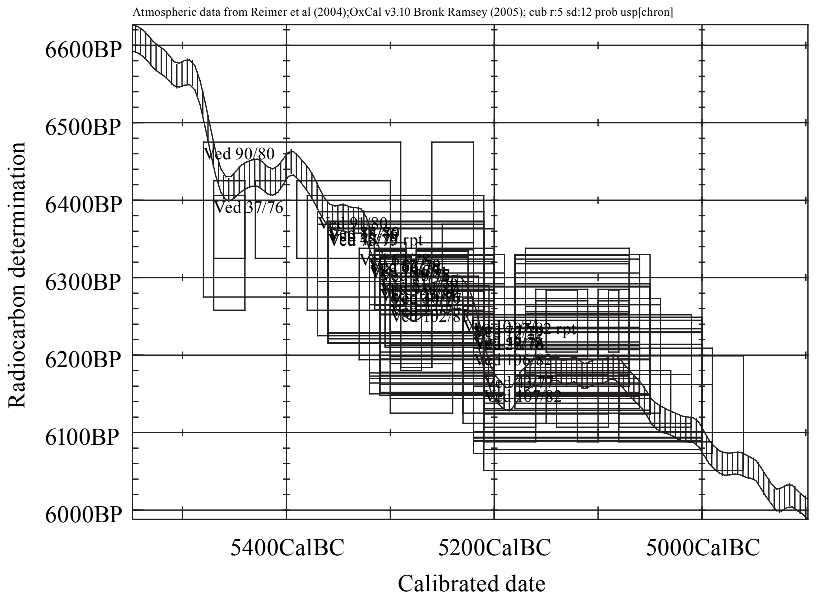

FIGURE 1. The Vedrovice ^{14}C measurements plotted against the INTCAL04 calibration curve (Reimer *et al.* 2004) using OxCal (Bronk Ramsey 2001).

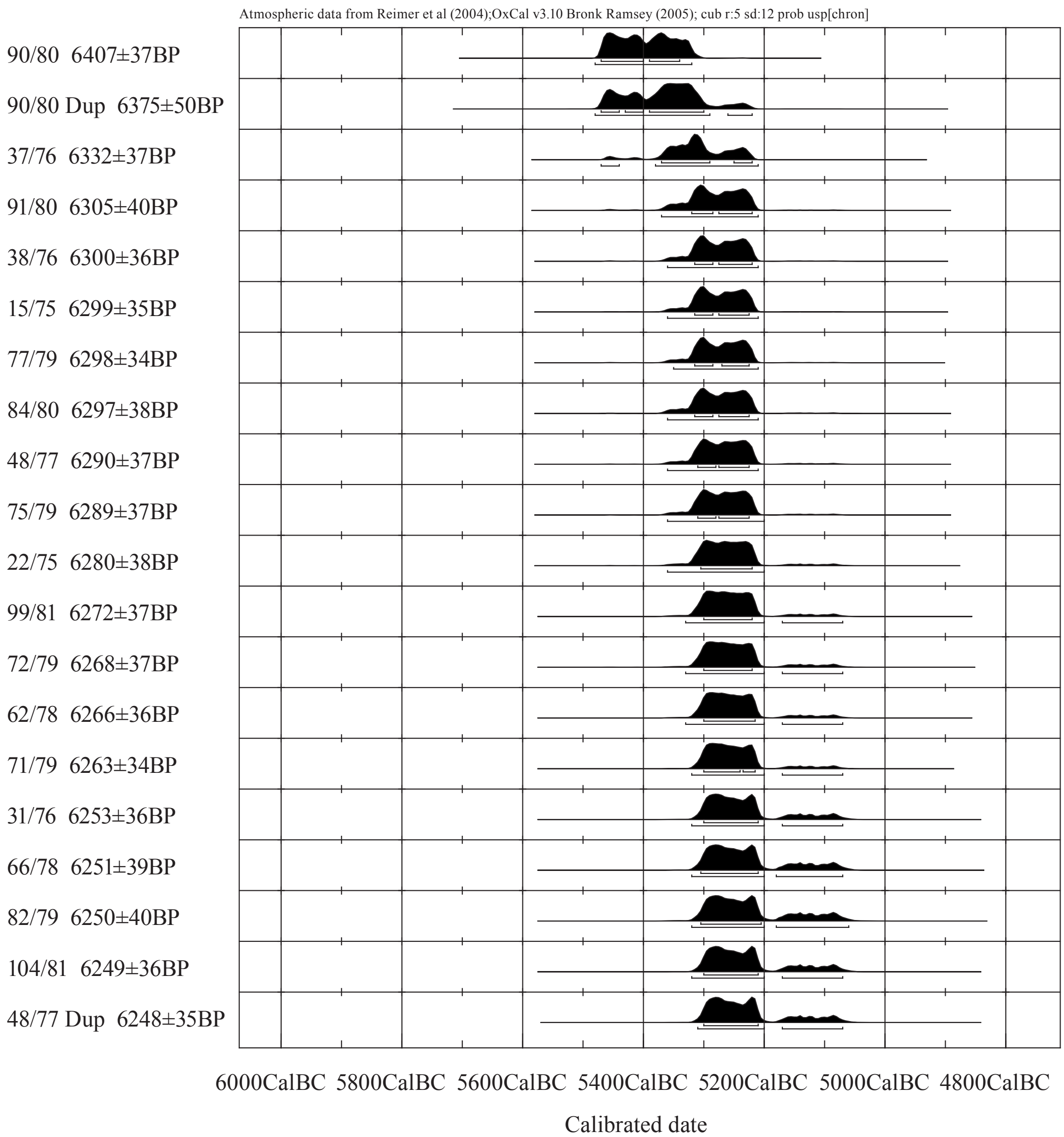

FIGURE 2a. Calibrated age ranges for the sampled Vedrovice burials. Listed by burial number and displayed in order of mean ages. Atmospheric data from Reimer *et al*. (2004); calibrated with OxCal v3.10 (Bronk Ramsey 2001).

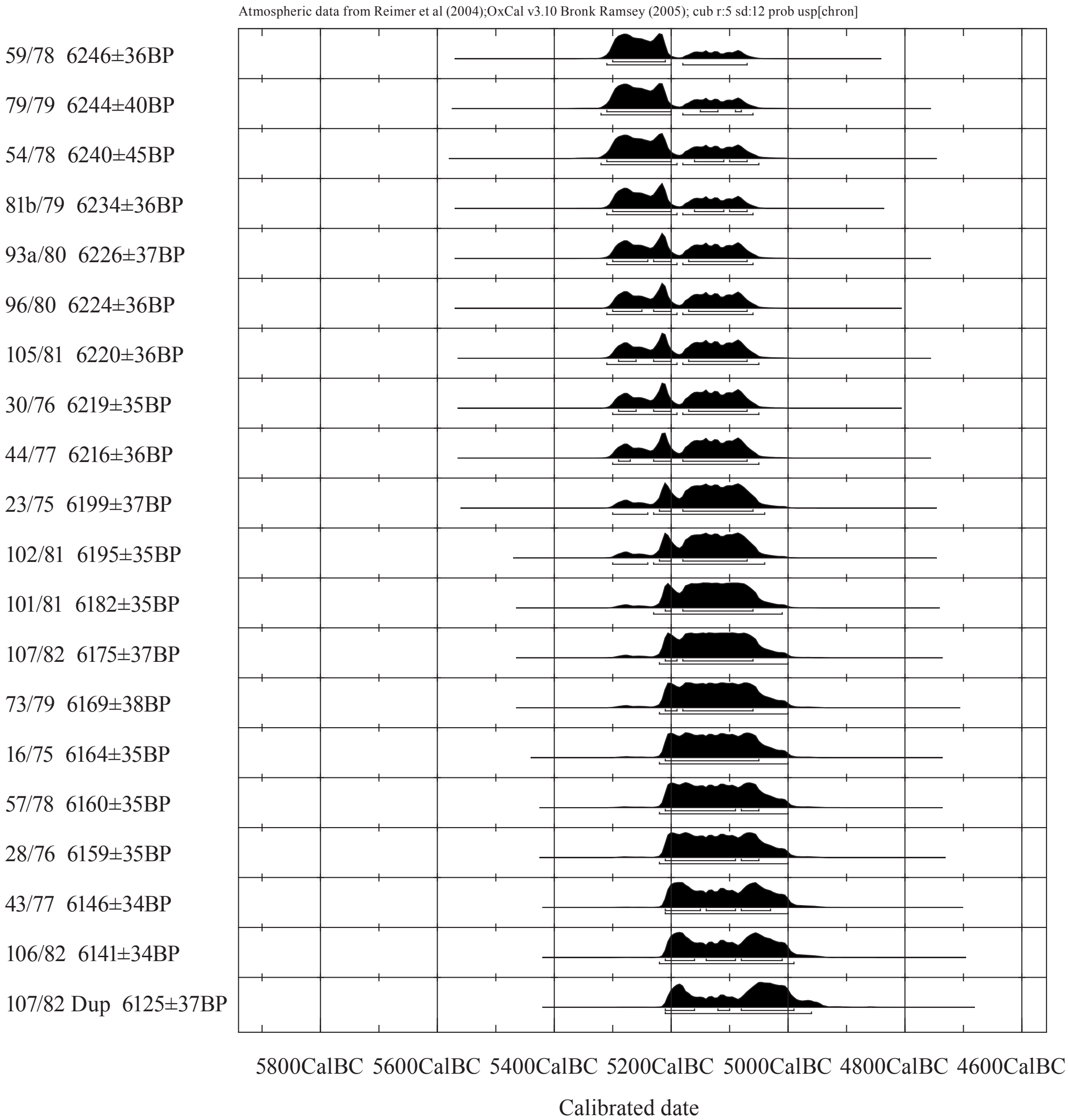

FIGURE 2b. Calibrated age ranges for the sampled Vedrovice burials. Listed by burial number and displayed in order of mean ages. Atmospheric data from Reimer *et al*. (2004); calibrated with OxCal v3.10 (Bronk Ramsey 2001).

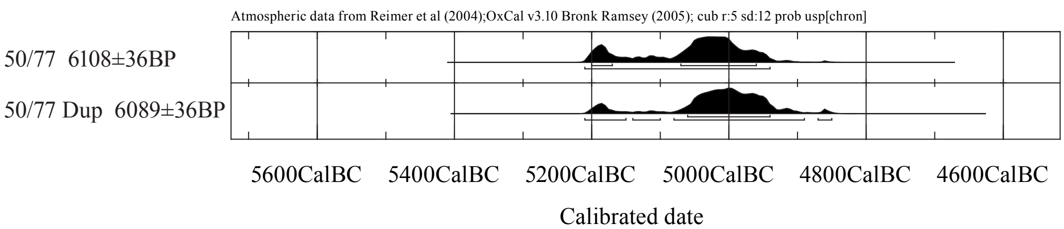

FIGURE 2c. Calibrated age ranges for the sampled Vedrovice burials. Listed by burial number and displayed in order of mean ages. Atmospheric data from Reimer *et al*. (2004); calibrated with OxCal v3.10 (Bronk Ramsey 2001).

can furthermore use assumptions about the chronological relationships of each burial based on ceramics-based phasing information to explore statistically this distribution and narrow it down further.

As phase-diagnostic ceramics were not recovered with all burials, and as these were not interred with all of the skeletons made available for us to sample for dating, there is insufficient *a priori* information which can be used to constrain the statistical distribution of the overall set of calibrated radiocarbon dates. We can, however, use what information is available to examine at least the relationship between two broad phases, as we shall come to below.

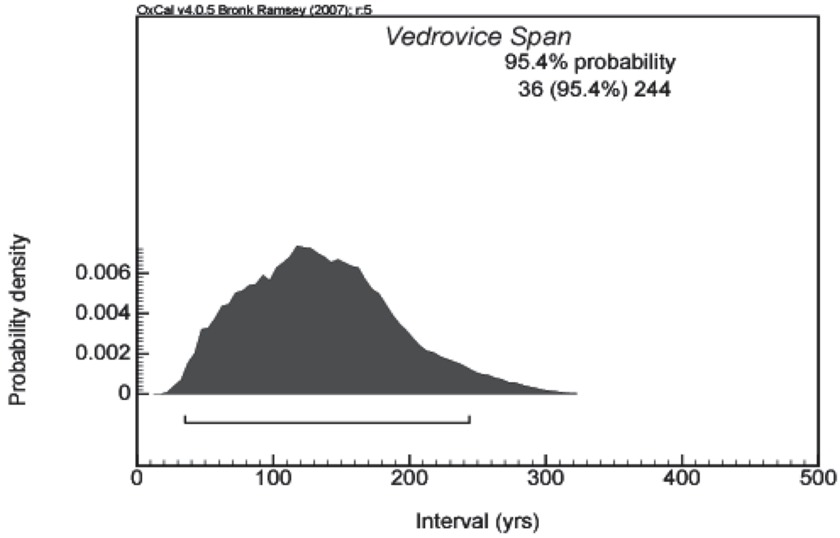

FIGURE 3. Estimation of the duration of deposition of the Vedrovice cemetery death assemblage available for the dating programme.

First, we can define the duration of the sampled cemetery as a whole, i.e. the time over which the death assemblage was deposited. We used the OXCAL programme (Bronk Ramsey 2001) to determine the best probability for the duration of the death assemblage, and this value is plotted in *Figure 3*. It is evident that a reasonable probability for use of the cemetery (assuming interment occurred within a few years of the death of each individual) ranges between about 60 to 180 years (with a 95% probability encompassed between 40 and 240 years). On the basis of the 81 burials available for study from the cemetery and assuming its actual extent is not considerably larger, this would give a figure of between 0.5 and 3 inhumations per year, which would not be surprising for a small agricultural community. Given the distribution of ages of the samples, however, a parsimonious reading of the age of the cemetery would fall entirely within the 53rd century BC and perhaps a little into the 52nd. If correct, one might expect five or six generations to have been deposited there.

COMPARISONS WITH THE CERAMICS-BASED CEMETERY PHASING

Although, as we noted above, ceramics-based phase information is not available for many of the dated burials, enough exists for us to constrain the calibrated age ranges and test whether the phase model is likely to be correct. Čižmář (2002) inferred from the ceramics contained within the graves that three main phases were represented in the cemetery, in order from the earliest: 1B1, 1B2 and 2A. Although most burials contained ceramics, this was only diagnostic of phase for 28 burials, of which we were permitted access to ten. In addition some ceramics were only attributable broadly to phase 1B rather than to 1B1, and only one burial was available from phase 1B2. Thus the radiocarbon dating programme was able to test the relative chronology in only a coarse way. *Figure 4* presents the calibrated age ranges of those burials we have dated which contained ceramics characteristic of phases 1B/1B1 and 2A.

From *Figure 4* it seems that phase 1B (including 1B1 and 1B2) was over by around 5200 BC. The chronology of phase 2A is less clear as the measurement for burial in all probability predates 5200 BC and is thus more in keeping with phase 1B. If one ignores this as a statistical outlier, the remaining two individuals suggest that this phase either began close to the end of phase 1B, i.e. around 5200 BC, or occurred somewhat later, i.e. in the 51st century BC. We can use the phasing information to constrain our modelling, at least knowing that phase 1 must pre-date phase 2. Given the lack of a suitable number of samples we have grouped all samples from phase 1B, 1B1 and 1B2 together. *Figure 5* presents the results of a preliminary modelling in which we assume only that phase 1 predates phase 2. The model generates probable ages for the beginning and end of phase 1 and the beginning and end of phase 2. Obviously the reliability of the ages at each end – the beginning of phase 1 and the end of phase 2 is dependent on whether we have sampled reliable indicators of these and should, at least in the case of the latter (for which we have a long tail) be taken with caution. The results, however, suggest a relatively brief duration for phase 1, perhaps lasting around 50 years from ~5300 to ~5250 BC at which point phase 2 begins.

We can model this further by assuming either that the two phases overlap each other, e.g that there is a period of contemporaneity between the two, or that they replace each other (i.e. phase 2 replaces phase 1, presumably evolving out of it). *Figure 6* presents the results assuming a period of contemporaneity, indicating a period of overlap of up to one century (~5300–5200 BC). *Figure 7* assumes no overlap, in which case the transition between phase 1 (one assumes 1B2 although we note we have only dated one burial from this phase) and phase 2A in all probability occurred at ~5200 BC. It can be seen that our probabilistic modelling becomes reliant on cultural assumptions about the nature of material cultural change in prehistory (at least in terms of ceramics). Whatever assumptions one makes, however,

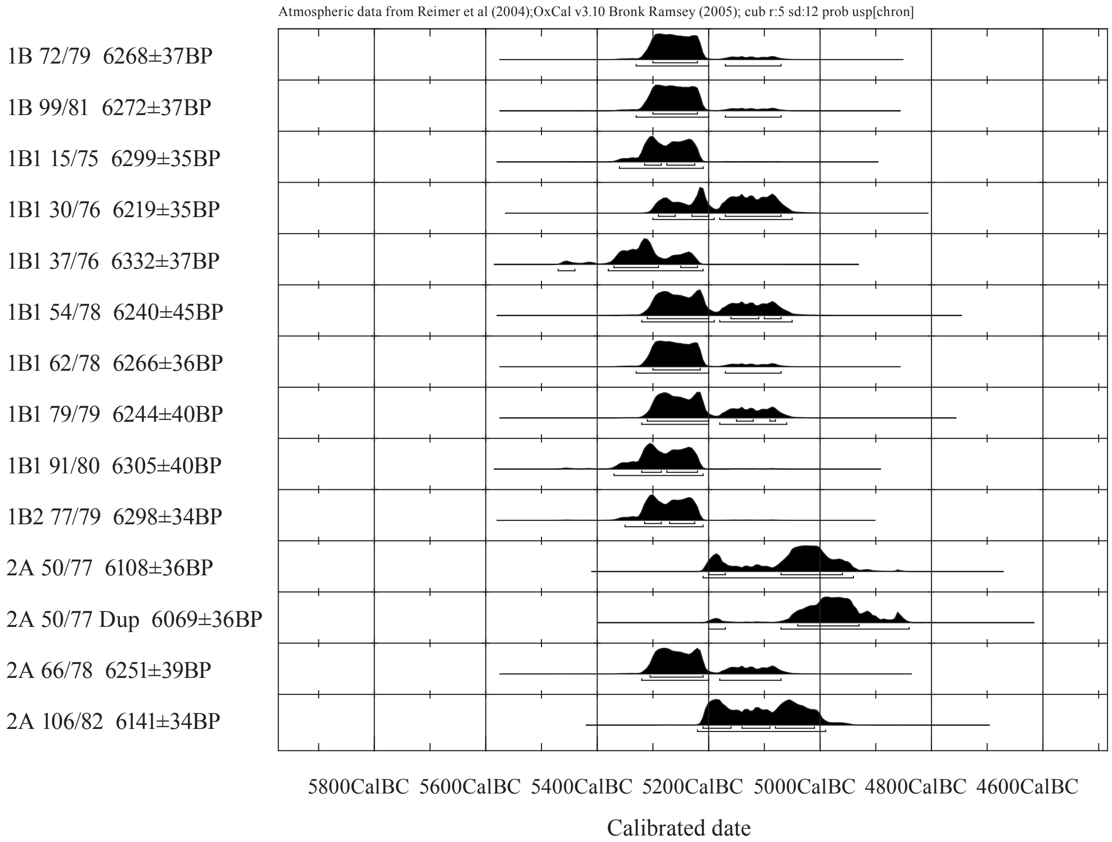

FIGURE 4. Calibrated age ranges of burials containing ceramic vessels diagnostic of phases. Listed by burial and organised by phase (in order, 1B/1B1, 1B2, 2A). Note that two measurements on burial 50/77 are included.

the results indicate that the dated burials, which represent half of the known cemetery, were deposited within a century or a little more, largely over the 53rd century BC. The transition over three main cultural phases occurred over this period, and the dating confirms the transition between two broad forms of these, and constraints it to the latter part of the 53rd century BC or the very early part of the 52nd century BC.

THE WIDER CONTEXT

Two decades ago, Modderman (1988) noted that the number of radiocarbon dates for LBK sites remained surprisingly small, and, sadly, these have not increased significantly since then. Ascertaining the precise age range of the earliest phases of the LBK has proven surprisingly elusive. To a certain extent we suspect that this will be due to the plateaux

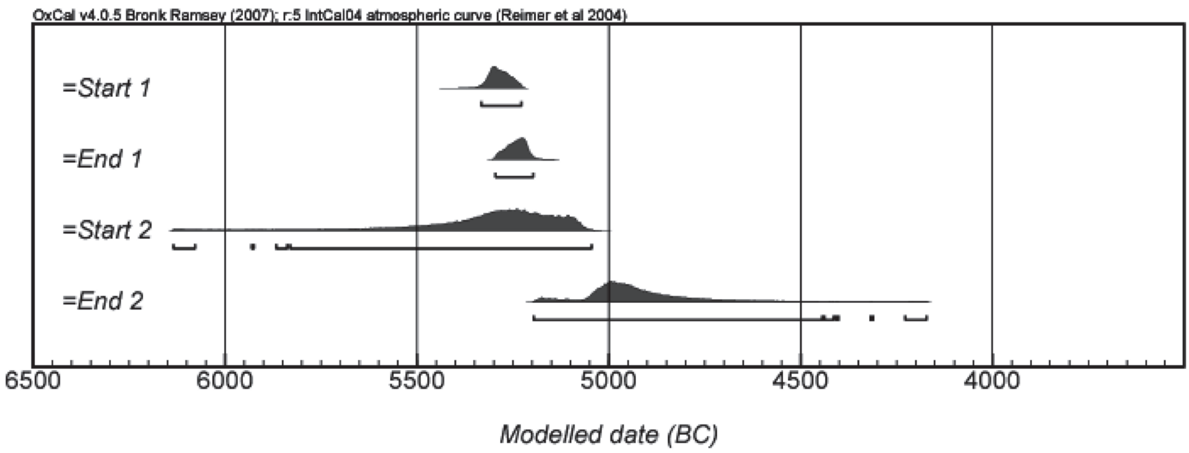

FIGURE 5. The two–phase chronological model for the Vedrovice cemetery: estimation of the start of Phase 1, end of Phase 1, start of Phase 2 and end of Phase 2.

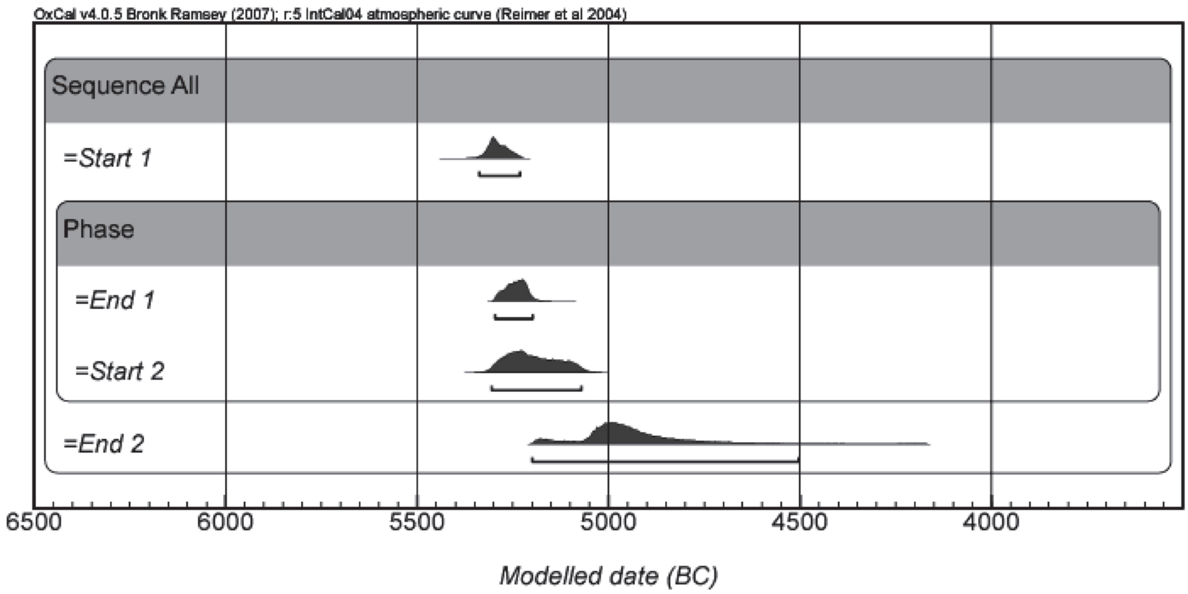

FIGURE 6. The two–phase model for the Vedrovice cemetery, assuming that both phases overlap.

encountered on the calibration curve as shown in *Figure 1*. Debate, however, has been centred on whether or not the "old wood" problem on carbonised wood samples has over-inflated the age of relevant sites (for a useful summary see Gronenborn 1999). Even the meticulous selection of small samples such as carbonised cereals from closed contexts produced surprisingly young dates (e.g. Whittle 1990). Lüning (1988) proposed an origin of the LBK ~5700 BC, with a duration of its earliest phase of ~400 years, i.e. to ~5300 BC. Stäuble (1995), by contrast, refined this to ~5500–5200 BC using rigorous selection methods and relying on short-lived materials from undisturbed features. Dolukhanov *et al*. (2005) subjected the existing ^{14}C database for the Central European LBK to statistical analyses, demonstrating that its chronology overall forms a Gaussian distribution with a 2σ range of 5600–4800 BC. They were unable to detect any temporal substructure within this, concluding that it probably spread too fast for this to register within the bounds of existing measurement precision. Despite their caution others have made sensible cases for a degree of observable chronological change in the earliest LBK. Gronenborn (1999), most usefully, compared existing ^{14}C dates with ceramics-based relative chronologies and suggested that the earliest phase, contemporary with the Starčevo/Körös culture and showing stylistic links to it, emerged in the late 57th and early 56th centuries BC;

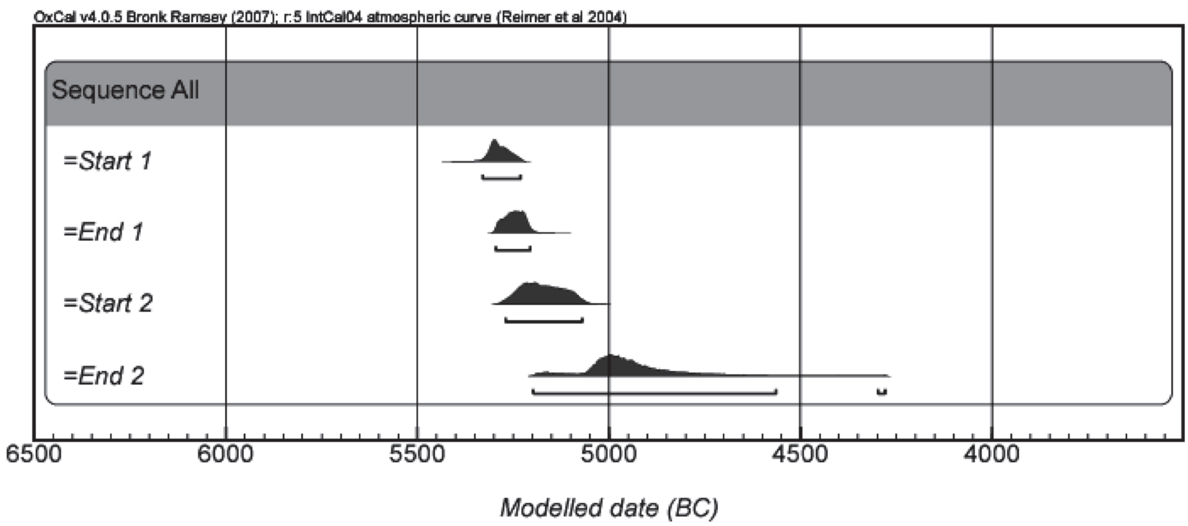

FIGURE 7. The two–phase model for the Vedrovice cemetery, assuming both phases abut each other (i.e. do not overlap).

and that a succeeding phase was contemporary with the early Vinča culture, also sharing similarities, emerged between the late 56th and early 55th centuries BC. He argues that the earliest LBK emerged in Transdanubia from ~5700 BC, spreading to Franconia by ~5500 BC and lastly towards the Rhine by ~5400 BC. The next advance he sees as occurring with the Flomborn phase in the 53rd century BC – the century which saw occupation at Vedrovice. Price *et al*. (2001) put the date of arrival in the Rhine and Neckar valleys back one century to ~5500 BC, although both agree that the next major expansion was in its Middle (i.e. "Flomborn") phase from ~5300 BC.

Vedrovice is younger than the earliest securely dated LBK sites of the circum-Danubian region which belong to the period 5700–5600 BC (Gronenborn 1999) and Hungary around 5500 BC (Price *et al*. 2001). It likely falls in the latter part of the Early LBK phase of Bogucki and Grygiel (1993). Given that the deposition of burials in the Vedrovice cemetery spans the 53rd century BC and perhaps a little of the early 52nd, it is fairly clear that the settlement was in existence in the same century as Flomborn, i.e. the very latest Early LBK or the beginning of the transition to the Flomborn phase (Gronenborn 1990). If Gronenborn (1999) is correct in identifying this phase with a major expansion of the LBK, then its arrival in Moravia would coincide with wider demographic processes.

CONCLUSIONS

The Vedrovice cemetery can be considered to be well dated. The results are internally consistent, and consistent with the two existing dates for the site which were measured in a separate laboratory to Oxford. A parsimonious interpretation of our results is that the burials were emplaced throughout the 53rd century BC, and perhaps a little into the earlier part of the 52nd century BC. This would mean that we have sampled approximately 5–6 generations. Our modelling of the phasing of the burials, based on ceramic typology, suggests that a major transition occurred around 5200 BC.

ACKNOWLEDGEMENTS

We gratefully acknowledge the help of Michael Dee in the application of OxCal to this dataset; the help of Tom Higham and Diane Baker of the Oxford Radiocarbon Accelerator Unit, and the staff of the Moravian Museum, Brno, particularly Ivana Jarošová, for their help and patience during the sampling of the human remains. Eva Marie Wild very kindly provided information about the two VERA dates on human bone from the Vedrovice cemetery, and we thank her warmly for her help.

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