

AMS DATING OF THE LATE COPPER AGE VARNA CEMETERY, BULGARIA

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Abstract

The Varna I cemetery, Bulgarian Black Sea coast, is one of the most remarkable sites in European prehistory, with the world's earliest large-scale assemblage of gold artefacts. Modeling of the first series of 14 AMS dates yielded a duration of c. 150 years, ~4600—4450 cal BC. However, there were insufficient paired human–animal dates for a full consideration of the question of the marine reservoir effect. Here, a fuller set of 71 dates from 53 graves is presented. We identify a small reservoir effect in a number of individuals based on ¹⁴C, carbon and nitrogen stable isotopes. We test the effect of this by building a series of different Bayesian models. Our favoured model, including a correction for some of the human determinations, shows activity at the cemetery starting at 4596—4516 cal BC (95.4%) and ending at 4427—4341 cal BC. The overall span of activity covers ~120–260 years (93.6% prob.). The modeling shows that Varna I falls towards the beginning of the Bulgarian Late Copper Age.

Keywords

AMS dating, marine reservoir effect, Varna cemetery, Bulgaria, Copper Age.

Introduction

The Varna I cemetery was discovered by accident in 1972 in the Bulgarian Black Sea coastal city of the same name. An area of 7500 m² yielded 315 graves (Figure 1) dating to the Eneolithic (Copper Age) period. What marked the site as truly significant was the large accumulation of gold objects recovered. Over 3,000 objects of a wide range of design and weighing more than 6 kg were excavated. The excavator of the site, Ivan Ivanov, claimed the material dated to the second half of 5th millennium cal BC, and was therefore the earliest evidence for goldwork in the world (Ivanov 1988; Ivanov and Avramova 2000). In addition to the goldwork, the grave goods included more than 160 copper objects, more than 230 flint artefacts, about 90 stone objects, about 1,000 beads made of different minerals, some vessels and figurines made of marble, more than 100 implements of bone and antler, and more than 700 clay products, as well as over 12,000 *Dentalium* shells and about 1,100 imported *Spondylus* shell ornaments (bracelets, necklaces and appliques). Amongst the burials were 49 graves with no human remains. Three of these so-called “cenotaph” graves contained clay heads with gold objects placed strategically on the location of eyes, mouth, nose and ears (Slavchev et al., 2016). Although the specific social structure underpinning the Varna I cemetery is disputed, from early state formation to chiefdom to non-hierarchical site

(Todorova 1978; Renfrew 1978; Raduncheva 1989; Chapman 1991; Whittle 1996; Bailey 2000; Chapman et al. 2007; Kienlin 2010), there can be little doubt of the hierarchical nature of the social relations that resulted in such a massive accumulation of exotic prestige objects (Slavchev 2010; Chapman & Gaydarska, 2014).

Bones for AMS dating were collected in late 2003 and again in mid-2004 from the Institute of Experimental Morphology, Pathology and Anthropology with Museum, Sofia. The first group of 14 AMS dates was published by Higham et al. (2007) and Chapman et al. (2007). Since the sample comprised a fraction of the human burials from the cemetery, a further 57 have now been dated, with one additional sample from the typologically earlier, Middle Copper Age Varna II cemetery (Ivanov 1978). The radiocarbon dates reported here constitute the complete run of AMS dates for the Varna I cemetery dating project.

One of the areas of uncertainty that has remained from the initial 2007 study, however, was the potential for carbon derived from the marine reservoir to be incorporated in the bone collagen of the human bone from the cemetery. An offset, systematic or otherwise, in the dated corpus might be a source of uncertainty in the overall chronometric analysis. For this reason, we have explored the possibility that some of the previous results, and those we have newly obtained, might be offset to their true age, in addition to generating a large new dataset of AMS determinations. This is one of the areas we tackle below.

<<FIGURE 1>>

Materials and methods

AMS radiocarbon dating was undertaken at the Oxford Radiocarbon Accelerator Unit (ORAU), University of Oxford. Methods applied are those outlined by Brock et al. (2010). The data obtained is shown in Table 1. Included are several dates obtained in earlier studies (Higham et al., 2007; Chapman et al., 2007). Since the final preparations for this article, a further six AMS dates have been published for six graves (Table 2) (Krauß et al. 2016, 284 – 6 & Taf. 2). It is acknowledged that the two dates based on *Dentalium* require a large marine reservoir correction given that they probably derive from the Mediterranean sea. The remaining four dates fall at the extreme range of the overall duration of the Varna I dates discussed here – both early and late but would fit in the overall time-span of the cemetery proposed here.

<<Insert Table 1 here>>

Honch et al. (2006) and Higham et al. (2007) have suggested previously that there might be a small marine reservoir effect derived from the Black Sea operating amongst some of the humans buried at Varna. Quantifying and assessing the effect of a small potential radiocarbon reservoir influence is not a simple procedure. One reason for this is that it is difficult to determine whether the carbon being fixed into bone collagen is via a pathway in which carbon is directly routed from the protein component of the diet, or whether it originates via a more mixed dietary pathway (the so-called ‘scrambling’ model) incorporating carbon from other dietary macronutrients such as lipids and carbohydrates into the bone collagen. The idea that C and N isotopes respond linearly to one aspect of diet might be more complicated than has been previously assumed (e.g. Craig et al. 2013). Recent work on the dating of known age samples of bone (from Herculaneum) by Craig et al. (2013), however, has at least shown

that the $\delta^{13}\text{C}$ values of bone collagen appear to predict the marine carbon component in collagen in a near linear manner, and therefore suggest that this method of correcting reservoir-affected samples might not be grossly wrong. Of course this is one instance, and it is possible that other cases are not so straightforward.

We examined the possibility of a reservoir effect initially by dating paired samples of human and animal bone excavated from the same graves (Table 3). Implicit within this analysis are the assumptions that; i) the AMS determinations are accurate, ii) that the association between the dated materials is reliably known, and; iii) that there is no heir-looming of the artefacts interred in the graves which could offset their age from that of the human bone artificially. If these assumptions are upheld, then the differences between the AMS dates are likely a function of the uptake of reservoir-depleted carbon into humans, probably from the Black Sea. There is also the possibility that some dietary protein might derive from the local riverine/aquatic environment; the latest studies of the Varna Lakes show their existence throughout the Holocene period (Vergiev et al. 2014). Offsets between the two substrates, with the animal bone being younger, would suggest the likelihood of a reservoir effect operating.

Some of the results of the stable isotope work obtained in Table 3 suggest that some of the animal bones sampled are more likely to be human bones. OxA-18575 and 23612, for example, from Grave 28, disclosed high $\delta^{15}\text{N}$ values, which reflect a probable human dietary signal. OxA-13690 falls into the same category; the isotope results here mirror those obtained for OxA-13689, the human bone from the same grave cut. OxA-23625 is similar. Because we could not be sure of the identification for these samples we left them out of the reservoir analysis below. For each case in which we had more than a single date from an animal or human in the same grave we calculated error-weighted means. In all cases the value for T was less than the value for chi-squared showing that the results are statistically identical. The paired animal/human calibrated results are shown in Figure 2a. We plotted the differences between the animal and human distributions using the **Difference** command in OxCal 4.3 and these are shown in Figure 2b. The results show that 2 of the 4 values overlap with 0, which means that they have no significant offset at 95% probability. However, two of the other pairs do not overlap, with offset values ranging from -263 to -16 years (95.4% prob.) and -174 to -22 years. This suggests there is a potential reservoir effect for these samples.

<<Insert Table 2 here>>

When the offset values are plotted against carbon stable isotope measurements, the offsets show an R^2 value of 0.58 (Figure 3). There is, however, a small number of data points, but the results from this and the paired analysis support an indication that some of the human bones enriched in $\delta^{13}\text{C}$ may well be affected by reservoir carbon. Elevated $\delta^{15}\text{N}$ values are often associated with radiocarbon reservoir offsets, since there are more trophic levels in complex foodwebs in the freshwater and marine biomes. When we plotted radiocarbon age offsets against $\delta^{15}\text{N}$ and $\delta^{13}\text{C}$, there was a poor correlation (Figure 3), but, again, paired data are few in number. Taken together, offsets do not appear to be consistent in terms of paired stable isotopes (Figure 4).

<<Insert Figure 3>>

<<Insert Figure 4>>

Previous work on human palaeodiet at the Varna cemetery has been undertaken by Honch et al. (2006). This consisted of carbon and nitrogen isotope analysis, without paired radiocarbon dating. The isotope data from Honch et al.'s (2006) work is shown in Figure 5. They suggested that the isotope values for the humans reflected dietary protein sources that ranged from terrestrial C3 protein sources to those that included a proportion of marine foods. Human $\delta^{15}\text{N}$ values greater than 11‰ and those greater than 1σ away from the mean of the $\delta^{13}\text{C}$ values ($-19.3 \pm 0.3\text{‰}$) were considered liable to be potentially affected by reservoir carbon (Honch et al., 2006:1499).

<<Insert Figure 5 here>>

<<Insert Figure 6 here>>

Modeling the AMS dates

We tested different Bayesian calibration models to explore the effect on the chronology of the site when different groups of samples are analysed in order to consider the effect of uptake of carbon via the marine reservoir effect. We focused initially on human bone determinations which were less enriched than -19.0‰ in $\delta^{13}\text{C}$ and less than 11‰ in $\delta^{15}\text{N}$. These we consider less likely to exhibit reservoir offsets based on Honch et al. (2006:1499). All determinations were placed into a single Phase model in OxCal 4.3 (Bronk Ramsey, 2009a). We used the General outlier model to consider whether there were any results that were outlying. We used an outlier probability of 0.05, that being the value typical for providing a 1 in 20 chance that the measurement needs shifting in some way (Bronk Ramsey, 2009b). We term this Model 1. The results are shown in Figure 6. The model yields a start boundary of 4576—4495 cal BC¹ and an end boundary of 4527—4442 cal BC, with an overall interval of time representing 0-121 years (95.4% prob.). (In the Supplementary Information we provide all CQL code for the various models run in this paper).

In Model 2, we added to the Model 1 human determinations AMS dates of animal bones that we can be fairly sure have no reservoir effect². We did not combine or mean animal and human bones from the same grave cut in this model. As expected, with additional AMS measurements the results show a wider range, with the boundaries become older and younger respectively, and with some animal determinations clearly in the younger end of the group (Figure 7). The boundaries show the start of cemetery use dating to 4619—4469 cal BC, and the end at 4476—4377 cal BC, with a wider overall span of 83-227 years. In Model 3, all of the results were included (again with the exception of the problematic samples above) (Figure 8). In cases where we had multiple dates or duplicates from the same grave, we used OxCal's R_Combine method prior to calibration. For this model, the results show a start boundary at 4621—4547 cal BC, an end at 4446—4386 cal BC, with an interval covering 129—278 years, in other words broadly similar to the data produced by Model 2. This suggests that there is not a significant overall offset or shift in the data due to variable reservoir effects, otherwise the inclusion of the remaining human bone dates would probably see older boundary ranges.

<<Insert Figure 7 here>>

<<Insert Figure 8 here>>

¹ In the following all modeled ranges are given at 95.4% probability.

² We exclude the problematic samples discussed earlier from Model 2.

Finally, we tested a fourth model (Model 4), in which we included a correction for some determinations based on their carbon stable isotope values. We used the method of Arneborg et al. (1999) to linearly interpolate values between a 100% terrestrial diet (-19.6‰) and a 100% marine diet (-12.5‰) to estimate likely proportions of marine protein for each dated skeleton at the site. The terrestrial estimate was derived from measured $\delta^{13}\text{C}$ values for *Bos* sp. and *Ovis* sp. outlined in Honch et al. (2006) dating to the Eneolithic from Bulgaria ($n=9$). In the age model we used a ΔR value of 50 ± 65 (calib.org; Reimer and Reimer 2001) and the Mixed Curves approach in OxCal 4.3, with the mixing estimate based on the interpolation value calculated and an uncertainty on each value of 10% (after Arneborg et al, 1999). If any of the human bone $\delta^{13}\text{C}$ values were less enriched than the terrestrial value we did not make any correction. The results for Model 4 are shown in Figure 10. The values for the start and end boundary of this model were 4451—4365 cal BC and 4427—4341 cal BC respectively (95.4%), so very marginally shifted younger compared with the other models as expected. We consider this to be the most reliable model of the group thus far tested in terms of the start PDF estimate since it takes into account the potentially reservoir effected human bone samples.

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The overall duration of the cemetery

The set of new AMS dates we analysed comprises 53 of the 315 graves, or about 17% of the total³. This provides a representative basis for the overall chronology of the cemetery although we cannot be certain that there are earlier or later burials if these are undated. This is for future researchers to test. Model 4 provides an overall span of activity at the cemetery of 120—264 years (at 93.6% with a modal value of 150 years). Considering the number of graves, which may well have exceeded 350⁴, this may well have been a short timespan of use, with around 2 burials per year on average, much higher than most other prehistoric cemeteries (Table 4), although the chronologies from these sites are not hugely refined or precise compared with Varna. While the concentrated sequence of burials at Varna limits the time-depth of the ancestral presence to perhaps six generations, the frequency of burial acts would have enhanced the abilities of the communities to compare and contrast the quantities of grave goods buried with the newly interred dead, as well as deepening the personal, emotional and kinship links between mourners at successive funerals.

The internal chronology of the six cemetery zones and the spread of the cemetery

³ If we exclude the 49 graves that contained no human bones, the dated graves amount to more than 19% of graves with bodies.

⁴ About 1/5 of the presumptive area of the cemetery remains unexcavated.

We have divided the territory of the cemetery into six equal zones. There is a variable number of AMS-dated graves in each of them, with comparable, high numbers of graves in three Zones ($n = 10$ —11 graves in the North-East, North-West and West-Central zones) and rather fewer AMS-dated graves in the remaining three zones (4 graves in the South-West zone, 7 graves in the South-East zone and 8 graves in the East-Central zones). However, the lack of human bones in the concentration of well-furnished cenotaph graves in the Southern zones – especially the South-West zone - means that AMS dates are lacking for some of the ‘richest’ graves in the entire cemetery; in general, there were museological and heritage objections to drilling even small samples from bone figurines. Nonetheless, the wide distribution of AMS-dated graves provides a reasonable basis for modeling the spatio-temporal spread of graves at Varna.

We analysed the start and end boundaries of the different burial zones of the Varna site. We used the determinations corrected and modelled above in Model 4. The results are shown in Figure 10. Each burial zone was treated as a single phase and we used a General outlier model to explore whether there were any determinations at odds with the prior framework. We then tested the significance of the boundaries by measuring the differences between the start boundaries of the main burial zones identified at the site using OxCal’s Difference command. The results are shown in Figure 11. In the main, the data show no significant difference between the parameters, because the distributions overlap with 0. However, some are significant. Areas EC, WC and NW, for instance, all begin earlier than area SE. The absence of a linear or zonal spread of early graves to late graves across the cemetery confirms the findings from the earlier set of 14 AMS dates. This suggests perhaps that several communities may have been burying clusters of burials in different areas of the cemetery from an early stage of its use rather than a single community burying their members in widely dispersed parts of the mortuary space. If this is true, their links to a widespread social network of communities would have required the negotiation of identities both within their own communities and between groups with recently developed exchange relations. The very establishment of a focal cemetery for this widespread network could have led to a strong development of place-value at Varna I, in turn strengthening the network as an emergent and significant socio-political force.

The internal chronology of graves of different grave good characteristics

The consideration of the quantity of grave goods in human and animal bones selected for AMS dating led to a search for a balanced range of samples from each of four classes of grave good wealth as graded by the number of categories of grave goods in each grave: A—7 or more categories; B—4-6 grave good categories; C—2-3 grave goods categories; and D—no grave goods or 1 category. A total of seven Rank A graves were dated, with 17 graves of Rank B, 15 of Rank C and 13 of Rank D (Table 5). Thus, while there is a bias towards graves with lower varieties of grave good categories, each grave class has at least seven samples and this gives some grounds for the selection of a representative sample for the establishment of an internal chronology for graves of different ‘wealth’.

A further issue clarified by the new AMS dates concerned whether or not there was any significant difference between the age of the dated burials that contained few grave goods, and those that contained more significant mortuary offerings. One way to investigate these hypotheses is to model graves from the four grave good rankings separately, irrespective of the spatial distribution of graves of different ‘wealth’. Again, we placed the different grave good groups into a uniform bounded Phase in OxCal. The result of this analysis is shown

in Figure 13 (see Figure 14 for the boundaries obtained from each phase). We analysed the significance of the differences between the boundaries using the `Difference` command in OxCal (Figure 15). (see Supp. Methods for model code). The results show no statistical difference between the start and end boundaries of any of the groups analysed (Figure 15), so we conclude that there is no statistical significance in the presence of grave goods at the site. This result contradicts the preliminary hypothesis of the early dates of Rank A graves based on the earlier set of 14 AMS dates (Higham et al. 2007; Chapman et al. 2007).

The internal chronology of individual artefact types within the cemetery

One aspect of the modeling of the Varna AMS dates that was impossible to explore with the first series was the consideration of date ranges for specific artefact types within the overall cemetery. The vast range of artefact types at Varna meant there were many types of interest for internal phasing. We focused on graves with a minimum of 5 AMS dates per grave type. This meant that many important types have been excluded from this analysis (e.g., gold appliqués and beads, copper chisels, bone figurines, faceted carnelian beads, jadeite axes and flint superblades). Nonetheless, it still left a total of 11 specific artefact types for modeling, as well as seven raw material classes or artefact groups.

The results indicate a variety of chronological ranges for the artefact types, with a strong overlap in the middle decades of the cemetery. As in the previous example of grave goods, modeling disclosed no differences between any of the various artefact types. For this reason we have presented the results in the form of a `Sum` distribution to show the range of the various radiocarbon ages corresponding to each group of dated artefact types (Figure 16). Artefact types appearing to start early included all polished stone axes and adzes, *Spondylus* bracelets and copper ornaments, although there is almost certainly no statistical support for this, it is simply based on the summed probability ranges. Those types continuing longer than others included all polished stone axes and adzes, miniature trapezoidal polished stone axes and possibly antler axes and shell ornaments in general. There are insufficient dated graves containing gold objects to provide any insights into the chronology of the Varna goldwork.

Implications for the Bulgarian Copper Age

The new set of dates has broadly confirmed the previous chronological position of the Varna cemetery in the mid-5th millennium BC. This sits in stark contrast with its 'relative' position in an overall Copper Age chronological scheme that puts it towards the end of the 5th millennium BC (Boyadziev 1995). This discrepancy explains the tacit rejection of the first series of dates by almost all Bulgarian prehistorians. The existing series of radiocarbon dates for other Late Copper Age sites (Boyadziev 1995), however, can be easily discredited in terms of modern standards on the basis of poor sampling strategy, lack of taphonomic awareness and number of dates per site; however they remain the preferred, if outdated, basis for the absolute chronology for the Bulgarian Copper Age.

Since the publication of the first series of Varna dates almost 10 years ago, new dates have come to light from sites in Bulgaria (Tsirtsoni 2016) and the neighbouring regions (Borić 2009; Reingruber 2015; Tasić et al. 2015; Tasić et al. in press; Schier et al. in prep.). On the one hand, they suggest that there is a case to be made for a revision of the current Late Copper Age absolute chronology (e.g. Durankulak, Smyadovo, Pietrele), and on the other hand they are showcases of how such a revision should be approached (e.g. Vinča-Belo Brdo and Uivar-Gomila).

The data in Table 4 puts Varna well *within* the Late Copper Age but one of the continuing problems is the overall paucity of dates for Middle Copper Age contexts, allowing the squeezing of the Middle Copper Age by the Late Copper Age, for which there are many settlement phases and many radiocarbon dates. The only date from the Varna II cemetery, dating to the Middle Copper Age, lies in the 49th—48th centuries cal BC (OxA-X-2414-52), almost a century earlier than the earliest Varna I date.

What is the position of the Varna cemetery in the Bulgarian Copper Age?

An important question concerns the place of the Varna cemetery within the Bulgarian Late Copper Age – at the beginning, throughout, or towards the end. The favoured view among Bulgarian prehistorians would be the third scenario, on the grounds that Varna represents the peak of Balkan Copper Age developments, fairly soon to be followed by the collapse of Eneolithic societies (Todorova 1995). The case is based upon stratigraphy, typological arguments for both pottery and metal, neither strands of which can be confirmed by AMS dating. The opposite view, hardly supported in Bulgaria (cf. Gaydarska 2011 with Boyadzhiev 2015) and based upon the Varna I dates, is that Varna I dates earlier in the Late Copper Age sequence. This would support the Childean view of increased complexity at a time of profound social change, followed by a long stabilization phase, mapped onto the cultural rather than the site level (Childe 1944). The third possibility is that the Varna cemetery lasted throughout the Late Copper Age. However, the long duration of the Late Copper Age, from 4600 to 4000 BC (Boyadzhiev 1995) is far longer than the one or two centuries for the duration of Varna I. A consideration of the vast cemetery of Durankulak, a little bit to the north of Varna, which covers broadly the whole period from the beginning of the Late Neolithic to the end of Final Eneolithic, we cannot recognize in the Varna cemetery the earliest and the latest phases of the Late Copper Age. Thus, our current thinking places Varna I right in the middle of the Late Copper Age illustrating the complex processes for that period in the North-East Pontic area.

Conclusions

Once based on gold artefacts and colourful jewellery, the Varna cemetery's continuing capacity to amaze and astound is nowadays based upon the new results of a wide range of scientific analyses, including AMS dating, petrology and gemmology. Taking a minor marine reservoir effect into account, the Bayesian modeling of the Varna I dates based on our favoured model (4) supports a start date of 4596—4516 cal BC (95.4%) and an end date of 4427—4341 cal BC (95.4% probability). This suggests that the Varna cemetery falls into an early part of the Bulgarian Late Copper Age. The AMS dates are currently unable to provide the basis for a fine-grained internal chronology, however, we note the Correspondence Analysis by Krauß et al. (2016) which will we think form the basis for a set of priors that could be used in future Bayesian models. We cannot presently distinguish a cluster of 'richer' graves or a set of 'poorer' graves in the early part of the cemetery's use on the basis of our modeling. However, the AMS dates can distinguish between three areas - the East Central and West Central areas and the North West - in which burials started before those of the South East area. The AMS dates cannot presently distinguish where the earliest grave clusters were located. However, there are some suggestive variations in the chronology of some important artefact types, including copper and shell ornaments, as well as polished stone axes and adzes and also pottery. Most of the pots were badly fired 'models' of the real vessels

especially for the funeral. A brief inspection of the Durankulak cemetery, that covered all phases of the Varna culture, demonstrated a lack of some late pottery types found in the Varna cemetery (Todorova 2002), indicating variable use of pottery in different cemeteries.

There was a variable 'Varna' effect on communities in the East Balkans, Eastern Europe and the Carpathian Basin, which was related to the important role that the Varna Lakes communities played in long-distance exchange networks (Chapman 2013). The dating of an Atlantic-Volga exchange network to the centuries when burials were taking place at Varna underlines the key role that the Varna communities played in Copper Age innovations in the mid-5th millennium BC.

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Figure Captions

1. Figure 1: Location of graves dated at the site of Varna, showing Cemetery areas and types of grave: Key: a - extended inhumation; b - crouched inhumation on right; c -

crouched inhumation on left; d - cenotaph; e - partly disarticulated skeleton; f - damaged or destroyed grave.

2. Figure 2a: Reservoir offsets plotted for paired human and animal bone AMS dates from the same grave contexts. See text for details. 2b: shows the **Difference** obtained between the human and animal data. The zero line denotes no offset. The results show that there are 2 pairs that show no statistical offset and 2 that do. The burial 286 offset does not contain OxA-23625, which we suspect strongly to be human on the basis of its stable isotopes (see text).
3. Figure 3: Left: Offsets in paired radiocarbon determinations plotted against $\delta^{13}\text{C}$ values (errors are not plotted but are $\pm 0.2\text{‰}$). Right: Offsets in paired radiocarbon determinations plotted against $\delta^{15}\text{N}$ values. Errors on the $\delta^{15}\text{N}$ values are not plotted on the figure but are $\pm 0.3\text{‰}$.
4. Figure 4: $\delta^{13}\text{C}$ values plotted against $\delta^{15}\text{N}$ values. Error bars are included in the figure ($\pm 0.3\text{‰}$ for N and $\pm 0.2\text{‰}$ for C). Square values denote high reservoir offsets, diamond values denote none.
5. Figure 5: Stable isotope values for C and N from previously analysed human bones at the Varna cemetery (after Honch *et al.*, 2006). Errors are not shown but are $\pm 0.2\text{‰}$ for C and $\pm 0.3\text{‰}$ for N.
6. Figure 6: Plot of Bayesian model 1 containing human bone determinations with $\delta^{13}\text{C}$ values $> -19.0\text{‰}$ and $\delta^{15}\text{N}$ values less than 11.0‰ . This is model 1 in the text. Modelled date (BC) on the *x*-axis refers to age ranges in cal BC.
7. Figure 7: Bayesian model showing calibrated radiocarbon determinations of animal bones and humans, the latter restricted to those determinations with $\delta^{13}\text{C}$ values $< -19.0\text{‰}$ and $\delta^{15}\text{N}$ values less than 11‰ . This is model 2 in the text. Modelled date (BC) on the *x*-axis refers to age ranges in cal BC.
8. Figure 8: Bayesian model showing determinations of animal bones and all human bones. Determinations from the same grave or with replicate measurements have been combined using the R_Combine function in OxCal. This is Model 3 in the text. Modelled date (BC) on the *x*-axis refers to age ranges in cal BC.
9. Figure 9: Bayesian model showing determinations of animal bones and all human bones, some of which have been corrected to account for estimated marine carbon uptake using a linear interpolation model and the Mixed Curves approach in OxCal 4.3. Determinations from the same grave or with replicate measurements have been combined using the Combine function in OxCal. This is model 4 in the text. Combine was used instead of R_Combine in this model because the latter is inappropriate for this type of mixed curve model (R_Combine combines the data first and then calibrates against a common curve rather than a mixed curve). Modelled date (BC) on the *x*-axis refers to age ranges in cal BC.
10. Figure 10: Summary of the analysis of different areas of the Varna site that received graves during the use of the cemetery.
11. Figure 11: Difference analysis between the boundary events shown in Figure 12 above. To be significant the PDFs being compared must not overlap with 0 at 95% probability. The results show that the vast majority of the PDFs overlap with 0 and therefore the comparisons between the two parameters (eg Start EC/Start WC) are not significant.
12. Figure 12: Summary of boundary events from Figure 11.
13. Figure 13: Bayesian models for the relative proportions of graves with grave goods (see text for details).
14. Figure 14: PDF boundaries for the model in Fig. 14 with results grouped by Grave Good numbers and type.

15. Figure 15: Summary of PDF differences between grave goods in groups A-D. Each difference overlaps with 0 at 95% probability, suggesting no significant difference between the measured parameters (the start and end PDFs of different groups). These are from the corrected AMS determinations.
16. Figure 16: Summed probability distributions generated from calibrated AMS determinations that date artefact types in the various graves of the cemetery. A minimum of 5 dated graves per type was the requirement for inclusion.

Table Captions

1. Radiocarbon AMS dates and associated analytical data from the Varna site. All dates are listed by their burial number, with multiple determinations from the same human or animal bone in the same grave shown grouped together. Radiocarbon age BP is the conventional radiocarbon age, expressed in years BP with BP being before 1950 AD. Stable isotope ratios are expressed in ‰ relative to VPDB and AIR with a mass spectrometric precision of $\pm 0.2\text{‰}$ for C and $\pm 0.3\text{‰}$ for N. Yield represents the weight of ultrafiltered collagen in milligrams. %Yld is the percent yield of extracted collagen as a function of the starting weight of the bone analysed (“Used” also in mg). %C is the carbon present in the combusted gelatin. CN is the atomic ratio of carbon to nitrogen and is acceptable if it ranges between 2.9—3.5 (DeNiro, 1985; Brock et al., 2010).
2. AMS dates for the Varna I cemetery, commissioned by the Tübingen team outside the current dating programme (source: Krauß et al. 2016).
3. Radiocarbon dates of paired human and animal bones from the Varna cemetery site. Higham et al. (2007) suggested that the date of the animal bone from grave 117 was potentially affected by low collagen yields and could be problematic. For this reason it is excluded from later analysis. Grave 28 contains stable isotopes from animal bones, which include a bone ascribed to ‘deer’, that are quite similar to the human values. This might indicate a possible problem of miss-identification, therefore it might be wise to be cautious over reading too much into this paired series of results. Unfortunately we do not have a wide dataset of animal stable isotope values from the Varna site, but even so values for deer ought to be substantially different to the values recorded here. In Grave 286, one of the animal bones yielded a $\delta^{15}\text{N}$ value of 10.4‰, which is very similar to the human values. Although we cannot exclude the possibility that this might be a carnivore bone, rather than an ungulate bone, it seems suspicious that the values for both isotopes mirror the human values. We leave the determination OxA-23625 out of the later analysis for this reason. Burial 294 contains a case in which the animal bone is significantly older than the human bone with which it is associated. This may be an example of miss-association, with the animal bone being residual. There is an alternative and more likely possibility, however, this sample had a very low target current when being AMS dated, less than a third of the usual expected. The standard error is much larger and the accuracy of the measurement is potentially likely to be affected. For this reason we exclude the determinations from Burial 294 in the analyses shown in Figure 2.
4. Estimated frequency of burials *per annum*, prehistoric cemeteries in Central and South-East Europe.
5. Dated graves by cemetery area and grave good 'wealth' category.