RECONSTRUCTING THE LIFETIME MOVEMENTS OF ANCIENT PEOPLE: A NEOLITHIC CASE STUDY FROM SOUTHERN ENGLAND

Janet Montgomery, Paul Budd & Jane Evans

BIOGRAPHICAL NOTES

Janet Montgomery is an NERC Research Student at the University of Bradford. Her PhD concerns the lead and strontium isotope composition of human dental tissues as an indicator of ancient exposure and population dynamics. Her interests also include lead exposure and past human health, biological anthropology and human palaeopathology, Anglo-Saxon settlement and burial, lead isotope provenancing in archaeology and promoting the understanding of science in primary and secondary education.

Address: Department of Archaeological Sciences, University of Bradford, Bradford, BD7 1DP, UK. [email: J.Montgomery@bradford.ac.uk]

Paul Budd is NERC Advanced Research Fellow in science-based archaeology at the University of Bradford. His research interests include the systematics of lead, strontium and oxygen isotopes in relation to archaeological biomaterials including the study of ancient population dynamics, diet and the impacts of geochemistry and pollution on past human health.

Address: Department of Archaeological Sciences, University of Bradford, Bradford, BD7 1DP, UK. [email: P.Budd@bradford.ac.uk]

Jane Evans is a research scientist at the NERC Isotope Geosciences Laboratory located at the British Geological Survey, Nottingham. The focus of her research is the behaviour of radiogenic isotopes during low temperature, and diagenetic processes and the influence that the rock substrate has on biological systems.

Address: NERC Isotope Geosciences Laboratory, British Geological Survey, Kingsley Dunham Centre, Keyworth, Nottingham, NG12 5GG, UK. [email: J.Evans@nigl.nerc.ac.uk]

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Abstract: A new procedure is described in which combined lead and strontium isotope analysis of archaeological human dental tissues can be used to comment on the life time movements of individuals. A case study of four Neolithic burials, an adult female and three juveniles, from a shared burial pit excavated at Monkton-up-Wimbourne, Dorset is presented. It is demonstrated that the adult's place of origin was at least 80km to the north-west in the area of the Mendips. It is also shown that all three juveniles moved over significant distances during their lives.

Keywords: Lead isotopes, strontium isotopes, human teeth, enamel, dentine, Neolithic, isotope dilution, TIMS, PIMMS.

INTRODUCTION

The possibility of reconstructing patterns of residency and mobility among prehistoric populations from the scientific analysis of their skeletal remains arises from the systematic variation within nature, and between localities, of stable and radiogenic isotopes (Faure 1986). These become incorporated in bone and teeth from the diet. Isotopes of strontium have been used in this way for some time (Ericson 1985), but interest is now growing in the possibility of supplementing strontium isotope data with additional information from lead in particular (Budd et al. 1997a, Budd et al. 1999). The useful application of all three measurements relies on the integrity of the trace element signal preserved within the tissue of interest and the ability to relate it to a particular period of life of the individual. This paper demonstrates the viability of the approach in a case study concerning the lifetime movements of four Neolithic individuals, an adult female and three juveniles, recently recovered from the excavation of a henge-type monument in southern England.

The burials examined date to the mid to late fourth millennium BC, towards the end of what is generally considered the 'earlier' Neolithic in England. A case study from this period is particularly topical given current interest in the nature of settlement and residential mobility associated with early agriculture and domestication. After a long tradition of archaeological thought in which the arrival of Neolithic cultural assemblage was considered synonymous with the establishment of permanent settlement and adoption of a sedentary life style, recent years have seen a significant revision of opinion. An absence of permanent settlement remains and evidence for broad-based subsistence strategies has promoted a consensus in which the earlier Neolithic is seen as having strong continuity with the preceding Mesolithic in terms of residential mobility. Whittle (1999) recently described the "transition from a mobile Mesolithic to a still mobile Neolithic". Thomas (1999, 29) highlights lithic and faunal evidence for a high degree of mobility in the Neolithic of lowland southern England, but also stresses the difficulty of assessing changes in subsistence and residency within the Neolithic (Thomas 1999, 223). The direct scientific approach outlined here offers the possibility to do just that and the results are an important indication of what could be achieved with more widespread application.

STRONTIUM AND LEAD ISOTOPE SYSTEMATICS IN RELATION TO HUMAN SKELETAL TISSUE

There has been considerable interest in strontium in archaeological skeletal tissue as a potential indicator of residence patterns. Strontium has four naturally occurring stable isotopes. One, ^{87}Sr, is produced by the radioactive decay of ^{87}Rb, which, like strontium, occurs naturally in many rocks and minerals. The abundance of ^{87}Sr is therefore dependent on both the Rb content and age of the rock or mineral in which it is found. Measured in comparison with its non-radiogenic sister ^{86}Sr, we find that ^{87}Sr/^{86}Sr ratios can vary from as little as ~0.703 for basic volcanic rocks of recent age to ~0.740 in continental granites for instance (Åberg 1995). Although these variations may appear to be small, modern mass spectrometers can routinely measure ^{87}Sr/^{86}Sr ratios to a precision of ±0.00002 (Sealy, Armstrong, and Schrire 1995).

Strontium is taken up by biological systems, but the relative proportions of its isotopes remains unaltered by such processes, so that soil, plant and animal strontium isotope ratios are all related to (although not necessarily exactly the same as) those of the underlying geology and local hydrology (Hurst 1981, Sillen et al. 1998). Since strontium isotope ratios vary in a systematic way between rock units of different ages and lithologies (Faure 1986:183-199), these differences are reflected in local soils and therefore in plants growing on them and the animals eating the vegetation. It is this which links the skeleton to the locality and provides the basis for the reconstruction of residency patterns.

Some strontium from the diet substitutes for calcium in the inorganic (hydroxyapatite) mineral lattice of bones and teeth, typically resulting in hard tissue strontium contents of a few hundred parts per million (Underwood 1977:445). As the isotopic composition of dietary strontium incorporated in this way is unaltered by the process of transport and bioaccumulation, the isotope ratios of strontium found in hard tissues after death reflect a time averaged signal representative of diet over some period of life, depending on the tissue under consideration. The different rates of strontium uptake and turnover in various skeletal components offer the possibility to compare the isotopic composition of different tissues in order to comment on changes in diet, and by implication residence, over time (Ericson 1985). In particular, the enamel of permanent teeth, thought to be representative of childhood diet, has been compared with bone, considered representative of the last 6-10 years of life. This methodology has been employed in life history reconstructions for archaeological burials in South Africa (Sealy, Armstrong, and Schrire 1995, Sealy et al. 1991), the south-west United States (Price et al. 1994), and southern Germany (Price, Grupe, and Schröter 1994, Grupe et al. 1997).

The use of lead isotopes to enhance and extend the strontium-based study of residency and mobility is an important new development highlighted in recent pilot studies (Barreiro et al. 1997, Budd et al. 1997a, Budd et al. 1997b, Budd et al. 1998, Budd et al. 1999). Combined lead and strontium isotope measurements have also been used to source modern rhinoceros horn to specific National Parks in southern Africa (Hall-Martin et al. 1991). In many respects the principles are similar to those underlying the strontium technique. In pre-industrial societies it is highly likely that lead incorporated into skeletal material was derived mainly, or solely, from the diet. The isotopic ratios of such dietary lead primarily reflect those of the soil and therefore of the underlying geology. Lead isotope ratios vary in a systematic manner in the geosphere as a result of radiogenic isotope evolution and therefore as a function of the age, parent isotope abundance, and subsequent remodelling of crustal material.

Bone is known to accumulate lead from the blood supply, although the mechanism is not properly understood. Recent studies of aqueous lead sorption by hydroxyapatite (Lower et al. 1998) cast doubt on earlier proposals that lead substitutes for calcium in a manner analogous to strontium. Whatever the method of incorporation, lead turnover in bone is variable depending on tissue remodelling rates, density and function. Rates of bone lead turnover have been estimated at about 1% per year for cortical bone (Rabinowitz et al. 1991) and dentine (Gulson, Jameson, and Gillings 1997) and rather faster in trabecular bone. Bone lead is therefore considered to represent a time-averaged exposure over a period of years, depending on the specific tissue selected.

There has been considerable interest in the lead content of human dental tissue in the reconstruction of exposure histories for modern individuals. Teeth are particularly advantageous in this respect in that different dental tissues preserve lead ingested at particular stages of life. Deciduous tooth formation is instigated in the developing foetus within 14-19 weeks of fertilisation and enamel mineralisation is complete within a year of birth. Once formed, the enamel is not remodelled so that its lead content is considered a reliable indicator of *in utero* or neonatal exposure (Gulson 1996). In contrast, secondary dentine, laid down within the pulp cavity after tooth formation, is thought to accumulate lead from the blood supply (Shapiro, Needleman, and Tuncay 1972) and has been considered representative of post-natal exposure (Gulson and Wilson 1994).

Although development of the permanent first molar is initiated *in utero*, most of the permanent dentition is formed in childhood from 3-4 months after birth until about 12 or more years of age. As with deciduous teeth, permanent enamel is thought to preserve lead ingested only during the period of formation whereas dentine is known to accumulate blood lead and, in adults, can be considered to represent a time-averaged signal accumulated prior to tooth loss or death. These differences between the lead retention characteristics of different human dental tissues make teeth potential archives of both the recent and more remote exposure of single individuals.

POST-MORTEM DIAGENESIS OF ARCHAEOLOGICAL BONE AND TEETH

The success of the isotope biogeochemistry approach to the reconstruction of residency and migration rests on the presumption that the elements of interest preserved within archaeological tissue are those incorporated *in vivo*, and that these are, at least substantially, unaffected by subsequent contamination. Strontium diagenesis has been addressed by Sillen (Sillen 1986, Sillen and LeGeros 1991) and Sealy et al. (1991) who have developed a decontamination procedure based on a suggested difference in solubility between biogenetic and diagenetic bone apatite. As the chemical composition of biogenetic mineral is closely constrained, it is considered to have a more fixed (and usually lower) solubility than diagenetic minerals, which may incorporate various ions from the burial environment. A pre-treatment, 'solubility profiling', involving repeated washing of the sample in a dilute acid solution is considered to remove the diagenetic strontium component. More recently doubt has been cast as to the reliability of such pre-treatments for the recovery of biogenic strontium from archaeological bone and dentine, although enamel appears to be a reliable reservoir of *in-vivo* strontium (Budd et al. 2000).

Caution is also needed in the consideration of lead uptake from the burial environment. Previous studies comparing modern and pre-industrial bone lead burdens (Grandjean 1988, Hisanaga et al. 1988, Patterson et al. 1991) appeared to show that modern bones have considerably elevated lead compared with their archaeological correlates, arguing for a lack of serious contamination of the latter. Studies of Roman individuals, on the other hand, appeared to indicate very high lead burdens (Mackie, Townshend, and Waldron 1975, Waldron, Mackie, and Townshend

1976). It is now understood that measured levels in bone were considerably elevated as a consequence of diagenetic accumulation (Waldron 1981). As with strontium, it appears that dental enamel is the most resistant tissue with respect to post-mortem lead diagenesis and this receives confirmation from recent pilot studies comparing the lead content of archaeological and modern human teeth (Barreiro et al. 1997, Budd et al. 1997a, Budd et al. 1998, Montgomery et al. 1999, Budd et al., In Press). Preliminary results suggest broad comparability between ancient and modern tooth enamel, although the same is not necessarily true of dentine. Lead distribution patterns across tooth components appear to be highly reproducible between ancient and modern individuals (Budd et al. 1998, Montgomery et al. 1999).

CASE STUDY: FOUR NEOLITHIC INDIVIDUALS FROM CRANBORNE CHASE

The four burials were excavated by Martin Green in 1997 on farmland near the village of Monkton-up-Wimbourne, Dorset, England. The site resembles a Neolithic henge monument dug into the chalk of Cranborne Chase (M. Green, pers. comm.). Neolithic Peterborough ware pottery was recovered from the excavated area and radiocarbon determinations on the skeletons gave a calibrated date range of 5500-5100 BP (M. Green, pers. comm.). The four individuals, were recovered from a single, oval grave pit cut into the chalk bedrock and backfilled with chalk blocks and rubble. The construction of the grave pit and the articulated and undisturbed nature of the bones was interpreted as one burial event at the time of initial construction of the site. Macroscopic skeletal preservation was excellent, but there was no osteological evidence to indicate cause of death (J. McKinley pers.comm.). Permanent and where present, deciduous tooth samples were taken from all four individuals: a young-middle aged adult female (C) and three juveniles aged 5, 8-9 and 9-10 years (A, B and D respectively).

METHODS

Each tooth was cleaned ultrasonically for 5 minutes in high-purity water and then acetone. Each was then divided longitudinally using a flexible diamond edged rotary dental saw to produce half-tooth samples for mass spectrometry. Enamel and dentine samples were separated using a tungsten carbide dental bur. Enamel was cleaned of all adhering dentine and abraded from the surface to a depth of >100μm using the bur.

The surface material was discarded to produce a sample of core enamel tissue. Samples of primary, crown dentine were obtained by removing all secondary dentine from the pulp cavity. Clean core enamel and primary dentine samples were then transferred to a clean (class 100, laminar flow) working area at the NERC Isotope Geosciences Laboratory (NIGL) for further preparation.

Samples of both the underlying chalk and soil excavated from the shaft on site were collected for lead and strontium isotope analysis to assess the isotopic composition of metals available to aqueous phases in the burial environment. Aqueous leaches failed to produce sufficient lead for analysis. Approximately 2g of chalk was isolated from the centre of a large block taken from the site in the low-lead laboratory, ground in a tungsten carbide ball mill and placed in an acid-leached teflon beaker. A finely divided soil sample of similar size was placed in a second beaker. Both samples were then leached overnight at room temperature in 5ml of 10% acetic acid and the leachates removed for analysis.

At NIGL, the samples were first cleaned ultrasonically in high purity water to remove dust, rinsed twice, dried down in high purity acetone and then weighed into pre-cleaned Teflon beakers. Solid samples were dissolved in Teflon distilled 16M HNO_3 and an aliquot (10% by volume) was transferred to a second pre-cleaned Teflon beaker and spiked with ^{208}Pb tracer solution for lead concentration determination using the isotope dilution method. Lead was collected from all samples using conventional anion exchange methods and the washes from the larger aliquot of each sample were spiked with ^{84}Sr tracer solution. Strontium was collected from this fraction using conventional ion exchange methods.

The lead isotope compositions were determined by Plasma Ionisation Multi-collector Mass Spectrometry (PIMMS) using a VG Elemental P54 mass spectrometer. Data were corrected for mass discrimination using the Tl spiking technique (Ketterer, Peters, and Tisdale 1991, Walder, Platzner, and Freedman 1993). Errors on the lead isotope ratios were determined from replicate analysis of the NBS 981 standard as 0.014% for ^{207}Pb/^{206}Pb and 0.024% for the ^{208}Pb/^{206}Pb (n=27, 2σ). The lead and strontium concentrations and the strontium isotope composition were determined by Thermal Ionization Mass Spectrometry (TIMS) using a Finnegan Mat 262 multi-collector mass spectrometer. The international standard for strontium gave a value of ^{87}Sr/^{86}Sr = 0.710200 ± 32 (2σ, n=10) during the period of analysis. All strontium ratios have been corrected to the accepted value for NBS 987 of 0.710235. The mean strontium blank was 300pg (range 33-400pg).

Isotope dilution elemental concentration accuracy can exceed 1% (2σ) for homogenous samples in favourable circumstances (Dickin 1995) and this value is widely quoted for strontium concentration determinations on rock powders (Evans 1996). However, dental tissues have not been well characterised with respect to compositional heterogeneity and preliminary LA-ICP-MS studies suggest a degree of lead and strontium variation within tooth enamel (Montgomery et al. 1999). Estimates of reproducibility for the current study are based on a preliminary study of three replicate tooth enamel measurements undertaken for both a permanent and deciduous tooth. These suggest errors of ±14% for lead and ± 10% for strontium (2σ, n=3).

RESULTS

Strontium and lead concentrations and isotope ratios for all of the Neolithic tooth samples are reported in Table 1. Lead isotope ratios are reported as the non-standard ^{207}Pb/^{206}Pb and ^{208}Pb/^{206}Pb ratios which are widely used in archaeological literature. Although it is desirable to facilitate the wider comparison of data by use of the standard ^{204}Pb ratios, the very low lead concentrations of the teeth in this case resulted in ^{204}Pb ratios of relatively poor precision. Since the main purpose of the study involves the inter-comparison of the teeth and local soil, ^{206}Pb ratios were adopted. Strontium and lead isotope ratios of the soil leachates are reported in Table 2.

Strontium isotope ratios for the samples are plotted in Figure 1. In all cases the dentine strontium isotope values are considerably closer to those of the soil values than those of the enamel. Taken together with the elevated strontium content of the dentine in comparison with the enamel, the results suggest diagenetic addition of soil strontium in these cases. The evidence for diagenesis of the dentine is discussed in detail elsewhere (Budd et al. 2000).

The enamel strontium concentrations are similar to those of modern people (Underwood 1977) suggesting that the enamel is more representative of the biogenic signal (Budd et al. 2000). It is immediately apparent that there are very significant differences between enamel values for each set of dentition for each of the juveniles and that they are very different from soil values. C's enamel, formed in her early childhood, has a strontium isotope composition very different to that of the Monkton geology. Her childhood strontium, with an $^{87}Sr/^{86}Sr$ ratio over 0.71, is far more radiogenic than that associated with the cretaceous chalk of the burial environment (typically ~0.707 consistent with the values reported in Table 2). Although diagenesis of tissue samples can never be wholly dismissed, it is evident that any soil contamination of C's could only cause an under estimate of the radiogenic signal within the enamel. In fact, in this case the excellent state of preservation and low values of both strontium and lead in the enamel strongly argue for its integrity.

C's dentine strontium isotope ratio, 0.70866, is intermediate between that of the enamel and that which might be expected in the area of the chalk downlands. Although this may partly reflect a change in her place of residence in later life, the dentine strontium content is approximately three times that of the enamel indicating a significant diagenetic addition to the former. For C, a similar pattern is confirmed by the lead isotope data (Figure 2), which show her enamel to have considerably elevated $^{207}Pb/^{206}Pb$ and $^{208}Pb/^{206}Pb$ ratios with respect to both the dentine and the soil leachate. The enamel lead isotope ratios are not sufficiently low to represent the local (chalk) geology, whereas the dentine values are intermediate between those of the enamel and those typical of the cretaceous chalk.

The opportunity to analyse both deciduous and permanent tooth enamel from the three juveniles and the accuracy with which it is possible to estimate their ages at death, make it possible to extract particularly detailed information with respect to changes in their dietary intake of lead and strontium in life. Figure 1 shows that all three juveniles experienced very significant changes in the isotopic composition of the strontium they ingested between birth and early childhood. In the case of the eldest two children, B and D, the change appears to have been from less (both have similar deciduous values) to more radiogenic strontium, perhaps reflecting a move away from the chalk after birth. For the youngest child, A, the change is in the opposite direction from a more radiogenic birth signal to a more 'chalk like' early childhood value. The lead data (Figure 2) are relatively ambiguous in this case. No change is indicated between the deciduous and permanent enamel for B, although both A and D would appear to have deciduous enamel lead-isotope ratios plotting at the edge of the chalk field and in the direction of C's childhood (enamel) values.

Given the very high probability that all four individuals died at the same time, and the known periods of formation of the enamel of the teeth concerned, it is possible to estimate the relative time at which each tissue was formed. The strontium data may thus be plotted so as to relate each sample on a single time scale (Figure 3). This shows the variation between each juvenile's diet at birth, represented by the deciduous enamel, and in early childhood, represented by the permanent enamel. Error bars associated with the permanent teeth represent the maximum period of enamel mineralisation (Hillson 1996), as the exact period during which metal entrapment take places in forming enamel is not yet fully understood. The adult female, C, is represented by dashed lines indicating the values of her enamel and dentine. All of the samples are very significantly different from one another and the pattern of variation is systematic over time.

The isotope dilution TIMS data (Table 1) show that all of the tissue samples contain levels of strontium comparable with those of modern people, indicative of good survival of the biogenic component (Budd et al. in press). Lead levels are about an order of magnitude lower than averages reported for modern UK adults, but comparable with modern children.

CONCLUSIONS

We conclude that the strontium and lead isotope signature of C's dental enamel cannot have arisen by diagenesis and is representative of her biogenic signal during early childhood. The radical difference between these ratios and those of the local chalk geology show that she cannot have spent her early childhood there. Rather, her childhood diet between the ages of about 2 and 6 years, after which the crown of the permanent maxillary second premolar is fully mineralised, appears to have contained strontium with a ^{87}Sr/^{86}Sr ratio of ~0.71 and ^{207}Pb/^{206}Pb and ^{208}Pb/^{206}Pb ratios of ~0.85 and ~2.08 respectively. The combination of lead and strontium isotopes gives us a considerable degree of resolution with which to identify her place of origin. Although there are a number of localities within the UK with this combination of lead and strontium isotopes, the nearest to Monkton-up-Wimbourne is the area of the Mendip orefield about 80km to the north-west (Figure 4). The next nearest matching locality is in the north Pennines, some 350km to the north. Although such long-range migration cannot be excluded, it seems more reasonable to postulate that individual C spent at least a part of her early childhood in the Mendips area.

The isotopic composition of the dentine from the same tooth from C, with both lead and strontium isotope ratios intermediate between those of the chalk and of the Mendip orefield is probably largely a result of diagenesis, although it is possible that she moved from the region in which she grew up, to the chalk, sufficiently early in adult life for her to have accumulated some of her dentine strontium and lead from the chalk geology. Whatever the timing, her ultimate move to the chalk land is, of course, evident from her place of burial.

Analysis of the enamel from both deciduous and permanent teeth for the three juveniles has been equally revealing. The eldest two, B and D, have deciduous enamel lead and strontium isotope ratios which are similar to one another and similar to the chalk geology. Their permanent enamel on the other hand has far more radiogenic strontium isotope ratios. It seems likely that both children experienced a change of diet between birth and early childhood certainly with respect to strontium. This may reflect movement away from the typical chalk geology to an area with more radiogenic strontium, but perhaps not radically different lead. The youngest child, A, shows the opposite trend with a deciduous tooth that contains more radiogenic strontium than that found in the permanent tooth. This suggests a move towards the chalk from elsewhere between birth and early childhood.

Taken as a whole the data suggest a considerable level of mobility for all of the individuals, even over the short lives of the juveniles. The adult female must have moved at least 80km between her early childhood and death. Considering the relative times of tissue formation between the various individuals, the strontium data at least are consistent with a similar pattern of movement for all three juveniles; from the chalk, to a more radiogenic area and back again. It is tempting to invoke the idea of all four individuals travelling together, perhaps as part of a larger group. Whilst such this last aspect of the interpretation remains purely speculative, the study has produced clear evidence for fairly long distance movement among a small group of Neolithic people. The results are consistent with the idea of the earlier Neolithic lifestyle in southern England as largely mobile involving, at most, only short term sedentism (Whittle 1999). It appears that an interest in the chalk downland environment, which distinguishes the earlier Neolithic from the preceding era, did not exclude the population from exploiting the environment of the Mendips once favoured by their Mesolithic forebears. This, perhaps, should not be seen as surprising in the context of an earlier Neolithic with considerable continuity of subsistence strategy from the Mesolithic and gradual adoption of cereal cultivation and domestication within a pattern of residential mobility.

ACKNOWLEDGEMENTS

The authors would like to thank Drs Jackie McKinley and Charlotte Roberts for their help and support and Martin Green, Julian Richards and Ian Potts for their encouragement and for providing the site information and providing the samples for analysis. Thanks also to Drs Barbara Barreiro and Geoff Nowell for analytical support at NIGL. Two of the authors (PB and JM) are supported by the NERC. NIGL Publication No. 419.

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TABLES

Table 1 Strontium and lead isotope ratios and compositions for the Neolithic tooth samples. En = enamel, De = dentine. Strontium isotope ratios were undertaken by TIMS, errors are ±0.0045% (2σ, n=10). Pb isotope ratios were undertaken by PIMMS, errors are ±0.014% for ^{207}Pb/^{206}Pb and ±0.024% for the ^{208}Pb/^{206}Pb (2σ, n=27). Isotope dilution errors also account for sample heterogeneity and are therefore estimated as ±14% for Pb and ±10% for Sr.

Sample	**Tooth**	**Tissue**	**Sr (ppm)**	**^{87}Sr/^{86}Sr**	**Pb (ppm)**	**^{207}Pb/^{206}Pb**	**^{208}Pb/^{206}Pb**
A_{decid}.	c^1right	En	75	0.70955	0.26	0.8378	2.0484
A_{decid}.	c^1right	De	230	0.70788	0.44	0.8326	2.0523
A_{perm}.	M^1right	En	71	0.70878	0.33	0.8321	2.0501
A_{perm}.	M^1right	De	207	0.70782	0.35	0.8288	2.0440
B_{decid}.	c^1left	En	103	0.70844	0.29	0.8324	2.0502
B_{decid}.	c^1left	De	248	0.70790	0.79	0.8301	2.0492
B_{perm}.	P^1left	En	57	0.70928	0.15	0.8318	2.0499
B_{perm}.	P^1left	De	184	0.70789	0.31	0.8287	2.0448
C_{perm}.	P^2right	En	55	0.71007	0.23	0.8498	2.0786
C_{perm}.	P^2right	De	162	0.70866	0.37	0.8386	2.0636
D_{decid}.	c^1left	En	72	0.70849	0.68	0.8356	2.0532
D_{decid}.	c^1left	De	282	0.70809	0.41	0.8269	2.0418
D_{perm}.	C^1left	En	54	0.70897	0.25	0.8279	2.0391
D_{perm}.	C^1left	De	250	0.70792	0.20	0.8288	2.0465

Table 2 Strontium and lead isotope ratios and compositions for the Monkton chalk (MC) and soil (MS) leachates. Strontium isotope ratios were undertaken by TIMS, errors are ±0.0045% (2σ, n=10). Pb isotope ratios were undertaken by PIMMS, errors are ±0.014% for $^{207}Pb/^{206}Pb$ and ±0.024% for the $^{208}Pb/^{206}Pb$ (2σ, n=27).

Sample	**$^{87}Sr/^{86}Sr$**	**$^{207}Pb/^{206}Pb$**	**$^{208}Pb/^{206}Pb$**
MC	0.70750	0.8275	2.0449
MS1	0.70754	0.8256	2.0414
MS2	0.70753	0.8245	2.0391
Mean	*0.70752*	*0.8259*	*2.0418*

FIGURE CAPTIONS

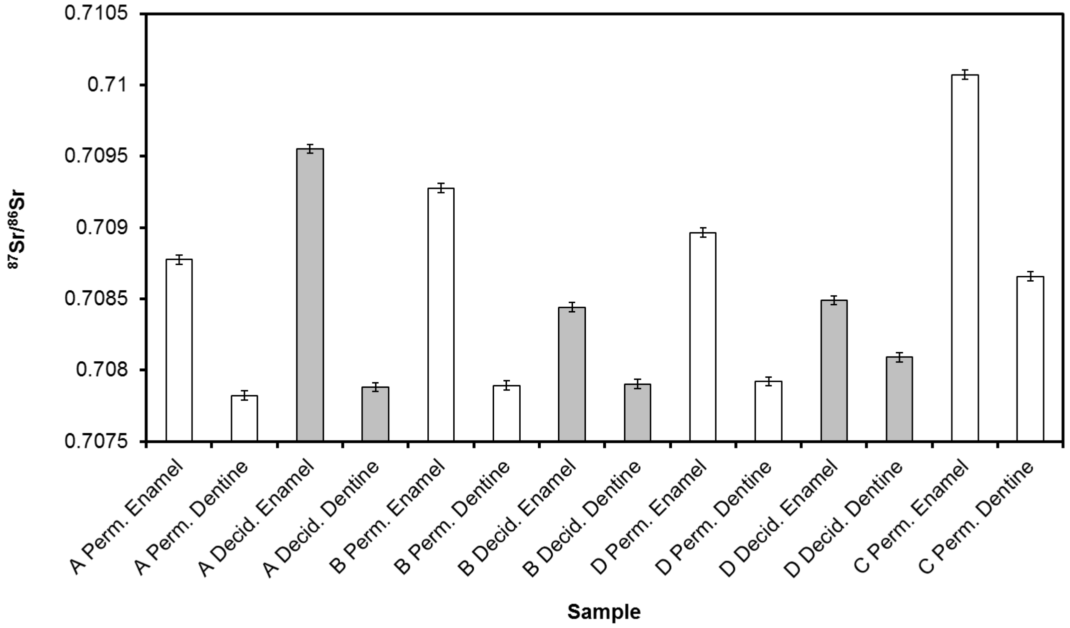

Figure 1

Strontium isotope ratios for the deciduous and permanent tooth enamel and dentine of the three juveniles (A, B and D) and permanent tooth enamel and dentine for the adult female (C). Error bars represent 2σ errors calculated from 10 replicates of the NBS987 standard.

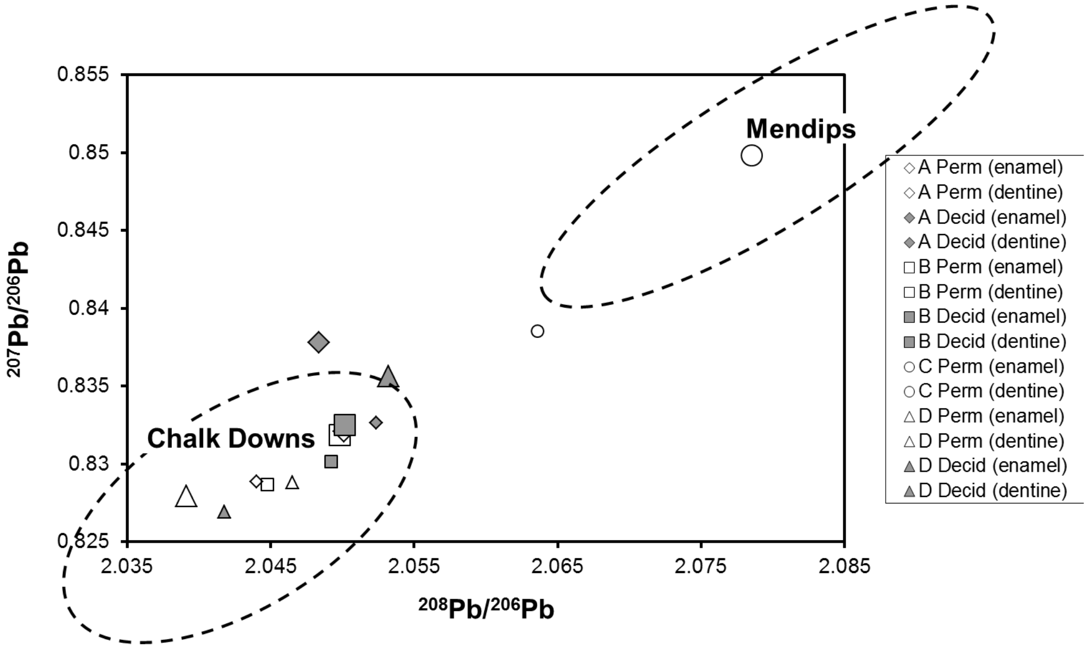

Figure 2

Lead isotope ratios for the deciduous and permanent tooth enamel and dentine (small symbols) of the three juveniles (A, B and D) and permanent tooth enamel and dentine for the adult female (C). Errors on the Pb isotope ratios were determined from replicate analysis of the NBS 981 standard as 0.014% for ^{207}Pb/^{206}Pb and 0.024% for the ^{208}Pb/^{206}Pb (n=27, 2σ). These are smaller than the symbols at this scale.

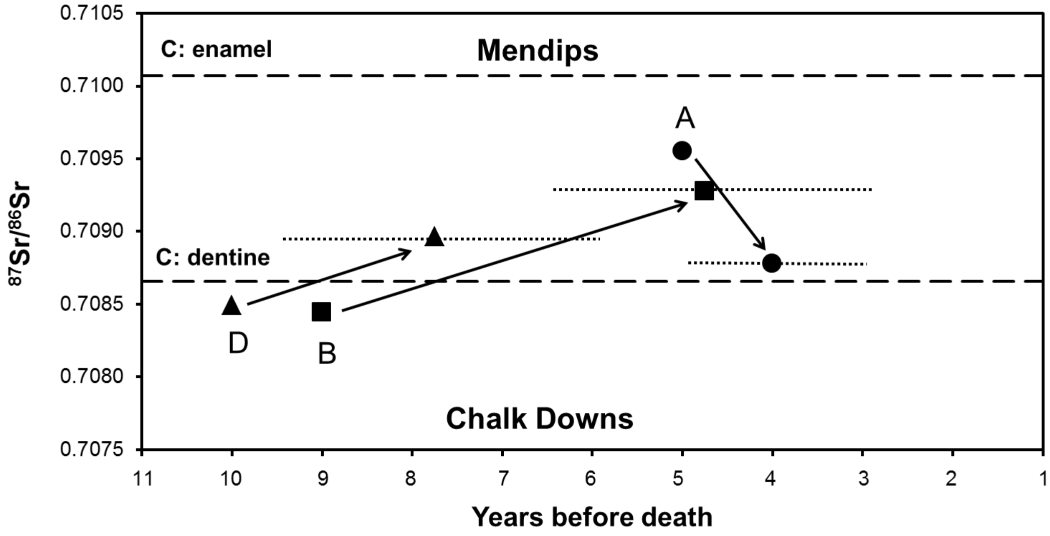

Figure 3

Strontium isotope ratios for the juveniles tooth enamel relative to its time of formation in years before death. Error bars associated with the permanent teeth represent the maximum period of enamel mineralisation. The adult female, C, is represented by dashed lines indicating the values of her enamel and dentine.

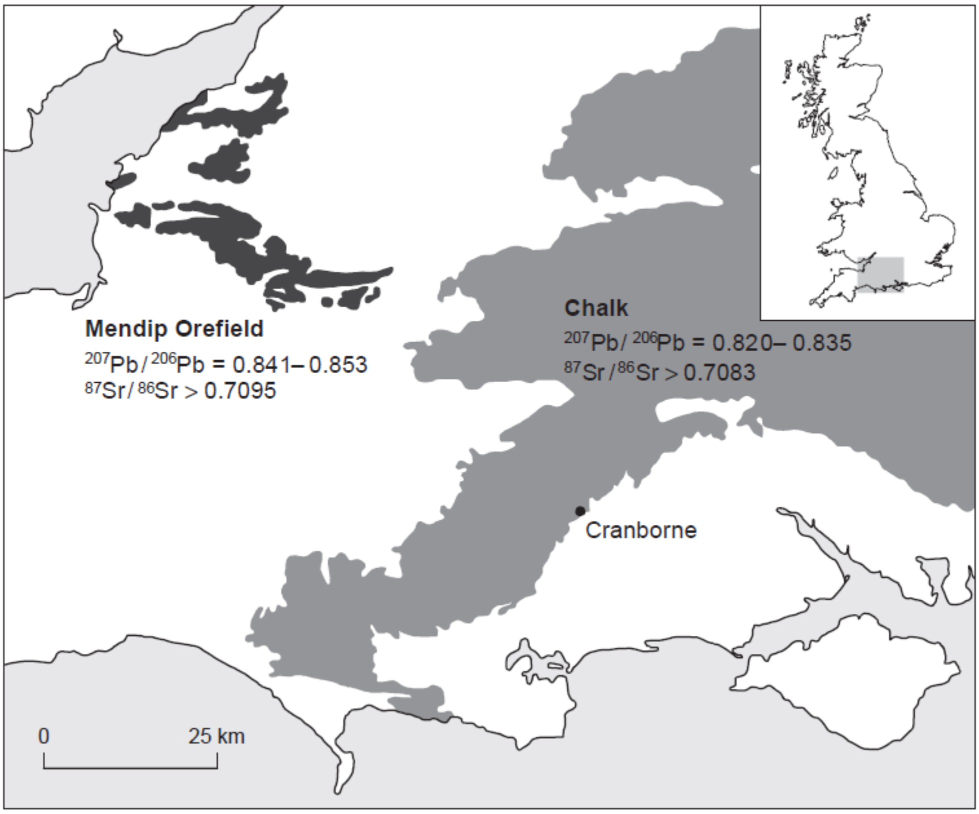

Figure 4

Location map showing the burial site at Monkton-up-Wimbourne relative to the approximate extent of the cretaceous chalk geology and the Mendips orefield to the north-west. Approximate ranges for lead and strontium isotopes for each geology are indicated.