CHAPTER 8

An Evaluation of Constraints on the Interpretation of Human $^{87}Sr/^{86}Sr$ Data

In Chapter 7 a study was undertaken, which aimed to assess $^{87}Sr/^{86}Sr$ variation in the dental enamel of domestic livestock in the context of local patterns of landscape variation. In contrast, the application of $^{87}Sr/^{86}Sr$ analysis to human remains in generally undertaken as an wholly exclusive technique; unless enamel values correspond to a ‘local’ range – determined by either a statistical measure of dispersion within a given assemblage, or by some form of biosphere reconnaissance – the local childhood origin of certain individuals is excluded as a likely possibility. However, if communities made use of a range of resources across a landscape, individual bulk enamel $^{87}Sr/^{86}Sr$ values cannot necessarily be compared directly to the control data obtained from any one geological division of the biosphere.

Human cemeteries are often treated as if they were the result of mortality in a single static population, both in the sense of demographic composition and geographic origin. However, the assemblage selected for analysis in this study was recovered from one of 27 Anglo-Saxon execution cemeteries (Old Dairy Cottage: 78 m OD, NGR 447260, 131410) identified in England by Reynolds (2009: 151–179). Such sites do not represent the effects of natural mortality, but result from the activity of a selective judicial process. Moreover, the distribution of these sites appears to be related to the distribution of the Chalk outcrops, providing a coherent group of cemeteries within one of the most well-defined biosphere ‘packages’ in the UK (see Evans *et al.* 2010b). This study attempts to address the following questions:

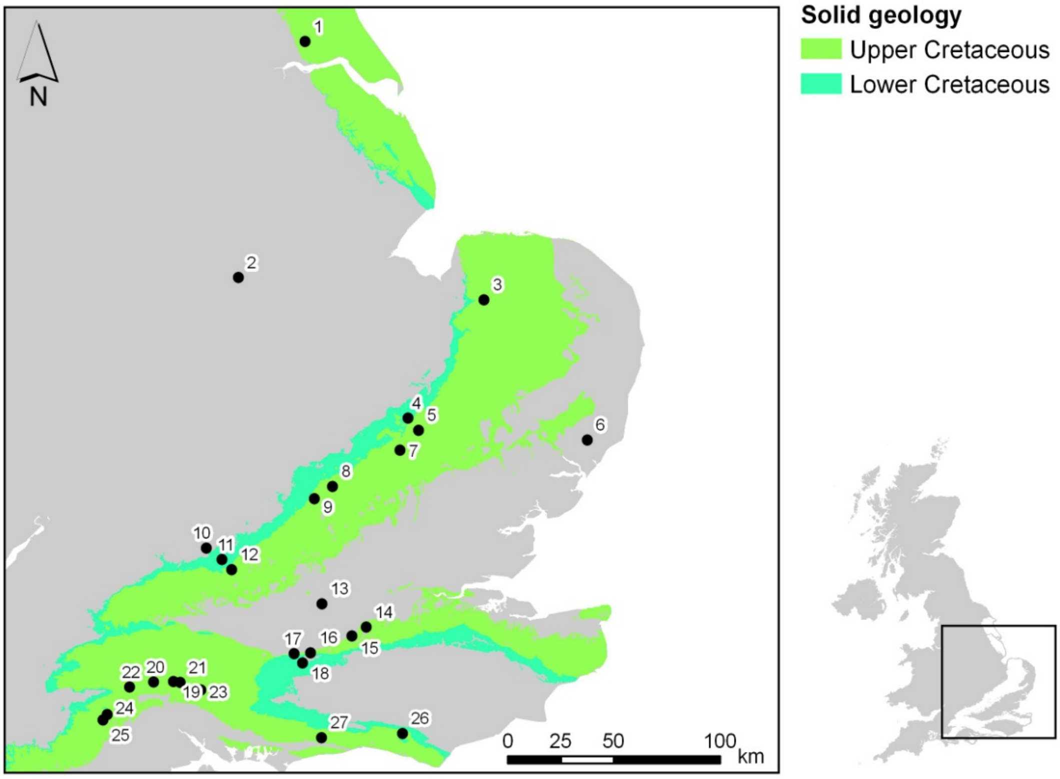
- Are the values obtained from individuals interred at Old Dairy Cottage consistent with a common geographic origin?
- Are the $^{87}Sr/^{86}Sr$ values consistent with the location of the city of Winchester, above the Chalk?
- To what extent is it likely to be possible to constrain the origin of the individuals interred at Old Dairy Cottage?

8.1 The significance for strontium isotope studies of the geographic distribution of putative Anglo-Saxon execution cemeteries

Reynolds (2009) has identified 27 Anglo-Saxon execution cemeteries excavated within the British Isles (Figure 8.01, overleaf), 20 of which are located in areas immediately underlain by the Chalk (Reynolds 2009: 152–153). These sites represent a mortuary context within which the remains of specific individuals were geographically separated from the majority of the dead of the contemporary local populations. The assemblages are marked by a high frequency of so-called 'deviant burial customs', including prone burial (and other postural anomalies), decapitation, and possibly the amputation of limbs and skeletal extremities (*ibid.*). It is argued that the absence of similar sites in the northern England, in Wales and in the South West may suggest some form of regional differentiation in judicial practice.

This class of sites relates to a particular type of mortuary behaviour, the expression of which appears restricted largely to a particular, broad geological domain (Figure 8.01). Reynolds (2009: 151–179) describes the typical local settings of the sites in distinctive terms, that are at once marginal but also prominent; that is, at some distance from settlements and important regional centres, but in close proximity to, and visible from, transport routes such as roads and waterways and often adjacent to pre-existing monumental earthworks. It is suggested that many of the sites may be, by that virtue, located with reference to local administrative boundaries. It is therefore legitimate to consider whether the individuals interred at such sites were resident normally within those boundaries above the Chalk.

As discussed in Chapter 5, the Chalk *sensu stricto* has a distinctive effect on the $^{87}Sr/^{86}Sr$ composition of those divisions of the biosphere influenced by Chalk groundwater discharge and carbonate-rich soil-parent materials. The narrow ambient biosphere $^{87}Sr/^{86}Sr$ range associated with some geographic settings, may also lead to a narrow range of $^{87}Sr/^{86}Sr$ values in animals and in humans. For example, serial analysis of the enamel of cattle and sheep/goat teeth recovered from the 'Chalk site' of Ward's Coombe (Chapter 7) returned $^{87}Sr/^{86}Sr$ values of 0.7078–0.7081, while the weighted mean composition of each tooth crown was 0.7080. These values are similar to the lowest reported human enamel bulk compositions currently attributed to a British Chalk origin, from Bell Beaker burials excavated on Boscombe Down (Wiltshire) and in the surrounding area; these range in four individuals, from 0.7078–0.7082 (Chenery and Evans 2011).



Based upon DiGMapGB-625, with the permission of the British Geological Survey.

1) Walkington Wold; 2) Croshill Tumulus; 3) South Acre; 4) Chesterton Lane; 5) Wandlebury; 6) Sutton Hoo; 7) Bran Ditch; 8) Galey Hill; 9) Five Knolls; 10) Box Hill; 11) Castle Hill; 12) Crowmarsh; 13) 42 – 54 London Road; 14) Galley Hills; 15) Astead; 16) Guilddown; 17) Hog's Back; 18) Eashing; 19) Meon Hill; 20) Roche Court Down; 21) Stockbridge Down; 22) Old Sarum; 23) Old Dairy Cottage; 24) Bokerley Dyke; 25) Wor Barrow; 26) Malling Hill; 27) Burpham.

Figure 8.01: Distribution of Anglo-Saxon execution cemeteries (N^{o} 23 = Old Dairy Cottage) identified by Reynolds (2009) in realtion to Cretaceous bedrock geology dominated by the Upper Cretaceous Chalk and the Lower Cretaceous Gault Formations.

In contrast, most archaeological human $^{87}Sr/^{86}Sr$ values reported from 'Chalk sites' fall into a higher range. Three major studies – Montgomery *et al.* (2005); Montgomery *et al.* (2007b); and Eckardt *et al.* (2009) – contain, on aggregate, only a small number of samples with $^{87}Sr/^{86}Sr$ values of 0.7082 or lower (i.e. < 5 % of all reported permanent teeth). Although each assemblage may contain individuals of non-local origin, this distribution of data appears counter intuitive if the Chalk *sensu stricto* was the only 'local' influence on human dietary $^{87}Sr/^{86}Sr$ values. However, the biosphere data presented in Chapter 5 suggest that soils developed in decalcified parent material, such as the Clay-with-flints and related Coombe deposits (Avery *et al.* 1959) may extend the $^{87}Sr/^{86}Sr$ range associated with the Chalk *sensu lato*.

Initially, this chapter sets out to define a simple model for $^{87}Sr/^{86}Sr$ variation in dental enamel, where dietary strontium is obtained from areas in southern England underlain by the Chalk, but where the Clay-with-flints or similar decalcified deposits are also present (Chapter 5). The range between the two potential biosphere end-members is assessed by comparing it to human data from the Roman cemetery of Lankhills (Eckardt *et al.* 2009), located in Winchester (Hampshire). Thus, the suggested intervals confer an implicit comparison with the largest available human $^{87}Sr/^{86}Sr$ data-set from a single cemetery in the British Isles, located above the Chalk.

This framework is used to assess the likely significance of the $^{87}Sr/^{86}Sr$ composition of bulk enamel samples obtained from the site of Old Dairy Cottage. Not only is the site located in close proximity to the Roman cemetery investigated by Eckardt *et al.* (2009), but it is one of only a few highlighted by Reynolds (2009) from which skeletal material survives, which were excavated to modern standards and that have been subject to a program of radiocarbon dating (see Figure 8.01: Walkington Wold; South Acre; Chesterton Lane; 4 –54 London Road). The results of the analysis can be interpreted in terms that relate to the selection processes which led to interment within an Anglo-Saxon execution cemetery:

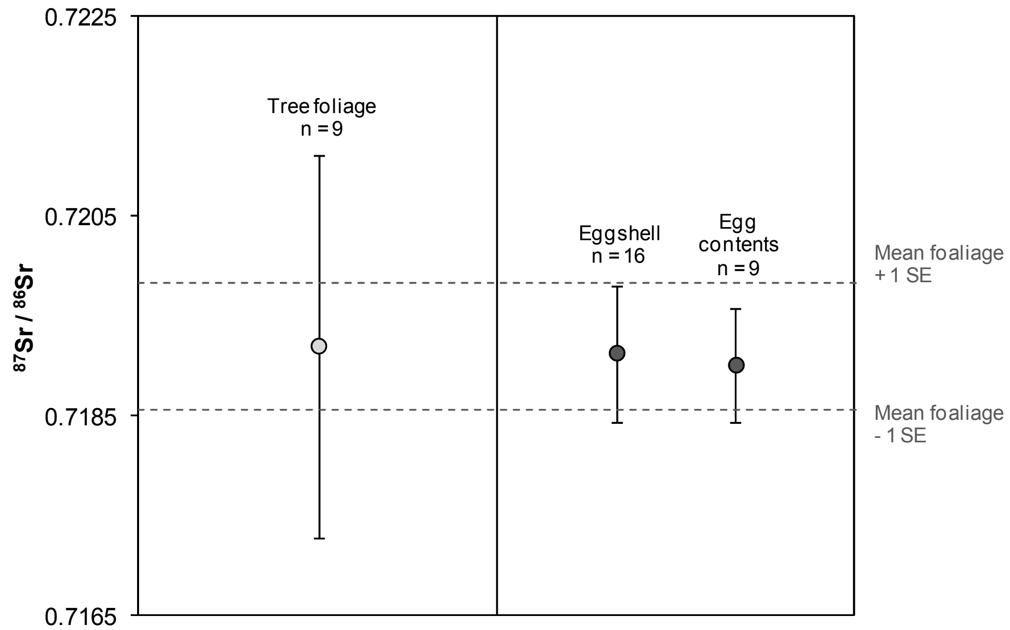
- Is any of the data consistent exclusively with the Chalk biosphere *sensu stricto*?
- Is it possible to exclude the possibility that some individuals had a Chalk-influenced childhood *sensu lato*?

8.1.1 A human $^{87}Sr/^{86}Sr$ range defined for southern England?

- **Empirical data show that the Chalk *sensu stricto* is associated with a restricted $^{87}Sr/^{86}Sr$ biosphere range that could result in a narrow spread of human and faunal $^{87}Sr/^{86}Sr$ values.**

It is reasonable to assume that, across wide areas of southern England underlain by Cretaceous rocks, biosphere $^{87}Sr/^{86}Sr$ variation is heavily moderated by the dissolution of Cretaceous marine carbonates. Data summarised in Chapter 5 indicate that, excluding samples influenced by the Clay-with-flints and mapped superficial deposits, vegetation varies in composition from approximately 0.7075–0.7088 (Table 5.06). Stream waters (Water) and vegetation samples (Wood) collected in Buckinghamshire, at the foot of Chalk escarpment the Chiltern hills, provide $^{87}Sr/^{86}Sr$ values that lie close the middle of this distribution (≈ 0.7080), and the measured biosphere range obtained from samples of vegetation (Wood and Grass) collected above Cretaceous mudstones (principally the Gault Formation) range from only 0.7079–0.7084 (Chapters 4 and 5). These data fall within the envelope of the Chalk biosphere *sensu stricto* and encompass previously published biosphere values associated with the same mudstones (Evans *et al.* 2010a).

If the data from the Chalk biosphere *sensu stricto* (Table 5.06) represent a single underlying biosphere distribution they can be used to predict the range of values displayed by individuals that obtained their dietary strontium from a similar biosphere domain. In the literature, the use of modern environmental samples in this way (e.g. Price *et al.* 2002; Bentley 2006) has been encouraged by a landmark ecosystem study undertaken by Blum *et al.* (2000) within Hubbard Brook Experimental Forest (New Hampshire, USA). In this experiment the authors (i*bid.*) compared the $^{87}Sr/^{86}Sr$ composition of bird eggs (black-throated blue warbler), with prey items collected within a few 100 m of each bird nest (caterpillars and snails), and with the foliage of individual trees gathered across the same area (Blum *et al.* 2000). The summary statistics contained by this publication (*ibid.*) and by a later paper (Blum *et al.* 2001) are reproduced in Figure 8.02 (overleaf).



Error bars indicate standard deviation (1 SD) associated with each sample class; dashed horizontal reference lines indicate the standard error (1 SE) for mean tree foliage. Data show a pronounced narrowing of variance from tree foliage (Blum *et al.* 2000) to eggs (shell and contents) (Blum *et al.* 2001).

Figure 8.02: Summary biosphere $^{87}Sr/^{86}Sr$ data from Hubbard Brook Experimental Forest (Blum *et al.* 2000; Blum *et al.* 2001), indicating the consistent central tendency within the local ecosystem and the change in variance between trophic levels.

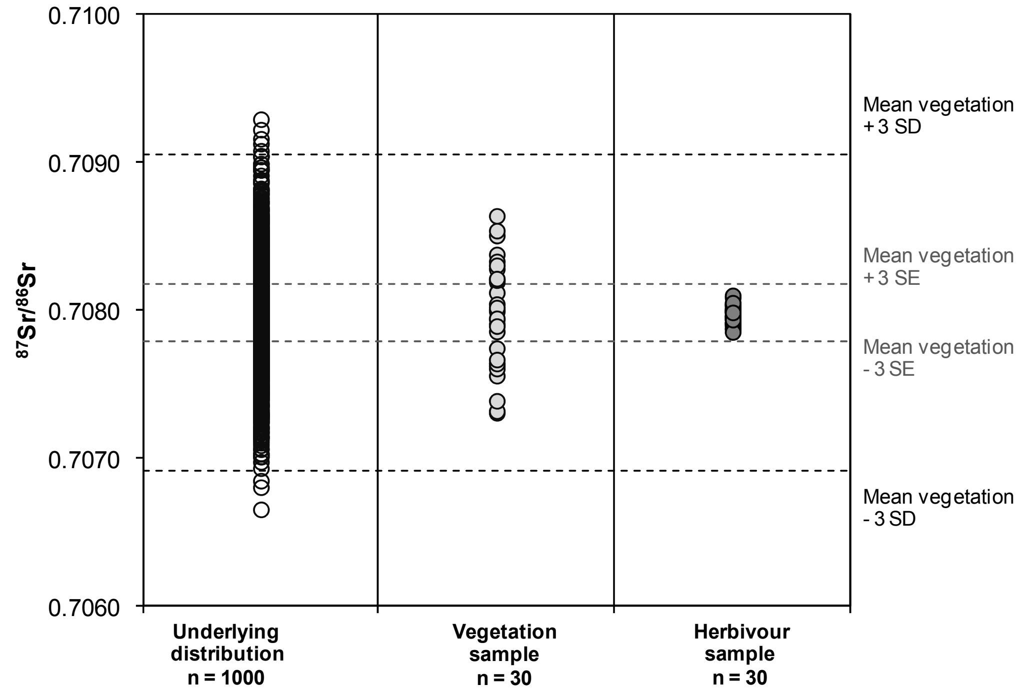
The biosphere data from Hubbard Brook show a systematic narrowing of variance between trophic levels (Blum *et al.* 2000; Blum *et al.* 2001), but the mean values of each of the samples are similar to each other. Whilst each individual prey item represents one small feeding territory within the total area used by the birds, each egg integrates strontium from a number of ‘local’ prey items. The standard deviations of the egg samples (eggshell and egg contents) are equivalent approximately to the standard error of mean foliage (Figure 8.02). Although the standard error is sensitive to the number of samples included in a given sample, the data suggest that the confidence interval for the mean $^{87}Sr/^{86}Sr$ composition of tree foliage provides a precise and accurate estimate of the range of $^{87}Sr/^{86}Sr$ values that can be expected from individual bird eggs.

The vegetation data-set from the Chalk *sensu stricto* (Table 5.06) has a mean $^{87}Sr/^{86}Sr$ composition of 0.7080 ± 0.0004 (1 SD, n = 14). This suggests that, if the data are normally distributed, 95.4% of vegetation samples from the Chalk biosphere *sensu stricto* are likely to yield individual

$^{87}Sr/^{86}Sr$ data-points of between 0.7072–0.7088 (i.e mean ± 2 SD). However, if the survey data provide a representative sample of the underlying biosphere distribution (i.e. ambient variation at the base of the food chain), the standard deviation of the sampling distribution may provide a more accurate and precise estimate of the $^{87}Sr/^{86}Sr$ composition associated with individuals that obtained their dietary strontium within a similar domain (i.e. the standard error, rather than the standard deviation). Hypothetically, under this model, each individual would provide a mean $^{87}Sr/^{86}Sr$ value representing a sample drawn from the underlying biosphere distribution.

Figure 8.03 (overleaf) illustrates the effect of re-sampling a normally distributed population (underlying distribution) with a mean of 0.7080 ± 0.0004 (1 SD, n = 1000). The simulated vegetation sample was drawn at random and with replacement from this population, and has a sample mean of 0.7080 ± 0.0004 (1 SD, n = 30). The simulated herbivore sample represents 30 such vegetation samples, drawn at random and with replacement from a population of 1000 herbivores (i.e. each herbivore represents a representative sample (n = 30) drawn from the underlying distribution); the herbivore sample mean is 0.7080 ± 0.0001 (1 SD, n = 30).

In this model, the standard deviation of the herbivore sample provides a 'bootstrap' confidence interval for the vegetation sample mean (Efron and Tibshirani 1986). Whilst the standard deviation of the vegetation sample accurately describes the dispersion within the underlying distribution, the standard error of the mean (± 0.0001) provides a reasonable estimate of the standard deviation of the herbivore sample. As $^{87}Sr/^{86}Sr$ analysis is used in archaeology as an exclusive method, Figure 8.03 shows the 3σ intervals, which are likely to encompass 99.7 % of the simulated herbivore data.



The underlying distribution (n = 1000) is normally distributed and has a mean $^{87}Sr/^{86}Sr$ composition of 0.7080 and standard deviation (SD) of ± 0.0004. The vegetation sample was drawn at random and with replacement from the underling distribution, and also has a mean of 0.7080 and standard deviation (SD) of ± 0.0004. The herbivore sample consists of 30 vegetation samples and has a mean of 0.7080 and standard deviation (SD) of 0.0001. The standard error of the vegetation sample mean (SE) provides the best estimate of the standard deviation (SD) of the herbivore sample. Distributions were generated using Microsoft Excel software.

Figure 8.03: Individual value plot demonstrating the narrowing of variance associated with iteratively re-sampling an underlying biosphere $^{87}Sr/^{86}Sr$ distribution.

- **Bisophere data suddest that the Chalk *sensu stricto* is not enough to explain the $^{87}Sr/^{86}Sr$ variation in reported archaeological assemblages.**

Using the data presented in Table 5.06, the standard error provides a confidence interval for the mean Chalk biosphere *sensu stricto* of 0.7080 ± 0.0003 (3 SE, n = 14). Potentially, this range (0.7077–0.7083) could be used as an estimate of the sampling distribution associated with individuals that obtained all of the strontium in their diet from a comparable Chalk biosphere domain. Although this is a relatively narrow range, around one quarter of the terrestrial mammal samples (other than humans) cited by Bentley (2006: Table II) as evidence for the reduction in biosphere variance associated with natural populations, are quoted with a coefficient of variation (2 RSD) of 0.03 % or smaller. Moreover, the time-related variation in animal teeth (Chapter 7) suggests that although it is possible to define discrete biosphere $^{87}Sr/^{86}Sr$ ranges for specific geographic units, bulk enamel compositions may represent varying mixtures derived from multiple geological domains within the wider landscape.

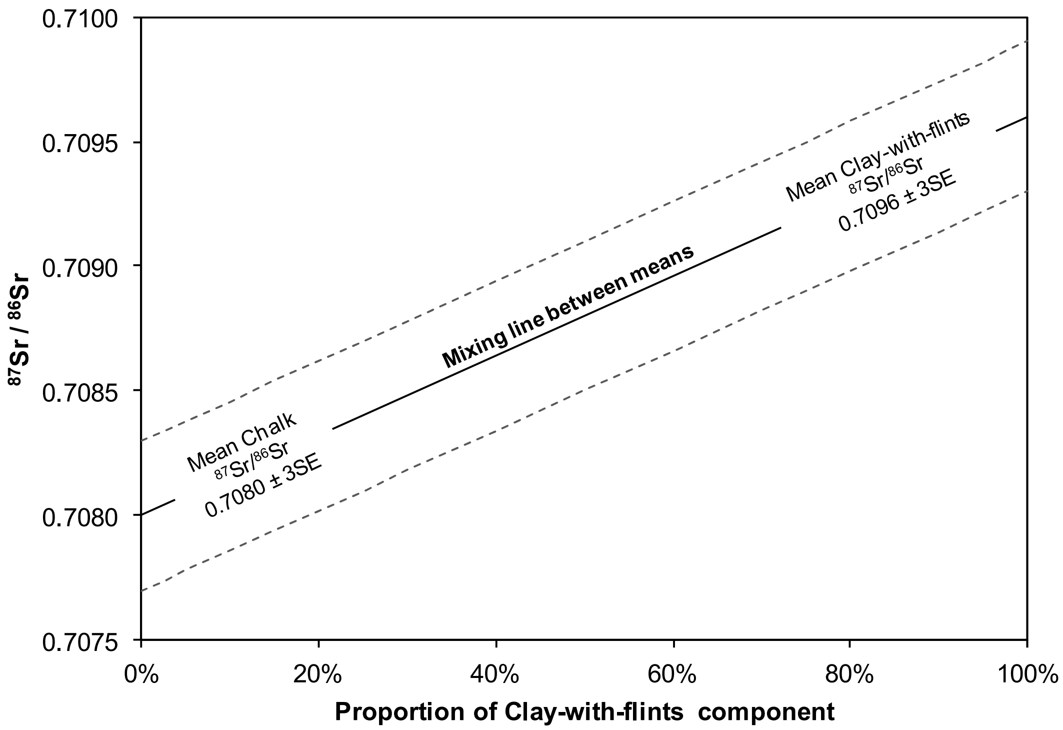
The difference between the statistical range provided by vegetation from the Chalk *sensu stricto* (mean ± 3 SE) and archaeological samples is clearly apparent in faunal $^{87}Sr/^{86}Sr$ data. Bendrey *et al.* (2009) provide a number of analyses from a 'local' control group of domestic taxa recovered from the excavation of Bury Hill (NGR 434600, 143560): an Iron Age hill fort located above the Chalk and at least 15 km from any other underlying solid geological formation. These teeth provide a tight cluster of data with a mean $^{87}Sr/^{86}Sr$ of 0.7086 ± 0.0002 (2 SD, n = 4). A similar range was obtained from serial samples taken from the 1st, 2nd, and 3rd lower molars of a horse mandible from the same site, with respective mean $^{87}Sr/^{86}Sr$ values of 0.7085 (n=6), 0.7088 (n=3), and 0.7087 (n=4). Nonetheless, the authors (*ibid.*) legitimately conclude that all the animals are of a similar local origin.

- **Humans and animals from the Chalk *sensu lato* may provide intermediate values that relate to at least two biosphere end-members.**

If the Clay-with-flints and similar decalcified soil parent materials are treated as a discontinuous biosphere unit that sits above the Chalk *sensu stricto* (Chapter 5), then the Chalk *sensu lato* can be considered to possess mosaic-like qualities. In their lifetime individuals (humans and animals) occupying the Chalk *sensu lato* can be expected to have made use of the full range of resources available to them within such an environment, possibly distributed across a multitude of discrete biosphere $^{87}Sr/^{86}Sr$ domains. These may, or may not, include the Clay-with-flints, glacial till and other superficial deposits. On this basis, although the underlying influence of Cretaceous marine carbonates (Chalk) may provide a degree of weighting towards those values associated with the marine isotope curve (McArthur *et al.* 2001), human and faunal $^{87}Sr/^{86}Sr$ values are likely to be influenced by the mixing of different dietary resources.

The Clay-with-flints is regarded as a product of intensive Chalk weathering (Catt 1986). Although it is a discrete geological map-unit in its own right (Chapter 5), the biosphere $^{87}Sr/^{86}Sr$ values that it provides could indicate the maximum range that Chalk regolith materials may tend towards as they become progressively decalcified and enriched in illuvial clay minerals (i.e. material displaced across the soil profile by percolating rainwater). Figure 8.03 (overleaf) shows a binary mixing line that extends between the mean $^{87}Sr/^{86}Sr$ value for the Chalk biosphere *sensu stricto* and the mean value obtained from the Clay-with-flints (Chapter 5). The estimate of the mean Clay-with-flints biosphere value is based on only three samples, compared to 14 from the Chalk *sensu stricto*. It has been assumed that the Clay-with-flints biosphere domain displays the same degree of variability as the Chalk *sensu stricto.* This graph provides a simplified model for the Chalk biosphere *sensu lato* that is sufficient for discussion, but it is not intended to be quantitative.

Under this simplified model, the Chalk $^{87}Sr/^{86}Sr$ biosphere range *sensu stricto* illustrated in Figure 8.04 (overleaf) is greater than that indicated by the Cretaceous marine carbonate curve (McArthur *et al.* 2001), but it also suggests that bulk enamel samples with a composition less than 0.7077 are unlikely to represent a dietary average drawn from the underlying biosphere distribution. At the other end of the scale, values of 0.7093–0.7099 may be commensurate with a diet drawn entirely from the Clay-with-flints. Given the discontinuous distribution of this deposit across areas otherwise dominated by Chalk rock, it is not clear that this could be achieved in many areas of southern England. Therefore, it is possible to suggest that bulk enamel $^{87}Sr/^{86}Sr$ values of 0.7093 of greater, are more likely to reflect a diet obtained beyond the direct the influence of the Chalk *sensu stricto*.



Parallel dashed lines join the 95% confidence intervals for each mean (2SE). Horizontal reference line ($^{87}Sr/^{86}Sr$ = 0.7088) represents a mixture of strontium from both sources; within 2SE of each mean, the same $^{87}Sr/^{86}Sr$ value could represent a mixture containing in the range of 32–67 % strontium from the Clay-with-flints.

Figure 8.04: Hypothetical mixing line between end-members representing the Chalk biosphere *sensu lato.*

Within the limits of the available data, Figure 8.04 can be used to estimate the proportion of strontium from each biosphere end-member required to achieve a mixture of a given $^{87}Sr/^{86}Sr$ composition. However, the strontium content of skeletal tissues is not directly proportional to the amount of strontium that is consumed, but reflects intake relative to the total available bone-forming cations within a given diet (Burton and Wright 1995). Moreover, interactions between the different components of a mixed diet, health status, and age can influence the extent to which strontium is absorbed relative to other nutrients (Elias 1980; Elias et al. 1982). Consequently, an estimated end-member contribution relates only to the proportion of strontium in a given enamel sample, not to the proportion of the diet that was obtained from a particular geographic zone.

As discussed in Chapter 7, serial enamel samples taken from the teeth of a sheep/goat mandible (IB_02) obtained from Ivinghoe Beacon (an

Iron Age hill fort located above the Chalk) show an inverse linear relationship between 1/Sr and $^{87}Sr/^{86}Sr$ in the direction of growth; from 0.7093–0.7083. The data may represent a mixing line governed by long-term averaging processes, following an abrupt change in the dietary source of strontium (Montgomery 2010). This interpretation implies that, during much of the period of enamel mineralisation, the diet of this animal may have been entirely derived from the Chalk *sensu stricto.* However, although the Chalk may account for the lowest values achieved within this tooth, it is impossible to rule out the influence of sources of strontium beyond the Chalk *sensu lato*.

Where the bulk $^{87}Sr/^{86}Sr$ composition of enamel (which provides no evidence of time-related change) falls into an intermediate range between two end-members it is difficult to make subtle subdivisions of the scale related to geographic origin, especially given some degree of variation in biosphere averages. For example, the mean values for each of the horse teeth from Bury Hill (see above) reported by Bendrey (2009) could be achieved with a Clay-with-flints contribution of ≤ 50 %. Accordingly, between $^{87}Sr/^{86}Sr$ values of 0.7083–0.7088, the Chalk biosphere *sensu stricto* could still be considered to represent the major source of strontium in most samples.

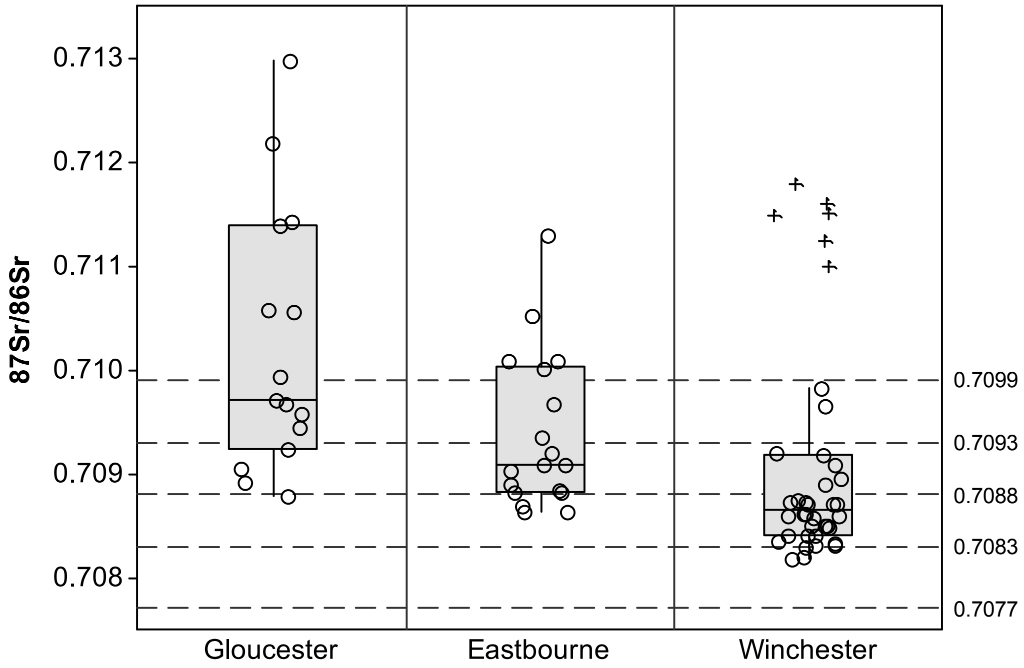
- **Ranges of $^{87}Sr/^{86}Sr$ values can be defined that, as classes of data, have specific interpretative significance in relation to the Chalk biosophere *sensu lato.***

The mixing model shown in Figure 8.04 suggests a series of arbitrary break-points that may be of significance when considering the likely local origin of individuals recovered from sites located in southern England above the Chalk. These are described in Table 8.01 (overleaf). It should be noted that the mean $^{87}Sr/^{86}Sr$ value reported for the Clay-with-flints (0.7096) is similar to the mean reported by Evans *et al.* (2010) for vegetation collected above Jurassic mudrocks (0.7097). Accordingly, as the ranges pass towards the average value associated with the Clay-with-flints, they are also likely to overlap with biosphere $^{87}Sr/^{86}Sr$ values associated with an increasing number of geological substrates, other than Chalk *sensu stricto* (Table 8.01).

Table 8.01: Significant break-points in the biosphere $^{87}Sr/^{86}Sr$ range associated human and faunal averages obtained from the Chalk *sensu lato.*

Range ($^{87}Sr/^{86}Sr$)	Description	Interpretative value
< 0.7077	Strontium in sample unlikely to represent an average value obtained from the Chalk *sensu stricto.*	Non-Chalk origin *sensu stricto.*
0.7077–0.7083	All of the strontium in the sample could have been obtained from the Chalk *sensu stricto.*	Consistent with an exclusive Chalk-dweller *sensu stricto.*
0.7083–0.7088	Chalk *sensu stricto* represents the major source of strontium in most samples	Consistent with a Chalk-dweller *sensu lato.*
0.7088–0.7093	Clay-with-flints represents the major source of strontium in most samples.	
0.7093–0.7099	All of the strontium in the sample could have been obtained from the Clay-with-flints.	Consistent with exclusive Clay-with flints dweller.
>0.7099	Strontium in sample unlikely to have been obtained from the Clay-with-flints.	Non-Chalk origin *sensu lato.*

Figure 8.05 (overleaf) shows a series of box-plots of the $^{87}Sr/^{86}Sr$ composition of permanent human teeth from 4 communal burial grounds in the British Isles thought to represent sedentary populations: a 2nd century Roman cemetery in Gloucester (Chenery *et al.* 2010); an early Anglo Saxon cemetery in Eastbourne (Sussex) in use between the 5th–6th century (Millard *et al.* 2005); and a late Roman Cemetery in Winchester (Hampshire) from the 4th–5th century (Eckardt *et al.* 2009). The plotted data (Figure 8.04) comprise only those teeth with enamel phosphate oxygen isotope values from which the authors (*ibid*) surmise that drinking water values ($\delta^{18}O_{dw}$) lay between -9.0 and -4.5 ‰. Based on the work of Darling *et al.* (2003) Chenery *et al.* (2010) suggest that this range is consistent with the use of available water sources within the UK.



Horizontal reference lines are obtained from Table 8.01. Outlying data points illustrated as '+'. Gloucester, underlain by Jurassic mudrocks (Chenery *et al.* 2010); Eastbourne, on the margins of the Chalk (Millard *et al.* 2005); Winchester, surrounded by the Chalk (Eckardt *et al.* 2009). Only $^{87}Sr/^{86}Sr$ data from permanent teeth with estimated $\delta^{18}O_{dw}$ -9.0– -4.5 ‰ (enamel phosphate oxygen) are shown.

Figure 8.05: Box-plots displaying archaeological human $^{87}Sr/^{86}Sr$ data drawn from communal burial grounds in England shown in relation to potential significant break points in the predicted range for human variation above the Chalk *sensu lato.*

As the city of Gloucester is situated above early Jurassic mudrocks near the English/Welsh border the data provided by Chenery *et al.* (2010) represent a 'non-Chalk' control sample. At the other extreme Winchester (Hampshire), in southern England, is surrounded for several km by the upper Chalk (Eckardt *et al.* 2009). In comparison, the site in Sussex represents an intermediate 'foothill' location; Eastbourne is located at the southern limit of the Chalk outcrop beyond the escarpment and in the coastal zone where, to the east the Lower Cretaceous and the Jurassic strata are also exposed (Millard *et al.* 2005). Although each data-set may contain some $^{87}Sr/^{86}Sr$ values of non-local origin it is usually assumed that cemetery assemblages are strongly weighted towards the inclusion of the remains of people of local descent.

Six $^{87}Sr/^{86}Sr$ values from Winchester (0.7110–0.7118) can be excluded as outliers; the remaining data encompass the greater part of the biosphere range from 0.7082–0.7098 indicated in Table 8.01. However, they overlap with 53 % of the data from Gloucester. This cross-over represents approximately one quarter of the measured range from Gloucester, which is made up of averages more likely to be drawn from an independent and contrasting $^{87}Sr/^{86}Sr$ biosphere domain. However, the gap between the lowest $^{87}Sr/^{86}Sr$ value from Gloucester and the end of the lower whisker extending from the Winchester data occupies the range 0.7082–0.7088 (Table 8.01). Excluding outliers, 78 % of the data from Winchester fall within this range.

Winchester (Hampshire) lies at the western end of the South Downs on the river Itchen, which communicates with Southampton Water 20 km to the SW; 6 km south of the city the Chalk bedrock is succeeded by the (Oligocene and Eocene) clays, sands and gravels of the London and Hampshire Basins. Faunal $^{87}Sr/^{86}Sr$ data reported by Sykes *et al.* (2006) from Fishbourne Roman Palace (Sussex) provide average biosphere values associated with these formations, which outcrop in the low-lying coastal zone between Southampton and Brighton; excluding duplicate samples, enamel from animals thought to have been raised locally range in $^{87}Sr/^{86}Sr$ composition from 0.7089–0.7097 and together provide a mean of 0.7093 ± 0.0005 (2 SD, n=8).

Despite the presence of a contrasting biosphere domain at a relatively modest distance from the city, the clustering of the Winchester data may be characteristic of the dominant influence of the Chalk in this region. Data from Eastbourne might also be expected to show a similar bias. However, the surrounding hinterland does contain a wider range of geological formations. This may be why the median and the inter-quartile range are significantly elevated with respect to the Winchester data. In Eastbourne three times as many values fall between 0.7088–0.7093 as do between 0.7083–0.7088, representing 50 % of the data. In Winchester the ratio between the two classes is approximately 1:5. Although it may be possible to achieve biosphere averages within the Chalk *sensu lato* that fall within the 0.7088–

0.7094 range, regional migration as well as larger-scale movement could enrich this ratio.

Under the model proposed in Figure 8.04 for southern England, the Chalk *sensu stricto* could be considered to be a major influence on enamel $^{87}Sr/^{86}Sr$ compositions from 0.7077–0.7088. However, data from Roman Winchester suggest that a significant proportion of individuals subsisting on the Chalk *sensu lato* could return bulk enamel $^{87}Sr/^{86}Sr$ values that fall within a non-diagnostic range, from 0.7088–0.7093; for these individuals a Chalk-influenced origin *sensu lato* still cannot be excluded. However, above this range enamel $^{87}Sr/^{86}Sr$ compositions are less likely to represent any significant input from the Chalk biosphere *sensu stricto* and thus a likely origin above the Chalk *sensu lato* can be excluded.

8.1.2 Site description

Old Dairy Cottage was excavated as part of a series of works undertaken by the Archaeology Section of Winchester Museums from 1989–1994 on the northern outskirts of modern Winchester (78 m OD, NGR 447260, 131410), during the development of the area for domestic housing. Following a post excavation assessment exercise (Powell 2007) the human bone assemblage has been subject to a full osteological analysis (Cherryson and Buckberry in preparation). It is one of three late Saxon execution cemeteries identified in Hampshire. The other two sites; Stockbridge Down (Hill 1937) and Meon Hill (Liddell 1933), lie seven and eight miles (check km) to the West of Winchester respectively. They are both adjacent to the Roman road between Winchester (Hampshire) and Old Sarum (Wiltshire).

Following the path of a separate Roman road that runs in a NW direction from to Mildenhall, Old Dairy Cottage is located approximately 1.5 km outside Winchester's Roman town walls. The cemetery lies on a low Chalk ridge, representing the second raised spur of land met after passing the northern gate. Four historic parish boundaries intersect at this point; the

SE to NW road dividing the two parishes of Weeke and Littleton to the east from St Bartholomew Hyde and Headbourne Worthy to the west (Helen Rees pers. comm.). This location represents the modern intersection between the parish boundaries of the City of Winchester, Headbourne Worthy and Littleton and Harestock.

Within an excavated area of measuring 12.4 × 3.7 m, adjacent to the SW side of the Roman road, Powell (2007) reports that human remains were recovered from 15 graves. These cut a variety of earlier (Romano-British) features. One cut contained the remains of at least two skeletons. The majority of the graves were aligned approximately SSE–NNW, simply parallel to the pre-existing Roman road. Of the individuals recorded in plan (Powell 2007 Figure 4) only one skeleton (576) was recovered with a skull in the normal anatomical position and in seven cases there is positive evidence for peri-mortem decapitation (Table 8.02, overleaf). A variety of body postures are also recorded, including two prone burials and, from the arrangement of the limbs, it is inferred (Powell 2007) that three individuals (560, 562 and 575/578) may have been interred with their upper limbs bound behind their backs.

Table 8.02 summarises selected data from the skeletal report provided by Cherryson and Buckberry (in preparation). The authors (*ibid.*) have identified the articulated remains of 16 individuals and a number of disarticulated skeletal elements from grave 128. These fragments represent the redeposited remains of at least 3 further individuals (Table 8.02). The demographic data follow a pattern similar to that established in a recent re-assessment an execution cemetery at Walkington Wold in East Yorkshire (Buckberry and Hadley 2007); the assemblage is dominated by the decapitated remains of adult males. Radiocarbon dates obtained from four individuals suggest that the cemetery may have been active during the late 8th and early 11th centuries AD (Table 8.03). The site epitomises a distinctive form of funerary provision within the Christian Anglo-Saxon period that can be characterised as punitive in nature.

Table 8.02: Selected burial data for articulated individuals from Old Dairy Cottage following Cherryson and Buckberry (in preparation).

Grave number	Skeleton number	Age category‡	Sex§	Burial position	Skull present?	Decapitation?
109	519	Older middle/mature adult	M	Supine	No	Unknown
110	522	Middle adult	M	Supine	No	Unknown
111	525	Middle adult	M?	Supine	Yes	Yes*
112	528	Young adult	M	Supine	Yes	Yes
113	531	Young adult	M	Supine	Yes	Yes*
117	580	adult	I	Supine	No	Yes*
121	553	Young adult	I	Supine	No	Unknown
123	560	Young adult	M?	Prone	Yes	Yes*
124	562	Young middle adult	M	Right side	Yes	Yes*
125a	577	Middle adult	F?	Left side	No	Unknown
125b	565	Young adult	M	Supine	Yes	Yes*
126	568	Young adult	I	Supine	No	Unknown
127	571	Sub-adult/Young adult	I	Supine	No	Unknown
128	575/578	Old middle adult	M	Supine	Yes	Yes*
129	576	10 – 12 years	I	Prone	Yes	No
130	588	Adult	I	Supine	No	Unknown

‡Age categories: Sub-adult < 18 years; Adult > 18 years; Young adult = 18 - 25 years; Young middle adult = 26 - 35 years; Middle adult = 26 - 45 years; Old middle adult = 36 - 45 years; Mature Adult > 45 years.
§M = male; M? = uncertain male; F = female; F? = uncertain female; I = indeterminate sex.
*Evidence for sharp force trauma to cervical vertebrae recorded in skeletal report (Cherryson and Buckberry in preparation).

Table 8.03: Radiocarbon dates from burials at Old Dairy Cottage following Cherryson and Buckberry (in preparation).

Grave Number	Skeleton Number	Laboratory reference number	Uncalibrated date (BP)	Calibrated date ranges (AD)	
				68.2% probability	95.4% probability
117	580	GU-19827	1170 ± 30	780 – 900	770 – 970
123	560	Ox-A-12045	1163 ± 25	780 – 955	775 – 965
128	575	Ox-A-12046	1088 ± 26	895 – 995	890 – 1020
129	576	GU-18215	1130 ± 30	885 – 970	780 – 990

8.1.3 Historical background

The period between the end of Roman rule in Britain (*ca.* AD 410) and the rise of the Anglo-Saxon kingdoms in the 7th century has been characterised as a time of great social and political upheaval. Against this background, Reynolds (1997) has linked the emergence of specific execution cemeteries during the late 6th and the 7th centuries to processes involving the creation and the maintenance of institutional authority. As highlighted by Buckberry and Hadley (2007), the identification of long-lived sites of this kind in northern England (Walkington Wold, East Riding of Yorkshire) and East Anglia (South Acre, Norfolk) suggests *"…the continuity, or at least the re-establishment of local judicial arrangements following the disruptions attendant on the Scandinavian conquest and settlements of the ninth and tenth centuries"* (Buckberry and Hadley 2007 325).

During the Anglo-Saxon period, burial practice came increasingly under the control of the Christian church (Zadora-Rio 2003) culminating in the formal consecration of cemeteries in the latter half of the 9th century (Gittos 2002: 201–202). The later Saxon period also saw the re-establishment of some Roman towns leading, in the case of Winchester to the refurbishment of its defences during the second half of the 9th century (Hinton *et al.* 1981) and the establishment of a new rectilinear street system (Biddle and Hill 1971). Cherryson (2005) argues that mortuary behaviour in the Winchester area can be therefore placed firmly within the context of the rising influence of the Christian church and that of an emergent state.

As described by Cherryson (2005), from the 7th century onwards an ecclesiastical complex within the SE quarter of Winchester became the focus for local burial activity. In addition Staple Gardens (Winchester Museums Service archive SG84 & SG89), a large contemporary burial ground located towards the west gate (Kipling and Scobie 1990) is likely to have been in use between *ca.* AD 850–1000 (Bayliss 2001). It is proposed that Staple Gardens may initially have served the lay population of Winchester, and that it gradually went out of use as the Minsters consolidated their control over burial rights (Cherryson 2005: 304). The author (*ibid.*) envisions a model whereby a number of cemeteries of varying status within the city walls provided the main focus for communal burial in the Winchester area.

Human bone assemblages recovered from communal burial grounds can be expected to provide similar proportions of male and female remains and an atttritional age-at-death profile: a high number of infant deaths, low numbers of adolescent deaths and a gradual increase in mortality throughout adulthood (Chamberlain 2009). The radiocarbon dates from Old Dairy Cottage indicate that those individuals analysed died during the period within which the Staple Gardens cemetery was active. However, Old Dairy Cottage overwhelmingly comprises the remains of adult men. The individuals interred at the site were physically separated from the bulk of the contemporary dead and denied the majority burial rite. Old Dairy Cottage can be seen as a manifestation of a selection process that lead to the construction of a distinctive type of archaeological assemblage in a distinctive type of geographic location.

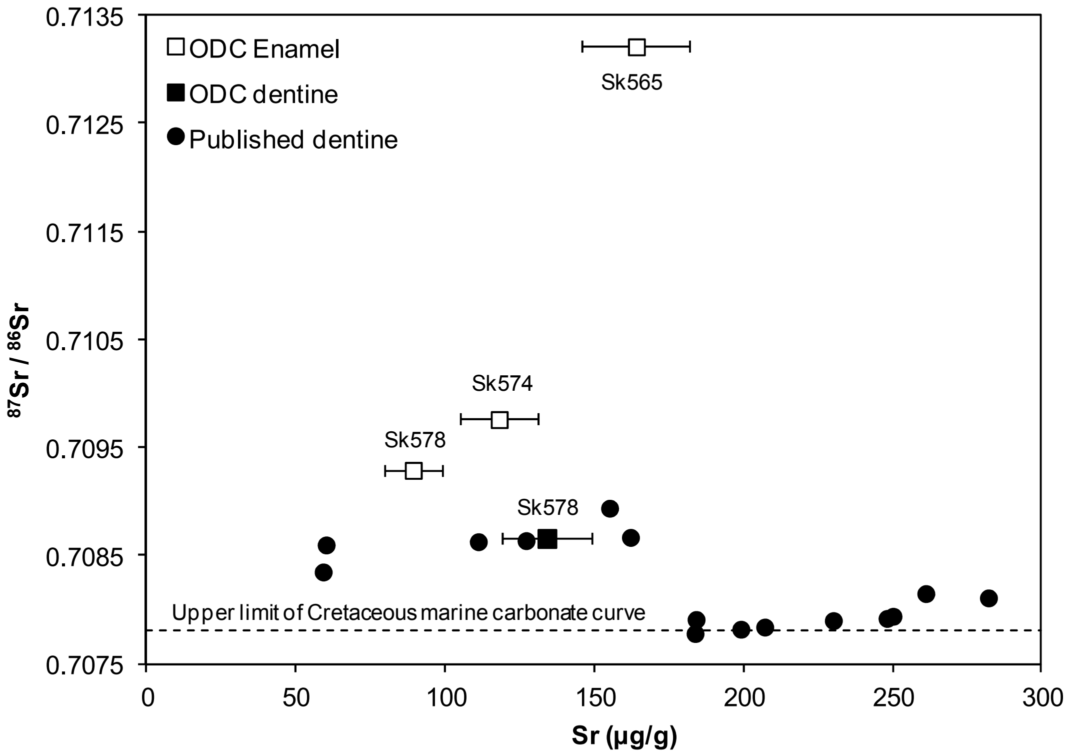
8.2 Description of samples

Selected teeth from the individuals interred at Old Dairy Cottage (ODC89) were provided by Helen Rees, the Curator of Archaeology at Winchester Museums Service (documented in Appendix B). Seven graves, each containing the articulated remains of one individual and including the remains of one skull, provided suitable in-situ teeth within the respective alveolar processes. In addition, an upper right second molar (M^2) was extracted from a maxillary bone fragment contained by grave number 128, identified as skeleton number 574. Although lost post-mortem, this individual provided evidence for the eruption of the third molars and sufficient teeth were present to suggest that the remains were those of a young adult (Cherryson and Buckberry in preparation).

8.3 Assessment of diagenesis

Although human dental enamel is generally held to provide a reliable record of endogenous strontium, high concentrations of strontium in archaeological samples may indicate some level of exogenous input (Budd *et al.* 2000). However, it has been shown that strontium from the burial environment accumulates preferentially in dentine and bone (Montgomery 2002; Chiaradia *et al.* 2003; Hoppe *et al.* 2003). Accordingly, the differences in composition between cogenetic primary dentine and core enamel may provide some indication of the likely diagenetic vector associated with the Chalk burial environment.

In Figure 8.06 the dentine and enamel data from the premolar obtained from Sk578 are shown in comparison to published human dentine values from Chalk burial environments. The relationship between the enamel and the dentine sample from Sk578 is consistent with a general diagenetic trend towards $^{87}Sr/^{86}Sr$ values similar to the estimated human or faunal range for the Chalk *sensu stricto* (Table 8.01). Accordingly, in some instances dentine will provide a poor diagenetic control as, in theory, 'local' Chalk-dwelling individuals are likely to provide a similar range of $^{87}Sr/^{86}Sr$ values. In this instance the enamel sample ODC_Sk560_E has $^{87}Sr/^{86}Sr$ composition similar to that of dentine sample ODC_Sk578_D but the concentration of strontium is relatively low in comparison.



Published archaeological human dentine values from Chalk burial environments (●): Montgomery *et al.* (2002); Evans *et al.* (2006b); Montgomery *et al.* (2007b); Evans *et al.* (2010b). Error bars have been applied enamel dentine from old Dairy Cottage equivalent to Sr ± 11 % (cf. Chapter 3). Enamel samples from Sk565 and Sk574 have also been plotted, as these provide relatively high Sr concentrations, but possess sufficiently radiogenic $^{87}Sr/^{86}Sr$ compositions to exclude a likely origin associated with the Chalk *sensu lato* (cf. Table 8.01).

Figure 8.06: Comparison of enamel and dentine data from Sk578 to published human dentine data from other Chalk burial environments.

Strontium concentrations of between 52–262 mg/kg, with a mean of 120 ± 76 mg/kg (n = 27, 2 SD) have been reported in the enamel of modern human teeth from the UK (Brown *et al.* 2004). These data (*ibid.*) are associated with enamel/dentine concentration ratios of between 0.8–1.6, with a mean of 1.1 ± 0.3 (2 SD, n = 8). This is consistent with the findings Montgomery (2002), which suggest that modern dentine generally contains less strontium than enamel per unit mass, prior to digenesis. Accordingly, it is possible that dentine sample ODC_Sk578_D (enamel Sr/dentine Sr = 0.7) is only marginally enriched in strontium from the burial environment.

Nonetheless, only two enamel samples from Old Dairy Cottage provide strontium concentrations that approach that of the dentine: ODC_Sk574_E and ODC_Sk565_E. Given the $^{87}Sr/^{86}Sr$ composition of ODC_Sk565_E, it is unlikely that the high strontium concentration represents a product of diagenesis, unless the initial enamel value was extremely radiogenic (Figure 8.06). In the case of ODC_Sk574_E the measured $^{87}Sr/^{86}Sr$ composition (0.7098) is sufficiently high to exclude an initial value related directly to the Chalk. None of the samples have a $^{87}Sr/^{86}Sr$ composition that that is equivalent to or lower than the dentine. There is no evidence that strontium from the burial environment makes a significant contribution to the measured enamel values.

8.4 Results

The results from Old Dairy Cottage are presented in Table 8.04 (overleaf) in ascending order of $^{87}Sr/^{86}Sr$ composition. None of the values fall within a range consistent with the Chalk *sensu stricto* (0.7078–0.7082) therefore, if any individuals did have a local childhood origin, additional sources of strontium must be invoked. The highest $^{87}Sr/^{86}Sr$ value – provided by ODC_Sk565_E – exceeds even the outlying values reported from 'Chalk-associated' sites within the UK, by Pitts *et al.* (2002), Montgomery *et al.* (2005), Evans *et al.* (2006a), Montgomery *et al*. (2007b) or Eckardt *et al.* (2009) by at least 0.1 %. It is also higher than the outlying value of 0.7113 reported by Millard *et al.* (2005) from an Anglo Saxon cemetery in Eastbourne (East Sussex) in the coastal zone of southern England.

Table 8.04: Results of $^{87}Sr/^{86}Sr$ analysis of enamel samples from Old Dairy Cottage.

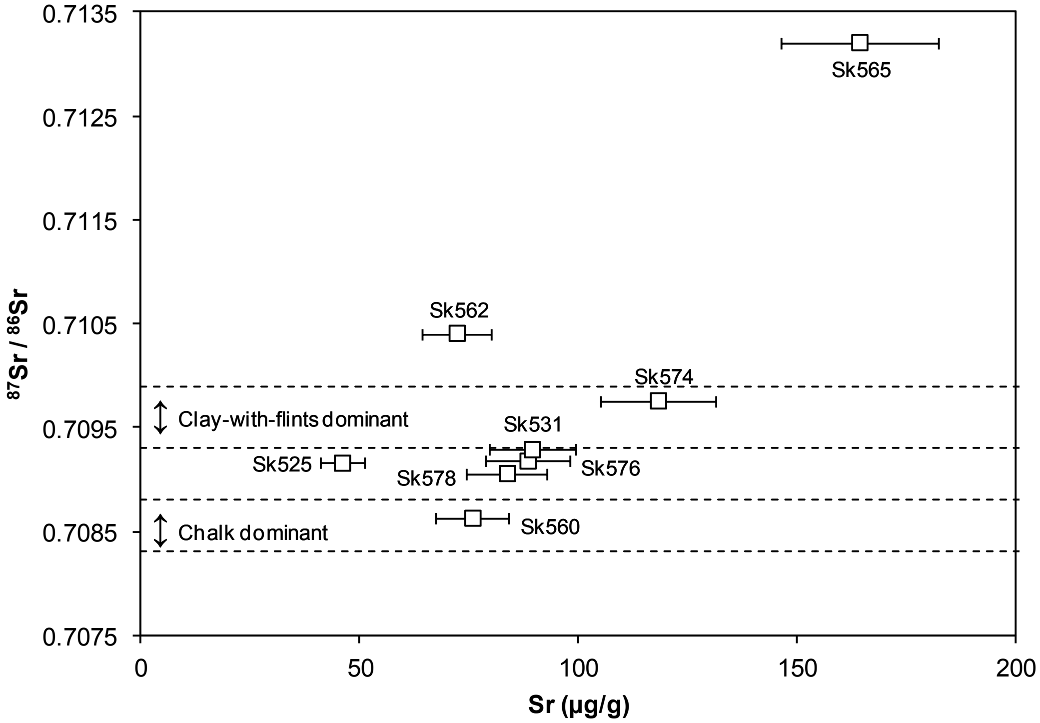
Sample	Sr (µg/g)	$^{87}Sr/^{86}Sr$
ODC_Sk560_E	75.6	0.70863
ODC_Sk531_E	83.5	0.70906
ODC_Sk525_E	45.8	0.70916
ODC_Sk576_E	88.2	0.70918
ODC_Sk578_E	89.2	0.70929
ODC_Sk574_E	118	0.70976
ODC_Sk562_E	72.0	0.71041
ODC_Sk565_E	164	0.71321

The $^{87}Sr/^{86}Sr$ values from Old Dairy Cottage range from 0.7086–0.7104. Biosphere values such as these can be attributed to a variety of Mesozoic sediments (Chapter 5). Two samples (ODC_Sk525_E, and ODC_Sk576_E) have ratios that are indistinguishable from the composition of modern seawater at 0.70917 ± 0.00001 (Hoddell *et al.* 1990). However, these values could also be achieved under a range of biosphere influences. Moreover, the concentrations of strontium in these two lower left second molars are significantly different from one another, suggesting perhaps that they were achieved under different geographic (Burton and Price 2003) or dietary regimes (Burton and Wright 1995). In contrast, when strontium concentration is taken into account, ODC_Sk531_E, ODC_Sk576_E, and ODC_Sk578_E form a tighter cluster of data points.

8.5 Discussion

The solid geology surrounding Winchester is likely to give rise to biosphere $^{86}Sr/^{86}Sr$ values that are strongly influenced by the Chalk. Although the floodplain of the river Itchen supports alkaline peat soils and a variety of alluvial soils (Jarvis *et al.* 1984), the region is dominated by shallow lithomorphic soils developed in chalky parent materials (Jarvis *et al.* 1984).

Where the Clay-with-flints is present across, these areas mapped with the soils of the Carstens Association (Thompson 1983): argillic brown earths developed in silty drift (Avery 1990). South of the Vale of Pewsey, Jarvis *et al.* (1984) state that the *"Carstens soils occur on the broader interfluves where the silty cover to the Clay-with-flints is consistently present"* (pp 115). This soil association is largely restricted to hilltops surrounding the city.



Error bars applied to data-points are equivalent to Sr ± 11 % (cf. Chapter 3)

Figure 8.07: Graph showing enamel results from Old Dairy Cottage in relation to reference lines suggested in Table 8.01.

Figure 8.07 shows the data from Old Dairy Cottage plotted in relation to the critical ranges developed using archaeological human data published by Eckardt *et al.* (2009) and modern plant samples reported in Chapters 4 and 5. These data suggest that if the assemblage from Old Dairy Cottage was dominated by individuals that obtained their diet from the local soil-resource, the majority of samples would have returned $^{87}Sr/^{86}Sr$ values of 0.7083–0.7088. This is not the case. The proportion of individuals with $^{87}Sr/^{86}Sr$ compositions of 0.7083–0.7088 (n = 1) and 0.7088–0.7093 (n = 4) is reversed with respect to the Roman data from Winchester (Figure 8.04). Only one sample (ODC_Sk560_E) falls into a range that suggests that Chalk biosphere *sensu stricto* supplied the majority of the strontium in the sample.

Samples from four individuals – Sk525, Sk531, Sk576, and Sk578 – provide a tight cluster of data-points. However given the site formation process suggested for Old Dairy Cottage and in the absence of any stratigraphic relationship between the grave cuts, there is no independent evidence for any close association between these individuals. The $^{87}Sr/^{86}Sr$ values themselves fall into a non-diagnostic range that could be associated with the Chalk *sensu lato*. While it is not possible to exclude the chance that these could represent a childhood diet derived from the Chalk *sensu lato,* a substantial proportion of non-Chalk dwelling individuals from the UK might also be expected to fall within this range, especially given the marine influence that may affect coastal regions of the British Isles (Evans *et al.* 2010b). Equally these values could be supplied by a range of lithologies, including those which succeed the Chalk in the coastal zone south of Winchester (Sykes *et al.* 2006).

Enamel with a $^{87}Sr/^{86}Sr$ composition ≥ 0.7099 may preclude a diet supplied by the resources available above the Chalk biosphere *sensu lato*. Accordingly, it is unlikely that sample from Sk574, and those of a more radiogenic composition, represent individuals whose childhood diet was obtained from the resource base surrounding Winchester. While samples from Sk574 and Sk562 fall into a biosphere $^{87}Sr/^{86}Sr$ range that could be supplied within a wide variety of geological domains within the British Isles, the $^{87}Sr/^{86}Sr$ composition of the sample provided by Sk565 is exceptionally high. In providing a strontium concentration greater than 150 μg/g, and a $^{87}Sr/^{86}Sr$ composition that diverges substantially from that of modern seawater, it is also unusual nationally (cf. Evans *et al.* 2012). Based on current knowledge, it is unlikely that this value relates to any geologically recent sedimentary formations or superficial deposits found in southern or eastern England (cf. Chapter 5).

8.6 Conclusions

The range of values shown in Figure 8.07 does not represent the predicted pattern for a population subsisting within the Chalk biosphere *sensu lato*. The data from Old Dairy Cottage do not show the characteristic clustering of values within the biosphere $^{87}Sr/^{86}Sr$ range 0.7083–0.7088 that is displayed by a the Roman assemblage from Winchester reported by Eckardt *et al.* (2009). It is unlikely that the Anglo Saxon data represent a sample drawn from a similar distribution. Nonetheless the assemblage does contain a group of samples clustered around the $^{87}Sr/^{86}Sr$ composition of modern seawater. It is difficult to assess the significance of this as similar biosphere values could be provided by a wide range of geological formations, including those present in the coastal zone only a few km from the City.

On the basis the available data from the Chalk biosphere *sensu lato* (cf. Table 8.01), the childhood origins of the majority of the individuals interred at Old Dairy Cottage are not consistent with the geographic location of Winchester and its environs. With reference to data provided by Millard *et al.* (2005), the apparent bias towards $^{87}Sr/^{86}Sr$ values in the range 0.7088–0.7093 may perhaps be more indicative of a population living in an environment at the margins of the Chalk outcrop, one incorporating a proportion of non-local individuals or even a transient population. Certainly, the assemblage contains one of the most radiogenic human values currently reported from southern England (cf. Evans *et al.* 2012). However, the assemblage does not reflect natural mortality within a living population. Accordingly, these data suggest a number of alternate hypotheses, with the caveat that the assemblage does not represent a single moment in time but the result biases built into a selection process that took place over an extended period:

- The resource footprint associated with Anglo Saxon Winchester was in some way detached from the Chalk influence, which appears to be prevalent in Roman data from the same area (cf. Figure 8.05).

- Local individuals interred at the site were drawn from particular sectors of society with a diet in early-life that was not dominated by a Chalk influence.

- The Anglo Saxon population of Winchester and its environs included a mobile or transient element that is disproportionately represented at Old Dairy Cottage.

- The childhood origins of the adult population of Anglo Saxon Winchester were more diverse than in the Roman period.