Investigating population movement by stable isotope analysis: a report from Britain

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Stable isotopes present in local ground water get into people's teeth before they are 12 years old, and act as a signature to the area where they grew up (and drank the water). In a review of recent work in Britain the authors show the huge potential of this method for detecting population movement – and thus ultimately for investigating questions of migration, exogamy and slavery.

Introduction

Isotopic methods, originally developed in geological and environmental science, and now applied to archaeological material, allow us to comment directly on the place of childhood residence of individual people from the study of their skeletal remains. We therefore now have the potential to test inferences about immigration suggested by the study of the material record and particularly from burial practice and grave goods. The results reviewed here show that analyses of oxygen, and to a lesser extent strontium isotope are now capable of identifying first generation immigrants among burial groups and, in some cases, of suggesting their probable place of childhood residence. However, fundamental problems remain regarding the geographic interpretation of some of the data so that determination of the place of origin remains elusive as a consistent and reliable tool for archaeological study. Here we discuss recent results in the context of the problems which remain and the steps needed to unlock the full potential of the technique.

Principles and potential

The link between skeletal composition and place of residence arises from natural systematic variations in the isotopes of particular elements between localities (Faure, 1986). *Strontium isotopes* have been used to study archaeological residential mobility since the mid 1980s (e.g. Ericson, 1985). One isotope, ^{87}Sr, is produced by the radioactive decay of rubidium; an element occurring in many rocks and minerals. The abundance of ^{87}Sr (measured as a ratio

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to the stable isotope ^{86}Sr) therefore depends on the initial Rb/Sr ratio and the age of the rock or mineral in which it is found. Strontium is taken up by organisms, but the relative proportions of its isotopes are unaltered in the processes, so that soil, plant and animal strontium isotope ratios have all been shown to be related to those of the underlying geological formations and local hydrology (Blum *et al.* 2000). The characteristic Sr-isotope ratios of particular geographical areas and their persistence in local foods and the tissues of feeding animals (including humans) provides the basis for the reconstruction of the place of residence at the time of the tissue formation.One difficulty which may arise in the use of strontium isotopes is the potential for post-mortem contamination, or diagenesis, of tissues in the burial environment. However, this may be successfully addressed by careful sample selection and in particular by selecting dental enamel, rather than bone, as the tissue of choice for analysis (Budd *et al.* 2000a; Trickett *et al.* 2003).

Oxygen isotopes also vary in the environment in a systematic way, but in this case as a result of differences in climate and geography rather than geology. In the body, the oxygen isotope composition of skeletal tissue is directly linked to that of oxygen consumed and this is controlled by drinking water (Longinelli 1984). Biological processes alter (or 'fractionate') oxygen isotopes (unlike those of strontium) quite readily. However, mammalian skeletal tissues form at a relatively constant body temperature so that the fractionation that does take place is very similar, both within and between species (Bryant & Froelich 1996; D'Angela & Longinelli 1990; Longinelli 1984; Luz *et al.* 1990; Luz & Kolodny 1985; Luz *et al.* 1984). Although there is some inter-species variation due to body mass, diet and metabolism, a number of researchers have developed calibrations that relate skeletal oxygen isotope ratios to those of drinking water. For humans, the calibration developed by Levinson *et al.* (1987) is most widely used.

In antiquity, drinking water was drawn from surface waters, near-surface groundwaters and collected from precipitation. Precipitation falling across Great Britain, as elsewhere, is not isotopically uniform, but varies in a systematic way with geographical location. This provides the basis to link tissue oxygen isotope composition to a person's place of residence when a particular tissue was formed. However, the oxygen isotope composition of precipitation may also be altered by climatic change over time and it is important to consider the possibility that differences observed may be influenced by climate change as well as population movement. Only in studies of broadly coeval burial groups do relative differences in oxygen isotope composition offer a relatively direct equation with place of origin (Budd *et al.* 2001; White *et al.* 1998).

Teeth are particularly advantageous for study not just because of the excellent preservation of biogenic elements in enamel, but also because different teeth are formed at particular stages of life. Once formed, the enamel is not remodelled so that its composition is a reliable indicator of childhood exposure (Budd *et al.* 2001). Although development of the permanent first molar is initiated *in utero*, most of the permanent dentition is formed in childhood from three to four months after birth until about 12 or more years of age. The teeth of an individual therefore provide a potential archive of both early and later childhood exposure to local ground water and its stable isotopes. These in turn may be attributed to geographical areas.

Immigration or local variation? The problem of resolution

The principles outlined make it clear that skeletal tissues, particularly tooth enamel, have the potential to retain isotopic 'signatures' characteristic of the former places of residence of long-dead individuals, but the crucial question remains, *how* characteristic are they? How do we relate the isotopic signals that we measure to locations on the map? Do large isotopic anomalies relate to large geographical distances or simply different localities within a site catchment? Conversely, is it possible to find widely separated geographical areas with exactly the same isotopic characteristics?

This 'resolution' problem is currently better understood in relation to oxygen isotopes than it is for strontium. The great advantage of oxygen isotopes over those of strontium is that they are, at the fundamental level, determined by climate and weather and are therefore tied to geography. This imposes a quantitative relationship between geographical factors such as latitude, altitude, distance from the sea and temperature and the isotopic composition of rainwater and resulting groundwater. Thus, in Great Britain, the maritime climate and prevailing westerly winds create a very distinctive pattern of west-east variation. The northerly latitude of the country means that the variations are comparatively large over a relatively small area making it possible to accurately map contours of rainfall and surface water oxygen isotope composition (Figure 1). In addition, we are particularly fortunate that Great Britain has recently been subject to a detailed rainfall, surface water and groundwater oxygen isotope survey conducted in relation to climate modelling (Darling *et al.* 1999; 2003; Darling & Talbot 2003).

Oxygen isotope measurements are expressed in terms of the difference in the proportion of the heavier ^{18}O isotope relative to an international standard known as Vienna Standard Mean Ocean Water (VSMOW). The difference, $\delta^{18}O_{VSMOW}$, is expressed in units of parts per thousand (‰). Survey data show that rainfall in Great Britain varies from relatively 'enriched' (in ^{18}O) values of up to about –4.5‰ in the extreme west to depleted values of about –8.5‰ in inland pockets of the north-east (Figure 1). It is possible to measure tissue oxygen isotope compositions with a reproducibility of about ±0.2‰ (2σ). After calibration this gives a precision of about ±0.35‰ for our estimate of the composition of any particular individual's childhood drinking water. Considering the scale of the variation represented in Figure 1, it is evident that it is potentially possible to pinpoint a person's place of origin with a useful resolution, particularly with respect to east-west differences. Oxygen isotopes also provide good discrimination across north-western Europe in general, although the quality and resolution of precipitation and groundwater data with which to compare archaeological measurements is variable. There are also some overlaps between the eastern parts of westerly islands like Great Britain and the western margins of parts of Continental Europe and Scandinavia.

Strontium isotope variation in the environment is much less clearly constrained than that of oxygen isotopes as it depends, at the fundamental level, on variations in the type and age of the underlying rocks. In some areas this can be very uniform over relatively large distances and in others far more varied. There are also complications in the relationship between the isotopic composition of the total strontium in the underlying geology and the composition of that portion which enters the soil, becomes available to plants and ends up in humans.

In small areas with relatively uniform geology it has been noted that $^{87}Sr/^{86}Sr$ ratios are the same in soils and throughout the food chain (Blum *et al.* 2000). However, in areas of more diverse geology others have found very wide ranges of $^{87}Sr/^{86}Sr$ in soils, but much less variation
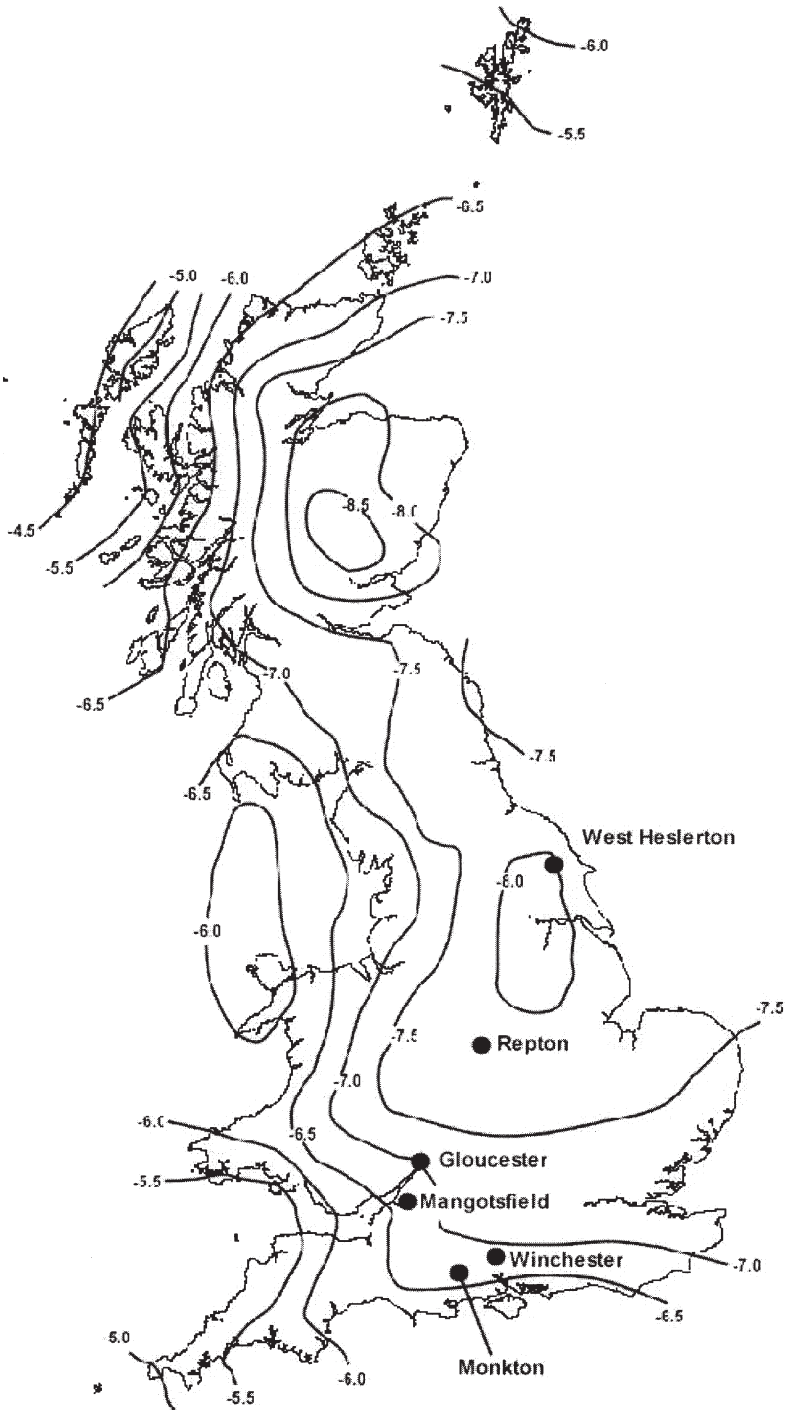
Figure 1 Map of Great Britain showing the location of the sites and contours of rainfall, surface water and groundwater δ¹⁸O relative to Vienna Standard Mean Ocean Water (SMOW) in units of per thousand (‰). Based on Darling et al. (1999; Darling & Talbot 2003).

in the mobile, or 'labile', soil strontium taken up by plants and humans (Sillen *et al.* 1998; Price *et al.* 2002). These results demonstrate that 'whole' rock and soil analyses are a poor guide to the isotopic composition of the bioavailable strontium that finds its way into the human diet. It also means that simplified geological mapping and a knowledge of strontium isotope geochemistry of rocks cannot always be reliably used to estimate the expected range of food $^{87}Sr/^{86}Sr$ for any particular locality.

Surface waters have been considered as a potential source of more homogenous strontium, representative of the diet (Chiaradia *et al.* 2003), but present day river waters are prone to contamination from a variety of sources (run-off from fertilised land, rainwater, effluents etc.) (Martin & McCulloch, 1999; Sillen *et al.* 1998). A better proxy for bioavailable strontium in the food chain is labile strontium in the soil (Capo *et al.* 1998) which can be extracted by leaching the soil in a weak acid. Initial soil leachate data for Great Britain suggest labile $^{87}Sr/^{86}Sr$ variations among soils overlying Mesozoic sedimentary rocks from about 0.7073 on Cretaceous chalk to 0.7115 on Triassic sandstone (Budd, unpublished data). Soils formed on igneous and metamorphic rocks as well as rubidium-rich clay soils are likely to have far higher ratios. Although the reported range for soils in sedimentary contexts may seem small, the very high precision with which we are able to measure $^{87}Sr/^{86}Sr$ makes it highly significant. Even this modest variation of 0.0058 is nearly 300 times greater than the typical reproducibility of measurement of 0.000020 (2δ).

An alternative approach to assessing 'local' strontium involves the measurement of animal tissues as a proxy for the human diet and this has recently been discussed in some detail by Price *et al.* (2002). In the most detailed study reviewed here, for early medieval West Heslerton, we have used tooth enamel from pigs coeval with the cemetery as a proxy for local human exposure.

Sites, samples and analysis

Tooth samples were collected from a total of 53 individuals excavated from six sites in England (Figure 1). Those data not published elsewhere are reproduced in Table 1. Sites and individuals were chosen primarily to investigate early medieval immigration, but the developmental nature of the research has been such that a number of additional case studies from a range of periods and contexts have also been considered to validate the technique.

Prehistoric individuals included four Neolithic individuals from Monkton-up-Wimborne, Dorset radiocarbon dated to *c.* 3500-3100 BC (Budd *et al.* 2000b, 2001, 2003a; Montgomery *et al.* 2000) and eight Early Bronze Age and Iron Age individuals from West Heslerton, North Yorkshire (Haughton & Powlesland, 1999). Romano-British samples were from two mid third century AD burials from Mangotsfield near Bristol, and four people from the mid fourth century AD cemetery at the Eagle Hotel site in Winchester (Budd *et al.* 2001). Thirty-two early medieval burials were examined from the fifth to seventh century Anglian cemetery at West Heslerton (Haughton & Powlesland 1999; Budd *et al.*, 2003b) and from seventh and ninth century contexts at Repton in Derbyshire (Biddle & Kjølbye-Biddle 2001). Three later medieval individuals were investigated from the twelfth to sixteenth century AD Blackfriars cemetery in Gloucester. All teeth were prepared and analysed using methods set out by Budd *et al.* (2001; 2003b).

Table 1 ^{87}Sr/^{86}Sr ratios of human tooth enamel of individuals from various sites in England with the δ^{18}O composition of childhood drinking water calibrated from that of tooth enamel. Data for Monkton and Winchester are given in (Budd *et al.*, 2003a) and (Budd *et al.* 2001), for Blackfriars (Gloucester) in (Budd *et al.* 2000a) and for early medieval West Heslerton in (Budd, 2003b). Sex: M-Male, F-Female, U-unsexed. Age (at death): CHI-Child, JUV-Juvenile, YAD-Young Adult, ADU-Adult (after Haughton & Powlesland 1999).

Sample	Sex	Tooth	Age	^{87}Sr/^{86}Sr	δ^{18}O$_{dw\ SMOW}$
West Heslerton Prehistoric					
2BA229	M	M$_1$ right	ADU	0.711033	−6.22
2BA283	F	M^3 right	ADU	0.709525	−7.31
2BA589	U	M^3 right	ADU	0.708926	−7.29
IR266	U	P$_1$ left	CHI	0.708814	−7.30
IR271	U	P$_1$ left	CHI	0.709022	−6.72
IR304	U	P$_2$ right	CHI	0.708975	−7.52
WHIA1	U	P$_1$ right	ADU	0.70843	−7.62
WHIA2	M	P$_1$ right	YAD	0.710971	−5.67
Mangotsfield					
SK1	M	C^1 left	ADU	0.710175	−6.62
SK2	F	C$_1$ right	ADU	0.709875	−6.87
Repton					
REP-97	U	C$_1$ left	JUV	0.711947	−5.69
REP-511	M	P$_2$ left	ADU	0.709597	−6.86
REP-529	M	M^2 right	ADU	0.711848	−10.84
REP-295	M	P^1 left	YAD	0.708979	−6.73
REP-X70	M	P$_1$ left	ADU	0.709901	−8.12
REP-X23	M	P$_1$ left	ADU	0.710508	−7.92
REP-X17	F	P^1 right	ADU	0.711998	−9.29
REP-X3	F	P^2 right	ADU	0.710964	−5.98

Results and discussion

Prehistoric

Although only small numbers of prehistoric individuals have so far been subject to combined oxygen and strontium isotope analysis, the two groups examined to date display quite different characteristics with respect both to their range and to how they compare with local signatures at the respective burial sites. The small Neolithic burial group of an adult female and three juveniles from Monkton-up-Wimborne, Dorset (discussed in detail in Budd *et al.* 2001) have ^{87}Sr/^{86}Sr ratios which are considerably more radiogenic (higher) than the local chalk soil. We have suggested, partly on the basis of additional information from lead isotopes, that these individuals were involved in a pattern of movement between the chalk uplands and an area with more radiogenic labile soil strontium and isotopically distinctive lead, probably in the Mendips to the north-west (Budd *et al.* 2001; Montgomery *et al.* 2000).

However, as we have noted elsewhere (Budd *et al.* 2001), the Monkton individuals also have tooth enamel which suggests a great range of drinking water oxygen isotope compositions, all of which have much higher δ^{18}O than precipitation falling in southern central England today (Figures 1 and 2a). We believe that this may be at least partly explained by the significantly warmer climate of the later climatic optimum which still prevailed at this time

(*c.* 5500BP) (Budd *et al.* 2001). Overall, however, the Monkton individuals appear to provide evidence for considerable mobility at the *c.* 100km scale, or possibly greater distance.

By contrast, most of the Bronze and Iron Age individuals from West Heslerton have both tooth enamel strontium isotope ratios and drinking water oxygen isotopes which closely correspond to the vicinity of their burial suggesting a much more sedentary life history. Although there is not inconsiderable variation between these individuals with respect to $^{87}Sr/^{86}Sr$ ratios, these may be accounted for by the relatively large variation between labile strontium from local soils (Table 2) which is discussed in more detail below. With respect to drinking water oxygen, the majority of this population
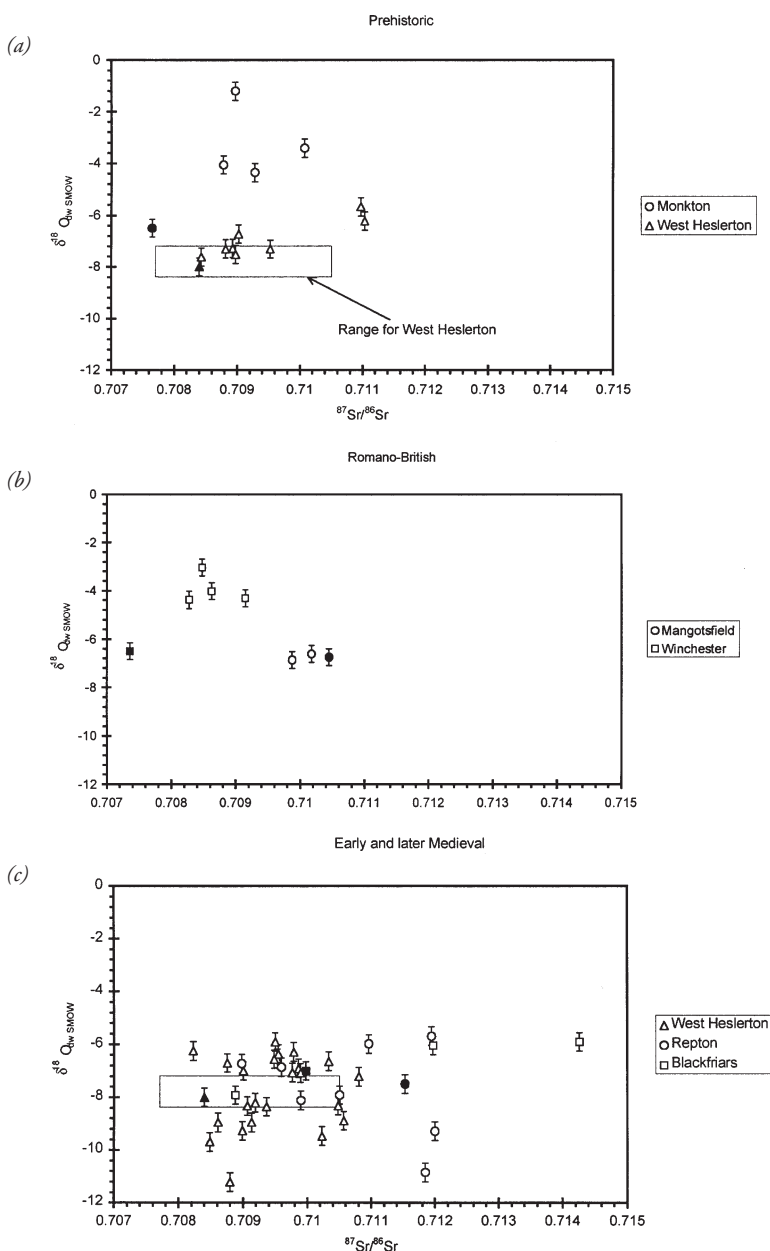
(a)

(b)

(c)

Figure 2 Plots showing the relationship between $\delta^{18}O$ of childhood drinking water and tooth enamel $^{87}Sr/^{86}Sr$ ratios for various individuals from Great Britain. Errors for the oxygen isotope results are 2σ. Errors for the strontium isotope ratios (2σ) are smaller than the symbols. The box represents the range of local surface water oxygen isotopes and of local labile soil strontium isotopes at West Heslerton. Data after Budd et al. (2000a; 2001; 2003b). Filled symbols represent estimates of local soil Sr isotope and surface water oxygen isotope composition for each site.

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plot within error of the range established for modern local ground and surface waters within

15km of the West Heslerton (–8.37 to –7.19‰) (Budd, unpublished data). Interestingly, two individuals, one Bronze Age and one Iron Age, plot close to one another with more radiogenic strontium and relatively enriched drinking water [18]O. For these two, a place of origin west of the Pennines seems probable, although it is not possible to be sure if a similar place of origin is implied or whether their correspondence on the plot is coincidental.

Romano-British

Two small burial groups have been investigated from Romano-British contexts (Figure 2b). The two mid third century AD burials from Mangotsfield have tooth enamel strontium isotope compositions similar to labile soil strontium at the burial location. They also have drinking water oxygen isotope compositions closely similar to those of meteoric water at the location today. There is no evidence to suggest that the Mangotsfield individuals were anything other than local.

In contrast, the four individuals from the mid fourth century AD cemetery at the Eagle Hotel site in Winchester have rather more radiogenic $^{87}Sr/^{86}Sr$ ratios than the local labile soil strontium, and, perhaps more significantly, have considerably more enriched drinking water $\delta^{18}O$ values than local waters in southern England today. The Romano-British period is considered to have enjoyed a relatively warm climate which gradually deteriorated after about AD400 (Lamb 1982). However, recent studies of northern European marine sediments and sea-water oxygen isotope measurements, suggest this 'Roman Climate Optimum' was mild and much less significant than the following decline (Haas, 1996). It therefore seems unlikely that climate change can have been responsible for the high oxygen isotope values apparent in this case. We expect rainfall $\delta^{18}O$ values to be around –4.5 to –3 0 in the western Mediterranean and North African coast today and a childhood origin in this area remains a possible explanation for the Winchester group.

Early medieval West Heslerton, North Yorkshire

Most of the data currently available for Great Britain relate to the post-Roman period, and have been studied with particular emphasis on early medieval immigration (Tables 1 and 2, Figure 2c). To date it is only for this period that we have sufficient data to start to approach correlations between the isotopic and archaeological evidence for personal mobility. In contrast to the earlier periods, some individuals have more depleted (lower) $\delta^{18}O$ in childhood than found at their place of burial. Indeed some have drinking water values of less than –9‰: values too depleted to occur in UK rainfall today.

Before jumping to conclusions regarding immigration, we have to consider the possible effects of climate change. The sixth to ninth centuries AD are considered to have marked a period of climatic deterioration in Great Britain, sometimes called the 'pre-medieval cold period' (Lamb 1982; Cowling *et al.* 2001). However, even mean annual temperatures 0.5°C cooler than today would reduce mean annual rainfall, and therefore drinking water, $\delta^{18}O_{VSMOW}$ values by no more than about 0.2‰ compared to the same areas today (Budd 2003b). Given that the most depleted UK groundwaters have $\delta^{18}O_{VSMOW}$ of approximately –8.5‰, and given our estimated error of ±0.35‰ it seems reasonable to conclude that individuals with childhood drinking water below –9‰ did not originate in Great Britain.

Table 2 The isotopic composition of labile soil strontium within 15km of the early medieval cemetery at West Heslerton together with that of tooth enamel for four pigs from contexts within the settlement coeval with the period of use of the cemetery.

Labile soil strontium			
Sample No.	NGR	Description	$^{87}Sr/^{86}Sr$
PLS17	SE479480	Lacustrine clay with chalk	0.710539
PLS18	SE486479	Lacustrine clay with chalk	0.708138
PLS18a	SE488478	Lacustrine clay with chalk	0.707517
PLS19	SE490477	Clay and aeolian sand	0.709834
WHS04	SE492476	Lacustrine clay, sand and chalk	0.707741
WHS05	SE492477	Aeolian sand	0.708186
WH-1	SE492476	Aeolian sand	0.708245
WH-2	SE492477	Aeolian sand	0.708378
WH-3	SE492478	Chalk	0.707408
Mean	0.708443		
Standard deviation	0.001058		
Pig tooth enamel			
Sample No.	Context	Tooth	$^{87}Sr/^{86}Sr$
HP2DA21	2694	M^1 right	0.710783
HP2DA14	7983	M^2 right	0.708645
HP2DA75	29867	M^2 right	0.710559
HP2DA156	49891	M^2 left	0.707986

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Of the 24 individuals from early medieval West Heslerton for which oxygen isotope data are available, four had childhood drinking water with $\delta^{18}O_{VSMOW}$ < –9‰. If this sample (selected primarily on the basis of enamel preservation) is representative of the 300 or so population of the cemetery as a whole, the data imply that around one in six of the population were first generation immigrants from either eastern Continental Europe or, more likely, Scandinavia. The four 'immigrant' burials span the *c.* 250 year period of use of the cemetery and are not spatially clustered. Therefore it seems unlikely that this immigration was a short-lived event involving a higher proportion of the population. However, the dating remains too poorly resolved to attach great certainty to this. Interestingly, these individuals also offer the best correlation to be found in this cemetery between isotopic and conventional archaeological data. All four are females (one juvenile and three adults) as are 13 of the sample of 24. They are also the only females in the sample to have been buried without brooches. Indeed all four graves are very poorly furnished overall, three with no grave goods at all and one (GN117) with just a single girdle hanger (Haughton & Powlesland 1999). Such paucity of grave goods is in marked contrast to all the other females in the sample.

Despite the obvious interest in these four individuals it is evident that the great majority of the early medieval West Heslerton population (20 of 24) had drinking water oxygen isotopes consistent with origins in Great Britain. However, particularly striking in this respect is the degree of variation, and therefore of 'regional' mobility, suggested. We noted above that most of the oxygen isotope data for the Bronze and Iron Age population at West Heslerton (Figure 2a) cluster in the region of –8 to –7‰ consistent with the local drinking water composition (Budd *et al.* forthcoming). In contrast, the childhood drinking water oxygen isotope composition

of the early medieval group from the site is much more varied (Figure 2c). There is a strong visual indication of a bi-modal distribution for the early medieval West Heslerton oxygen data. The probability that they form two overlapping normal distributions cannot be evaluated with so few cases, but a Shapiro-Wilks test of the population as a whole allows us to reject a hypothesis of normality (p=0.054, n=24).

The gap between the two probable oxygen isotope populations at West Heslerton occurs for $\delta^{18}O_{VSMOW}$ between about –8.2‰ and –7.2‰. Interestingly, surface water and groundwater of this composition is found in the (presumably sparsely populated) Pennine uplands and the implication is of two groups with childhood origins on either side of the Pennines. Of the 20 individuals in the sample (14 female, five male and 1 unsexed), only seven appear to originate east of the Pennines and locally to West Heslerton with 13 giving a more westerly signal with drinking water between –7.2‰ and –5.9‰. The implication is that a very high proportion of the buried population were first generation immigrants to the area from the west (Budd *et al.* forthcoming). If this is the case it suggests a remarkably high degree of mobility with a considerable influx of people from previously settled areas of sub-Roman Britain and a smaller, but significant, proportion of continental immigrants.

It was hoped to refine the interpretation using strontium isotope analysis. Unlike the prehistoric data however, there is no correlation between the early medieval strontium and oxygen data, nor are the strontium data bi-modal. Rather, the early medieval strontium isotope compositions are normally distributed (Shapiro-Wilks, p=0.303, n=32) about the same mean (0.7095±0.0014, 2σ, n=32) as the prehistoric data (0.7095±0.0020, 2σ, n=8). Although this mean is higher (more radiogenic) than that of the local soils measured to date (0.7084±0.0021, 2σ, n=9), it is within the range of labile soil strontium recovered from within 15km of the site, 0.70741-0.71054 (Table 2). This very large local environmental strontium isotope range is a major obstacle to the interpretation of the archaeological data as it appears that the range of locally bioavailable strontium isotope ratios is as great as that of a large area of northern England. Under such circumstances there may be no clear correlation between tooth enamel $^{87}Sr/^{86}Sr$ ratios and geographic location.

As a further check on the isotopic composition of bioavaiable strontium around early medieval West Heslerton, we have measured the $^{87}Sr/^{86}Sr$ ratios of the tooth enamel of four domesticated animals (pigs) from contexts within the West Heslerton settlement which are coeval with the period of use of the cemetery. These also have a wide range of isotopic composition (Table 2) with $^{87}Sr/^{86}Sr$ from 0.7080 to 0.7108, although more samples are required to assess the significance of this distribution more fully.

The large range in the isotopic composition of locally available strontium at West Heslerton and the likelihood that it may be as great as variation on the regional scale may explain the lack of correlation between the oxygen and strontium datasets. It may also explain why the tooth enamel Sr-isotope data at West Heslerton show no correlation with any one of the large number of archaeological parameters considered. These include physiological factors such as age at death, sex, tooth type, pathology; grave goods such as weapons, dress fastenings, accessories, ornaments, textiles; and burial conditions including location, soil type, burial position and orientation.

Anglo-Saxon and Norse burials at Repton, Derbyshire

To date, the isotopic work at Repton has focussed on burials associated with the Viking occupation of the site in AD 873-4 (Biddle and Kjølbye-Biddle, 2001). Three individuals, Graves G295, G511 and G529, dating to this period are considered to be of almost certain Scandinavian origin on the basis of highly distinctive grave goods and burial style (Biddle *et al.* 1986; Biddle & Kjølbye-Biddle 1992; Biddle & Kjølbye-Biddle 2001) and one purpose of the study was to compare their place of origin with four people of unknown origins from the Repton charnel deposit. The latter contained the disarticulated bones of at least 264 individuals, probably once surrounding a central burial, over which a large mound was constructed during the Viking occupation. The high proportion of males (*c.* 80 per cent), their robust build and age distribution have been taken to suggest that the deposit may be made up from members of the Danish Great Army. Developing this scenario further it has been suggested that the smaller female element of the charnel deposit population would be more likely than the males to be of local, or at least English, origin. Radiocarbon dates from the charnel deposit (Biddle & Kjølbye-Biddl 2001: Appendix A) suggest that at least half the bones dated derive from an earlier period (late seventh to early eighth century), but the character and taphonomy suggest that the deposit is homogenous. The skulls of two male (X23 and X70) and two female individuals (X3 and X17) from the charnel deposit were selected to examine the various hypotheses concerning the origin of the individuals represented.

The later ninth century marks the end of the pre-medieval cold period (Lamb 1982) and it is likely that the climate and therefore precipitation oxygen isotope ratios would have been similar to those prevailing today. The range of the of bioavailable $^{87}Sr/^{86}Sr$ around Repton has yet to be evaluated, but a single soil leachate ($^{87}Sr/^{86}Sr$ = 0.71153) suggests it may be relatively radiogenic in comparison with other UK soil samples from sedimentary contexts.

Two of the Viking individuals (G511 and G295) show similar characteristics to one another with respect to both ratios (Table 1), as might be expected from the close link suggested by their joint burial. Both ratios are also outside the range which might be expected in the immediate locality of Repton. G511 and G295 have drinking water oxygen isotope compositions (both just over –7‰) too high for local precipitation. Within Great Britain such values would be associated with the western part of the country (Figure 1), but they are also consistent with parts of northern France, the Low Countries and the west coast of Denmark. These two individuals also have the least radiogenic Sr-isotope compositions (*c.* 0.709-0.710). Labile Sr of this composition has been reported from soils overlying Upper Cretaceous sedimentary rocks in East Anglia and lower Jurassic mudstones near Gloucester (Budd, unpublished data). Lithologies similar to the latter outcrop only about 35km east of Repton and the Jurassic and Cretaceous sedimentary sequences characterise much of the east Midlands and East Anglia. However, the same sequences also underlie much of Denmark and outcrop in north-western Jutland and strontium isotopes cannot be used to differentiate between such broadly defined localities.

The third Viking burial (G529) has a tooth enamel strontium and oxygen isotope composition which is widely divergent from G511 and G295. The O-isotope composition of G529's enamel (–10.1‰) is far too low for precipitation falling in Great Britain but characteristic of rainfall in eastern Sweden, Baltic Europe and parts of eastern central Europe and south-western Russia. This individual also has a comparatively radiogenic tooth enamel

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strontium isotope composition. Given existing knowledge of the extent of Viking influence in the later ninth century, it seems possible that G529s place of origin may have been south-eastern Sweden. It is notable in this context that the gold finger ring with which he was buried has close parallels at Birka near present day Stockholm and at Fyrkat in north Jutland (Aitken & Arwidsson 1986; Roesdhal, 1977)

Of the other individuals investigated, both of the charnel deposit male skulls (X70 and X23) have tooth oxygen isotope ratios consistent with local meteoric water at Repton, but this also overlaps with western parts of Denmark and the low countries. Their strontium isotope ratios are somewhat less radiogenic than those of the Repton soil leachate, but probably within the range of bioavailable strontium from the site catchment. Such values however would also be expected for parts of Denmark. Both oxygen and strontium data are consistent with local origins, but a childhood spent in parts of Denmark cannot be excluded as a possibility on the available evidence.

The charnel deposit females, on the other hand, are quite different both from the males and from one another. Skull X3 has a relatively high oxygen isotope composition which suggests a place of childhood residency to the west and south of Repton, possibly mid-Wales, south-eastern or south-central England. The other female skull (X17) has much lower oxygen isotope values more typical of mid-Continental or Baltic Europe. Tooth enamel strontium isotope compositions are also significantly different between each of the charnel house females with skull X17's being similar to the Viking G529.

Finally, the late seventh century individual (G97), a child 8–11 years old, has a tooth enamel Sr- and O-isotope composition with Sr ratios as radiogenic as those of G529 and skull X17, but with oxygen isotope ratios similar to those of the other charnel house female skull (X3). As with skull X3, it seems probable that G97 was not resident in the Repton area during early childhood, but in some other part of Great Britain to the west and south.

Later medieval Blackfriars, Gloucester

The principal objective of this small study was to compare the place of origin of one particular individual, a young adult female (B77) displaying lesions consistent with tertiary phase syphilis (Roberts 1995), with other individuals within the cemetery. The three individuals investigated had very widely varying tooth enamel $^{87}Sr/^{86}Sr$ from 0.7089 to 0.7142. B89 (a juvenile) had the least radiogenic value, considerably lower than that recorded for labile soil strontium at the site (0.7010), whereas both B77 and B341 were far more radiogenic. Given the uncertainties associated with the quantification of local strontium isotope variation the significance of this is uncertain, although it does suggest a different place of origin for each of the individuals.

Once again, the oxygen isotope data can be more easily interpreted. All three individuals had childhood drinking water with oxygen isotope compositions consistent with those found in Great Britain, although different places of childhood origin are suggested with B77 and B341 appearing to come from the west of Gloucester and B89 to the north and east. There is no suggestion that B77 was of non-British origin, although she probably did not grow up in the immediate area of Gloucester.

Conclusions

The results presented here represent the outcome of a series of pilot studies which assess the feasibility of the use of combined oxygen- and strontium-isotope analysis for detecting the movement of population. The technique is still under development and the analysis remains technically difficult, labour intensive and expensive. Consequently, most of the studies have been small-scale and the results are very preliminary for most periods and locations Ongoing work aims to provide more detailed information by considering further sites and larger populations and by making the technique more accessible to the archaeological community at large.

Oxygen isotope analysis is proving a highly effective tool by which to trace population movements at the regional and international level. Strontium isotopes offer the potential to provide independent but complementary data, but the magnitude of local strontium isotope variation appears, at least in some cases (like that of West Heslerton), to be comparable with that of its regional variation. Under such circumstances it would appear unwise to try to interpret archaeological strontium isotope data without a detailed environmental strontium survey at site catchment resolution. At present, it appears quite possible to gain useful information about immigration from oxygen isotope data without the use of strontium, but not *vice-versa*. On the other hand, it may be that strontium isotope data can play an important role in identifying population movements at the local level to refine the picture emerging from oxygen.

Despite the current limitations and the need for further development, some important conclusions are already emerging. Population movement, as suspected, appears to be a continual possibility from the prehistoric period onwards. The explanations can be very varied. At the beginning of the early medieval period at least some settlements appear to have been dominated by first generation immigrants. These may have had a Scandinavian component, but appear also to have involved a pattern of re-settlement from across sub-Roman Britain. Perhaps most significantly, it appears that it is possible to identify first generation northern European and Scandinavian immigrants in early medieval England. Correspondence between existing archaeological evidence and the isotopic data go along way towards establishing the veracity of the latter, even though it does hint that Continental European or Scandinavian immigrants might be identified in early Anglo-Saxon cemeteries only by their *lack* of grave goods.

In a wider context, the objective identification of first generation immigrants and the reconstruction of their movements offers additional potential. One area of particular interest is the impact of population movement on human health. The appearance of new diseases in hitherto unaffected areas with non-resistant populations and the converse exposure of immigrants to diseases not previously encountered are directly linked to population dynamics. Combined isotopic and palaeopathological investigation could be a powerful new tool with which to investigate the development and transmission of communicable disease. Finally, extension of the same techniques to animal remains opens the possibility to explore issues of land use, husbandry and trade. Although much development remains to be done, the isotopic investigation of immigration and mobility clearly has a great deal to offer.

Method

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Method