STRONTIUM AND OXYGEN ISOTOPE ANALYSIS OF BURIALS FROM WASPERTON, WARWICKSHIRE.

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1. Introduction

Strontium and oxygen isotope analysis were carried out to investigate geographical origins of 20 individuals from the 4th – 7th century AD cemetery at Wasperton, Warwickshire. Strontium is incorporated into tooth enamel at the time of mineralization (i.e. childhood) and is not remobilised, providing an enduring isotopic signature linking the person to the rocks in the region where they obtained their food and drink. Oxygen is also incorporated into enamel during mineralization, but is an indicator of the climatic regime (e.g. latitude, altitude, distance from the coast) in which an individual's drinking water fell as rain.

1.1 Site Geology

Wasperton is located 5 miles south of Warwick (NGR SP265 5851) on a Quaternary gravel terrace on the east bank of the River Avon. The surface geology of the Warwickshire region is varied. Palaeozoic rocks, predominantly dating from the Carboniferous period, crop out to the north around Coventry, Nuneaton and Dudley, although many are very limited in expression: for example, the Cambrian volcanic ridge of quartzite at Hartshill between Nuneaton and Atherstone. A succession of Jurassic sedimentary Lias rocks, mainly clays, sands, limestones and ironstones, form the higher land to the south and east. However, the rocks that crop out in the Wasperton region are sedimentary Triassic sandstones and mudstones including Keuper Marl (now Mercia Mudstone), Dolomitic Conglomerate and Rhaetic mudstone deposits (British Geological Survey, 2001; Hains, 1969). Triassic rocks are a thick layer of unfossiliferous, sediments that become progressively finer grained and lie between the Coal Measures and the marine deposits of the Jurassic (Ager, 1961). They crop out over a larger area in Britain than do any other system and practically all of them are red in colour and of desert origin, being frequently termed the "New Red Sandstone". In Warwickshire, these rocks contain sand and pebbles produced by the erosion during the Triassic period of the Cambrian quartzite ridge to the north. However, pebbles in the Quaternary gravel and glacial till that occurs extensively in the region appear to be predominantly of locally occurring rock-types such as the Carboniferous sandstone from the Warwickshire coalfield.

1.2 Samples and methods

Preservation of skeletal remains at Wasperton was generally poor with many individuals being represented by only body stains and teeth. Where teeth were present, many were in an advanced state of decay with little or no dentine surviving. However, of the samples selected, tooth and enamel preservation was highly variable (Figure 1). Samples are listed in Table 1. Four burials (1, 27, 46 and 180) provided enamel with good preservation (i.e. hard, translucent and glossy) and eleven enamel with satisfactory preservation. Many samples investigated, however, looked fine on first inspection but when dissected revealed beneath an outer hard, glossy "skin", core enamel that was soft, opaque and chalky. Some burials had teeth that were stained blue or green, suggesting copper-alloy grave goods had been present in the grave. Whilst the visible state of preservation is no guide to biogenic isotopic integrity (Burton et al., 1999; Radosevich, 1993; Reeser et al., 1999), it does appear that the incompletely mineralised enamel of unerupted juvenile teeth is an unreliable archive for strontium (Montgomery, 2002; Montgomery et al., 2005), although whether this is also true for oxygen in bioapatite is not clear. Similarly, it is not known whether this loss of biogenic information also occurs in enamel that is in the process of demineralising, as appears to be the case in the "chalky" samples found at Wasperton.

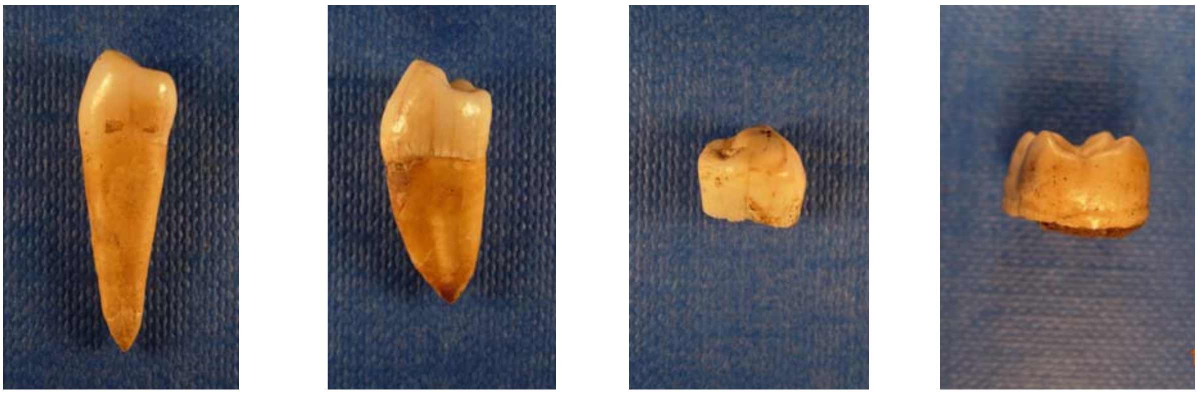

Figure 1. Photographs illustrating the range of tooth preservation. From left to right: Burials 46 (good), 153 (satisfactory), 193 (poor) and 143 (soft and chalky).

Tooth samples were chosen from those available on the basis of visible preservation and avoiding those with extensive staining, cracking or obvious signs of decay. In many cases, choice was limited by poor preservation. Second molar teeth (crown mineralization ~2 ½ and 8 years of age) were preferred as they represent the best compromise between teeth that mineralise post-weaning (to avoid a major breastfeeding contribution in the oxygen isotope result) but as early in childhood as possible (to increase the chance of identifying early migration). When second molars were not available, premolars (crown mineralization ~1 ½ and 8 ½ years of age) were the second choice and then first or third molars were selected. All teeth were gently washed in deionised water, photographed (archived on attached CD), identified and assessed for tissue preservation, attrition and root development/survival as per the table given in Buikstra & Ubelaker (1994) and Montgomery (2002) prior to sampling.

Core enamel and crown dentine were removed from the tooth sample and mechanically cleaned using tungsten carbide dental tools following the procedure given in Montgomery (2002). For strontium, all further preparation and analysis was carried out within the class 100, HEPA-filtered laboratory facilities at the NERC Isotope Geosciences Laboratory (NIGL), Keyworth, UK. Full details are given in Montgomery (2002). The isotope compositions of strontium were obtained using a *ThermoFinnigan Triton multi-collector mass spectrometer*. The reproducibility of the international strontium standard, NBS 987, during a period of analysis did not exceed ±0.000003 (2σ) or ±0.004% (2σ, n = 27). All samples were corrected to the accepted value of $^{87}Sr/^{86}Sr$ = 0.710250 to ensure that there was no induced bias through mass spectrometer drift. Strontium isotope data are presented as $^{87}Sr/^{86}Sr$ ratios. Laboratory contamination, monitored by procedural blanks, was negligible.

Oxygen isotope analysis was also carried out at NIGL. Phosphate oxygen was extracted from enamel bio-apatite and converted to silver phosphate for analysis using a modified method of O'Neil (1994). Analytical measurement was by Continuous Flow Isotope Ratio Mass Spectrometry (CFIRMS) using a TC/EA (high temperature conversion elemental analyser) coupled to a *Thermo Finnigan Delta Plus XL isotope ratio mass spectrometer* via a ConFlo III interface. The sample was analysed in triplicate, corrected and converted to the SMOW scale against NBS120C in-house reference material. The reproducibility over the analytical period for NBS120C and 'batch control' ACC1 were ±0.18 and ±0.16‰ respectively. Full details of analytical method and calculations are given in Chenery (2005).

2. Results

Data are presented in Table 2. Where shown on plots, the error bars on the oxygen isotope data points are the mean of the 1sd $\delta^{18}O_{dw}$ (i.e. +/- 0.26 ‰) shown in Table 2. For $^{87}Sr/^{86}Sr$, 2σ errors are contained within the symbols.

2.1 Preservation of enamel samples

Strontium results are plotted in Figure 2 on the basis of enamel preservation. The samples that were unusually soft and chalky show very little variation in $^{87}Sr/^{86}Sr$ coupled with high strontium concentrations that are similar to the three dentine samples. Dentine, but normally not enamel, is highly susceptible to post-mortem uptake of strontium (Budd et al., 2000; Trickett et al., 2003). Dentine was analysed to estimate the $^{87}Sr/^{86}Sr$ value of locally available strontium. The lack of $^{87}Sr/^{86}Sr$ variation in the "chalky" enamel samples supports the suggestion that they, like the dentine, have also been contaminated with strontium from the burial environment. In contrast, samples with good and satisfactory preservation show a wide range of $^{87}Sr/^{86}Sr$ and, with the exception of the only deciduous tooth analysed, strontium concentrations <140 ppm. Human enamel strontium concentrations of ~50-150 ppm are consistent with those usually found in English archaeological and modern populations (Brown et al., 2004; Evans et al., 2006; Evans and Tatham, 2004; Montgomery, 2002; Montgomery et al., 2000; Montgomery et al., 2005).

Clearly, enamel from individuals of local origin is difficult to distinguish from enamel that has been contaminated post-mortem by strontium from the burial soil, apart from such anomalously high strontium concentrations. Contaminated samples could have been originally either local or non-local in origin. If post-mortem contamination has occurred, the resulting effect will be to artificially increase the number of individuals who appear to be of local origin (Bentley et al., 2004). However, whether contaminated or not, they are an indicator of locally available biosphere $^{87}Sr/^{86}Sr$ which, based on the data presented here, we would estimate to range from ~0.7100 to 0.7107.

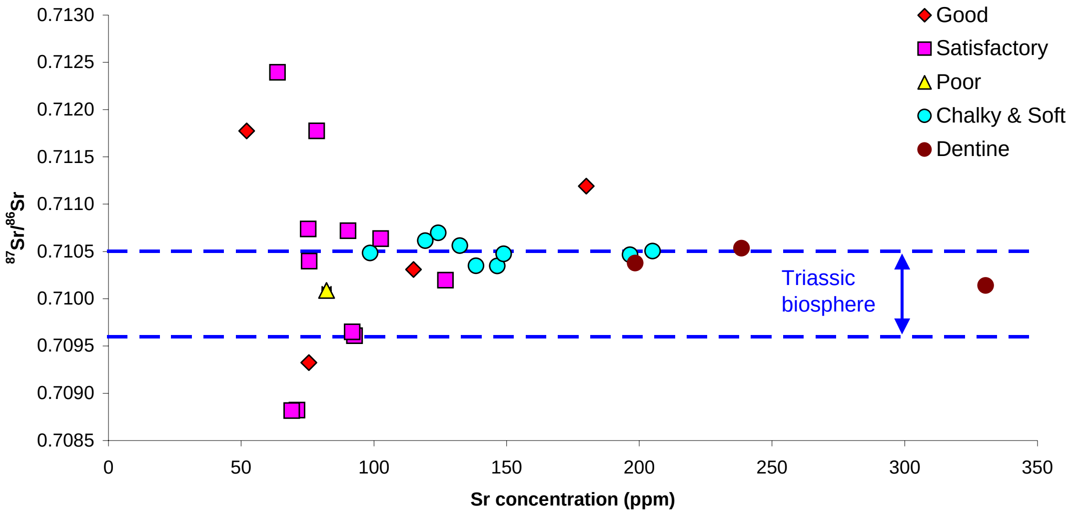

Figure 2. Plot of strontium concentration versus $^{87}Sr/^{86}Sr$ for Wasperton enamel and dentine samples. The blue dashed lines define the ratio range obtained from Triassic-sourced mineral waters, and archaeological dentine excavated from Triassic sediments in England (Montgomery, 2002; Montgomery et al., 2006). Strontium-rich samples have $^{87}Sr/^{86}Sr$ ~0.7105 and are predominantly dentine and the poorly preserved soft, chalky enamel samples.

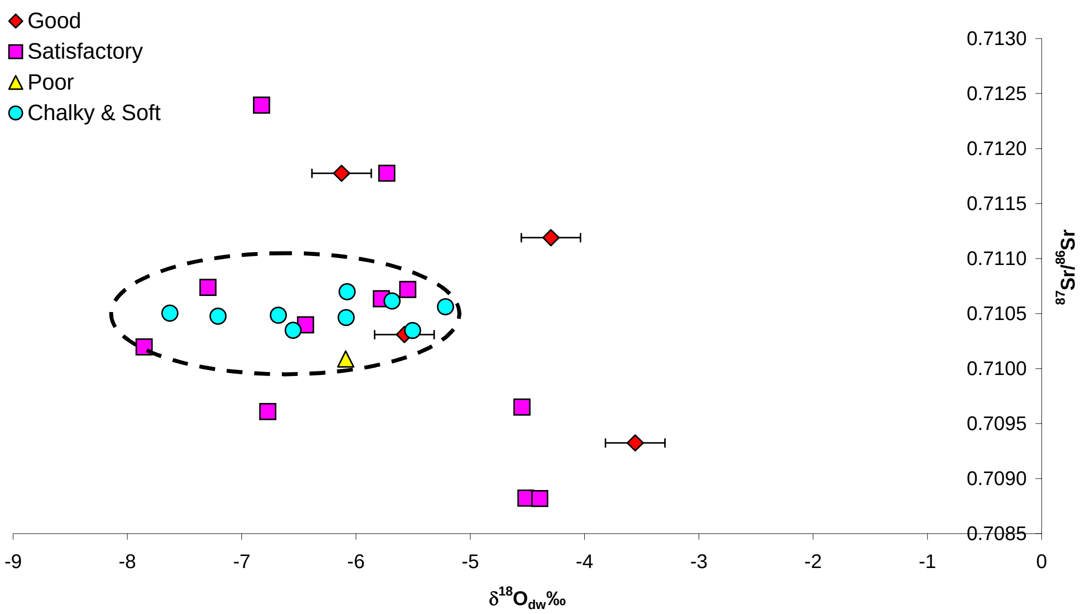

Figure 3. Plot of $\delta^{18}O_{dw}$‰ versus $^{87}Sr/^{86}Sr$ by enamel preservation. The group enclosed within the dashed oval has strontium ratios consistent with the locally available strontium.

Enamel preservation does not, however, appear to be correlated with oxygen isotope value. Figure 3 shows that chalky samples have a wide range of oxygen isotope values and rather than clustering around a value, are spread throughout the central group defined by the black dashed oval. It is of note that all samples outside this central group produced enamel that was either of good or satisfactory preservation.

We conclude from Figures 2 and 3 that the strontium values of the poorly preserved enamel samples are an unreliable indicator of lifetime strontium values but are nonetheless useful, in the absence of other biosphere data such as animals, in defining locally available biosphere strontium.

2.2 Oxygen isotope results

The measured $\delta^{18}O$ ‰ values of enamel phosphate have been converted to drinking water values using the Levinson et al. (1987) calibration in order to be able to compare them with geographical groundwater contours in Figure 4. With the exception of extreme westerly locations such as the Outer Hebrides, the range of average annual modern $\delta^{18}O_{dw}$ ‰ values in Britain is –5 to –9 ‰. Wasperton is located within the light green area in Figure 4 (–7 to –8 ‰). However, given seasonal variation, analytical error and biological variability it is unlikely that everyone originating from Wasperton would have an oxygen isotope value within this range. The mean $\delta^{18}O_{dw}$ ‰ is –5.75 ‰ +/- 2.19 (2s, n =20), or when the "chalky" enamel samples are discounted, -5.71 +/- 2.40 (2s, n = 16), which is somewhat higher than would be predicted for a population of purely local origin based on modern day precipitation (Figure 4). It is currently not well established how much oxygen isotope values should vary within a contemporaneous village-sized human community, and how much variation increases when burials spanning many years are included in a sample. Modern mammals from a single location can vary by less than analytical error, which is approximately +/- 1 ‰ on drinking water values (Fricke et al., 1995; Luz and Kolodny, 1985; Luz et al., 1984). However, given the above considerations and the likelihood that human burials at most archaeological cemeteries span several centuries, estimates suggest

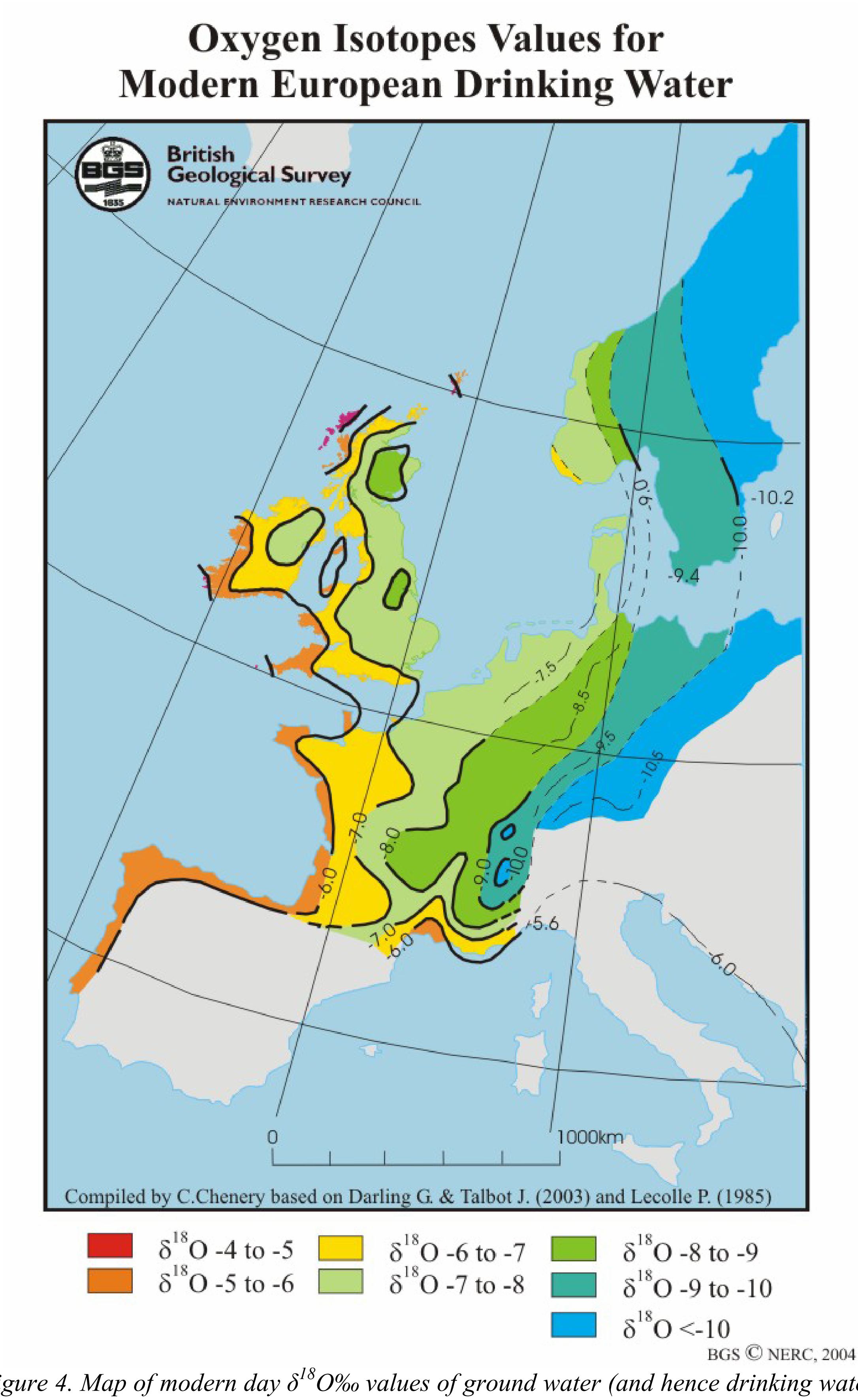

Figure 4. Map of modern day $\delta^{18}O$‰ values of ground water (and hence drinking water) in NW Europe. Copyright of the British Geological Survey/NERC.

it is not likely to be less than +/- 1.5 $‰_{dw}$ (Evans et al., 2006; Tatham, 2004). This is consistent with the range seen in the proposed local group of Wasperton burials (mean = -6.32 ‰ +/- 1.6 2s, n = 16) contained within the dashed oval in Figure 5.

At Lankhills Roman cemetery in Hampshire, Evans et al. (2006) proposed a maximum range for local people of ~4 ‰ but obtained only two $\delta^{18}O_{dw}$ values above –5 ‰; both of these were from deciduous teeth which are likely to be enriched in $\delta^{18}O$ because they mineralise before birth and during breastfeeding (Wong et al., 1987) and thus cannot be compared directly with the data from permanent teeth. The authors point out that without the metabolic pre-weaning effects their tooth enamel would plot within the local field. Likewise at the West Heslerton Anglian cemetery, values above –5 ‰ were rare (Budd et al., 2003) and this is also the case at other sites from England, although one individual with an oxygen value ~ -4 ‰ was found at the 2nd-3rd century AD Roman cemetery at Driffield Terrace, York (Montgomery, Evans & Chenery unpublished data). It is of note, however, that amongst the five individuals analysed from the 1100 – 1600 AD cemetery at Risby, Denmark, Fricke et al. (1995) found bone enamel phosphate ratios ranging from 16.9 ‰ to 18.9 ‰, which are comparable with the total range found at Wasperton (Table 2). However, the burials do not date from the same period, may span 500 years during which there were large climate fluctuations and there is of course, the possibility that some did not originate in Denmark.

At Wasperton, only one deciduous tooth (Burial 180) was analysed, and this has a $\delta^{18}O_{dw}$ value of –4.29 ‰ (Figure 5). This is noticeably enriched compared to the majority of samples from the site but given the possibility that this is due to the metabolic effects of breastfeeding this is perhaps not significantly different to the proposed local group. However, there are four other permanent teeth samples (Burials 46, 174, 190 and 190), which have both high $\delta^{18}O_{dw}$ values, and low $^{87}Sr/^{86}Sr$ values compared with the central group. These four are contained within the red circle on Figure 5 onwards.

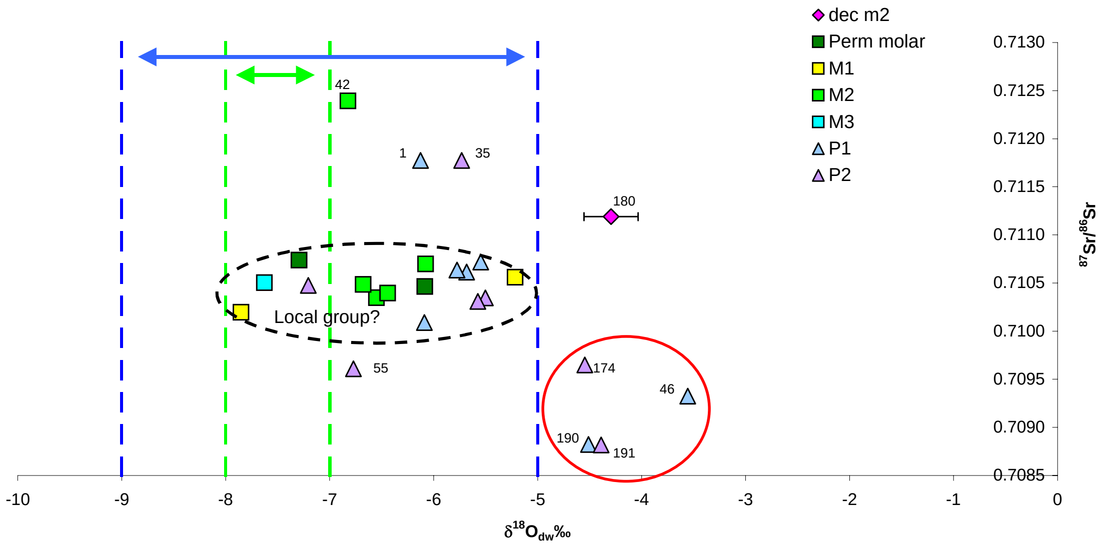

Figure 5. Plot of $\delta^{18}O_{dw}$‰ versus $^{87}Sr/^{86}Sr$ by tooth type. The $\delta^{18}O$‰ of precipitation at the equator = 0 and generally decreases with increasing latitude, altitude and distance from the coast. The range of modern average precipitation in England and Wales (-5 to –9 ‰) is defined by the blue lines. Wasperton falls within the green lines. The four samples within the red circle have unusually enriched oxygen values for England.

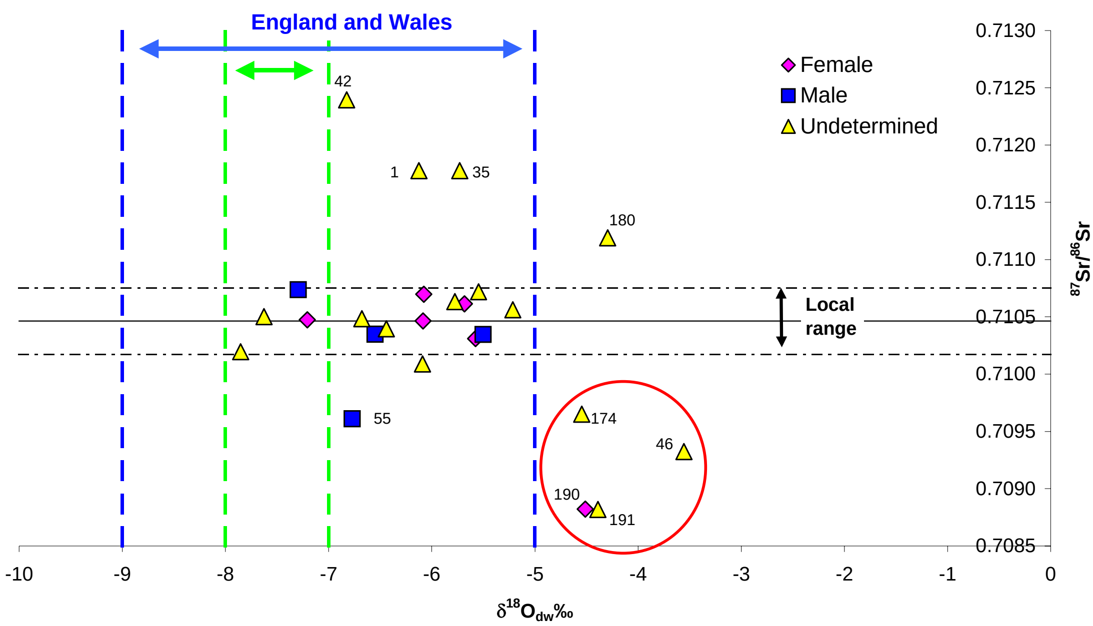

Figure 6. Plot of $\delta^{18}O_{dw}$‰ versus $^{87}Sr/^{86}Sr$ by gender as determined by grave goods. The local $^{87}Sr/^{86}Sr$ range as defined by the mean and 2sd of the dentine and "chalky" enamel ratios is indicated by the solid and dashed black lines.

2.3 Strontium Isotope Results

The enamel $^{87}Sr/^{86}Sr$ values from Wasperton range from 0.70882 to 0.71239 with a mean 0.7104 +/- 0.0019 (2s, n = 20), or alternatively 0.7104 +/- 0.0020 (2s, n = 16) when the "chalky" enamel samples are discounted. For Central England, this is a large range of human isotope values and is unlikely to derive solely from food and drink sourced from Triassic rocks. The central group of individuals enclosed within the black dashed oval have very similar $^{87}Sr/^{86}Sr$ values (mean = 0.7104 +/- 0.0005 2s, n = 7), which overlap with the range of known Triassic biosphere values (Figure 2). An estimate of the local strontium isotope range is often obtained by calculating 2 sd of the mean bone values (Bentley et al., 2004). At Wasperton no bone was analysed, but this estimate of the local range, calculated from the dentine and "chalky" enamel, is illustrated in Figure 6. Four burials (1, 35, 42 & 180) have higher strontium values and five burials (46, 55, 174, 190 & 191) have lower strontium values.

To the best of our knowledge, there is currently only very limited human data from British archaeological sites located on Triassic rocks against which to compare the individuals from Wasperton. Two individuals excavated from a 3rd – 4th century AD stone sarcophagus at Mangotsfield, Bristol produced enamel values ranging from 0.7097 to 0.7102 (mean = 0.7100 +/- 0.0003, 2s, n = 7) (Montgomery, 2002) which is consistent with the central Wasperton group, and soil leaches of 0.7104 which is identical to the Wasperton mean.

Data from archaeological sites located on younger Jurassic clay-carbonate lithologies, which are found to the south and east of Wasperton, tend to produce soil, dentine and enamel values which are on the whole slightly lower than those of the Central Wasperton group (Evans and Tatham, 2004; Grupe et al., 1997; Montgomery, 2002). Spring water from Jurassic limestone host rocks has $^{87}Sr/^{86}Sr$ = 0.7086 (Montgomery et al., 2006). Evans and Tatham (2004) found a human enamel mean value of 0.7098 +/- 0.0018 (2s, n = 22) at 10th – 12th century AD Ketton, in Rutland. However, the tighter cluster of data obtained from juveniles at this site, who are probably more likely to originate locally, was even lower at 0.7094 +/- 0.0002 (2s, n = 7). Similarly, at the 5th – 7th century AD cemetery at West Heslerton, the juveniles produced a mean value of 0.7090 +/- 0.0008 (2s, n = 13)

(Montgomery, 2002; Montgomery et al., 2005), which may reflect a contribution from Chalk as the settlement was located at the foot of the Yorkshire Wolds. Populations excavated from Cretaceous Chalk, which has a $^{87}Sr/^{86}Sr$ value of ~0.7075 (McArthur et al., 2001) and produces spring water with a value of 0.7077 (Montgomery et al., 2006), tend to produce individuals with strontium ratios slightly lower than Jurassic lithologies and usually in the region of ~0.7080 to 0.7090 (Evans et al., 2006; Montgomery, 2002; Montgomery et al., 2000; Montgomery et al., 2005). However, origins on Chalk and Jurassic rocks *in England* are unlikely to explain the low values seen in burials 46, 174, 190 and 191 as these have oxygen values that would appear to be inconsistent with English origins.

Enamel strontium ratios higher than 0.7117 (Burials 1, 35 & 42) are unusual amongst humans excavated in southern, eastern and Central England and require a considerable contribution from rocks that are older or more radiogenic than those that predominate in these regions. Rocks that produce radiogenic biospheres tend to be silicate rocks such as granites and sandstones rather than the carbonate rocks which are conducive to good bone preservation. Consequently, there is currently only limited archaeological human data from regions where high strontium ratios are found and usually, as is also the case at Wasperton, only one or two individuals with such ratios at archaeological cemeteries on carbonate terrains. Spring waters with strontium ratios above 0.7117 are hosted in Carboniferous millstone grits, Devonian sandstones, Silurian and Ordovician mudstones and Cambrian and PreCambrian granites (Montgomery et al., 2006). As discussed in section 1.1, such rocks occur to the north around Coventry, Nuneaton and Dudley and also to the west near Malvern, in Wales and in the south west around Bristol, Devon and Cornwall (British Geological Survey, 2001). It must be remembered, however, that the rocks must contribute to biosphere values and enter the foodchain to influence the human values.

Few sites have been investigated in these regions but two individuals with $^{87}Sr/^{86}Sr$ = 0.7120 and 0.7144 were found at the mediaeval Blackfriars cemetery in Gloucester. The latter remains one of the highest $^{87}Sr/^{86}Sr$ values obtained to date from an English burial site (Montgomery, 2002). It is therefore possible, although there is little direct evidence from such places, that individuals 1 and 35 have origins on Palaeozoic, though not

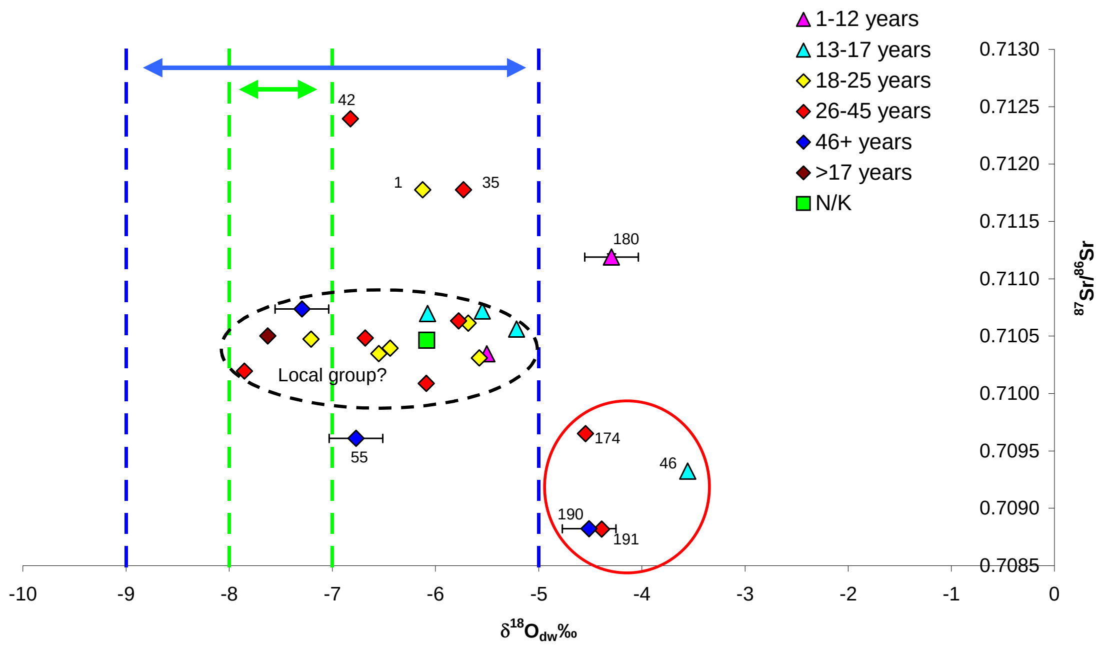

Figure 7. Plot of $\delta^{18}O_{dw}$‰ versus $^{87}Sr/^{86}Sr$ by age at death.

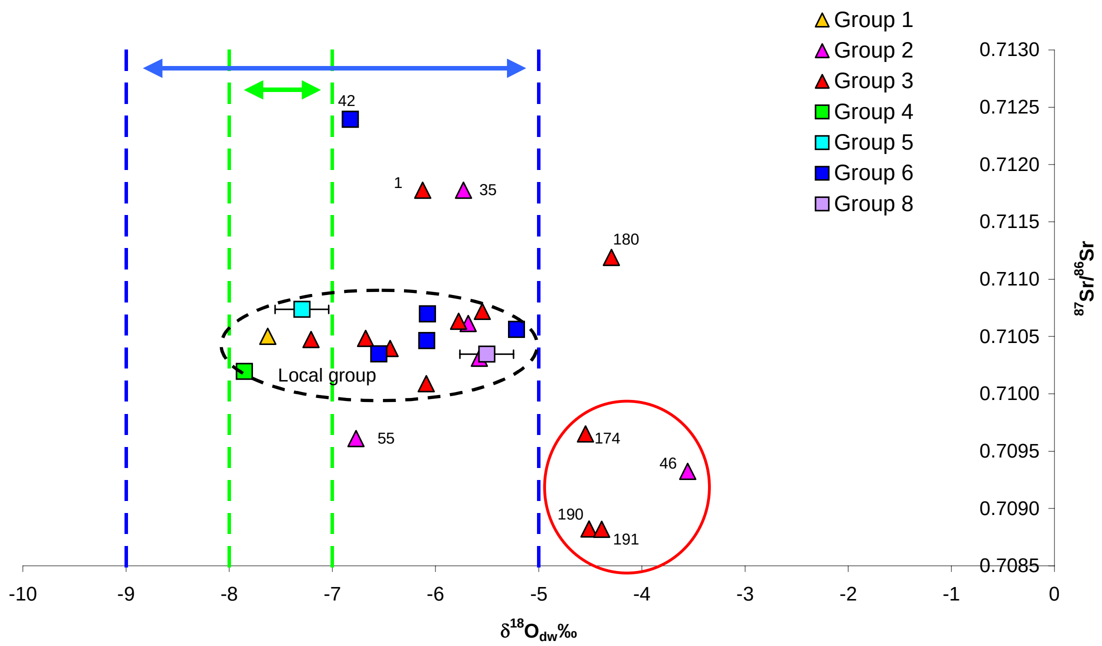

Figure 8. Plot of $\delta^{18}O_{dw}$‰ versus $^{87}Sr/^{86}Sr$ by cemetery group.

Triassic, silicate rocks which are found to the north, the southwest of England and in Wales, which are also consistent with their oxygen values. Burial 42 has a significantly higher strontium ratio ($^{87}Sr/^{86}Sr$ = 0.7124) than 1 and 35 and the, albeit limited, evidence currently available would suggest that such an enamel ratio is unlikely to be obtained from Carboniferous or Devonian rocks and origins on rocks of Silurian age or older are more likely (Bentley and Knipper, 2005; Montgomery and Evans, 2006; Price et al., 2006).

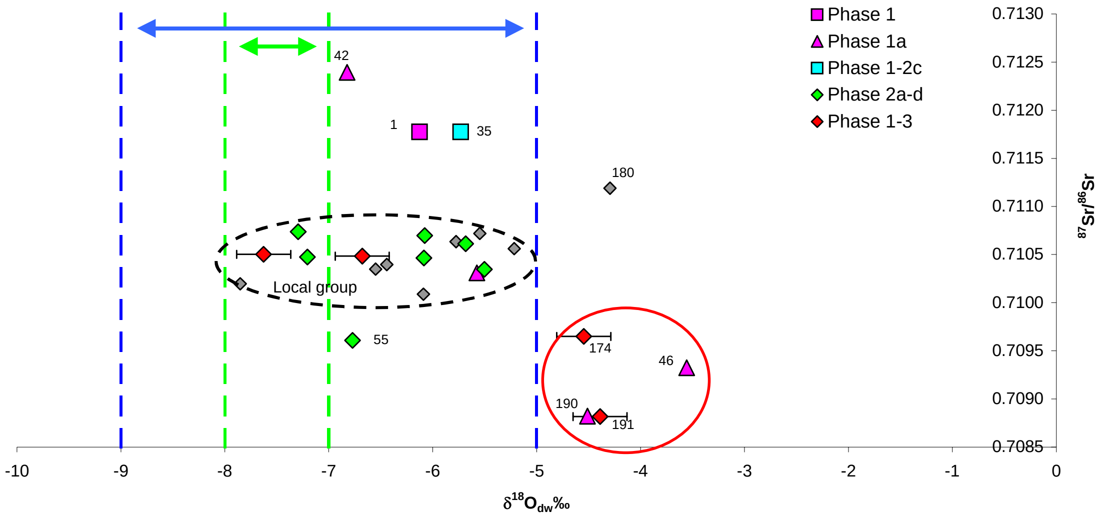

Figure 9. Plot of $\delta^{18}O_{dw}$‰ versus $^{87}Sr/^{86}Sr$ by cemetery phase.

3. Discussion of archaeological indicators

3.1 Gender

Due to the poor bone survival at Wasperton biological sex could not be determined. Where possible, gender was assigned according to grave assemblage. Most burials where male or female gender could be determined fall into the local group (Figure 6). Only two gendered burials were non-local: Burial 55 was a mature male adult and Burial 190 a mature female adult.

3.2 Age

In most of the samples analysed, age was determined according to the categories in Figure 7. The local group contains individuals from all age categories including four of the six sub-adults (although as mentioned in section 2.1 the local group may be artificially increased due to the possible diagenetic contamination of some enamel samples). The "exotic" group of individuals contained within the red circle contains one adolescent (Burial 46) and the rest are adults (Burials 174, 190 & 191), as are the other four non-local individuals (Burials 1, 35, 42 & 55). The deciduous tooth of Burial 180, a juvenile, can be discounted however due to a possible pre-weaning signature (see section 2.2).

3.3 Burial Group

The local group contains individuals from all areas of the cemetery (Figure 8). Burial 42, which has the highest $^{87}Sr/^{86}Sr$ ratio, was excavated from Group 6 and all other "exotic" and non-local individuals were excavated from Groups 2 and 3.

3.4 Cemetery Phase

With the exception of Burial 55, none of the non-local and exotic individuals are securely dated to Phase 2 of the cemetery; all that are, fall in the local group. The exotic group contains two individuals from Phase 1 and two who cannot be securely assigned a phase and contain no diagnostic grave goods. The non-local individuals with high $^{87}Sr/^{86}Sr$ (1, 35 & 42) are also dated to the earlier phases of the cemetery,

4. Conclusions

The isotope data from Wasperton has indicated, but cannot prove, a main group of individuals that appear to be consistent with origins on the Triassic rocks of the region (Figure 6), although available biosphere data is limited. It is possible that this group is artificially large as it includes several samples exhibiting extremely poor enamel preservation which may be diagenetically altered (Figures 2 & 3). The mean oxygen isotope value of this group is ~ 1 ‰ too "warm" for the Wasperton region when compared with modern values, but the range is consistent with that of southern England and at ~3 ‰ it is not unusual for an archaeological population spanning several centuries (Figures 4 & 5). It must be remembered, however, that this type of analysis cannot rule out origins in places where strontium and oxygen values overlap with those at Wasperton and there is currently little or no comparative data available from individuals excavated from cemeteries in many parts of Europe.

One individual (55) falls just outside the group but could be explained by origins on the Jurassic clay-carbonate rocks that occur in south and east Warwickshire (Figure 6). Four individuals (1, 35, 42 & 180) exhibit higher strontium ratios indicative of origins on older Palaeozoic rocks which occur to the north and west and in Wales, Devon and Cornwall. Three of the four have oxygen values which are consistent with England and Wales. The fourth (180) is a deciduous tooth (Figure 5) and, as previously explained, cannot be directly compared with the remaining permanent teeth. If the value were to be corrected for a pre-weaning signature, it would be consistent with the main group of individuals.

The remaining four individuals (46, 174, 190 & 191), one of which is of female gender, are perhaps the most interesting group as they have oxygen isotope ratios that are higher than the other Wasperton samples and which appear to be inconsistent with known modern oxygen isotope values for England and NW Europe. In addition, their strontium ratios are significantly lower than the main Wasperton group and are consistent with origins in a region (or regions - 190 and 191 are different to 174) of younger or less radiogenic rocks such as Jurassic clay/carbonates or Chalk . It is noteworthy that two of the four date from the earliest phase of the cemetery and the remaining two are difficult to date. Figure 4 indicates that modern average $\delta^{18}O_{dw}$‰ values higher than –5 ‰ occur only on the extreme west coast of Britain, e.g. the southernmost tip of Cornwall and the Outer Hebrides, and the SW of Ireland. Alternatively, they are characteristic of a warm, Mediterranean climate and, on the assumption that the climate in the 4th to 7th centuries AD was not significantly different from today, these individuals are consistent with origins in a region of young Mesozoic rocks in southern Europe, such as those found in Italy and Spain. It is not possible, however, to rule out origins in regions elsewhere in the world where similar ratios may be obtained

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Table 1. Samples analysed

Burial	Feature	Group	Phase	Age[1]	Gender[2]	Tooth[3]	Preservation Scores Enamel[4]	Attrition[5]	Root[6]
1	56	3	1	YA	u	P^1R	3	2	5
6	237	6		YA	m	M^2R	4	2	X
8	240	6	2a-c	AD	f	M^2R	5C	2	X
24	302	2	2c	YA	f	P^1	5C	3	X
27	309	2	1a	YA	f	P^2L	3	2	5
28	325	4		M	u	M^1	4	6	X
35	347	2	1-2c	M	u	P^2	4	4	X
42	373	6	1a	M	u	M_2	4	5	X
43	377	6	2b2	NK	f	M?	5C	4	X
46	382	2	1a	AD	u	P_1R	3	3	5
48	385	5	2b2-d	MA	m	M?	4	4	X
55	418/419	2	2d	MA	m	P^2R	4	4	X
115	1582	8	2a-c1	M	m	P^2	5C	4	X
138	3043	1	1 to 3	A	u	M^3R	5C	4	X
143	3054	6		AD	u	M^1	5C	0	1
153	3080	3		AD	u	P_1R	4	2	5
167	3107	3	2a-b	M	f	P_2	5C	3	X
173	3120	3	1 to 3	M	u	M^2	5C	4	X
174	3122	3	1 to 3	MA	u	P^2	4	4	X
180	3142	3		J	u	m_2	3	1	X
190	3159	3	1a	MA	f	P_1	4	4	X
191	3161	3	1 to 3	M	u	P^2	4	4	X
193	3163	3		M	u	P_1R	5	4	X
194	3166	3		M	u	P^1	4	5	X
195	3171	3		YA	u	M^2R	4	4	X

[1] J = juvenile, 1-12 years; AD = adolescent, 13-17 years; YA = young adult, 18-25 years; M = young to middle aged adult, 26-45 years; MA = mature adult, 46 years+; A = adult >17 years.
[2] Gender is by grave goods only. M = male; f = female; u = undetermined.
[3] P = premolar; M = molar; M = permanent; m = deciduous; superscript = maxillary; subscript = mandibular; L = left; R = right.
[4]Scored using the table in Montgomery (2002): 3 = preservation good, 4 = preservation okay, 5 = preservation poor. C = soft, "chalky" enamel.
[5]Scored using the table given in Montgomery (2002) adapted from Buikstra & Ubelaker (1994): 0 = none; 1 = negligible; 2 = slight; 3 = slight-moderate; 4 = moderate; 5 = moderate-severe; 6 = severe.
[6] Scored using the table given in Montgomery (2002) adapted from Buikstra & Ubelaker (1994): 1 = no root formation; 5 = roots complete apices closed or closing; X = no root present due to post-mortem decay.

Table 2. Isotope data

Sample	Sr ppm	$^{87}Sr/^{86}Sr$ [1]	Mean $d^{18}O_{PO4}$ [2]	1 sd	n	Mean $d^{18}O_{DW}$ [3]	1 sd	n
1	52	0.711775	17.98	0.17	3	-6.13	0.36	3
8	124	0.710697	18.00	0.16	3	-6.08	0.34	3
24	119	0.710614	18.19	0.05	3	-5.68	0.11	3
27	115	0.710310	18.24	0.05	3	-5.58	0.11	3
28	127	0.710196	17.19	0.17	4	-7.85	0.37	4
35	78	0.711775	18.16	0.12	3	-5.73	0.27	3
42	64	0.712394	17.66	0.09	3	-6.82	0.20	3
46	75	0.709324	19.16	0.15	3	-3.56	0.32	3
48	75	0.710737	17.44	0.07	3	-7.29	0.15	3
55	93	0.709609	17.69	0.07	3	-6.77	0.16	3
143	132	0.710561	18.40	0.12	4	-5.22	0.26	4
153	90	0.710719	18.25	0.14	3	-5.55	0.31	3
173	99	0.710484	17.73	0.18	3	-6.68	0.40	3
174	92	0.709650	18.71	0.11	4	-4.55	0.24	4
180	180	0.711190	18.82	0.06	5	-4.29	0.13	5
190	71	0.708822	18.72	0.18	4	-4.51	0.39	4
191	69	0.708818	18.78	0.13	3	-4.39	0.28	3
193	82	0.710088	18.00	0.10	3	-6.09	0.22	3
194	103	0.710634	18.14	0.13	3	-5.78	0.29	3
195	76	0.710396	17.84	0.17	3	-6.44	0.38	3
Min	*52*	*0.708818*	*17.19*			*-7.85*		
Max	*180*	*0.712394*	*19.16*			*-3.56*		
Mean	*96*	*0.710440*	*18.16*	*0.12*		*-5.75*	*0.26*	
2 sd	*60*	*0.0018509*	*1.01*			*2.19*		

[1] NBS987 = 0.710265 ± 0.000003 2s, n=27

[2] Mass spectrometer control reproducibility 0.18‰

[2] Batch control reproducibility 0.16‰

[3] Calculated using Levinson's equation (Levinson *et al*., 1987) after correction for the difference between the average published values for NBS120C and NBS120B used by Levinson